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Risk Based Requirements for Long Term Stewardship:
A Proof-of-Principle Analysis of an Analytic Method Tested on Selected Hanford Locations

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The authors give appreciation for and credit to Antone Brooks, Ph.D., Washington State University, for his thorough external peer review. Appreciation also goes to Mary Feild Jarvis, Ph.D., Washington State University, for asking the simple “hard” questions about stewardship, risk assessment, and their practical application.

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1.0 Introduction

Since 1989, the Department of Energy's (DOE) Environmental Management (EM) Program has managed the environmental legacy of US nuclear weapons production, research and testing at 137 facilities in 31 states and one US territory. The EM program has conducted several studies on the public risks posed by contaminated sites at these facilities. In *Risks and the Risk Debate* [DOE, *1995a]*, the Department analyzed the risks at sites before, during, and after remediation work by the EM program. The results indicated that aside from a few urgent risks, most hazards present little inherent risk because physical and active site management controls limit both the releases of site contaminants, and public access to these hazards. Without these controls, these sites would pose greater risks to the public. Past risk reports, however, provided little information about post-cleanup risk, primarily because of uncertainty about future site uses and site characteristics at the end of planned cleanup activities. This is of concern because in many cases current cleanup technologies, and remedies, will last a shorter period of time than the waste itself and the resulting contamination will remain hazardous.

This document is part of a larger effort by the DOE EM Office of Strategic Planning and Analysis [USDOE 1997a] to develop an EM position on long-term site stewardship. DOE defines the terms "cleanup" and "long-term stewardship" as follows:

> *"Cleanup* refers to active remediation and waste management to stabilize, contain, and/or dispose of radioactive and hazardous waste and contamination. Completing cleanup <u>does not</u> necessarily indicate that sites will be returned to levels acceptable for unrestricted use"; and
>
> *"Long-term stewardship* encompasses all activities required to maintain an adequate level of protection to human health and the environment from the hazards posed by nuclear and/or chemical materials, waste, and residual contamination remaining after cleanup is completed."

In addition, "post-cleanup risk" is defined in this document as follows:

> *"Post-cleanup risk* is the probability of human health harm, to a hypothetical receptor, as a result of a potential exposure to expected site residual contamination."

This document describes and tests a method for establishing tentative stewardship requirements based on reasonable estimates of long-term public health risk, given current closure plans. This work is also designed to visually illustrate, in a non-numeric manner, the long-term stewardship requirements for several currently contaminated areas within the DOE complex..

The intent of this method is to identify potentially long-term hazards if long-term stewardship is not implemented, and to characterize the potential for such hazards in order to establish a basis for defining stewardship requirements. Potential hazards are categorized by broad risk management goals that would be protective of public health and safety under current standards. Specific controls, if necessary, are the responsibility of a long-term stewardship program.

This work is a proof-of-principle demonstration. A proof-of-principle demonstration applies the newly developed methodology, or technology, to real-world situations to prove, or disprove, that it will work successfully. The proof-of-principle demonstration is commonly required prior to adopting a new methodology, or technology, for large-scale application.

This report is structured into five (5) sections. Section 1.0 provides a description of the method utilized for the analyses, and a list of assumptions and limitations. Section 2.0 provides a general description of the five study locations used in the analyses. Section 3.0 presents the results of the analyses, and Section 4.0 presents conclusions. Section 5.0 provides the references cited in this analysis, inclusive of appendices. Appendix A presents the technical assumptions and documentation used in the analyses, for each of the five study locations. In addition, Appendix A presents any special stewardship conditions. Appendix B presents the detailed discussion of methods used in the study together with results for each of the five study locations.

1.1 Stewardship Assessment Overview

A logical and systematic method for determining stewardship requirements is needed to identify and manage long-term hazards and commitment of budget. Existing site information and available scientific expertise can provide insights on current remediation plans relative to long-term stewardship goals. These insights can support decisions by DOE program managers, regulators and the public. The decisions may, in turn affect risk, cost, and specific stewardship controls. This document proposes such a systematic method for application on contaminated sites within the DOE complex of nuclear/industrial works.

The approach used in this report requires four fundamental types of information:

- Estimates of contaminants remaining at a facility at the end of site cleanup,
- Evaluations of environmental pathways from contaminated sites to hypothetical receptors,
- Proposed site cleanup end-state configurations, and
- Human health effects models and protection standards.

This method uses, as a starting point, available information on individual contaminants, contaminant concentrations, and site closure configuration. Because remediation and clean up are not currently complete at most sites, residual contamination (or source term) and final site configuration are assumed based on current DOE documents that address site objectives.

Environmental pathways for potential release of residual contamination---both chemical and radiological---are the result of natural processes, such as erosion or groundwater movement. Fate and transport computer models predict the speed and amount, of the contaminants, that could move through these pathways. Evaluations in this report relied on values for Hanford environmental pathways in common use at this time.

If contaminants move from a site, they would contact various environmental media, such as soil, unconsolidated geology, groundwater, surface water and ambient air. Each environmental medium has unique pathways through which humans become exposed to the contaminants. For example, water can be ingested or used to water crops, and contaminants in air may be inhaled. Current knowledge about human interactions with the various environmental media is used to predict how future human activities could expose humans to the contaminants.

Finally, contaminants impact human health in specific ways. For example, excessive exposure to chemicals or radiation will cause illness or cancer. Current accepted values for predicting health damage are used in this study to convert exposure estimates to risk.

Five locations are selected at Hanford to demonstrate the method. These locations bracket a range of potential post-cleanup conditions. However, this selection process is restricted to study locations that have data on their contaminants, end-state descriptions, and evaluations of the available environmental pathways. Expanding the method at Hanford, and elsewhere, is likely to require additional data evaluations, and the integrated analysis of multiple contaminated locations that is not currently available.

This proof-of-principle analysis uses hypothetical risks to humans as the demonstration model; other environmental receptors are not evaluated. The method can be expanded to evaluate the stewardship requirements of any number of environmental receptors.

1.2 Environmental Media

This approach evaluates seven (7) principal environmental media. Figure 1.1 visually depicts, via graphics, the relationship among the seven environmental media. Figure 1.2 visually depicts the relationship of hypothetical contamination and the environmental media. Six of those media---air, soil/biota, unconsolidated geology, bedrock geology, groundwater, and surface water---are parts of the natural environment. The seventh medium ---"hazardous structures"--- is a human artifact (built by humans) that may become part of the environmental ecosystem post-remediation. These media are believed to represent all potential contaminant locations and pathways for movement in the environment that would apply to DOE sites after remediation. We assumed that active release points such as stacks and discharge pipes would not be part of post-cleanup site facilities. These seven environmental media are described, in the text that follows.

"Hazardous structures" are human-built features remaining, after remediation, that would present a hazard to health, either because of their radiological and chemical contamination, or because they are a physical hazard. These structures may include buildings, tanks, buried pipes, French drains, ducts, tunnels, utility lines, towers, cribs, or ponds.

Figure 1.1. Relative Relationship Among Environmental Media

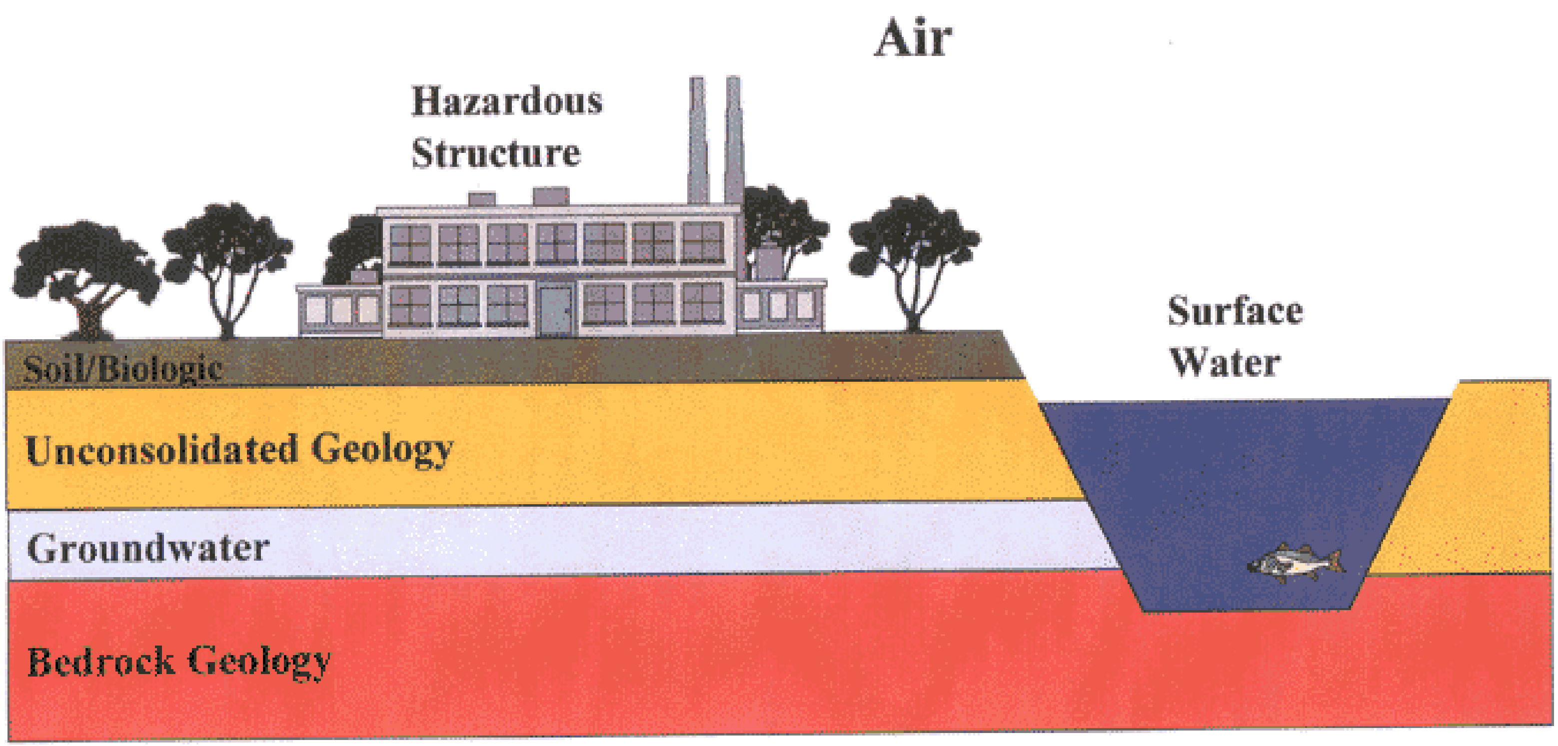
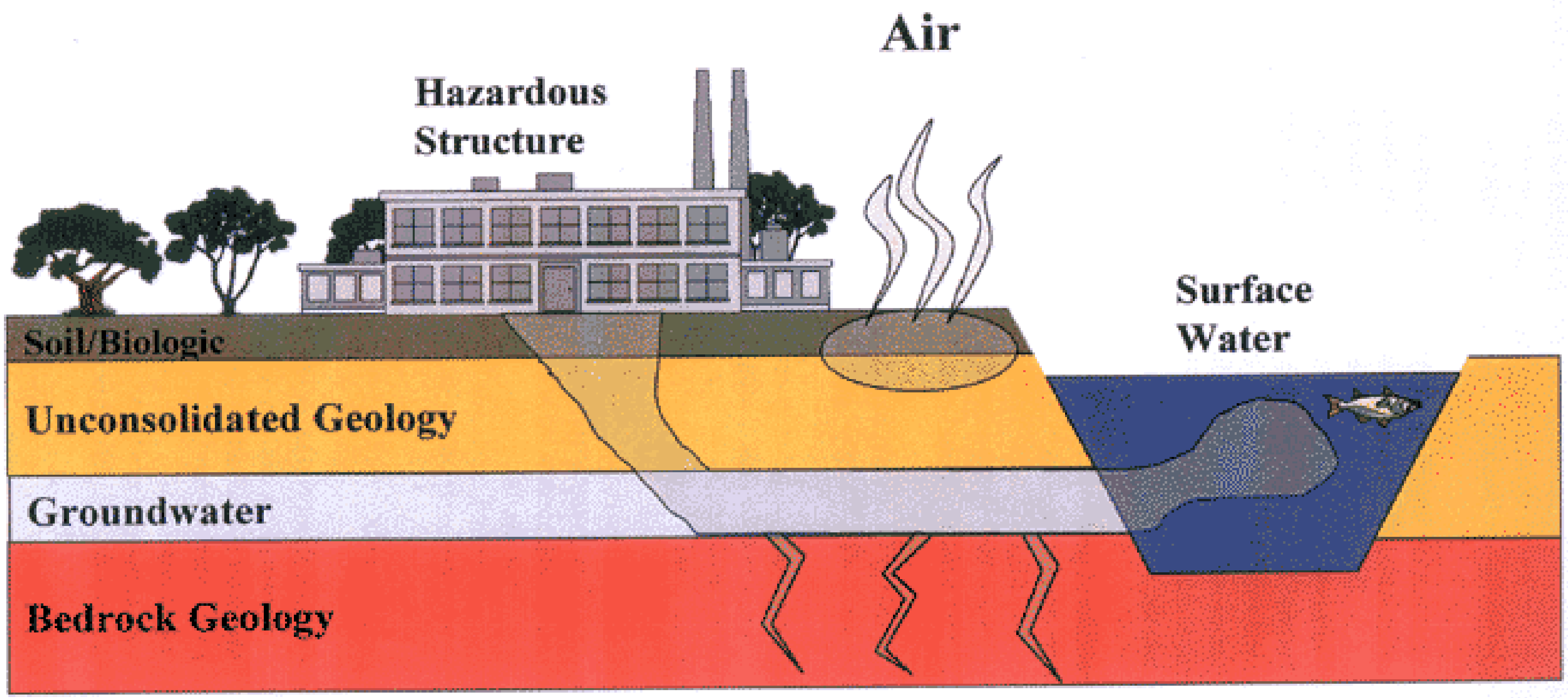


Figure 1.2. Common Migration Routes of Contaminants Among Environmental Media



"Air" includes any gas or particulate that may be inhaled or ingested via airborne transport or resuspension. This applies to sites that have vented tanks, vented structures, contaminated particulates, contaminated surface soils, or volatile chemicals that may become airborne.

"Soil/biota" is so named because it refers to the natural soil layer that supports life and hence the associated ecosystems. This medium overlies the unconsolidated geology and bedrock, shown in Figure 1.1. The soil profile begins at the surface, when present, and can fluctuate in depth from a few decimeters to a few meters. The soil profile is of great importance to stewardship because it is the basis for the continuation of terrestrial life. Plants require the soil profile to grow, and animals are dependent on the plants for life. In addition, the soil maintains a prolific population of insect and microbial life. For this reason, the soil, flora, and fauna are considered herein as one medium, (i.e., soil/biota). If any one component of this life system is contaminated, then the other components may be contaminated.

The "unconsolidated geology" medium is basically sterile (i.e., very few life forms). In many locations, this zone may be comprised of erosion deposits of small rock and loose materials, imported construction fill, or loose material resulting from the weathering of the underlying bedrock. At many sites, the unconsolidated geology is at the surface, because the soil profile was removed during construction or as part of remediation.

The "bedrock geology" medium refers to the sedimentary, metamorphic, or igneous rock formations that underlie all DOE facilities.

The "groundwater" medium refers to any underground water system that underlies a site, and can exist in either the unconsolidated geology or in the bedrock geology. Groundwater generally flows as a distinct system---referred to as an aquifer. As it moves it may carry contamination. Thus, a contaminated aquifer may carry contamination into areas that are otherwise free of contamination.

"Surface water" refers to any water available at ground surface for use by living systems. This includes rivers, ponds, springs, wetlands, and runoff. Because the flora and fauna usually have unrestricted access to surface water, it can be assumed that the contaminated surface water leads to contaminated flora and fauna within the associated ecosystem. Surface water can also transport contaminants into areas otherwise free of contamination.

1.3 Stewardship Levels

This analysis defines four (4) relative levels of stewardship effort. The end stewardship goal remains constant---protect public health and the environment in an economical manner. Thus, the level of stewardship effort must change to provide protection over a broad range of post-cleanup hazards. Starting with Stewardship Level 1, each level of stewardship becomes less restrictive until reaching Stewardship Level 4, which has no land-use restrictions, represents an end to stewardship. No assumptions on ultimate land ownership are made for any stewardship level. The four different stewardship levels are defined as follows.

Stewardship Level 1: *Deny Site Access.* This stewardship level is applicable to hazards with the potential for harm to human health given a brief exposure period. This stewardship level may require extensive physical barriers and/or active site controls. These may include activities such as security personnel stationed on-site to deter access, together with physical barriers to access, application of institutional controls, and installation of signs to warn against access. Also, site personnel may be required to assure compliance with stewardship agreements such as access control, sampling and analyses of environmental media, or containment status reporting. Public access would most likely not be allowed unless special conditions exist. Institutional controls could include governmental exclusions, such as prohibitions to granting drilling permits, excavation permits, mining permits, building permits, land-use permits, surface water rights, or groundwater rights.

Stewardship Level 2: *Limited Site Access.* This stewardship level is applicable to hazards with potential for harm to human health given periodic exposure. Stewardship Level 2 would require stewardship activities necessary to assure that members of the public would not be exposed to residual hazards for any extended period of time. Such activities may include physical barriers to access, signs warning against access, and periodic onsite inspections by security personnel. Inspections could be necessary to determine the functionality and repair status of warning signs and barriers; plus, inspections would verify compliance with institutional controls. Personnel could also be required to assure compliance with stewardship agreements. The frequency of inspections would be determined for each site, individually, depending on the nature and extent of risk and the expected challenges to access barriers. In addition, institutional controls would be required for this stewardship level.

Stewardship Level 3: *Restricted Site Use.* This stewardship level is characterized by the potential for harm to human health, given long-term exposure. Stewardship Level 3 is applicable to sites hazards where chronic exposures could result in significant health risks from exposure to contaminated environmental media. Level 3 could rely mainly on institutional controls to avoid access to media that would cause an unacceptable health risks. This level may require extensive record keeping, monitoring and land use restrictions. Warning signs, onsite inspections or physical barriers may not be required. The institutional controls could include governmental exclusions or prohibitions on granting drilling permits, excavation permits, mining permits, building permits, land-use permits, surface water rights, or groundwater rights.

Stewardship Level 4: *Unrestricted Use.* This level is applicable to sites with negligible site hazards. This stewardship level requires no controls and allows uncontrolled use of the media. No active controls, restricted activities, institutional controls, or anticipated liabilities are associated with this stewardship level. This does not necessarily mean that no hazard exists, but the hazard for the foreseeable exposure scenarios would not warrant limitations on use. Records of the hazard characterization and location may be maintained.

This approach utilizes a three-part procedure, for assigning of stewardship levels to the study locations at various points in time. The procedure is similar to the U.S. Environmental Protection Agency [USEPA, 1991] guidance for sites under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) [Public Law 96-510). This three-step procedure is summarized in the following paragraphs:

1. Categorize each study location into a "tentative stewardship level" using calculated, or modeled, human health risks for the maximum exposed individual via valid environmental media and exposure pathways. The actual exposure conditions that will exist in the future can not be known, therefore stewardship levels are tentatively assigned relative to the magnitude of the calculated potential health risks. The ranges of risk values for establishing tentative stewardship levels are defined below, and presented in graphic form in Figure 1.3 and Figure 1.4.

   - Stewardship Level 1 is a risk greater than one chronic disease case in an exposed population often thousand (10,000), or greater than a 0.1 probability of acute injury, or a Hazard Index of greater than 0.1.
   - Stewardship Level 2 is a risk range is from one chronic disease case in an exposed population of one hundred (100), to one chronic disease case in an exposed population of one million (1,000,000), or the probability of acute injury less than 1.0 but greater than a 0.01, or a Hazard Index of less than 1.0 but greater than a 0.01
   - Stewardship Level 3 is from one chronic disease case in an exposed population of one thousand (1,000), to one chronic disease case in an exposed population of one hundred million (100,000,000), or the probability of acute injury less than 0.1 but greater than a 0.001, or a Hazard Index of less than 0.1 but greater than a 0.001.
   - Stewardship Level 4 has a risk acceptance range that is less than one chronic disease case in an exposed population often thousand (10,000), or the probability of acute injury less than 0.1, or a Hazard Index of less than 0.1.

   The risk criteria that correspond to these stewardship levels are based upon the U.S. Environmental Protection Agency guidelines [13SEPA, 1991] for remediation of CERCLA sites. The EPA has adopted the risk range of 1E-4 to 1E-6 as the target range for lifetime risk of a member of the public contracting a chronic disease from an exposure. Under EPA implementation this risk range serves as a guideline only, with the final determination being made by the EPA Project Manager in consultation with environmental health professional familiar with the CERCLA site.

   The risk ranges presented are adapted to approximate the kind of flexibility a steward would need to protect public safety in an economical manner. A risk of 1E-2 or greater exceeds the risk that is acceptable for workers in hazardous professions [29 CFR 1910] and is thus assigned Stewardship Level 1. The lower limit of Stewardship Level 1 is extended to 1E-4 to provide flexibility to the location manager and environmental health professionals to consider uncertainties in the calculated results, and site data not included in the risk calculations. Stewardship Level 2 encompasses conditions where the site is not

Figure 1.3. Risk Categorization Criteria for Chronic Diseases

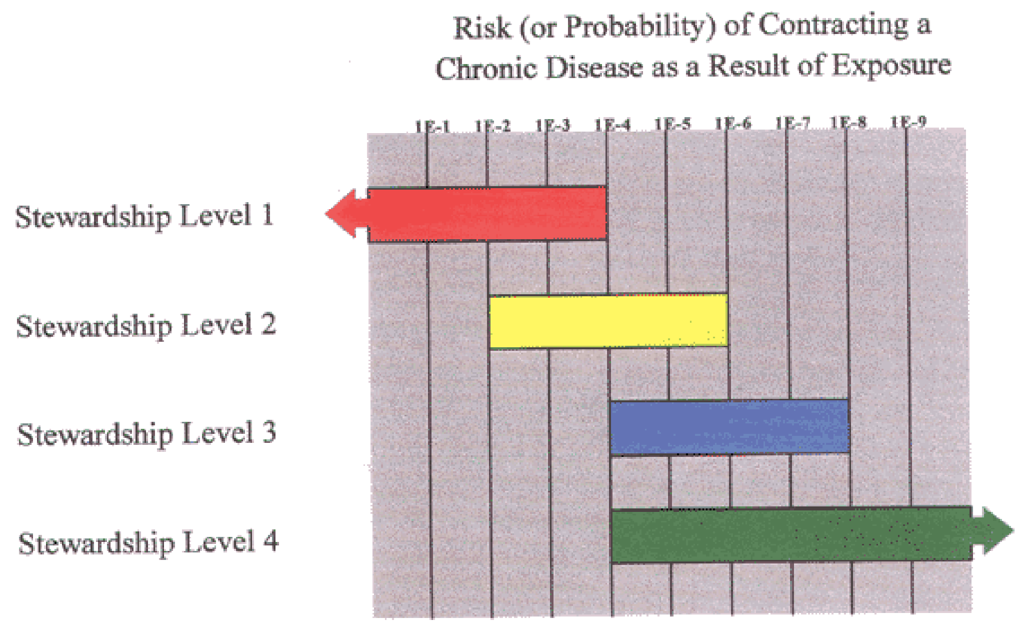
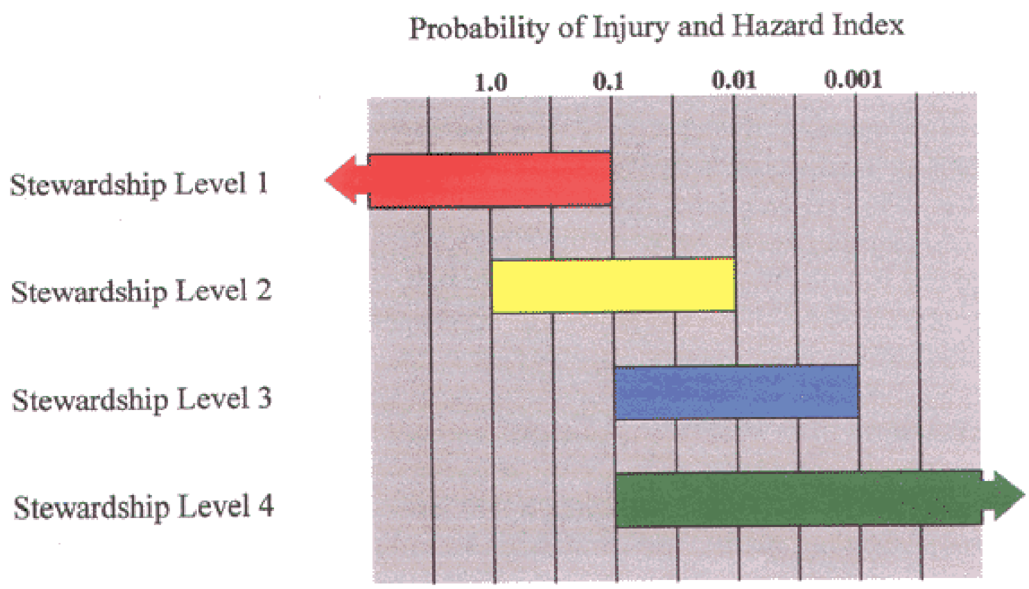


Figure 1.4. Risk Categorization Criteria for Acute Injury and Disease



safe for uncontrolled public use (risk less than 1E-6), but site conditions are less than a risk of 1E-2. Again, the range is large and intentionally overlaps ranges for Stewardship Levels 1 and 3 50 that the location manager and environmental health professionals are provided the flexibility to consider uncertainties and other site data in assigning stewardship actions. Stewardship Level 3 assumes that institutional controls will suffice to control exposures to contaminated media to risk levels below 1E-4 for foreseeable uses of the location. Thus, Stewardship Level 3 starts when risks are less than 1E-4, and, may be extended to risk as low as 1 E-8 to address uncertainties in future contaminant movement and uses of the site. Stewardship Level 4 could be assigned to a location when risks are less than 1E-4, and no other site circumstances warrant concern.

2. A team of environmental professionals review and revise the tentative stewardship levels, and produce "proposed stewardship levels". The environmental professionals are to consider additional site characteristics not directly considered in the computer model. This judgement is required under the criteria identified in Step 1. For this evaluation, toxicity of the contaminant, route of exposure, potentially exposed populations, and other pertinent information are used to assign "proposed stewardship levels." Details on the study location judgements are provided in Appendix B.

   The proposed stewardship levels are estimated to be appropriate for set periods of time and reviewed for consistency. The length of time assigned to each stewardship level is dependent on the amount of material available for release and natural attenuation (e.g. radioactive decay, biodegradation) of the contaminants in the environmental pathway. Consistency is reviewed from the perspective of natural attenuation. For example, it would be inconsistent to assign a groundwater-fed surface water body a Stewardship Level 1, while assigning the groundwater feeding the surface water body a Stewardship Level 4, given that exposure to both medium is equal.

3. Review and revision of the proposed stewardship levels via external stakeholder comments, resulting in "final stewardship levels." This step in the procedure is not tested in this analysis. It is envisioned that the stakeholders would have access to all parts of the process and the opportunity to comment on input parameters, such as exposure scenarios. We recognized that risk is one of several criteria DOE, regulators, and stakeholders consider in selecting remedies. These stewardship levels are intended to provide a risk-based starting point for that decision process.

1.4 Limitations and Analytical Tools

This analysis uses published remediation information for each study location, including DOE project documentation, studies, and compliance agreements. The information is used as the source terms for input into a computer-based modeling program, which calculates the migration of contaminants, and the resulting concentration of contaminants in the various media over time. These contaminant concentrations are used to calculate the human health risks for the appropriate human exposure scenario. The computer-based program utilized by this analysis is MEPAS

(Multimedia Environmental Pollutant Assessment System [Buck, 1995b, Whelan, 1987]). MEPAS is an environmental fate, transport, and exposure/impact computer model that calculates the contaminant concentrations, and human health risks to receptors, given the contamination source term.

For each environmental medium, at each location studied, the residual conditions are determined (i.e., conditions immediately after completion of all planned remedial activities as defined in project documents, studies, and compliance agreements). These residual conditions are used as initial source terms for running MEPAS, which calculates the transport of contaminants through each medium, and the contaminant, flux (mass transfer) from one medium to another. The changes in contaminant concentrations, as a function of time, are plotted, and converted into human health risks via exposure pathways. These human health risks are converted to stewardship levels and plotted over time to give a visual illustration of stewardship requirements.

All risk estimates contain uncertainty. Uncertainties in evaluating stewardship risks are exacerbated because of several key elements of the risk assessment process:

Time. Computer models for environmental transport, data on contaminant locations and human exposures are all more uncertain in the future than in the near future. For example, climatic change and extreme geologic events could dramatically affect future environmental transport. These effects are not considered in this analysis.

Location and Characterization of Contaminants. It is not certain what quantities, when, and in what concentrations residual contaminants move from one environmental medium to another. In some cases, this movement could make contaminants more accessible to humans and other life forms. Often the movement of a contaminant from one medium to another results in a reduction in the concentration of the contaminant. However, this same movement often results in an increase of the total area contaminated. These changes in contaminant location, and concentration together with the decay of radioactive contaminants are considered in this analysis. Two to five contaminants from each study location are used as indicator contaminants in calculating human health impacts. These indicator contaminants are selected using three criteria:
1) high residual concentration, 2) high toxicity, and 3) long radiological half-life or environmental persistence.

Only Primary Pathways Considered. This analysis is limited to an examination of primary fate and transport of the contaminants from selected study locations. No consideration is given to more complex secondary fate and transport aspects of the contaminants. A full understanding of the secondary fate and transport aspects of study location contaminants, and impacts to environmental receptors, could alter the area encompassed by DOE stewardship activities.

Primary pathways include the initial movement of contaminants among the seven environmental media discussed in Section 1.2, until the facility boundaries are encountered. Secondary pathways include contaminant movement outside the facility boundaries and multiple migrations among the environmental media. Examples of secondary pathways include contaminated surface water used to irrigate crops which are in turn consumed by beef cattle that humans consume, or fauna becoming contaminated at a facility and spreading the contamination beyond facility boundaries via their natural migrations.

Cumulative Risks. Each study location in this evaluation is considered independent of the other study locations and not all anticipated contaminants are covered by study locations in this evaluation. Determining the affects on stewardship levels from multiple contamination sources impacting the same media (i.e. cumulative impacts) is not considered but is within the capability of the methodology.

Engineered Containment Performance. It is assumed that contaminant-containment structures, such as water infiltration barriers or entombment buildings, would function properly for their designed life expectancy. It is further assumed that failure of the structure would occur at the end of its designed life expectancy.

Future Stewardship Goals. We assume that future stewardship goals are similar to those expected today. It is also assumed that risk acceptance criteria, for future societies, will be similar to risk acceptance criteria currently used. These assumptions provide a stable frame of reference to visualize future hazards.

2.0 Description of Case Study Locations

Five (5) study locations are selected from DOE's complex of nuclear/industrial works at Hanford to demonstrate the stewardship risk evaluation methodology. The study locations included a nonradioactive hazardous waste landfill, a high-level waste tank complex, a contaminated aquifer system, a Class I nuclear facility, and an open area (i.e. a vegetated area without structures) with radioactive contamination in the soil.

2.1 A Nonradioactive Hazardous Waste Landfill

This study location is a landfill repository for nonradioactive hazardous wastes, which has received Resource Conservation and Recovery Act of 1976 (RCRA) [Public Law 94-580] wastes from industrial operations and laboratory wastes. When remediated, the landfill's surface will be a RCRA cap covering the buried cells of hazardous wastes. The landfill serves as a comparison between hazardous waste sites, and radioactive waste sites to demonstrate the expected differences in time requirements of stewardship programs. This study location is discussed in greater detail in Appendix A, Section A. 1, and in Appendix B.

2.2 A High-Level Waste Tank Complex

The liquid waste byproducts of DOE's plutonium production mission are stored in large underground tanks. The stored waste is both highly radioactive and chemically hazardous. In addition, the tank wastes exist in various physical states (i.e., liquid, sludge, saltcake, hardpan, and vapor). High-level waste tanks have the potential to require substantial stewardship budgets for a protracted period of time. This study location, consisting of 11 tank farms that include a total of *25* double-shell tanks and 66 single-shell tanks, is selected for analysis herein. This study location is discussed in greater detail in Appendix A, Section A.2, and in Appendix B.

2.3 A Contaminated Aquifer System

At this study location, an aquifer stretches from beneath an area containing several nuclear facilities, with associated contamination, to a nearby river. This aquifer is contaminated with both radionuclides and hazardous chemicals, and it flows under both surface-contaminated and underground-contaminated sites. Records indicate that liquid discharges and seepage from waste burial grounds contaminated this aquifer. This study location is discussed in greater detail in Appendix A, Section A.3, and in Appendix B.

2.4 A Class I Nuclear Facility

This study location is a large Class I nuclear facility whose mission was to separate strontium and cesium from the fission product waste stream. This study location is representative of other DOE nuclear facilities (i.e., canyon buildings and the plutonium production reactors). These facilities have unique stewardship requirements because of the sizeable amount of residual radioactive contamination that will remain, and the hazards inherent to the structures. This study location is discussed in greater detail in Appendix A, Section A.4, and in Appendix B.

2.5 An Open Area with Radioactive Contamination

This study location is included on the U.S. Environmental Protection Agency's National Priority List under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 [public Law 96-510]. The study location is near nuclear facilities, that have ceased operations, and is near a river. Former waste-disposal practices associated with operation of the nuclear facilities resulted in releases of radionuclides and chemicals to soil and groundwater. The primary source of contaminants was reactor core-cooling water, which was stored in numerous tanks, cribs, and retention basins for cooling and radiological decay prior to discharge to the river, however these human-built structures have since been removed. This study location is discussed in greater detail in Appendix A, Section A.5, and in Appendix B.

3.0 Results

This section provides results of the stewardship analysis for each of the five (5) study locations used in this evaluation. The results are illustrated in bar chart format in Figures 3.1 through 3.5, and described below for each of the affected environmental media.

The time scale intervals in the following five figures occur in units of calendar years and cover 2,000 years into the future. We assume that long term stewardship responsibilities will begin on, or near, the year 2000 A.D. A long-time period is needed to address the range of stewardship issues encountered, from relatively short-term concerns (e.g., short half-life radionuclides) to long-term concerns (e.g., transuranics). In all study location analyses, the exposure scenarios for groundwater and surface water assume residential drinking water use.

3.1 A Nonradioactive Hazardous Waste Landfill

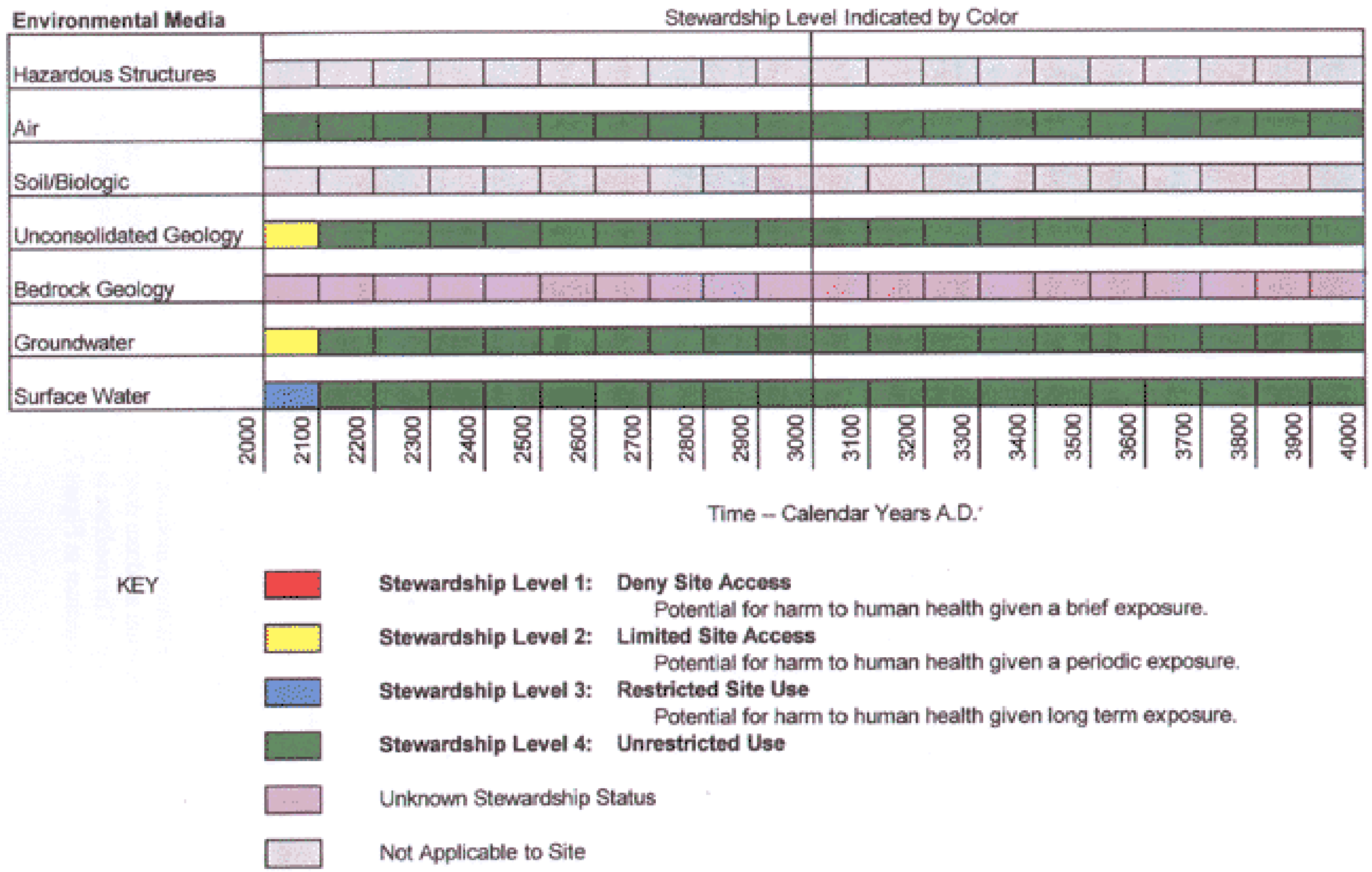
Figure 3.1 shows the potential stewardship levels for environmental media that could be affected by contaminants in the RCRA landfill study location after the design life of the containment system. The landfill was closed in 1994, an earthen infiltration-restrictive cap is to be constructed, and there are no published analytical data suggesting that waste contaminants have migrated beyond the landfill's cells in the unconsolidated geologic media. However, after the cap's thirty (30) year design life, waste contaminants buried in the landfill could be expected to migrate from the earthen cells, contaminating more of the unconsolidated geology as infiltrating water moves among the contaminants. Subsequently, computer modeling indicates that contaminants would be carried into the groundwater, and via the groundwater into the surface water medium---the river. Experience to date [40 CFR 258] indicate that engineered land-based disposal facilities, without maintenance, will eventually be ineffective in containing contaminants, resulting in spread of contamination into environmental media.

Hazardous Structures: No hazardous structures exist at the landfill. Therefore, hazardous structures are not considered in evaluating stewardship levels for this study location. This condition is indicated by the gray bar color in Figure 3.1.

Air: Release of contaminants into the vapor phase, and hence into the ambient air, is expected to occur at the RCRA landfill study location. However, predicted concentrations of vapor contaminants in the ambient air indicate that Stewardship Level 4---unrestricted land use---may be the appropriate stewardship level for this medium.

Soil/biota: The soil/biota medium was removed during landfill construction. Therefore, the soil/biota environmental medium does not need to be considered in this study location's stewardship planning. The medium is not applicable to the stewardship issues---as indicated by the gray bar for this medium in Figure 3.1.

Figure 3.1. Stewardship Levels for a Nonradioactive Hazardous Waste Landfill



Unconsolidated Geology: The unconsolidated geology is estimated to require Stewardship Level 2---limited site access---through the year 2100. After the year 2100, the stewardship level could be reduced to Stewardship Level 4---unrestricted land use. This is because the majority of the waste contamination will move to the groundwater system, eventually flushing the unconsolidated geology of contaminants.

Bedrock Geology: The status of the bedrock geology is unknown, and could not be evaluated for this analysis, as indicated by the purple color in Figure 3.1.

Groundwater: Groundwater is assigned Stewardship Level 2 until the year 2100. By the year 2100, the majority of the contaminants within the landfill are predicted to have moved to surface water via groundwater transport. After the year 2100, the groundwater is expected to return to a Stewardship Level 4---unrestricted site use.

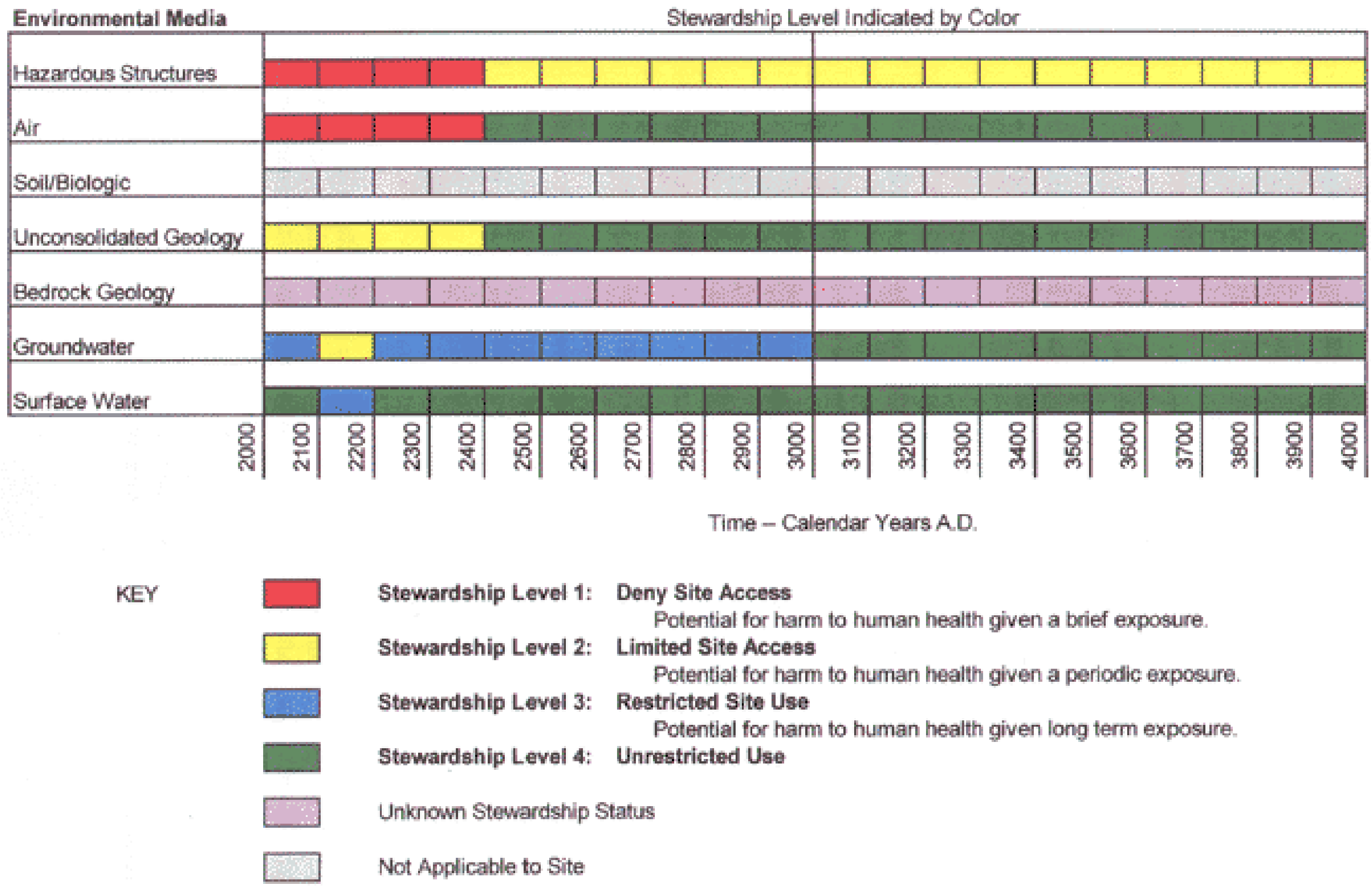
Surface Water: The surface water is assigned Stewardship Level 3---restricted site use---until the year 2100, as the groundwater discharges into the river and becomes dilute. After the year 2100, contaminant discharge to the surface water declines and the surface water is at Stewardship Level 4, where unrestricted use would be appropriate.

3.2 A High-Level Waste Tank Complex

Figure 3.2 shows the potential stewardship levels for environmental media that could be affected by contaminants in the high-level waste tank study location after their design life. Plans for the tanks are to close them in the next fifty (50) years. Further, no more than one-percent (1%) of the tank waste by volume is expected to remain in the tanks after waste retrieval. One percent (1%) of the tank waste by volume is used in this analysis. The residual waste left in the tanks could be expected to migrate, as infiltrating water moves among contaminants, from the tanks and spread to underlying unconsolidated geology. Computer modeling indicates that contaminants are subsequently carried into groundwater, and from groundwater into the Columbia River.

Hazardous Structures: The drained concrete and steel tanks (hazardous structures) present a physical, chemical, and radiological hazard. The radiological and chemical hazards require the structures to be at Stewardship Level 1--- deny site access---through the year 2400. The tank shell itself may present a physical hazard as it degrades, thereby requiring Stewardship Level 2---limited site access---after that time. The wastes remaining in the tanks after waste recovery would decay and/or leach into the soil. After the year 2400, radiation levels in the tanks are estimated to be low. The calculation assumed that the residual waste in the tank consists of radionuclides with half-lives of less than forty (40) years, such as cesium-137, strontium-89, or strontium-90. This assumption will underestimate the toxicity of the residual waste, if the residual waste is composed of long-lived radionuclides such as plutonium-23 9, uranium-235, or uranium-238.

Figure 3.2. Stewardship Levels for a High-level Waste Tank Complex



Air: The air medium is directly affected by surficial contamination. Therefore, through the year 2400, Stewardship Level 1 is indicated. After 2400, surficial contamination is estimated to be low, and the Stewardship Level 4---unrestricted use for air---is indicated.

Soil/biota: The soil/biota medium is removed from the tank farm areas before tank construction. Therefore, the soil/biota medium is not considered in this study location, as indicated by the gray color in Figure 3.2.

Unconsolidated Geology: Through the year 2400, the unconsolidated geology is assigned Stewardship Level 2 because contamination from the tank is assumed to migrate progressively through the unconsolidated geology. After the year 2400, to Stewardship Level 4---unrestricted site use---is indicated, as the majority of the waste contamination decays and/or leaches to the groundwater system.

Bedrock Geology: There is no direct sampling of the bedrock material, nor is the groundwater system understood to the depth of the bedrock geology. Therefore, the status of the bedrock geology is unknown and is not evaluated, as indicated by the purple color in Figure 3.2.

Groundwater: The groundwater is assigned multiple stewardship levels because contaminants migrate at different speeds based on their physical and chemical properties (e.g., distribution coefficient, solubility). By the year 2100, the more mobile contaminants may leach from the tanks to the unconsolidated geology and then to the groundwater, resulting in groundwater concentrations that are assigned Stewardship Level 3. From the year 2100 to the year 2200, the concentrations of the most mobile contaminants continue to increase in the groundwater and are assigned Stewardship Level 2. From the year 2200 to 3000, the groundwater concentrations are estimated to decrease and are assigned Stewardship Level 3.

In approximately year 2900, a second groundwater concentration peak is predicted, consisting of the less mobile tank waste contaminants. However, the groundwater concentration of these contaminants is not sufficient to require revising the stewardship levels. After the year 3000, groundwater contaminant concentrations would decrease and Stewardship Level 4---unrestricted site use---is assigned.

Surface Water: The surface water concentrations are directly related to the groundwater concentrations, except for a dilution factor. Through the year 2100, the surface water is assigned Stewardship Level 4, because contaminants have not yet reached the surface water through the groundwater system. Groundwater could eventually discharge into the river and dilute. At the year 2100, the surface water could warrant Stewardship Level 3. This increase in stewardship level is caused by the groundwater discharging higher concentrations of contaminants into the river. By the year 2200, Stewardship Level 4 is indicated.

3.3 A Contaminated Aquifer System

Figure 3.3 shows projected stewardship levels for the contaminated aquifer system study location. The aquifer currently holds contaminants, both chemical and radioactive, from numerous sources. Computer modeling indicates that these contaminants are migrating toward and discharge into the river. A key assumption for this analysis is that no new sources will contaminate the aquifer. Therefore, the contaminant concentrations, currently measured in the plumes, are assumed to be the only source of contamination.

Hazardous Structures: Because the study location is a contaminated aquifer, the hazardous structure's medium does not exist, as indicated by the gray color in Figure 3.3.

Air: Because the study location is a contaminated aquifer, the air environmental media does not exist -- *as* indicated by the gray color in Figure 3.3.

Soil/biota: Because the study location is a contaminated aquifer, the soil/biota environmental medium does not exist, as indicated by the gray color in Figure 3.3.

Unconsolidated Geology: The unconsolidated geology stewardship level is consistent with the groundwater stewardship level because the two are linked physically and chemically. The unconsolidated geology is assigned Stewardship Level 2 until the year 2100. Natural attenuation via steady flushing to the river would occur. As a result, after the year 2100, the stewardship level is reduced to Stewardship Level 4.

Bedrock Geology: There is no direct sampling of the bedrock material, nor is the groundwater system understood to the depth of the bedrock geology. Therefore, the status of the bedrock geology is unknown, and is not evaluated, as indicated by the purple color in Figure 3.3.

Groundwater: The groundwater is assigned Stewardship Level 2 until the year 2100. As in the unconsolidated geology, natural attenuation via flushing to the river would occur. As a result, after the year 2100, the stewardship level is reduced to Stewardship Level 4---unrestricted site use.

Surface Water: Surface water is assigned Stewardship Level 3 through the year 2100. After 2100, it is estimated that all organic chemicals and highly mobile radionuclides will have been diluted to levels allowing unrestricted use---Stewardship Level 4.

3.4 A Class I Nuclear Facility

Figure 3.4 shows the projected future stewardship requirements for the Class I nuclear facility study location. No design life is specified in the remediation documentation for the planned structural containment of the Class I nuclear facility. Entombment of the facility is proposed and we assume, in this analysis, that it will be successful at containing the contaminants. Entombment includes plugging of all exits from building interior (e.g. pipes,

Figure 3.3. Stewardship Levels for a Contaminated Aquifer

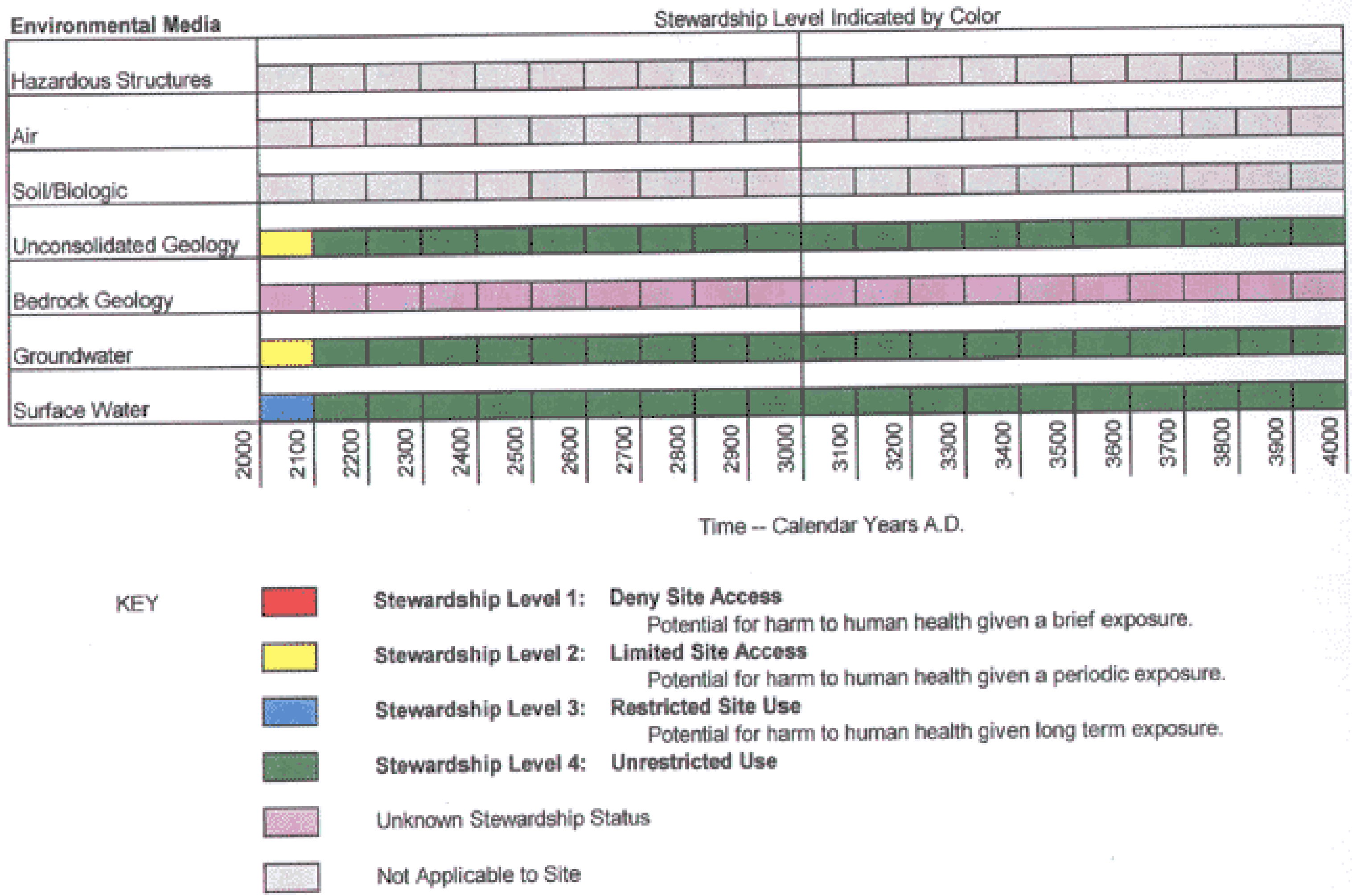
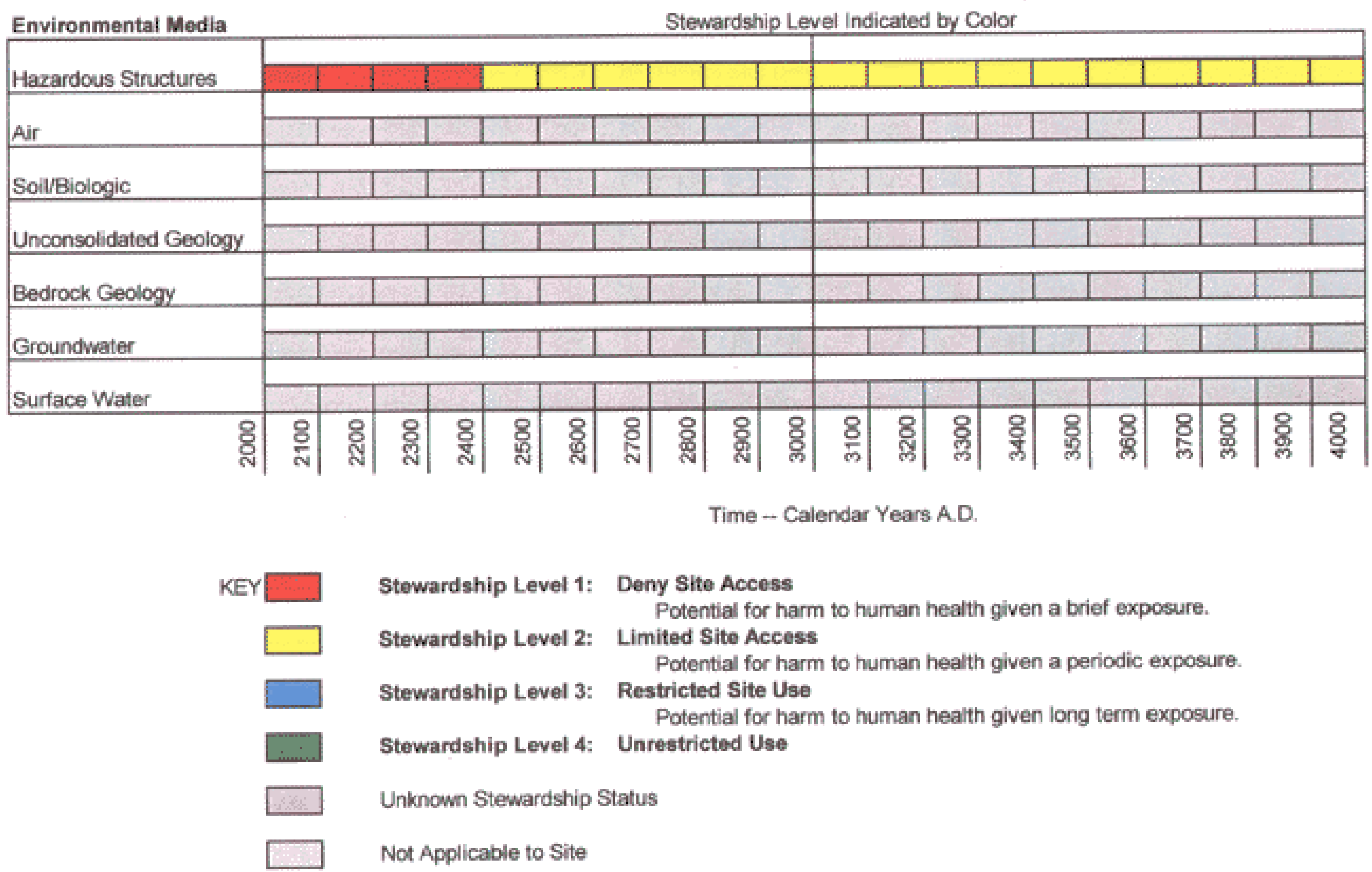


Figure 3.4. Stewardship Levels for a Class I Nuclear Facility



windows, access holes, power lines), removal of all exterior nonstructural components, and placement of access barriers. To demonstrate the impact on stewardship levels of minimizing the effects of environmental pathway attenuation, it is assumed for this study location that the entombment will be maintained and repaired so that it does not breach in perpetuity. Such maintenance is an example, with periodic inspection, of activities that could be conducted at the site to achieve Stewardship Level 1 for the contaminated media.

Hazardous Structures: The structure is assigned Stewardship Level 1 through the year 2400. Radionuclides contained within the structure will decay over time until they are not an immediate threat to health from short-term exposures. After that time, Stewardship Level 2 is assigned. However, the structure will present a physical hazard (e.g., trip and fall hazards, falling object hazards, confined space hazards) for an undetermined length of time.

The hazardous structure is the only medium of concern for this analysis. Therefore, no impacts to any other environmental media are postulated. The air, soil/biota, unconsolidated geology, bedrock, groundwater, and surface water environmental medium associated with this study location are assumed to be uncontaminated as indicated by the gray color in Figure 3.4.

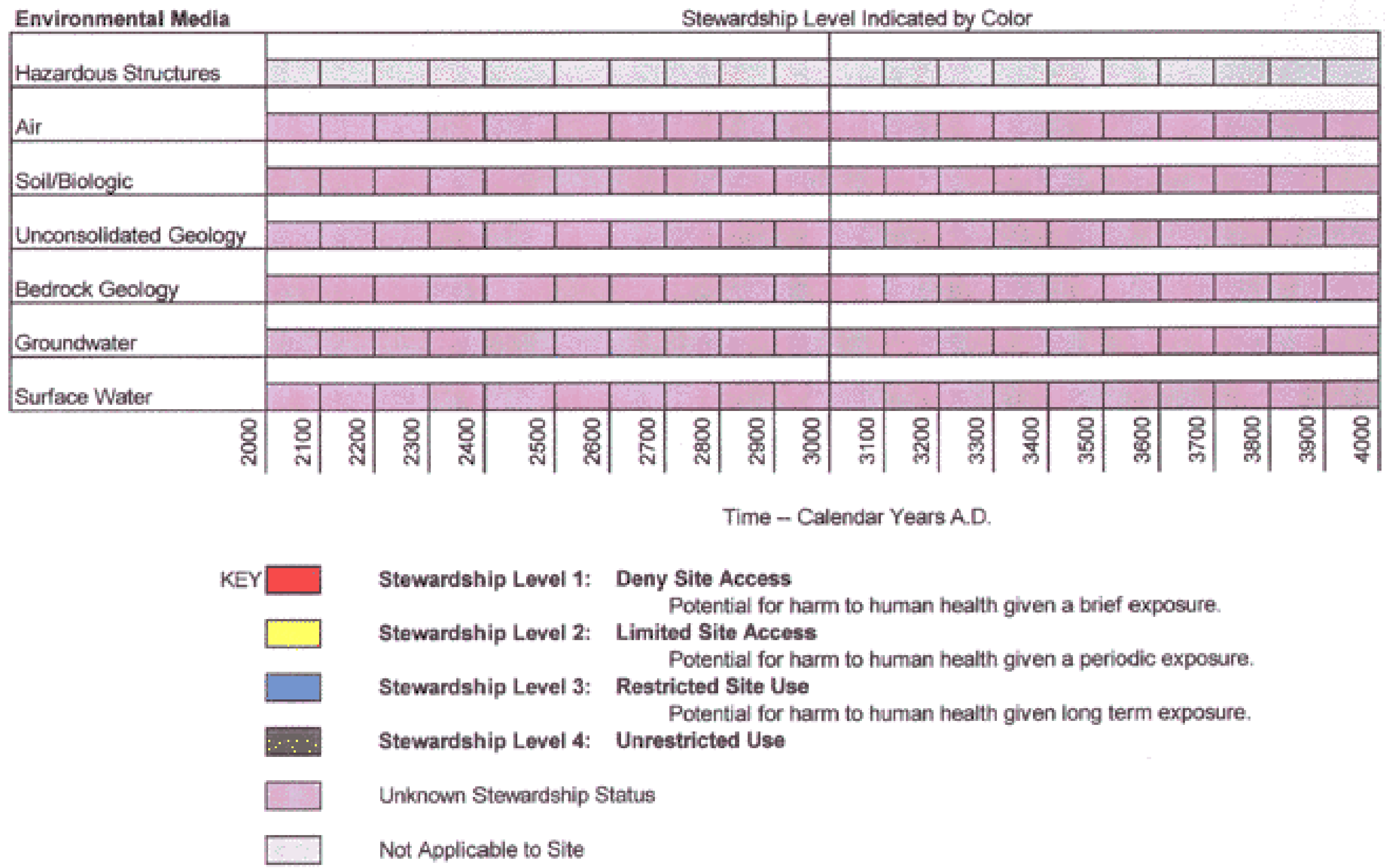
3.5 An Open Area with Radioactive Contamination

Future stewardship levels for this study location are not assigned because of data gaps in the documentation of the study location. Figure 3.5 reflects this lack of information. This study location is included in the evaluation because it is believed to be representative of many locations throughout the DOE complex. Obtaining comprehensive and credible data is crucial to the assignment of appropriate stewardship levels. Data gaps are divided into two categories.

First Data Gap: The first data gap concerns the existing characterization data for the study location. Published data exists on the nature of contamination in the unconsolidated geology, to a depth below the surface of eight (8) meters. However, these data are inconsistent with the characterization data for the unconsolidated geology collected from the surface to a depth of five (5) meters. Other published information regarding the extent of contamination in the unconsolidated geology is not available.

Second Data Gap: The second data gap concerns the published remediation goals for the soil/biota media. The published remediation goals are inexplicit and open to multiple interpretations. The range of possible interpretations results in great uncertainties in assigning stewardship levels and duration. Section A.5 of Appendix A contains additional details regarding these data gaps.

Figure 3.5. Stewardship Levels for an Open Area with Radioactive Contamination



4.0 Conclusions

The objectives of this evaluation are to propose a methodology that: 1) estimates and assigns tentative stewardship requirements, based on reasonable estimates of long-term public health risk; 2) identifies and characterizes potentially long-term hazards in the event that long-term stewardship is not implemented; and 3) trial run the proposed methodology using characterization data, corresponding to contaminated locations. The following text summarizes the proof-of-principle work and its results.

4.1 Post-Remediation Risks

Currently, many remediation or closure plans inadvertently call for leaving significant amounts of chemical and radioactive contaminants in place. This analysis includes contaminated locations covered under such plans. It is generally accepted that over time, contamination will steadily move from its present location, i.e., it will breach its engineered storage, containment, or repository. While natural attenuation, processes are important; it is unlikely that natural attenuation processes alone will achieve health-protective, remediation end states. Many attenuation processes exist naturally which can, and are being utilized daily to clean contamination, e.g. leaf decomposition which is essentially release of nitrogen compounds, and the production of water, CO2 and methane. In contrast, one may also naturally enhance natural processes to perform more effectively, yet still maintain it as a natural process, e.g. composting. Other natural attenuation processes include, but are not limited to: bioremediation, landfarming, UV light exposure, ionizing radiation exposure, chemical decomposition, radioactive decay, composting, vegetation uptake of metals, fire, lightening, filtration, chemical immobilization, and soil washing. Unfortunately, natural attenuation is not a panacea for cleanup problems. Natural attenuation will usually lessen, but will not attenuate the health hazard and its associated risk to a future receptor. Currently most DOE site planning documents (e.g., CERCLA ROD, EIS ROD, and for compliance with RCRA regulations and permit conditions) do not consider contaminant migration, and the associated risk to future receptors. To adequately managing contaminant hazards, the risk manager needs to have a good estimate of the likely future risk to a receptor and the population. This is accomplished by extrapolating from current contamination and exposure location data, over a long time period. Further the contamination at a location must be tracked as it moves through various environmental media.

4.2 Risk-Based Stewardship Level Assignment

The proposed process for assigning stewardship levels using risk assessment tools, and professional judgement provides a reasonable starting point for considering stewardship requirements. However, the methodology has not yet been tested using stakeholder review and input. This proof-of-principle demonstrates that the methodology is successful, and may be used for its designed purpose. The methodology proposed here links stewardship responsibilities to future public health/safety risk using existing published information and data. The project results suggest that stewardship needs can be assigned at multiple locations, based on common parameters, and presented in a uniform manner. Results for the study locations suggest that stewardship should consider both maintenance of engineered features, and the need to effectively manage contaminated environmental media. This study finds this stewardship methodology to be directly applicable to other DOE facilities.

4.3 Interaction between Stewardship Levels and Cleanup Remedies

Natural attenuation (e.g. radioactive decay, biodegradation) is sometimes relied upon as a cost-effective cleanup remedy at some sites. This analysis indicates that reliance upon natural attenuation can result in an increase in stewardship timeframe and facility life cycle costs. The results on a Class I Nuclear Facility (Section 3.4) serve as an example of this phenomenon. The four sets of preliminary results suggest that cleanup remedies and stewardship responsibilities must be viewed together for effective planning and decision making.

The presence of hazardous structures may present a major stewardship issue for DOE in the future because these structures require active surveillance over long periods of time. Large contaminated structures, such as nuclear facilities or high-level waste tanks, pose at least three different types of safety issues. First is the issue of potential harm to health from residual radiological and chemical contamination. Second is the potential for physical harm because of degrading structural integrity. Third is that they serve as a habitat for animal life and plant life. A species of endangered bat was found roosting in a contaminated Hanford facility. Contaminated crickets have been squashed under foot in one Hanford facility. Radioactive ants have been located. Occasionally vagrants are found living in buildings on RattleSnake Mountain. Tumbleweeds, some of which are frequently found to be contaminated, accumulate near and or inside the structures.

The potential for radiological and chemical harm will persist for long periods of time, dependent on the half-lives and refractile properties of the contaminants. The potential for physical harm can persist for longer time periods with no clear demarcation into lower stewardship levels.

The value of natural attenuation is highly variable for hazard mitigation. For example, the duration of stewardship levels for groundwater and surface water media, is highly dependent upon the mobility of the contaminant in the groundwater, and the distance from the source to the receptor. The landfill study location, and the high-level waste tanks' study location, illustrates different stewardship duration for the same environmental media. The time differences are attributable to different physical and chemical properties of each study location's respective contaminants. The river’s stewardship levels are dependent on the groundwater contaminants, but are less restrictive because of the river's immense dilution factor. This finding is unique to water bodies with large flows and strong currents. As such, it may be unique to the study locations used in this analysis, and likely cannot be extrapolated to surface water bodies adjacent to DOE facilities elsewhere.

4.4 Data Availability for Evaluation of Stewardship Levels

Selection of study locations for this evaluation is constrained by available data for estimating the nature and extent of contamination in the post remediation stage. In many cases, these data are not available because remediation plans have not been addressed or are in their infancy. Even at locations, that have characterization documentation, there is insufficient data to determine the long-term stewardship requirements. The results on the Open Area with Radioactive Contamination study location (Section 3.5) serve as an example of this phenomenon. Specification of post remediation conditions early in the remediation process may allow an insight on potential stewardship needs to be obtained. The risk-based approach to assigning stewardship levels has specific data requirements that are comparable to the data requirements for characterization of CERCLA sites.

5.0 References

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APPENDIX A
Remediation and Stewardship Plans

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List of Tables

The residual contamination, i.e., the contamination remaining after remediation has been completed, is estimated for each of the five (5) study locations. The residual contaminants -- both chemical and radioactive -- are identified together with their respective concentrations and environmental transport characteristics.

A.1 Nonradioactive Dangerous Waste Landfill (NRDWL)

The Nonradioactive Dangerous Waste Landfill (NRDWL) is a landfill repository for nonradioactive hazardous wastes. NRDWL is situated on the 200-Area plateau of Hanford. The Landfill has received Resource Conservation and Recovery Act of 1976 [Public Law 94-580] wastes from industrial operations and laboratory wastes. When remediated, the landfill's surface will be a Resource Conservation and Recovery Act (RCRA) cap covering the buried cells of hazardous wastes. The landfill serves as a comparison between hazardous waste sites and radioactive waste sites, to demonstrate the expected differences in time requirements of stewardship programs. It should be noted that the State of Washington laws refer to RCRA hazardous wastes as “dangerous” waste. Thus, this landfill, which contains RCRA hazardous wastes, is referred to as a dangerous waste landfill.

In this analysis, the assumptions are: 1) that the RCRA cap works as designed, for its intended 30-year life, after which the buried hazardous waste is leached to the groundwater system; 2) the groundwater system transports the hazardous waste to the Columbia River; and 3) the landfill itself will be released for unrestricted residential use when the human health risk drops to an acceptable level for such land use.

A.1.1 Contaminated Environmental Media Prior to Remediation

This landfill currently has documented contamination in only two media: the unconsolidated geology and the groundwater. The contamination status of the bedrock geology under this landfill is unknown because no sampling has been done below the upper portion of the aquifer. A summary of the status of contamination at this landfill is given in Table A.1.

There are no hazardous structures at this landfill, and all native soils and vegetation (i.e., soil/biota medium) have been removed. There are no surface water bodies or drainage ways, thus eliminating the potential for surface water contamination. Volatile organic contaminants at this landfill are escaping to the atmosphere, potentially contaminating the air medium.

Table A.1. Location of Existing Contamination at NRDWL

Environmental Media	Status	Reference
Hazardous Structures	Absent	USDOE 1990
Air	Contaminated	USDOE 1990
Soil/Biota	Absent	USDOE 1990
Unconsolidated Geology	Contaminated	Refer to Section A. 1.1
Bedrock Geology	Unknown Status	USDOE 1990
Groundwater	Assumed Uncontaminated	Refer to Section A. 1.1
Surface Water	Absent	USDOE 1990

A.1.2 Remediation Plans

According to closure plans, no remediation of any medium is anticipated. All waste will be left in place, and an RCRA-approved (30-year design life) cap will be constructed over the landfill. The cap will consist of a vegetated top layer, and a series of moisture barriers (both synthetic and earthen) designed to allow nine (9) liters of water per hectare per day into the landfill [USDOE,1990]. Construction of the final RCRA-approved cap over the landfill was originally scheduled for completion in December 1994. However, construction of the cap has yet to begin, and no firm completion date has been established.

A.1.3 Special Stewardship Requirements

The special stewardship requirements consist of the following activities:

Site Security: Site access will be restricted to authorized personnel only, for 30 years following closure. An 8-foot-high fence with locked gates and warning signs will be built and maintained around the site. The site will be patrolled to ensure that unauthorized access is minimized [USDOE,1990]. The groundwater-monitoring wells will have locking caps to prevent tampering, and will be surrounded by four steel guard posts to prevent damage to the well [USDOE,1990].

Inspection Plan: Inspections will be conducted on a quarterly basis, except for benchmark inspections that will be performed on an annual basis. Inspections will be conducted for a minimum of 30 years [USDOE,1990].

Quarterly inspections of the following items will be conducted: 1) security control devices; 2) erosion damage; 3) settlement, subsidence, or displacement of cover; 4) vegetative cover condition; 5) drainage-control structures; 6) functionality of cover drainage system; 7) gas ventilation system; and 8) groundwater-monitoring well condition. Integrity of the surveying benchmarks will be inspected annually, checking both the physical condition and the surveying accuracy of the benchmarks [USDOE, 1990].

Maintenance Plan: Any damage to the systems, structures, or components found during the inspection will be repaired, rectified, or replaced within 90 days of discovery [USDOE,1990].

Monitoring Plan: Groundwater is the only environmental medium to be monitored alter closure. Quarterly samples of groundwater will be taken from nine groundwater wells for a minimum of 30 years, and continue until concentrations of 20 indicator constituents drop below their individual target detection limits. The groundwater data will be statistically analyzed to account for background concentrations of applicable contaminants, and the data packages will be submitted to the State of Washington Department of Ecology [USDOE,1990].

Postclosure Contact: The U.S. Department of Energy (DOE) will maintain, for a minimum of 30 years, at least two individuals in Richland, Washington as contacts for matters concerning this landfill. One individual will be a DOE employee (i.e., the Director of Environmental Restoration Division); the other will be a contractor employee [USDOE,1990].

Deed Restrictions: DOE will sign, notarize, and file for recording a notice with the auditor of Benton County, State of Washington. This notice will identify the site as a Nonradioactive Dangerous Waste Landfill, and will restrict site use under terms of 40 CFR 264.117 [40 CFR 264] and WAC 173-303-610[7][d] [WAC 173-303], as cited in the *Nonradioactive Dangerous Waste Landfill Closure/Postclosure Plan* [USDOE,1990].

A.2 200-Area Tank Farms

Hanford's high-level waste tank complex is comprised of 177 tanks that currently hold 56 million gallons of radioactive hazardous waste-byproducts of Hanford's plutonium production mission. The wastes in these tanks are radioactive, chemically hazardous, and generally highly alkaline. In addition, the tank wastes occur in various physical states, i.e., liquid, sludge, saltcake, hardpan, and vapor. The tank complex is divided into two main sets of farms -- the 200-East and the 200-West.

This analysis was modeled after the 200-East Tank Farms (11 tank farms that include 25 double-shell tanks and 66 single-shell tanks). Closure plans for these tank farms are not final. However, the Hanford Tank Initiative is to provide the procedures necessary to retrieve the high-level waste and permanently close the underground storage tanks [USDOE, 1997b].

A.2.l Contaminated Environmental Media Prior to Remediation

This analysis assumes that the tanks of the 200-Area Tank Farms contain the waste, and that the tanks are in open vapor phase communication with the ambient atmosphere. Although the groundwater and unconsolidated geology under the 200-Area Tank Farms are currently contaminated, they are considered initially uncontaminated for this analysis. This assumption is made so that the impact of the 200-Area Tank Farms could be evaluated independently from other contamination source impacts in the area.

Currently, no surface water or soil/biota media exist at the tank farms. The soil/biota media were removed during construction of the tanks. Reestablishment of these media has never been allowed. A summary of the status of contamination, by media, at the 200-Area Tank Farms is given is Table A.2.

Table A.2. Location of Existing Contamination at 200-Area Tank Farms

Environmental Media	Status	Reference
Hazardous Structures	Contaminated	WHC 1993a, 1993b
Air	Contaminated	WHC 1993a, 1993b
Soil/Biota	Absent	WHC 1993a, 1993b
Unconsolidated Geology	Assumed Uncontaminated	WHC 1993a
Bedrock Geology	Unknown Status	WHC 1 996a
Groundwater	Assumed Uncontaminated	Refer to Section A.2.1
Surface water	Absent	WHC 1993a, 1993b

Information about the identity and quantity of waste held in the high-level waste tanks has been developed and collected from many different sources. Waste inventory data for single-shell tanks and double-shell tanks are presented in documents prepared for Westinghouse Hanford Company by WASTREN, Inc. [WHC 1993a, and WHC 1993b respectively). Five (5) tanks have no quantitative waste inventory data available. Since completion of the Integrated Risk Assessment Program scoring methods and results study [Buck, 1995a], several other quantity-related reports have become available. Some of these reports contain historical tank content estimates [Brevick, 1997].

A.2.2 Remediation Plans

It is expected that remediation plans for the high-level waste tanks will include retrieval of contamination and closure of the tanks [WHC, 1996a]. The assumption for this analysis is that a minimum of 99% of the waste, by volume, will be removed from the tanks. This analysis assumes a maximum of one percent (1%) of the current tank contents will be the residual contamination via the proposed cleanup plan. The tanks are expected to remain in their existing locations. We also assume that contaminant inventories used for this analysis are one percent (1%) of the waste inventory currently reported to be in the 200-Area Tank Farms.

A.2.3 Special Stewardship Requirements

No special stewardship requirements for the 200-Area Tank Farms are located in the literature. It appears that the lack of final-disposition plans for the tanks has deterred the establishment of stewardship plans or requirements.

Given that a maximum of one percent of the existing waste volume will remain in place (approximately 500,000 gallons of highly radioactive hazardous waste), it can logically be assumed that some stewardship requirements will be necessary. These stewardship requirements include establishing access barriers, posting warning signs, and locating onsite personnel to ensure that access barriers are maintained and not challenged. It is also assumed that an ongoing groundwater-monitoring program would be required to track the radionuclides and hazardous chemicals, as they are released from the tanks into the unconsolidated material and to the groundwater. As disposal plans for the tanks are developed, the stewardship requirements can be expected to change.

A.3 200-Area Aquifer

At Hanford, an aquifer stretches from beneath the 200-Area in two directions to the Columbia River. Groundwater moves into the 200-Area from the neighboring basalt ridges and Cold Creek Valley situated to the west of Hanford. This groundwater moves under the 200-Area, becomes contaminated with radionuclides, hazardous chemicals, and moves away from the 200-Area in two directions, North and East. Contamination of this aquifer was caused by the historical liquid discharges to the U Pond, B Pond, and various cribs and trenches, dating from as early as the mid-1940s. The liquid effluent retention facility, single-shell tanks, and low-level burial grounds also appear to contribute waste to the 200-Area aquifer. The North arm of the aquifer, and East arm of the aquifer, both eventually discharge into the Columbia River. Contamination in the aquifer is defined by groundwater analysis performed in fiscal year 1996 [Hartman, 1997].

A.3.1 Contaminated Environmental Media Prior to Remediation

The aquifer is contaminated with both radionuclides and hazardous chemicals. The summary of the status of contamination, by environmental media, for the 200-Area Aquifer is provided in Table A.3.

Table A.3. Location of Existing Contamination at 200-Area Aquifer

Environmental Media	Status	Reference
Hazardous Structures	Absent	Refer to Section A.3
Air	Uncontaminated	Refer to Section A.3
Soil/Biota	Uncontaminated	Refer to Section A.3
Unconsolidated Geology	Contaminated	Hartman 1997
Bedrock Geology	Unknown Status	Hartman 1997
Groundwater	Contaminated	Hartman 1997
Surface water	Uncontaminated	Refer to Section A.3.1

A.3.2 Remediation Plans

No remediation plans are being considered for the East arm of the 200-Area aquifer. Remediation plans for the North arm of the aquifer consist of two (2) pump-and-treat systems for control of localized hot spots. A pump-and-treat system is in place on the north side of the 216-U-17 crib. The system is constructed to contain and treat elevated concentrations of uranium and technetium-99 in the groundwater. A pump-and-treat system is also located north of the Plutonium Finishing Plant. The system is constructed to contain and treat carbon tetrachloride, chloroform, and trichloroethylene.

A.3.3 Special Stewardship Requirements

Groundwater monitoring will continue according to plans given in the groundwater protection management plan [Barnett, 1995]. The existing pump-and-treat systems are committed to operate until contaminant concentrations are below the Maximum Contaminant Levels (MCLs).

A.4 B Plant

This facility is located in the approximate middle of Hanford. The plant was constructed between 1943 and 1945, and was originally designed to process spent nuclear fuels in support of the Manhattan Project. After its original mission was completed, the plant was modified to separate strontium and cesium from the fission-product waste stream from the PUREX Plant. B Plant is representative of other Hanford nuclear facilities, i.e., canyon buildings (e.g., Plutonium Finishing Plant or PUREX Plant) and the plutonium production reactors. These facilities have unique stewardship requirements because of the sizeable amounts of residual radioactive contamination that will remain, and the hazards inherent to the structures.

Building 221-B (i.e., B Plant) is a reinforced concrete structure. The processing portion of the plant consists of a canyon and craneway, 40 process cells, a hot pipe trench, a ventilation tunnel, and a railroad tunnel. B Plant was eliminated from future processing missions, and a shutdown order was issued in 1995 [WHC, 1996b].

In this proof-of-principle analysis, it is assumed that B Plant is sealed in place, with all residual contamination contained within the structure. It is further assumed that no structure failure would occur that would allow release of the contaminants to the ambient environment. In addition, it is assumed that B Plant will have barriers to access and warning signs posted.

A.4.1 Contaminated Environmental Media Prior to Remediation

The legacy of B Plant's long history of radiochemical separation processes is a substantial inventory of poorly characterized radioactivity. This inventory is in the form of stored process liquids (including liquid organics); kilocurie quantities of solid particulate strontium and cesium, contained in underground high-efficiency particulate air (HEPA) filters; and a highly contaminated facility structure [WHC, 1996c]. The status of environmental contamination prior to remediation is presented in Table A.4.

Table A.4. Location of Existing Contamination at B-Plant

Environmental Media	Status	Reference
Hazardous Structures	Contaminated	WHC 1996c
Air	Assumed Uncontaminated	Refer to Section A.4. 1
Soil/Biota	Absent	WHC 1996c
Unconsolidated Geology	Assumed Uncontaminated	Refer to Section A.4.1
Bedrock Geology	Unknown Status	WHC 1996c
Groundwater	Assumed Uncontaminated	Refer to Section A.4. 1
Surface water	Absent	WHC 1996c

A.4.2 Remediation Plans

Although remediation plans for B Plant are not yet final, it is assumed in this analysis that remediation efforts will include; removal of detachable components from inside the structure, removal or plugging of all pipe works from the structure, removal of all power lines from the structure, stabilization of liquid wastes, decontamination of the exterior, construction of an exterior envelope, and construction of access barriers and warning signs around the structure. No access to the interior of the structure is expected post-remediation [WHC, 1996c].

A.4.3 Special Stewardship Requirements

No post-remediation monitoring plans were located for B Plant. However, it is inferred that long-term maintenance of the building's access barriers and warning signs will be required. In addition, the physical structure of B Plant will need periodic inspection, to ensure that it can safely contain the radioactivity within the structure [WHC, 1996c]. Air monitoring and environmental dosimetry may be necessary to detect failure of the structure to contain contamination.

A.5 100 B/C Area Retention Basins

The 100 Area is one of four areas at Hanford that have been included on the U.S. Environmental Protection Agency's National Priority List under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980[Public Law 96-510]. The 100 Area is located in the north-central part of Hanford along the southern shoreline of the Columbia River. Between 1943 and 1962, nine water-cooled, graphite-moderated, plutonium production reactors were built in the 100 Area. The nine reactors have ceased operations.

Liquid radioactive effluent disposal sites that have leaked contaminants into the groundwater -- and subsequently into the Columbia River -- are selected in the 100 Areas Record of Decision

[USDOE, 1995b] as high-priority waste sites for remediation. One of these high-priority waste sites is evaluated in this proof-of-principle analysis. The waste site chosen includes the 116-C-5 retention basins, a set of two circular steel tanks set on a concrete liner. The 100 B/C Retention Basins are a part of the Operable Unit 100-BC-1 (surface) and 100-BC-5 (groundwater). Each tank is 101 meters in diameter and 5 meters deep. The basins held cooling water from the B and C Reactors for cooling and radionuclide decay before release into the Columbia River. Failure of the basins resulted in large leaks of effluent to the soil. According to a feasibility study for the 100-BC-1 Operable Unit [USDOE,1994b], 23,805 cubic meters of soil were contaminated at the 116-C-5 retention basins.

A.5.1 Contaminated Environmental Media Prior to Remediation

The current contamination status of the environmental media of the 100 B/C Area retention basins is shown in Table A.5. The 100 B/C Area retention basins have documented contamination in the soil, groundwater, surface water, and unconsolidated geology. The air medium is also considered contaminated because of resuspension of the contaminated soils.

Table A.5. Location of Existing Contamination at 100 B/C Area Retention Basins

Environmental Media	Status	Reference
Hazardous Structures	Absent	USDOE 1995b
Air	Contaminated	USDOE 1994a
Soil/Biota	Contaminated	USDOE 1994a
Unconsolidated Geology	Contaminated	USDOE 194a
Bedrock Geology	Unknown Status	USDOE 1994a
Groundwater	Contaminated	USDOE 1993
Surface water	Contaminated	USDOE 1994a

A.5.2 Remediation Plans

According to the Record of Decision for the 100 Areas [USDOE, 1995b], execution of the remediation plans will: (1) remove contaminated soil (to a maximum of 5 meters depth), remove structures, and debris; (2) conduct soil washing for volume reduction or to meet waste-disposal criteria; (3) dispose of contaminated materials at the Environmental Restoration Disposal Facility; and (4) backfill excavated areas followed by revegetation. The groundwater at the 100 B/C Area retention basins is not currently scheduled for remediation.

A.5.3 Special Stewardship Requirements

Monitoring Plan: Groundwater will be monitored to ensure compliance with the Safe Drinking Water Act--Maximum Contaminant Levels [4OCFR141]. The point of compliance will be beneath or adjacent to the waste site in the groundwater. Surface water will be monitored to ensure compliance with the Clean Water Act, using the ambient water quality criteria to measure protection of fish. The point of compliance will be a near-shore well downgradient from the waste site [USDOE, 1995b].

Access Restrictions: Institutional controls will be implemented until site monitoring indicates compliance with contaminant concentration limits in the groundwater and surface water [USDOE, 1995b].

APPENDIX B
Materials and Methods Used in Residual Risk Determination

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List of Tables

B.1 Introduction

This appendix provides detailed discussion of the methods and data used to estimate the stewardship levels, and their respective time frames, for the five study locations presented in the report.

B.2 Source Terms and Selecting Contaminants of Concern

The source term for this analysis was established, by definition, as the individual contaminants and their respective concentrations, that current planning documents state will remain after all remediation and cleanup activities are completed. The documents reviewed to determine the source terms, as well as the derived source terms, and any special stewardship requirements are discussed in detail in Appendix A.

The documents, from which the source terms were derived, are required to be non-classified, available in hardcopy format, and to directly address the study location in question. No interpretation is made of information presented in the reviewed documents. The authors do not question the accuracy or validity of the information presented in the documents -- all data are accepted as presented. Further, the feasibility of cleanup goals presented in the documents is not considered in this work. Cleanup goals, including time frames, are accepted as presented in the documents.

Because of project scope requirements, the total number of contaminants identified at a study location are not used to estimate residual risk. The total list of contaminants is reviewed; and contaminants with the highest concentrations, highest human toxicity, and greatest mobility are selected as contaminants of concern for each study location. The data for these contaminants of concern are used to make estimates of residual risk. This method yields results, which are study-location-specific, reproducible, and meet the requirements for a proof-of-principle demonstration. In application, all contaminants that add to human risks or to ecological risks should be used to estimate the residual risks. The contaminants of concern used to estimate the residual risks at the five (5) study locations are presented below. The reasons and assumptions used are discussed for each study location.

B.2.l Nonradioactive Dangerous Waste Landfill (NRDWL)

The unconsolidated geology is the only environmental medium that is currently contaminated. No remediation is planned; therefore, the unconsolidated geology is the only medium that will remain contaminated immediately post-remediation. This is expected to change as contaminants migrate from the landfill cells. For this analysis, it is assumed that the groundwater is not contaminated. Therefore, the aquifer is considered contaminant-free, and the analysis represents the impact from future landfill leaching only.

Table B.l provides a summary of the hazardous wastes that will remain in the unconsolidated media after landfill closure, i.e. at the start of stewardship. No cleanup goals are established for the unconsolidated geology. The chemicals used in this proof-of-principle analysis are trichloroethylene (assumed 4,400 kg), methyl ethyl ketone (assumed 4,400 kg), and sulfuric acid (assumed 430 kg).

Table B.1. Summary of Hazardous Wastes at the NRDWL

Hazardous Waste Chemicals	Amount	Units	Reference
Solvents and Paints	8,800	kilograms	USDOE 1990
Cyanides and Sulfides	30	kilograms	USDOE 1990
Mineral Acids	430	kilograms	USDOE 1990
Asbestos	28,000	cubic meters	USDOE 1990

The selection of these chemicals is based upon toxicity, quantity, environmental stability, and other factors affecting their availability. Trichloroethylene was selected because of its high potency for cancer induction, large amount placed in the landfill, stability in the environment, and water solubility factors. Methyl ethyl ketone was selected because of its high systemic toxicity, large amount placed in the landfill, stability in the environment, and water solubility factors. Sulfuric acid was selected as a proxy for the many acids placed in the landfill. The acids are of interest because they can greatly alter the mobility and toxicity of heavy metals placed in the landfill in the form of paints and lab chemicals. It is assumed that the acids will carry the heavy metals through the environmental media to the exposure points.

B.2.2 200-Area Tank Farms

Remediation of the tanks, via removal of at least 99% by volume of the existing contamination, will leave considerable residual contamination. This residual contamination will be released over time into other environmental media.

The tanks will remain in place underground following remediation. However, their venting systems and pipe structures will remain on the surface. Eventually, the earthen cover above the tanks will erode, and the domes of the tanks will collapse. Thus, the tank structures themselves (minus the chemical and radiological hazards) are considered hazardous because of confined-space hazards, falling object hazards, and height hazards.

The contaminants evaluated for this portion of the tank remediation stewardship are selected from the contaminants reported to be associated with the greatest human health risks in Buck et al. [1995a]. The objective of that analysis is to qualitatively rank Hanford high-level waste tanks according to their potential public health impacts through various exposure pathways. The contaminants evaluated in this analysis are Carbon-14, Iodine-129, Technetium-99, Selenium-79, and Uranium-235. Table B.2 shows the inventory of the contaminants of concern used as the source term for the 200-Area Tank Farms.

Table B.2. Source Term Inventory for 200-Area Tank Farms

Parameter	C-14	1-29	Se-79	Tc-99	U-235
Volume(cm^3)	1.18E+09	1.18E+09	1.18E+09	1.18E+09	1.18E+09
Inventory (Ci)	80.5	0.243	4.63	183	0.103

B.2.3 200-Area Aquifer

The maximum concentration of selected contaminants in the 200-Area Aquifer is shown in Table B.3. The contaminants listed had samples that exceeded or are close to exceeding the U.S. Environmental Protection Agency's Drinking Water Standard or the Maximum Contaminant Level (MCL) [40 CFR 141]. Remediation Plans for the 200-Area Aquifer contend that existing pump-and-treat operations will remove the existing contaminants until their concentrations are below their respective MCLs. Therefore, this analysis uses the MCL for the contaminants listed in Table B.3 to determine the human health risk of cancer directly following remediation.

Table B.3. Contaminant Concentrations in the 200-Area Aquifer, FY 1996

Contaminant	Maximum Concentration	MCL
Tritium	1,100,000 pCi/L	20,000 pCi/L
Strontium-90	3,100 pCi/L	8 pCi/L
Technetium-99	21,000 pCi/L	4 mrem/y
Iodine-1 29	66 pCi/L	4 mrem/y
Uranium	2.8 mg/L	4 mrem/y
Chromium	0.29 mg/L	0.1 mg/L
Nitrate	1,l00 mg/L	l0 mg/L
Carbon tetrachloride	4.3 mg/L	4.3 mg/L
Trichloroethylene	0.01 mg/L	0.005 mg/L

Of the nine chemicals with measured concentrations above the MCL in the 200-Area Aquifer (refer to Table B.3), two are selected for determination of residual risk in this proof-of-principle analysis. Technetium-99 is selected because of its availability to living organisms and its mobility in the environment. Carbon tetrachloride is selected because of its high potency for cancer induction, stability in the environment, and water solubility factors.

Remediation Plans for the 200-Area Aquifer contend that existing pump-and-treat operations will remove the existing contaminants until their concentrations are below their respective MCLs. Therefore, this analysis uses the MCL, for both Technetium-99 and carbon tetrachloride, as the source term for determination of the residual risk presented by the 200-Area aquifer. For Technetium-99, the source term selected is 2.10E-11 curies per milliliter of groundwater (Ci/ml). For carbon tetrachloride, the source term selected is 4.3E-09 grams per milliliter of groundwater (g/ml).

B.2.4 B Plant

It is assumed that residual radioactive contaminants contained in B Plant in post-remediation will remain in the structure and will not migrate to other media. Therefore, hazardous structures are the only media considered for analysis. The interior of the structure is expected to be highly contaminated with residual strontium and cesium. In addition to the radiation hazard, it is expected that the structure itself will present physical hazards (e.g., tripping, failing-objects, and confined space hazards) to anyone gaining access to the building for monitoring, surveillance, repairs, or unofficial reasons. Table B.4 shows the residual radiological inventory expected to be in B Plant following planned remediation [WHC, 1996b & 1996c].

Table B.4. B Plant Radiological Inventory [WHC, 1996c]

Location	Sr90 Curies	Cs137 Curies	Pu239 grams
Cells	9,096	13,644	0
Cells	2,420	3,630	0
Pipes	1,250	850	0
Filter A	12,000	18,000	1
Filter B	29,000	43,000	1
Filter C	16,000	25,000	1
Filter D	50,000	550,000	1
Sand Filter	3,000	2,000	11
Canyon	400,000	600,000	0
Cask Loading	400	600	0
Total	523,166	1,256,724	15

Cesium-137 and Strontium-90 were used for this analysis. Plutonium-239 is not used because of uncertainty regarding its post-remediation location. The source term used for Strontium-90 is 523,166 Curies, and the source term used for Cesium-137 is 1,256,724 Curies.

B.2.5 100 B/C Area Retention Basins

The current contaminant concentrations are taken from the *Limited Field Investigation report for the 100-BC-1 Operable Unit* [USDOE, 1994a] for soils and unconsolidated geology and from the *Limited Field Investigation report for the 100-BC-5 Operable Unit* [USDOE, 1993] for groundwater. The contaminant inventories by environmental media are presented in Table B.5.

Table B.5. Contaminant Inventory for the 11 6-C-S Retention Basins

	Groundwater Concentration (pCi/L)	**Soil Concentration at 0-5m depth (pCi/kg)**	**Soil Concentration at 5-8 m depth (pCi/kg)**
Radionuclides			
Am-241	NR	6.98E+05	4.00E-03
C-14	4.10E+02	2.56E+08	4.10E-01
Cs-134	NR	2.40E+03	3.91E-03
Cs-137	NR	6.25E+03	8.30E+01
Co-60	NR	1 .45E+03	5.00E+01
Eu-152	NR	3.47E+03	1 .72E+02
Eu-154	NR	3.05E+03	4.83E+01
Eu-155	NR	2.12E+05	3.32E+00
H-3	2.40E+04	4.27B+09	ND
Pu-239	NR	1.00E+06	1.90E+00
Sr-90	5.70E+01	6.41E+06	5.43E+00
Tc-99	9.30E+01	1.76E+08	ND
Th-228	2.00E+01	2.23E+03	4.40E+00
Inorganics	(mg/L)	(mg/kg)	(mg/kg)
Cadmium	NR	4.00E+01	8.40E-01
Chromium*	1.1 7E-01	4.00E+02	ND
Thallium	1.30E-03	5.60E+00	NR
* valance state not specified. ND = Not Detected NR=Not Reported			

Contaminant concentrations in the unconsolidated geology, between five (5) meters and eight (8) meters in depth, are assumed unchanged. Thus, contaminate concentrations given in USDOE [1994b] are used in this analysis. Contaminant concentrations in the unconsolidated geology below eight (8) meters are unknown.

Cleanup criteria call for removal of contaminated soils or unconsolidated geology to a maximum depth of five (5) meters. For inorganic chemicals, the State of Washington's Model Toxics Control Act [WAC 173-340] is used to determine allowable contaminant concentrations. For radionuclides, a contaminant concentration equivalent to fifteen (15) mrem/y dose, above background and from all pathways [40 CFR 196], is specified.

The remediation criterion of fifteen (15) mrem/y dose gives insufficient information for stewardship evaluation. The criterion is in the metric "dose" and stewardship evaluation is measured in the metric "harm". To convert dose into the metric harm, or vice versa, requires numerous assumptions. The amount of "harm" a specified "dose" will yield is dependent upon the receptor receiving the dose, the pathway by which the dose enters the body, the radionuclide delivering the dose, and the organ system impacted by the dose.

Because of gaps in the existing characterization data and insufficiently defined remediation goals, analysis of the 100 B/C Area Retention Basins cannot be completed. A determination of the contaminants of concern cannot be made on the existing information. Therefore, the stewardship requirements for this study location cannot be calculated.

B.3 Modeling Contaminant Movement and Residual Concentrations

The Multimedia Environmental Pollutant Assessment System (MEPAS) [Buck, 1 995b; Whelan, 1987] was used to model the movement of contaminants thorough the environmental media that are applicable to each study location. Starting with source terms for the contaminants of concern, for each study location, concentration of the contaminant is calculated at its exit from the media. If the contaminant enters another medium upon its exit from these media (such as from unconsolidated geology into groundwater, or from groundwater into surface water), the exit concentration is used as the source term for the next media.

Residential exposure scenarios are used to determine residual risks and are calculated at a predetermined location, within each medium, that corresponds to a potential exposure point. The exposure parameters used by the residential exposure scenarios are published in *Evaluation of Unit Risk Factors in Support of the Hanford Remedial Action Environmental Impact Statement* [Strenge, 1994]. For this proof-of-principle analysis, MEPAS computer runs made for previous studies are used to determine contaminant concentrations at potential exposure points. New studies using this methodology would need to run MEPAS (or comparable environmental fate and transport program) to determine the contaminant concentrations for calculating residual risks.

Study locations that do not require migration modeling (e.g., sealed building, entombed reactors) base residual risk calculations upon the decay time, or half-life, of the contaminants. This is accomplished by determining the time required for contaminants to decay to a level of acceptable risk of disease.

B.3.1 Nonradioactive Dangerous Waste Landfill (NRDWL)

For this proof-of-principle analysis, MEPAS computer runs made for previous studies are used to determine contaminant concentrations at the potential exposure points. For NRDWL, the movements of the contaminants are modeled from their origination point in the unconsolidated geology medium, downward to the groundwater medium. In the groundwater medium, movement of contaminants is calculated along the groundwater gradient to a discharge into the surface water medium.

It is assumed that the human exposure point for the unconsolidated geology medium is at the present landfill and that exposure to the unconsolidated material is direct. It is also assumed that the exposure point for the groundwater medium is 0.4 km down gradient (East, 900) of the landfill and, for the surface water medium, the City of Richland potable water intake structure 6.44 km downstream of the outfall. The contaminant fate and transport modeling results from the *Hanford Remedial Action Environmental Impact Statement* [USDOE, 1 996a] are used in this proof-of-principle analysis to predict the fate and transport, whereas exposure concentration for the contaminants of concern are from *Evaluation of Unit Risk Factors in Support of the Hanford Remedial Action Environmental Impact Statement* [Strenge, 1994). The fate and transport modeling was completed in 1995. Any media concentrations, exposure concentrations, or human health risks presented in this work are limited to the accuracy of the referenced reports, and to the extent that conceptual models and input parameters between the studies agree.

B.3.2 200-Area Tank Farms

For this proof-of-principle analysis, MEPAS computer runs made for previous studies are used to determine contaminant concentrations at the potential exposure points. For 200-Area Tank Farms, movements of contaminants are modeled from their origination point in the unconsolidated geology medium, downward to the groundwater medium. In the groundwater medium, movement of contaminants is calculated along the groundwater gradient to a discharge into the surface water medium. The tank structures proper are treated as a hazardous structure medium that required no transport modeling of contaminants.

It is assumed that the human exposure point for the unconsolidated geology medium is at or near the tank farm complex and that exposure to the unconsolidated material is direct. The exposure point for the groundwater medium is assumed to be 16.1 km down gradient (East, 90^{o}) of the tank farm, and for the surface water medium the City of Richland potable water intake structure 32.2 km downstream of the outfall. The contaminant fate and transport modeling results from the *Hanford Remedial Action Environmental Impact Statement* [USDOE, 1996a] are used in this proof-of-principle analysis to predict the fate and transport, whereas exposure concentration for the contaminants of concern are from *Evaluation of Unit Risk Factors in Support of the Hanford Remedial Action Environmental Impact Statement* [Strenge, 1994]. The fate and transport modeling was completed in 1995. Any media concentrations, exposure concentrations, or human health risks presented in this work are limited to the accuracy of the referenced reports and to the extent that conceptual models and input parameters between the studies agree.

B.3.3 200-Area Aquifer

For this proof-of-principle analysis, MEPAS computer runs made for previous studies are used to determine contaminant concentrations at the potential exposure points. For 200-Area Aquifer, movements of contaminants are modeled from their origination point in the groundwater medium. In the groundwater medium, movement of the contaminants is calculated along the groundwater gradient to a discharge into the surface water medium.

For the groundwater medium, the human exposure point is assumed a well in and around the 200 East Area of Hanford, located in the path of the maximum groundwater contaminant concentrations. For the surface water medium, the human exposure point is assumed the City of Richland potable water intake structure 32.2 km downstream of the groundwater outfall to the Columbia River. The contaminant fate and transport modeling results from *The 1996 Baseline Environmental Management Report* [USDOE, 1996b] are used in this proof-of-principle analysis to predict the fate and transport, whereas exposure concentrations for the contaminants of concern are from *Evaluation of Unit Risk Factors in Support of the Hanford Remedial Action Environmental Impact Statement* [Strenge, 1994]. The fate and transport modeling was completed in *1995.* Any media concentrations, exposure concentrations, or human health risks presented in this work are limited to the accuracy of the referenced documents, and to the extent that the conceptual models and input parameters agree among the studies.

B.3.4 B Plant

The structure of B Plant proper is treated as a hazardous structures medium, that required no transport modeling of contaminants. All contaminants are assumed to remain within the structure, with no leakage or interaction with other environmental media, for the time increment often (10) half-lives of the longest lived radionuclide.

B.3.5 100 B/C Area Retention Basins

For this proof-of-principle analysis, MEPAS computer runs made for previous studies are used to determine contaminant concentrations at the potential exposure points. For the 100 B/C Area Retention Basins, movements of contaminants are modeled from their origination point in the unconsolidated geology medium, downward to the groundwater medium. In the groundwater medium, the movement of contaminants is calculated along the groundwater gradient to a discharge into the surface water medium.

It is assumed that the human exposure point for the unconsolidated geology medium is the immediate retention basin area itself and that exposure to the unconsolidated material is direct. It is also assumed that the exposure point for the groundwater medium is 0.4 km down gradient (North, 0^o) of the contaminated area, and for the surface water medium, the City of Richland potable water intake structure 57.9 km downstream of the outfall. The contaminant fate and transport modeling results from the *Hanford Remedial Action Environmental Impact Statement* [USDOE, 1996a] are used in this proof-of-principle analysis to predict the fate and transport, whereas exposure concentration for the contaminants of concern are from *Evaluation of Unit Risk Factors in Support of the Hanford Remedial Action Environmental Impact Statement* [Strenge, 1994]. The fate and transport modeling was completed in 1995.

B.4 Calculating Risk and Criteria Comparison

The human health risks, that represent the residual risks, are calculated for each contaminant of concern at potential exposure points. The risks of both chronic disease and acute disease are calculated as part of this proof-of-principle analysis. However, only the risk of chronic disease is used to determine stewardship levels for this proof-of-principle analysis. The relationship between stewardship levels and risk is discussed in Section 1.3 *Stewardship Levels* in addition to the multi-step method for final stewardship level determination.

Both chronic human disease and acute human disease risks can be calculated and used to determine tentative and final stewardship level classifications. Acute disease risks are reported as a ratio of the calculated potential exposure over the daily acceptable exposure.

B.4.1 Nonradioactive Dangerous Waste Landfill (NRDWL)

The chemicals selected for use in this analysis for NRDWL are trichloroethylene, methyl ethyl ketone, and sulfuric acid. Trichloroethylene reaches its peak concentration (0.01 mg/l) at the groundwater exposure point in the year 2052 A.D., whereas methyl ethyl ketone reaches its peak concentration (0.03 mg/l) in the year 2041 A.D. Sulfuric acid reaches its peak concentration (0.19 mg/l) at the groundwater exposure point in the year 2043 A.D.

Given a residential exposure scenario, with home use of the contaminated groundwater, the calculated risk of cancer from trichloroethylene exposure is 8.0E-6. The risk of an adverse toxicological response to methyl ethyl ketone exposure was calculated to have a Hazard Index of 3.5E-2. The Hazard Index for sulfuric acid was calculated to be 1.0E00, but is also used as an indicator of potential heavy metal exposure because the metals in the landfill would become mobile in the acid environment and follow the acid to the receptor.

At the surface water exposure point, the contaminant trichloroethylene reaches its peak concentration (2.9E-6 mg/l) in the year 2053 A.D., methyl ethyl ketone reaches its peak concentration (8.9E-6 mg/l) in the year 2042 A.D., and sulfuric acid reaches its peak concentration (6.2E-5 mg/l) in the year 2044 A.D.

Given a residential exposure scenario, with home use of the contaminated surface water, the calculated risk of cancer from trichloroethylene exposure is 2.4E-9. The risk of an adverse toxicological response to methyl ethyl ketone exposure was calculated to have a Hazard Index of 1.1E-5. The Hazard Index for sulfuric acid was calculated to be 3.3E-4, but is also used as an indicator of potential heavy metal exposure because metals in the landfill would become mobile in the acid environment and follow the acid to the receptor.

The risk of cancer and other toxicological harm is near the Stewardship Level 2 levels for groundwater exposures. Because other contaminants, not analyzed in this proof-of-principle, are believed to move from the landfill to the groundwater, the designation of groundwater as a Stewardship Level 2 is warranted until the year 2100 A.D. The contaminants must move through the unconsolidated geology to travel to, and with, the groundwater; thus, the unconsolidated geology also warrants Stewardship Level 2. Because contaminants are removed quickly from the landfill and through the groundwater system, both the groundwater medium and the unconsolidated geology medium warrant Stewardship Level 4 after the year 2100 A.D.

For the surface water medium, the risk of cancer and other toxicological harm is within the Stewardship Level 3 criteria. Because the groundwater delivers contaminants to the surface water, once the contaminants have been removed (flushed) from the groundwater, the surface water will move the contaminants beyond the surface water exposure point soon afterward. Therefore, the surface water medium is at Stewardship Level 4 after year 2100 A.D.

B.4.2 200-Area Tank Farms

The chemicals selected for use in this analysis for the 200-Area Tank Farms are Carbon-14, Iodine-129, Technetium-99, Selenium-79, and Uranium-235. Carbon-14 reaches its peak concentration (3.2E-12 Ci/l) at the groundwater exposure point in the year 2135 A.D., whereas Iodine-129 reaches its peak concentration (1.1E-14 Ci/l) in the year 2136 AD. Technetium-99 also reaches its peak concentration (8.1E-12 Ci/l) in the year 2136 A.D., Selenium-79 reaches its peak concentration (2.1E-13 Ci/l) in the year 2135 A.D., and Uranium-235 reaches its peak concentration (4.1 SE- 16 Ci/l) at the groundwater exposure point in the year 3138 A.D.

Given a residential exposure scenario, with home use of the contaminated groundwater, the calculated risk of cancer from Carbon-14 exposure is 7.3E-7, for Iodine-129 exposure is 5.0E-8, for Technetium-99 exposure is 7.7E-7, for Selenium-79 exposure is 3.2E-8, and for Uranium-235 exposure is 5.1E-10.

At the surface water exposure point, Carbon-14 reaches its peak concentration (8.6E-16 Ci/l) in the year 2137 A.D., and Iodine-129 reaches its peak concentration (3.0E-18 Ci/l) in the year 2138 A.D. Technetium-99 reaches its peak concentration (1.4E-14 Ci/l) in the year 2136 AD., Selenium-79 reaches its peak concentration (1.3E-16 Ci/l) in the year 2135 A.D., and Uranium-235 reaches its peak concentration (5.2E-19 Ci/l) at the surface water exposure point in the year 3138 A.D. Given a residential exposure scenario, with home use of the contaminated surface water, the calculated risk of cancer from Carbon-14 exposure is 1.4E-9, for Iodine-129 exposure is 9.5E-11, for Technetium-99 exposure is1.4E-9, for Selenium-79 exposure is 6.0E-11, and for Uranium-235 exposure is1.0E-12.

The unconsolidated geology medium has initial concentration of 3,880 pCi/ $gram_{soil}$ for Carbon-14; 117 pCi/ $gram_{soil}$ for Iodine-129, 88,100 pCi/ $gram_{soil}$ l for Technetium-99, 2,230 pCi/ $gram_{soil}$ for Selenium-79, and 49.6 pCi/ $gram_{soil}$ for Uranium-235. It is assumed that the radionuclides will be present at near these concentrations until residual contaminants in the tank complex, which continually migrate to the unconsolidated geology, have decayed by ten (10) radiological half-lives. Direct exposure to the unconsolidated geology medium results in a calculated risk of cancer of 6.2E-5 for Carbon-1 4, 4.0E-4 for Iodine-129,4.6 for Technetium-99, 1.4E-4 for Selenium-79, and 3.4E-4 for Uranium-235.

The risk of cancer peaks at the Stewardship Level 2 levels for groundwater exposures between the years 2100 A.D. and 2200 A.D. Because the groundwater is currently contaminated, the groundwater starts at Stewardship Level 3, returns to Stewardship Level 3 after the year 2200 A.D., and remains at that level until the year 3000 A.D. The contaminants move through the unconsolidated geology at different speeds. This lag causes the risk of cancer from direct exposure to the unconsolidated geology to warrant Stewardship Level 2 through the year 2400 A.D., alter which Stewardship Level 4 is warranted.

For the surface water medium, the risk of cancer is within the Stewardship Level 3 criteria between the years 2100 A.D. and 2200 A.D. Because the groundwater delivers the contaminants to the surface water, once the contaminants have been removed (flushed) from the groundwater, the surface water will move the contaminants beyond the surface water exposure point soon afterward. Therefore, the surface water medium is at Stewardship Level 4 after year 2200 A.D.

The tank structures proper are considered hazardous structures that have contamination associated with the structure. Contamination is in the form of radionuclides that will decay over time and thus reduce to an acceptable range the risk of cancer from exposure. It is assumed that a decay time of ten (10) half-lives must pass in order for a safe level of radiation to exist. This is calculated to occur by the year 2400 A.D. for the 200-Area Tank Farms and, thus, the tanks warrant Stewardship Level 1 until the year 2400 A.D. Because the domes of the tanks will collapse, radionuclides within the tanks will have a direct route to the ambient air. Thus, the air medium will have the same risk as the tanks themselves, and thus warrant Stewardship Level 1 until the year 2400 A.D. The tank structures proper will remain a physical hazard that warrants Stewardship Level 2 for an indeterminate length of time.

B.4.3 200-Area Aquifer

The chemicals selected for use in this analysis for the 200-Area Aquifer are Technetium-99 and carbon tetrachloride. Technetium-99 has an initial concentration of 2.1E-5 Ci/l, at the groundwater exposure point, whereas at the same exposure point carbon tetrachloride has an initial concentration of 4.3E-3 mg/l. It is assumed that no new contaminants enter the 200-Area Aquifer and that the residual contaminants are carried to the Colombia River via groundwater outfall. Given a residential exposure scenario, with home use of the contaminated groundwater, the calculated risk of cancer from Technetium-99 exposure is 2.0E-3 and for carbon tetrachloride exposure is 1 .7E-5, in addition the Hazard Index for carbon tetrachloride is 2.1E-5.

By the year 2002 A.D., contaminants in the aquifer under the 200-Area have traveled to, and been discharged into, the Columbia River. Within this time frame, Technetium-99 reaches a peak concentration of2.1E-8 Ci/l, and carbon tetrachloride reaches its peak concentration of 4.3E-6 mg/l, at the surface water exposure point. Given a residential exposure scenario, with home use of the contaminated surface water, the calculated risk of cancer from Technetium-99 exposure is 2.1E-6, and for carbon tetrachloride exposure is 3.2E-8, in addition the Hazard Index for carbon tetrachloride is 2.1E-8.

The unconsolidated geology medium for this study location is, by definition only, the unconsolidated geologic material that holds the aquifer. It is assumed that unconsolidated geologic material is in chemical equilibrium with the groundwater, which flows through this medium. Thus, the residual risks for the unconsolidated geology medium are equal to the risks calculated for the aquifer, with a lag of approximately five years caused by the phenomenon of chemical movement retardation in a porous, but electronically charged, medium. This lag time assumes that, alter the year 2000 A.D., no contaminants enter the aquifer.

The risk of cancer from groundwater exposures warrants Stewardship Level 2, between the years 2000 A.D. and 2100 A.D. Because the groundwater is currently contaminated, the groundwater starts at Stewardship Level 2, returns to Stewardship Level 4 after the year 2100 A.D., and remains at that stewardship level. The unconsolidated geology medium also warrants Stewardship Level 2 through the year 2100 A.D., based on the risk of cancer from direct exposure to the unconsolidated geology. After the year 2100 A.D., the risk of cancer from direct exposure to the unconsolidated geology medium warrants Stewardship Level 4.

For the surface water medium, the risk of cancer is within Stewardship Level 3 criteria between the years 2000 A.D. and 2100 A.D. Because the groundwater delivers the contaminants to the surface water, once contaminants have been removed (flushed) from the groundwater, the surface water will move the contaminants beyond the surface water exposure point soon afterward. Therefore, the surface water medium warrants Stewardship Level 4 after year 2100 A.D.

B.4.4 B Plant

The B Plant structure proper is considered a hazardous structure that has contamination associated with the structure. The contamination is in the form of radionuclides that will decay over time, and thus reduce the risk of cancer from exposure to an acceptable range. It is assumed that a decay time often (10) half-lives must pass in order for a safe level of radiation to exist. This is calculated to occur by the year 2400 A.D. for B Plant. Thus, B Plant warrants Stewardship Level 1 until the year 2400 A.D. The B Plant structures proper will remain a physical hazard that warrants Stewardship Level 2 for an indeterminate length of time.

B.4.5 100 B/C Area Retention Basins

Because of the vague nature of the remediation plans for the 100 B/C Area Retention Basins, it is impossible to scientifically determine initial source concentrations for the contaminants of concern. Thus, no fate and transport modeling is preformed for the 100 B/C Area Retention Basins, no potential human health risks are calculated, and no stewardship levels are assigned to the applicable environmental media.

APPENDIX C
Materials and Methods Used in Residual Risk Determination

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C.1 Introduction

Typically as remediation increases, the need for stewardship decreases. Consider two extremes. If remediation successfully removes one hundred percent (100%) of all hazards, there are no subsequent stewardship requirements. Conversely, in the absence of remedjation, protection of public health and the environment becomes the obligation of a stewardship program. Still and all, the most likely scenario is that remediation work will remove contamination that is affordable and technologically feasible to remove, while a stewardship program will protect public health and the environment from the affects of residual contamination.

To correctly plan remediation work, it is necessary to understand the influence of essential parameters on the relationship between remediation and stewardship. This proof-of- principle examines a new stewardship methodology to use to bridge this gap. The methodology takes environmental data to determine a location's future Stewardship Levels. As such, the proof-of-principle methodology itself is independent of the methods used to measure or model environmental parameters, and the interactions among environmental parameters. However, reviewers felt that a sensitivity analysis would enhance the understanding of how Stewardship Levels are influenced by major environmental parameters. A sensitivity analysis is a systematic and objective method, used to determine the relative influence of various parameters on an outcome (in cases where multiple parameters describe a system.).

Any parameter will influence an outcome. Typically, however, some parameters will influence an outcome, to a higher degree than will other parameters. The sensitivity analysis is one approach used to answer the following question: How does the activity and half-live of a radioactive contaminant affects the level and duration of stewardship?

The results of the sensitivity analysis are very linear over time, because of the inherent linearity of radioactive decay over time, and (although equivocal) the linearity of the dose-response relationship for radionuclides.

Section C.4 compares the sensitivity analysis performed and reported in Sections C. 1 -C.3 herein, to another report titled "Sensitivity Analysis of Computer Codes," (Doctor 1990). Doctor 1990 is a different, but related sensitivity analysis, conducted on certain fate and transport parameters. Such parameters also influence Stewardship Level and duration. Doctor, 1990 also analyzes parameter sensitivity in the fate and transport model, used in this proof-of- principle, i.e., the Multimedia Environmental Pathway Analysis System (MEPAS). The environmental parameters are generally applicable to any type of fate and transport model.

C.2 Methodology

This section presents the methodology used to perform the stewardship sensitivity analysis.

The sensitivity analysis considers two basic parameters, i.e., (1) the activity of a radionuclide, and (2) the radioactive half-life. The two parameters are induced to vary, mathematically; hence, indirectly deciding the Stewardship Level and duration. In this statistical relationship, all parameters are kept constant (controlled variables), except the independent parameters of activity and half-life (independent variables).

C.2.1 Activity of a Radionuclide

Plutonium 238 (Pu-238) is the test radionuclide for the sensitivity analysis. Plutonium 238 has a relatively short half-life of 2.77E+09 seconds----comparable to the average half-life of various radionuclides detected in wastes stored in the High-Level Waste Tanks.

The analysis assumes that eight different activity levels of Plutonium 238 (expressed here in curies) exist at starting or initial conditions (termed "Time Zero"). The methodology makes eight separate evaluations, which correspond to the eight different activity levels. Over time, radioactive decay reduces the amount of activity initially present. The analysis extrapolates the decrease in Plutonium 238 activity, over a span of 2,000 years. The resulting activity levels are the exposure source terms, from which an associated excess cancer risk caused by external radiation exposure is calculated. Finally, the excess cancer risk is screened for stewardship applicability and the resulting Stewardship Level and duration is plotted.

C.2.2 Radioactive Half-life

To assess the consequences of radioactive half-life on the duration of stewardship at each Stewardship Level, the evaluation use a hazardous structure. In the proof-of- principle report, a hazardous structure is classed as "medium," and includes such examples as the Hanford High-Level Waste Tanks. Using a hazardous structure (medium) to assess consequences eliminates the need to account for the influence of many variables that affect environmental transport of radionuclides, and may serve only to confound the results.

The examination evaluates eight radionuclides; each radionuclide has a different half-life (expressed here in "5" for seconds), and each radionuclide has reportedly been detected in tank waste samples. Table C. 1, "Radionuclides Evaluated, Activity (at Time Zero) and Half-Lives," lists the starting/initial conditions ("Time Zero") half-lives, of the eight radionuclides selected. For Time Zero, the analyses assume that all eight radionuclides have an identical activity, 5E+05 curies. Over time, radioactive decay reduces the amount of activity initially present. The analysis extrapolates the decrease in activity, over a span of 2,000 years. The resulting activity levels are the exposure source terms, from which an associated excess cancer risk, from external radiation exposure is calculated. Finally, the excess cancer risk is screened for stewardship applicability, and the resulting Stewardship Level is plotted. Radionuclides evaluated, and their corresponding radioactive half-lives are presented in Table C.1

Table C.1. Radionuclides Evaluated, Activity (at Time Zero) and Half-Lives

		Time Zero	
Radionuclide	Symbol	Activity (Ci)	Half-Life (s)
Uranium-238	U238	5.0E+05	1.41E+17
Neptunium-237	NP237	5.0E+05	6.75E+13
Plutonium-239	PU239	5.0E+05	6.75E+1 1
Plutonium-238	PU238	5.0E+05	2.77E+09
Cesium-134	C5134	5.0E+05	6.5E+07
Barium-137m	BA137M	5.0E+05	2.2E+05
Antimony- 126	SB 126	5.0E+05	1.1 4E+03
Protactinium-234m	PA234M	5.0E+05	7.02E+0 1

C.3 Results and Discussion

Figures C.1 and C.2 present the results of the sensitivity analysis in graphical form. This section interprets and discusses the study's findings. The process of assigning Stewardship Levels and duration is sensitive to (or influenced by) the parameters studied, a radionuclide's activity and half-life.

C.3.1 Stewardship Level versus Activity of a Radionuclide

Figure C.1, "Stewardship Level as a Function of Radioactivity and Time," displays the three-dimensional relationship that exists among time, Stewardship Level and duration of stewardship, activity (an independent variable in the statistical analysis). The figure shows the strong influence (sensitivity) of Time Zero activity on Stewardship Level and duration.

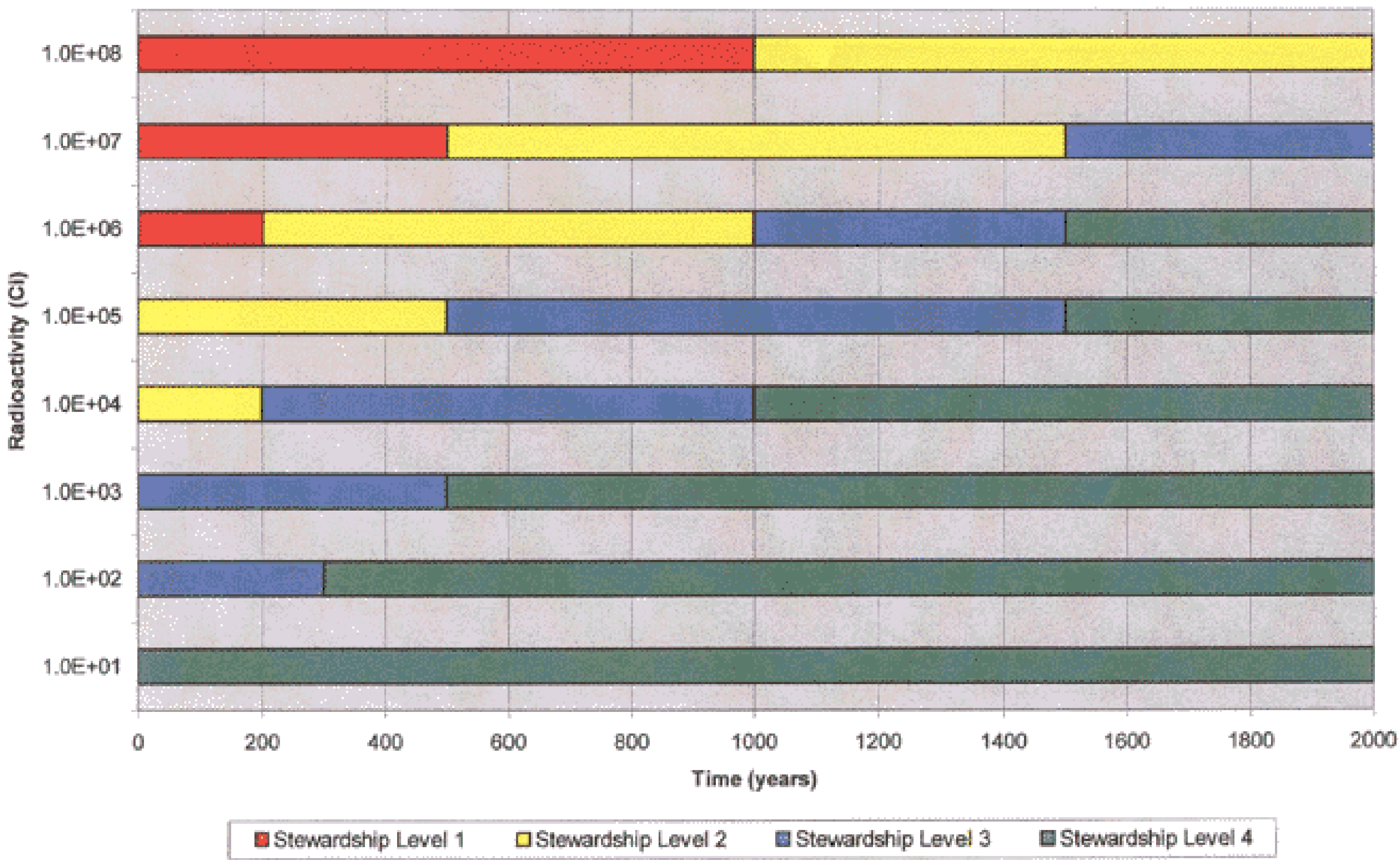
The dominant relationship or trend is that the higher the Plutonium 238 Time Zero activity, the higher the prescribed Stewardship Level and the longer its duration. In other words, the greater the hazard, the greater the safety precautions. The more radioactive waste remains in the post-remediation phase, the more demanding the stewardship requirements of that site.

Reasonably, this relationship will exist in assessing stewardship needs for environmental media, other than hazardous structures. However, biological and physical forces, that influence contaminant toxicity and transport, will modify the actual results.

C.3.2 Stewardship Level versus Radioactive Half-life

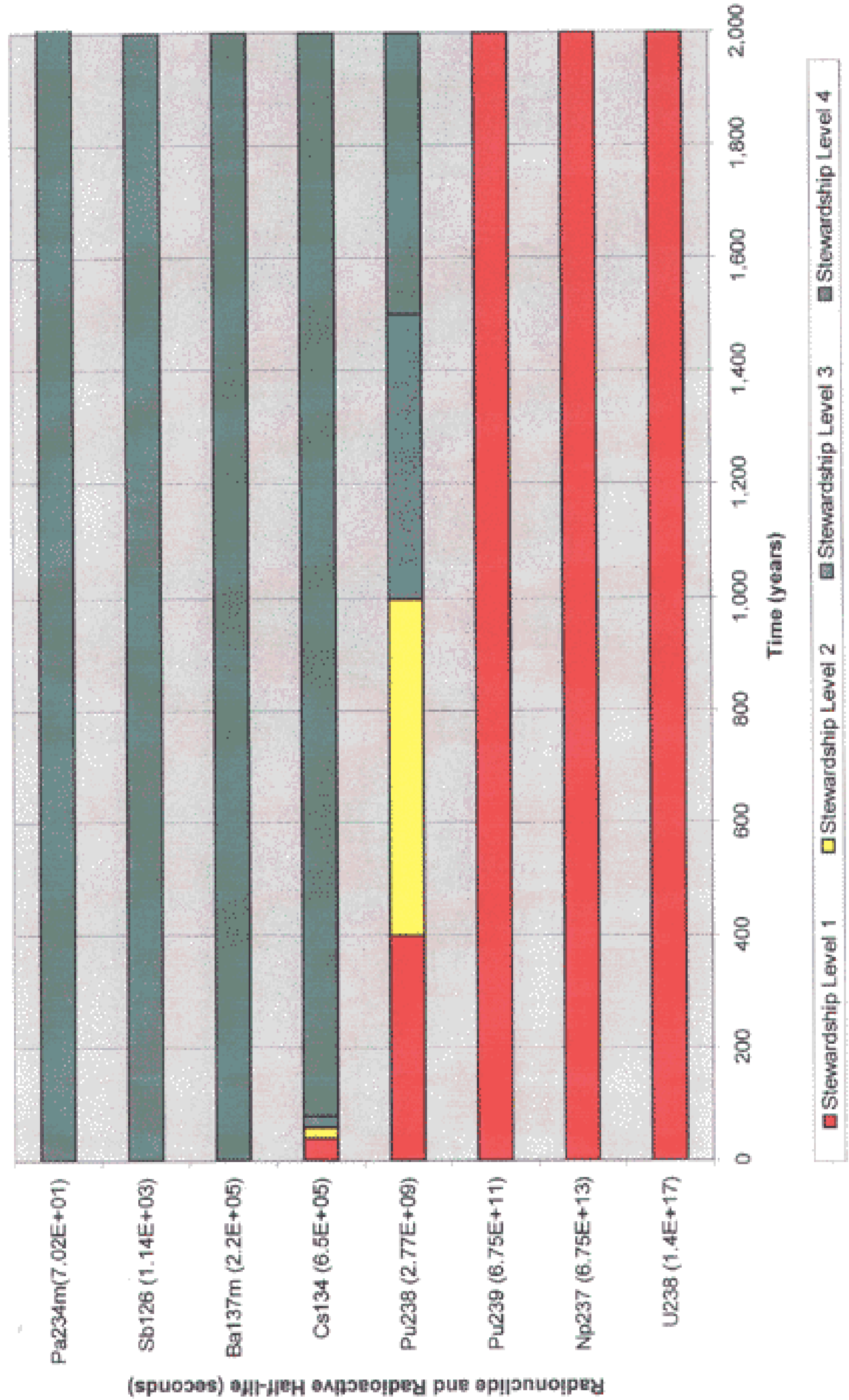
Figure C.2, "Stewardship Level as a Function of Radioactive Half-Life and Time," depicts the three-dimensional relationship that exists among the level and duration of stewardship, half-life (an independent variable in the statistical analysis), and time. The figure shows the strong

Figure C.1. Stewardship Level as a Function of Radioactivity* and Time



* Calculations based on various activities of Pu238.

Figure C.2. Stewardship Level as a Function of Radioactive Half-life and Time



influence (sensitivity) of radioactive half-life on Stewardship Level and duration.

The dominant relationship or trend is that the longer the radionuclide's half-life, the more rigorous the prescribed Stewardship Level and the longer its duration. In other words, the longer the hazard remains; the longer safety precautions must remain. The longer the radioactive waste will exist in the post-remediation phase, the more demanding the stewardship requirements prescribed for that site.

Figure C.2 also demonstrates that for radionuclides with half-lives, near or below 1.0E+05 seconds, little or no stewardship concerns exist. Conversely, for radionuclides with radiological half-lives near or greater than 1.0E+l 1 seconds, no alternative to the most stringent, long-term care (i.e. Stewardship Level 1) is available.

Logically, this relationship will exist in assessing stewardship needs for environmental media, other than hazardous structures. However, biological and physical forces, that influence contaminant toxicity and transport, will modify the actual results.

C.4 Sensitivity Analysis on Fate and Transport Parameters

This section compares the sensitivity analysis performed and reported in Sections C.1-C.3 herein, to another report titled "Sensitivity Analysis of Computer Codes," (Doctor 1990). This section also summarizes the pertinent aspects of a related sensitivity analysis conducted on fate and transport parameters (Doctor, 1990). Doctor 1990 is a different, but related sensitivity analysis, conducted on certain fate and transport parameters. Such parameters also influence Stewardship Level and duration. Doctor, 1990 also analyzes parameter sensitivity in the fate and transport model, used in this proof-of- principle, i.e., the Multimedia Environmental Pathway Analysis System (MEPAS). The environmental parameters are generally applicable to any type of fate and transport model. The sensitivity analysis addresses the sensitivity of public health risks to basic forces that influence contaminant fate and transport.

In a situation of contaminants transport via suspension into the ambient air, the dominant parameter that influences exposure is wind speed. This has application to Remediation Sites with exposed waste piles, contaminated soils, and deterioration of buildings containing contaminants. The general tendency is that the higher the wind speeds across a contaminated area, the higher the prescribed Stewardship Level. However, the duration of stewardship at an assigned Stewardship Level would not be appreciably affected. The number of days of precipitation (as a transport parameter) has the greatest influence on overland migration of contaminants. The general relationship is that the higher the precipitation the higher the prescribed Stewardship Level, if there is the potential for overland migration at a Remediation Sites. This would affect locations having contaminated soils, exposed waste piles, or contaminated structures.

The speed of contamination transport via groundwater is most strongly influenced by the pore-water velocity of the aquifer, the solubility of the contaminant being transported, and the rate at which the contaminant enters the aquifer. Thus, the groundwater media of a Remediaton Site with "fast" aquifers will require a higher prescribed Stewardship Level than the groundwater media of a Remediaton Site having a "slow" aquifer. The same relationship exists between highly soluble contaminants and higher prescribed Stewardship Levels. In addition, the groundwater media of a Remediaton Site which releases contaminants to an aquifer at a higher rate, will have a higher prescribed Stewardship Level than slower contaminant releases rates.

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