PNNL 11302

RISK CONSTRAINT MEASURES DEVELOPED FOR THE OUTCOME-BASED STRATEGY FOR TANK WASTE MANAGEMENT

September 1996

BL Harper[1]
SJ Gajewski[1]
LD Muhlestein[2]
CL Glantz[1]
DM Kashporenko[1]
GR Bilyard[1]
AM Nazarali[3]
AJ Brothers[1]

Prepared for the U.S. Department of Energy
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[1]Pacific Northwest National Laboratory
Operated for the U.S. Department of Energy by Battelle

[2]ARES Corporation, Richland

[3]Jacobs Engineering, Kennewick

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Executive Summary

This report is one of a series of supporting documents for the outcome-based characterization strategy developed by PNNL. This report presents a set of proposed risk measures with risk constraint (acceptance) levels for use in the Value of Information process used in the NCS.

The characterization strategy has developed a risk-based Value of Information (VOI) approach for comparing the cost-effectiveness of characterizing versus mitigating particular waste tanks or tank clusters. The preference between characterizing or mitigating in order to prevent an accident depends on the cost of those activities relative to the cost of the consequences of the accident. The consequences are defined as adverse impacts measured across a broad set of risk categories such as worker dose, public cancers, ecological harm, and socio-cultural impacts. Within each risk measure, various "constraint levels" have been identified that reflect regulatory standards or conventionally negotiated thresholds of harm to Hanford resources and values. The cost of consequences includes the "costs" of exceeding those constraint levels as well as a strictly linear costing per unit of impact within each of the risk measures.

In actual application, VOI based-decision making is an iterative process, with a preliminary low-precision screen of potential technical options against the major risk constraints, followed by VOI analysis to determine the cost-effectiveness of gathering additional information and to select a preferred technical option, and finally a posterior screen to determine whether the preferred option meets all relevant risk constraints and acceptability criteria.

This report has assembled a set of 20 risk measures (and associated constraint levels) based on laws and regulations, stakeholder values, scientific/technical standards and practices, past negotiated Hanford agreements, Department of Energy policies, and/or other logical ways of measuring impacts in a format that will be useful for decision making, negotiating, and communicating. The Hanford risk landscape spans four categories: Public/Worker Health, Environmental/ Ecological impacts, Socio-Cultural Quality of life, and Programmatic impacts.

- The Human Health Category is concerned with public and worker health effects associated with routine operations and accident conditions, and includes multigeneration effects.

- The Environmental Category is concerned with contamination of and physical impacts on environmental media (air, water and soil) and living resources, habitats, and systems.

- The Socio-Cultural Category evaluates impacts to community quality of life and cultural resources.

- The Programmatic Category considers impacts on mission (including achievement of specified goals and implementation of technical options), cost and schedule.

The risk measures have been selected from each of these risk dimensions and assembled into a menu from which subsets of measures relevant to particular decision contexts can be chosen. Risk constraint levels are identified for each measure. They may be legal limits or ranges of impacts that are likely to be applicable to both routine events and the various accident frequency classes. For example,

accidents with relatively high frequencies of occurrence will have lower levels of acceptable impacts than accidents that are unlikely. These measures, together with their identified constraint levels, provide a risk-based definition of various safe, clean, and/or acceptable operating envelopes. It should be emphasized that we have provided descriptive placeholders for risk acceptance criteria for each risk measures, but they have not been reviewed by technical, regulatory and public stakeholders.

Table 1. Risk Measures (See Attachment 1 for more detail)

CATEGORY: PUBLIC/WORKER HEALTH	CATEGORY: SOCIO-CULTURAL QUALITY OF LIFE
H1. Short-term public/worker radiological dose	S1. Community Quality of Life
H2. Short-term public/worker non-radiological exposure.	S2. Tribal Quality of Life
H3. Annual worker radiological dose	S3. Intra- and Intergenerational Equity
H4. Annual public radiological dose	S4. Impacts to cultural resources
H5. Annual population radiological dose	CATEGORY: PROGRAMMATIC
H6. Lifetime individual cancer and non-cancer risk from chronic exposures	P1. Penalties for non-compliance
H7. Multigeneration risks	P2. Shutdown costs
CATEGORY: ENVIRONMENTAL IMPACTS	P3. Response and repair costs
E1. Contamination of environmental media	P4. Mission impacts
E2. Ecotoxicity and Habitat impacts	P5. Interprogram and Sitewide impacts
E3. Environmental disturbance during emergency response or remedial action	P6. Cost of stakeholder non-involvement

To be included in the proposed set of risk measures, individual measures had to meet the following criteria: (1) they must measure the "right" risk information (i.e., be directly useful for demonstrating risk reduction) without duplication, (2) they must, in total, represent the whole problem, (3) they must have enough measurement flexibility so that they can be used for probablistic evaluations as well as deterministic and qualitative evaluations, (4) they must be independent enough to be useful in situations where it is appropriate to construct a sufficient but "least set" (or subset) of risk measures, (5) they must be amenable to being "rolled up" into combined metrics for Value of Information analysis, (6) they must retain clear traceability to their legal, technical, values, and health/safety roots, and (7) they must supply information really needed to make key decisions that are technically defensible, politically acceptable, and stable.

The risk measures and their constraint levels can be used to:

- help define acceptable safety guidelines and endstates for safe storage and disposal decisions;
- help define operational guidelines for staying safe while achieving successful outcomes and clean endstates;
- screen out unacceptable technical options from consideration before performing detailed Value of Information (VOI) analyses of proposed characterization activities;
- evaluate the acceptability of preferred technical options across all the measures of risk that are likely to be decision criteria;
- form part of the cost-risk-benefit basis for comparing the cost of the consequences across the risk categories to the cost of mitigation and cost of characterization.
- provide robust supporting information for decisions where it is necessary to make risk tradeoffs and/or negotiate alternative ways to meet protectiveness goals for environmental health & safety;
- help define how much uncertainty a decision can tolerate and still be technically sound and defensible.
- help improve decisions by tying accuracy to the consequences of making a bad decision, tying characterization information to real decisions, and linking the information directly to risk reduction across the four basic categories of risk.

This paper provides the theoretical basis for selecting the risk measures and identifying the associated constraint levels. The steps for an actual implementation of this method are as follows (see also Attachment 5):

1. Stakeholders and regulators are consulted for approval and refinement of the risk measures and associated constraint levels for the various accident severity classes. Stakeholders and regulators also review modeling codes and assumptions before proceeding to Step 2. This is then used to prepare tables of contaminant-specific environmental concentrations that define the constraint levels. Other factors, such as contaminant persistence, are also included in these tables.

2. The regulators and stakeholders help the decision maker and/or analytical team select relevant risk measures, depending on the estimated probability of the event being evaluated and the estimated potential severity of the consequences. A preliminary screen of the existing tank waste conditions and mitigation options against the risk constraint levels provides initial estimates of existing risk and the decision space.

3. The analytical/management team develops source term input information for environmental fate and transport modeling, and ensures that appropriate output data are obtained. *Note:* the modeling has been modularized at Hanford so that it need not be repeated for each application. It is also likely

that the interim data files from the TWRS EIS can be used with little or no modification.

4. The team compares the environmental concentrations for the particular event to the tables compiled in step 1, and evaluates the concentration isopleths for the area impacted and duration of impact. This, in effect, converts concentration isopleths to risk isopleths. Again, the interim data files from the TWRS EIS can probably be used, with supplementation by the additional risk measures.

5. The team (with regulators and stakeholders) assigns a cost per unit of impact for each measure or for the entire event or accident under evaluation, according to the precision needs of the particular decision.

6. The team performs any further iterations as necessary (for example, if the preferred technical alternative requires additional evaluation to demonstrate risk acceptability across all constraint levels, or to support risk-based negotiations).

GLOSSARY

RISK = probability of an in-tank event times the probability and severity of an impact resulting from that event. Risk might be unacceptable due either to an unacceptably high probability of an event or to unacceptably high impacts, or both.

HAZARD = the presence of some material that, if it were released, would have an adverse impact.

IMPACT = any kind of adverse consequence to the program, to values, to policies, to schedules, to environmental media, to natural resources, to human or biotic receptors, and/or to socio-cultural resources and quality of life. Harm to an environmental medium can occur without measurable biotic damage: degradation of soil or groundwater violates DOE anti-degradation policies, and can also put the program and values at risk.

RISK CATEGORIES = the major risk categories: public/worker health, ecological/environmental impacts, socio-cultural quality of life, and programmatic impacts.

RISK MEASURES = individual impacts within the risk categories. For example, within the public health category, annual radiological dose, lifetime cancer risk and multi-generation risk are different, non-overlapping impacts.

RISK CONSTRAINT LEVELS = identifiable points along each risk measurement scale which describe compliance limits or target acceptance ranges.

RISK ENVELOPES = the decision boundaries that roughly describe whether risk is acceptable for different frequency classes. The envelope which defines safe normal operations and clean endstates can be described using any or all of the risk measures, depending on the information needs of the particular application. The constraint levels for normal operations for each measure are presented in Attachment 1, The envelopes defining acceptable risk for various accident frequencies (suggested descriptions are given in Attachment 2) can be developed to complement existing human dose limits.

1.0 INTRODUCTION

This report presents a set of risk measures and identifies risk constraint (acceptance) limits applicable to both Hanford waste tank safe interim storage, and to tank waste pretreatment, disposal and closure options. This report was prepared to provide a defensible risk-based structure for the Value of Information (VOI) approach of the Outcome-Based Characterization Strategy.

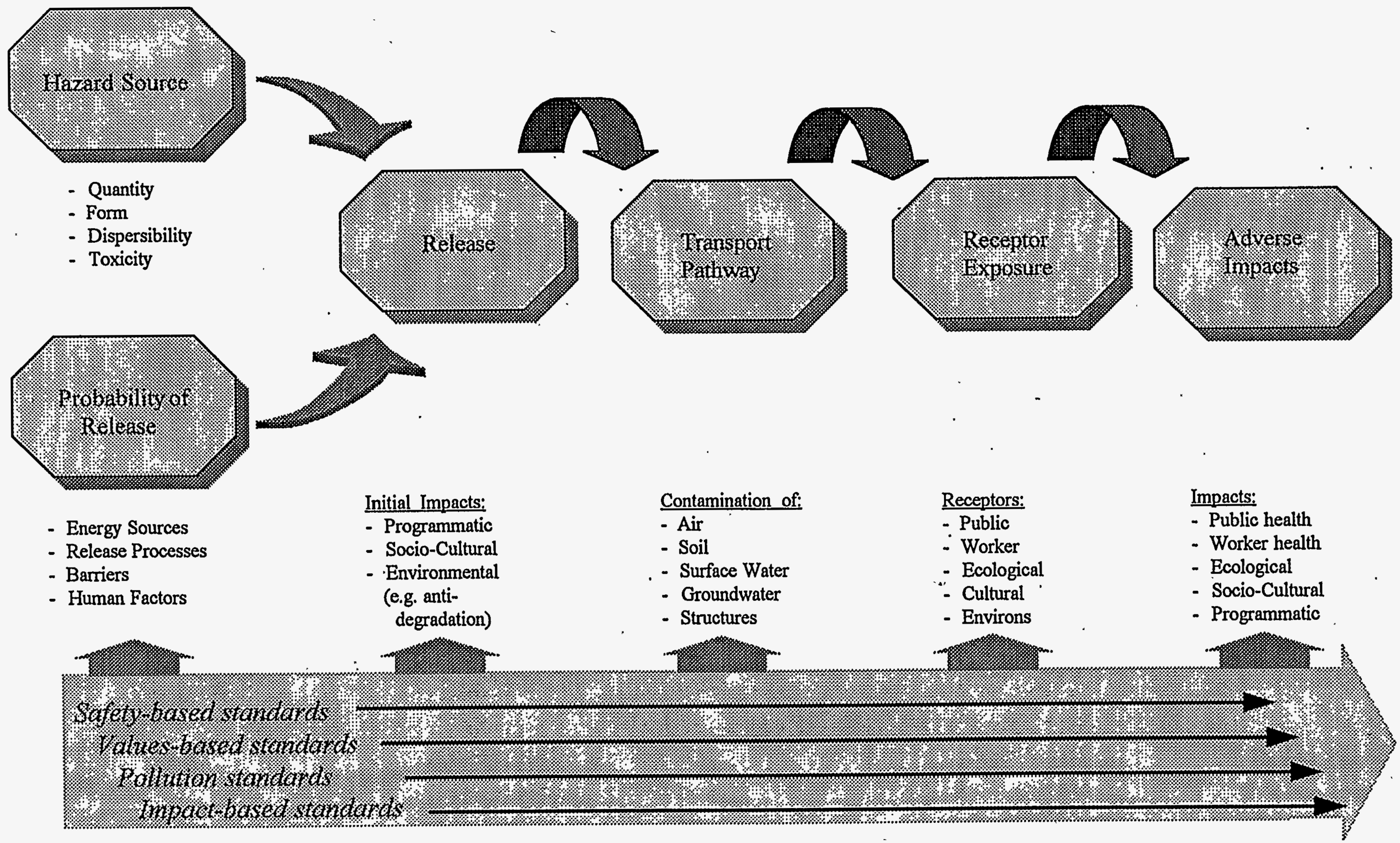
The basic premise of Value of Information (VOI) is that better information should lead to better decisions, that the degree of improvement can be compared to the cost of gathering the information, and that there is an identifiable point in each decision process beyond which it is not cost-effective to gather more information. In the TWRS context, VOI refers to the value of gathering better information regarding the state of waste in a waste tank and its associated risks, thus allowing clearer discrimination among possible technical options for resolution of safety issues, disposal, and/or closure.

In order to be both scientifically defensible and politically acceptable, decisions must be supported by solid and appropriate risk information. The risk measures presented here are based on regulations, Site values, standard risk assessment practices, and measures commonly requested by Hanford stakeholders and decision makers. Figure 1 shows how the overall risk paradigm can be divided into several parts, and that there are various types of regulatory standards and guidance that apply throughout the paradigm that should be linked to individual risk measures. It is important to recognize that risk can be unacceptably high at any point throughout the entire paradigm, not just at the last step where visible harm to tangible receptors occurs.

Not all risk measures will be applicable, useful, or necessary to every decision. The particular decision context and technical problem statement determine which risk measures are relevant, and VOI determines the value of gathering information about those risk measures. For this project, the risk measures were designed to be applicable in at least four types of TWRS decision contexts:

- resolution of tank safety issues (defining the risk information necessary to determine whether the tank or proposed action is within acceptable risk limits or the "safe envelope");
- prevention of human health and safety problems during waste retrieval and processing (defining the information needed to estimate the probability of release and the potential degree of exposure);
- risk-based performance measures for processed waste (defining the information needed to demonstrate that short-term storage and/or long-term disposal will be within the "safe" and "clean" envelopes);
- risk levels after tank farm closure (defining the information needed to demonstrate that the post-closure risk will be within the "clean" envelope).

Figure 1. Risk Assessment Paradigm



The risk measures with their constraint levels presented in this report are useful for defining operational guidelines for staying safe while achieving successful outcomes and clean endstates. They were designed using the regulatory or conventional definitions of "safe" and "clean." Because they are applicable both to normal operations and to accident analyses, they help define the safe operating envelope in a manner that supplements the Safety Analysis Manual. To the extent that the Safe and Clean envelopes are also recognized as "acceptable," the risk constraint levels also describe risk-based performance measures or a risk-based technical safety basis.

2.0 RISK-BASED DECISION MAKING (RBDM) AND COMPLIANCE-BASED DECISION MAKING

This report does not attempt to promote either risk-based decision making or compliance-based decision making as a preferred method, nor does it intend to imply that decisions based on risk versus compliance are in any way incompatible. Rather, the report attempts to show that for each selected risk measure there are compliance thresholds and/or conventional target ranges that together define whether the particular technical alternative is likely to be "acceptable." Risk-based decision making (RBDM) has been proposed as a method for defining solutions to problems in addition to strict compliance (rule-based) solutions or engineering (technology-based) solutions. While both compliance strategies and technology selection may be based in part on risk or protectiveness, many practical situations occur in which the same goals might be met with more flexible approaches. Because the burden is on the proponent of the alternate solution (or cleanup level) to demonstrate that the alternative will protect human health and the environment, the measures proposed in this report were specifically selected to reflect this anticipated need.

RBDM does not require final decisions to be driven by a particular type of risk, or even by risk at all. A particular decision may be driven by political, legal, or financial factors, but in an RBDM process, the decision makers will have information about the risk implications of that particular decision. This information then may be used to negotiate appropriate outcomes, and is particularly useful if rational tradeoffs among various risks and benefits are needed. The risk measures are generally "negative impacts to be minimized." Individual decisions would likely use additional decision criteria for "positive benefits to be maximized", such as effectiveness of the technology in reducing cost or compressing a schedule, or experience gained in solving complex mixed waste problems. True benefits-based budgeting would include both minimized risks and maximized benefits (not exactly the inverse of each other) as decision criteria. VOI can be used to evaluate either expected costs or expected value (benefits), or both.

The types of risks that should be considered in the RBDM process are those that arise from legal requirements, from scientific and technical standards and practices, and from stakeholder values and expectations. A narrow view might hold that it is necessary to evaluate only specifically prescribed risk limits in the decision process. A broader view (and one also upheld by law) includes statutory requirements to evaluate certain types of impacts even when specific acceptance criteria are not provided, and also includes the interests of unrepresented stakeholders (e.g., future generations). In the environmental arena, risk standards are generally found in a wide variety of laws and other guidance documents that protect human health and the environment, including various social and cultural values and resources. For all of these categories (including socio-cultural), federal guidance on evaluation methods is available, even when specific acceptance criteria are not, and this report is based on that guidance as well as on specific statutes and rules.

3.0 USING RISK MEASURES IN VALUE OF INFORMATION (VOI)

The particular method proposed in the Outcome-BasedCharacterization Strategy for applying these risk measures will use a Value of Information (VOI) approach.

The quality of the assessment is dependent on the accuracy (or diagnosticity) of the measurements (i.e., are we measuring the right thing?) and the precision (are we measuring it with a suitable degree of precision such that uncertainty is within tolerable limits?). Information can be accurate (i.e., true) even if it is imprecise (i.e., with large error bars). Accepting a given amount of uncertainty (imprecision) in a particular decision context does not necessarily make the information any less accurate or the decision any less valid. In fact, increasing the precision of the information may not improve the decision at all. Some decisions are best supported by a broad but less precise information base, while others require narrowly focused but highly precise data. One utility of VOI is to clarify where imprecise data are cost-effective to a decision process (i.e., which decisions can tolerate more uncertainty or which factors would benefit the decision the most if their measurement precision were increased).

The first step in using a risk-based VOI approach is to clearly define "risk" and "risk reduction" in the context of tank waste characterization. Since risk is defined in terms of both the event probability and the potential consequences of the event, VOI would be used to determine the value of gathering information that includes both the frequency and consequences of the potential event. Note that the word "consequence" is used in characterization evaluation in two ways: the *internal event* is the consequence of the tank conditions, and the *external impacts* are the consequences of the event. This report uses the latter definition to specify that the risk measures apply to the outside-the-tank impacts, although these impacts include programmatic impacts even if no material actually escapes into the environment.

The second step in a risk-based application of VOI is to determine what information is likely to be needed to discriminate among the particular set of technical options that can be used to address a technical problem, and to determine how much that information is "worth." The value of knowing how a preferred alternative is predicted to perform with respect to all applicable risk constraints (such as standards or target risk ranges) is part of establishing the value of the information.

Three types of "costs" are used in the TWRS VOI approach: the cost to characterize the waste, the cost to mitigate or prevent an unwanted event, and the cost of potential consequences. These costs may be paired in various ways, depending on the issue to be decided, or they may be used simultaneously. For example, does the cost of collecting the information outweigh the cost of falsely assuming that a tank or action is "safe" when in fact it isn't and the event and its consequences occurs? Or, given that some information about a tank already exists, is it cost-effective to mitigate without further characterization? Or, are the costs of the potential consequences estimated to be higher or lower than the cost to mitigate (with or without knowing more about tank conditions)? This report focuses on the constraint measures that are likely to be required during characterization decision making and that, therefore, will also be used as costs in the VOI process.

When evaluating technical options, a subset of the proposed risk measures may be identified as most relevant to the problem and then each alternative can be evaluated for how well it performs for the selected measures. However, the VOI approach requires assigning monetary value to the consequences of a particular event, and therefore all measures that would be adversely impacted during (or as a result of) that event must be included because VOI requires comparison between the comprehensive costs of the consequences and well-defined mitigation or sampling costs. Using relative risk information (and a subset of risk measures) is adequate for ordering the options in terms of risk preference but is inadequate for making cost comparisons unless all elements of the cost are included. Further, less information (or less precise information) is likely to be needed to rank the options than to support a No Action decision because the No Action remedy generally implies a final and permanent remedy that must meet all constraints and applicable or relevant and appropriate requirements (ARARs).

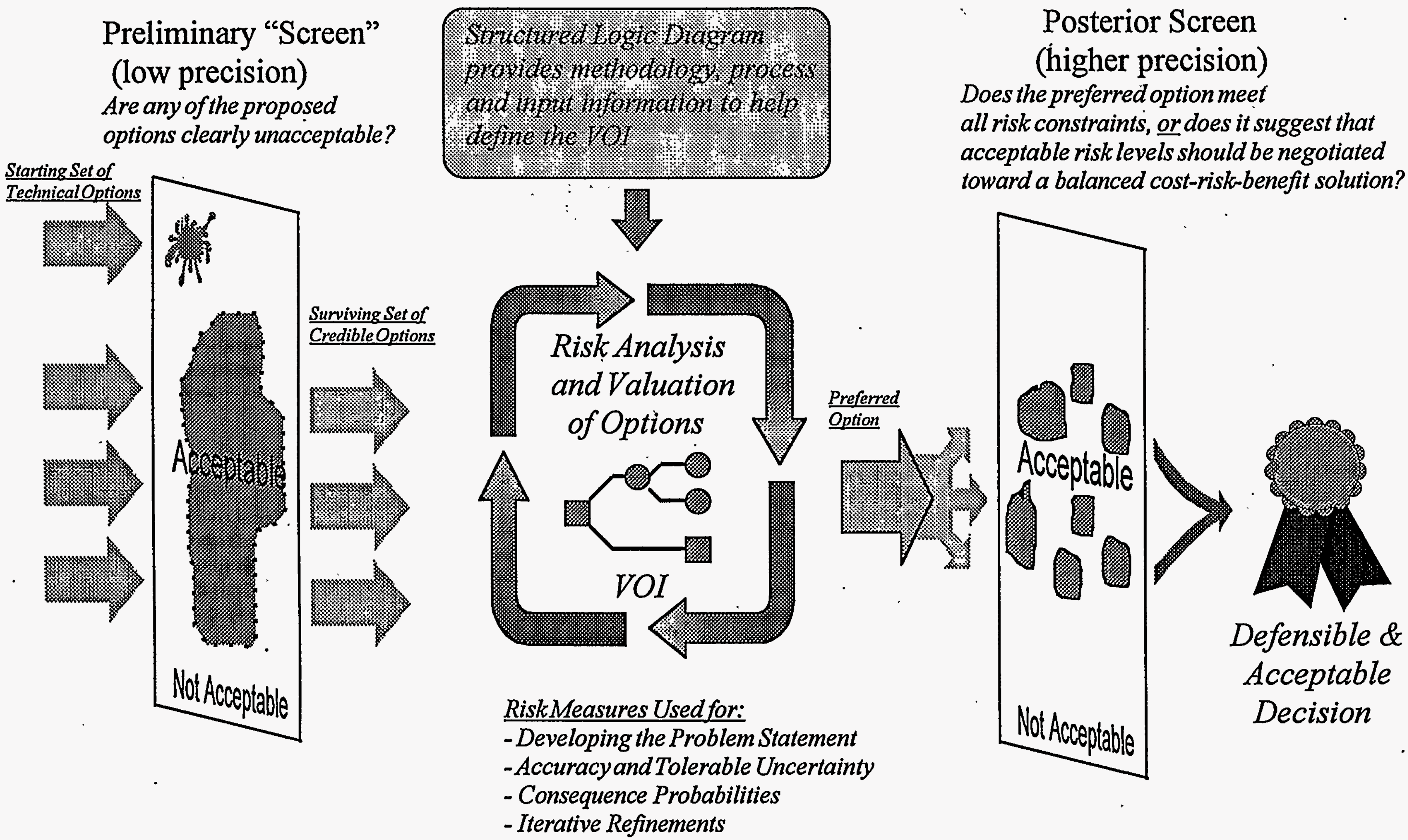
In practice, the selection of a preferred technical option is likely to be an iterative process (Figure 2). An initial screen of the options against the values and constraints will eliminate options that are clearly unsatisfactory. During the VOI analysis, risk assessment information is used by converting risk results to dollars per unit of impact for comparison to other costs. After the evaluation, the preferred option can be evaluated more carefully for its performance relative to the full set of risk constraints, and presented to stakeholders and regulators for review and negotiation. The advantage of this approach is that it provides the basis for demonstrating that, in certain situations, alternative cleanup or risk-based standards may meet the environmental management goals in a more cost-effective but equally protective manner. The disadvantage in this approach is that if only three to four measures are used to discriminate among technical alternatives but compliance/acceptance must be demonstrated for additional measures, then an alternative that appears at first to be the best may later be rejected if it fails on an inflexible measure that was not previously included.

4.0 DEVELOPMENT OF RISK MEASURES AND RISK CONSTRAINT LEVELS

In order for risk-based decisions to be both technically defensible and politically acceptable, they must use risk measures that are rooted in laws and regulations, in stakeholder values, interests and concerns, and in scientific and technical standards and practices. As shown in Figure 1, the risk measures must be able to evaluate impacts to nonphysical receptors (values, statutes, policies, credibility, quality of life, aesthetics, schedules, and environmental media) as well as to human and ecological receptors. Harm to nonphysical receptors can be just as real and quantifiable as harm to physical receptors, just as grounded in compliance and convention, and, in many cases, temporally precedes the harm to physical receptors. Demonstrable and quantifiable harm to nonphysical receptors is now an accepted (and expected) part of Comparative Risk Analysis (EPA, 1993)[1], and results in better strategic planning decisions.

U.S. EPA. A Guidebook to Comparing Risks and Setting Environmental Priorities. EPA/230-B-93-003 (1993).

Figure 2. The Use of Risk Acceptance Measures/Constraints



For each selected risk measure, identifiable limits that serve as constraints on their acceptability can be described. Particular measures are often reportable in specific recognizable metrics (units) according to various levels of prescription, ranging from mandatory to common sense. For example, there are statutory reporting requirements relating to permitted activities, such as annual worker and public dose and specific environmental pollution limits. There are professional and Hanford-specific reporting practices that have become standard procedure, such as evaluating environmental impacts in part by estimating harm to the homerange of local threatened and endangered species. Additional measures may be needed to make cost-risk decisions, such as estimating environmental harm in terms of cleanup and restoration costs. Finally, there are measures that are typically requested by stakeholders, such as the potential harm to future generations. There are also a series of measures that have a clear statutory basis even though they are not typically used in prospective decision making, such as the potential for disturbing cultural and historic resources. For each measure included in Attachment 1, the legal or conventional basis for its inclusion and its reporting units are given.

4.1 Terminology and Issues in Risk Evaluations

4.1.1 Risk: Probability of an Event x Probability of Adverse Impacts

Although tank contents and phenomenology influence both the event probability (e.g. due to speciation and ignitability) and the consequences (e.g. due to dispersibility and toxicity), the risk constraint levels themselves are independent of the event probability. Any exceedance of the risk constraint limits during normal operations (for example, exceedance of an annual dose limit) may put the activity, tank, program or Site out of compliance whenever it occurs, and this is independent of the event probability. In practice, however, the degree of "risk" that the Site or program is willing to accept depends on both the magnitude of potential consequences and estimated probability of occurrence. Therefore, a discussion of some of the basis for developing constraint levels for accident risks is included in Section 4.4.

This report does not include a discussion of the various accident scenarios themselves, but does include risk measures related to both an event and its consequences. When considering risk constraint measures, there is sometimes confusion about whether risk stems from hazards, consequences, or both. The *hazard* (the conditions in the tank), the *likelihood* (the mitigation and operational practices that influence the probability of an event or release), and the *consequences* (the nature, and magnitude of adverse impacts if the event or release occurs) all contribute to risk. Risk may be unacceptable due to either high event probability or to severe consequences, and therefore the risk measures must address both.

Risk is actually a function of not just a single event probability, but of a series of probabilities (the probability of an initiator, probability of propagation, probability of barrier breach, probability of material release, probability of exposure with health effects, probability of other adverse effects not necessarily related to human exposure, etc.). During the evaluation process, either point estimates or probability density functions for each of these items can be used; VOI generally requires the latter because VOI refers to the value of knowing the probability distributions more precisely.

4.1.2 The Problem of Proxy (Surrogate, Representative) or Condensed Metrics.

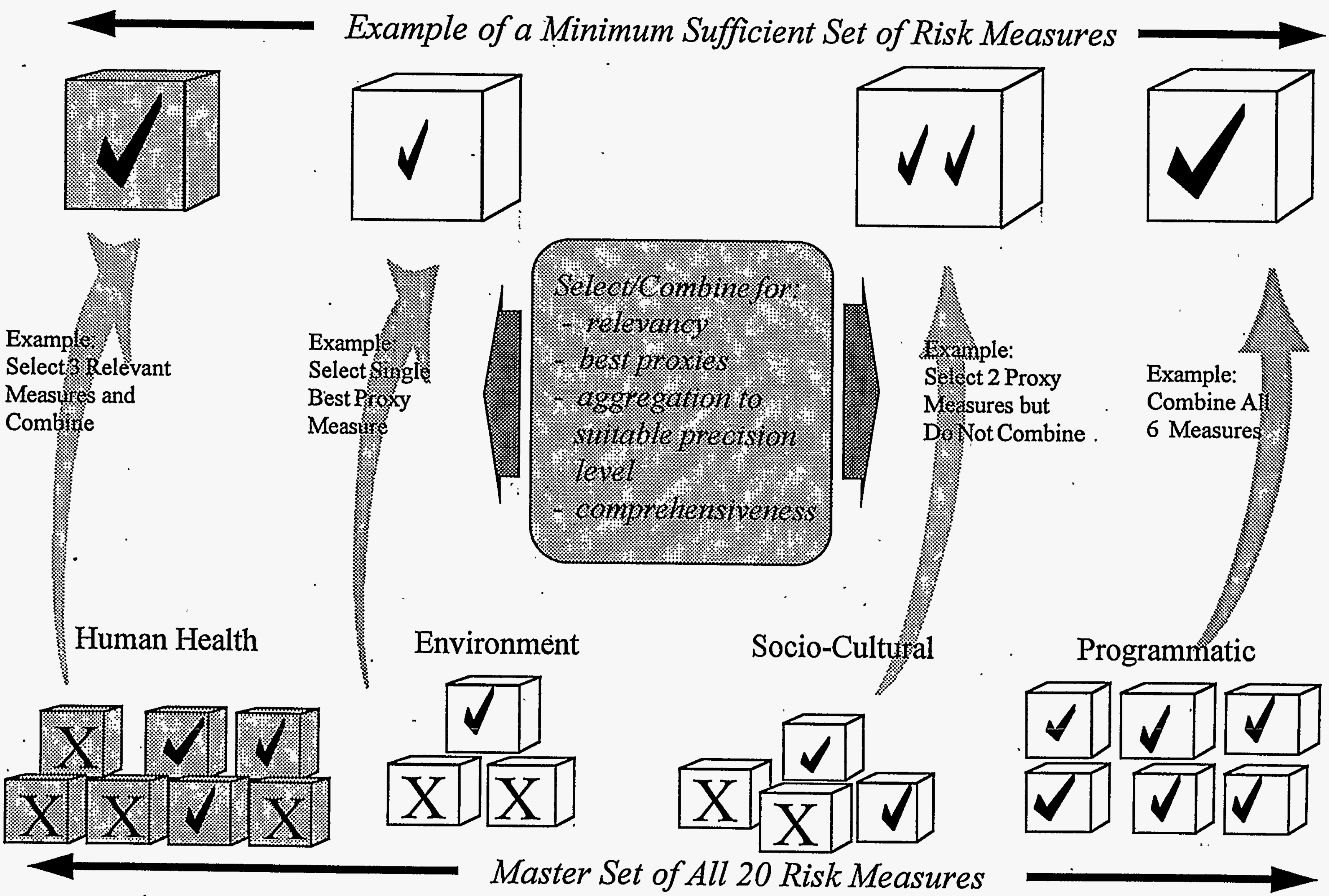
The issue of how many measures are needed in any risk analysis is not trivial. A determination must be made for each decision context whether one measure can be used as a proxy for other measures, or whether multiple measures can be condensed into meta-measures.

It is doubtful whether there is a single representative "least set" of measures that fits all decision types. The list of 20 measures in this report is felt to be parsimonious (i.e., a minimal set but adequate to demonstrate compliance and meet stakeholder needs), while at the same time recognizing the variety of ways that a single event could put the action, the program, or the entire Site out of compliance. In practice, a particular decision may require only some of these measures if relative risk information is all that is needed in order to discriminate among technical options or to prioritize actions. However, in a decision context where the true and complete costs of an event are important, then every measure that could be adversely impacted must be included. The judicious use of such proxy measures, if demonstrably connected to the underlying "compliance" measures, can be a powerful tool for negotiating operational and cleanup objectives at the Site.

In other decision contexts, the question might be whether protecting one type of receptor (e,g, workers) will protect all other receptors (in the broadest sense of the word). In all likelihood, a single proxy measure such as public/worker dose limits does not automatically guarantee that the environmental, socio-cultural, or programmatic measures are also within acceptable limits. It would be possible to run test cases to determine under what circumstances one measure is a more sensitive "indicator measure" than other measures in the same category. There are clearly situations where small localized releases might affect worker and programmatic measures but nothing else. However, this may not mean that there is a nested set of 20 geographic impact zones, with particular measures being the first to be impacted at different distances from the source. Such a spatial set might be developed, since the threshold limit for each measure is related to an environmental concentration, and environmental concentration is proportional to the distance from the source, but this is likely to be at least partially contaminant-specific.

Figure 3 shows several ways to construct a subset of risk measures, should this be warranted. Some measures might be carried through the analysis unchanged, some might be combined into a single measure, and others might not be needed. Constructing the subset can be done in such a way that each risk category carries equal weight in the decision process. Alternately, each measure can be counted equally, so that the risk dimension with the most risk measures carries the most weight. Other potential methods for combining measures include multi-attribute utility analysis (which is difficult to use when there are multiple value sets, as is the case at Hanford), and approaches that assign different weights to different risk measures.

Figure 3. How to Construct a Decision-Specific Set of Relevant Risk Measures



4.1.3 Static Measures for Dynamic Risks

The measures presented in this paper are typically used to develop a risk "snapshot" at a pre-selected time point. Decision Analysis is specifically designed to provide answers given the information that is available at a specific time, but implicitly depends on multiple iterations as new information becomes available. In reality, not only is new information continually becoming available, but risk is also constantly changing due to moving plumes, moving receptors, changes in facility inventory or safety practices, changes in structural integrity, and changes in activities over the lifecycle of the facility or remedial action. In some instances, a risk snapshot is adequate to make a decision while in others it is necessary to integrate the total area under a risk curve that extends for tens of thousands of years. The temporal integration of each type of risk over some selected timeframe of analysis must be determined early in the decision process.

Risks may also change over time due to the movement of the physical receptor. Changes in institutional controls and changes in interim land use designations will allow the public to have access closer to Hanford's Central Plateau in the near future, with potentially increased risks as people move closer to the source. The Point of Compliance will (by statute) change over time, also moving the human receptors closer to the hazards. The size and shape of various safety zones (the Exclusive Use Zone and the Emergency Planning Zone) will also cause risks to change because different land uses allow different activity patterns and therefore different exposures and risks. For example, recreational activity patterns, which are less frequent and have lower rates of contact with environmental media, result in a lower exposure than year-round residence at the same environmental contaminant levels.

4.1.4 Envelopes.

In order to define the risk constraints for both normal operations and accidents, the concept of "envelopes" was used to examine the commonalities in risk definition and management. Simplicity and logic appear to recommend a conceptual correlation between "How Safe Is Safe" and "How Clean is Clean." The approach used here first anchors the routine (i.e., anticipated or P=1) risk and dose limits to regulations and typical target risk ranges and then discusses the basis for setting risk thresholds for lower frequency events (Step 4, below).

The Safe Envelope applies to hazards under active containment, while the Clean Envelope applies to hazards under passive containment or no containment (i.e. post-closure, post-remediation, or disposal performance conditions). The Safe Envelope assumes active maintenance and engineered barriers while the Clean Envelope, since it must be effective in perpetuity, does not assume active maintenance or enforcement of institutional controls beyond the time period mandated in the Tri Party Agreement. Neither the Safe nor Clean Envelopes are zero risk envelopes, and they may or may not be *de minimis* levels.

This conceptual model assumes that the Safe and Clean envelopes can be defined in terms of a set of all relevant compliance measures or, where regulatory standards are lacking, a set of conventional (acceptable) target ranges. Thus, there should be thresholds for each measure defined as regulatory compliance limit or conventional target ranges. Each mitigation option can then be evaluated for where on each relevant scale it falls relative to the compliance or acceptance limit. The risk profiles for the options across the risk categories (and through time) can then be compared and contrasted. For example, there may be alternatives for which most measures are within compliance limits but one or two fall just outside. As another example, it might make sense to seek a waiver to allow higher limits for one year in order to achieve lower risks later. Knowing how an alternative rates relative to *all* the compliance/acceptance limits over time might enable such alternatives to nevertheless be chosen despite marginal or temporary non-compliance.

One advantage of describing a generic envelope in terms of protectiveness or acceptability across a wide range of measures is that, to a large degree, there is an automatic normalization among disparate types of impacts. The question of how to compare health versus environmental impacts, for instance, is frequently sidestepped due to lack of agreement about relative "worth." By defining conceptually similar constraint levels for each measure (such as what is probably acceptable or, at the other extreme, probably catastrophic), the severity scales are automatically aligned. The inter-conversion of these envelope-defining metrics to a common currency such as dollars is a mutual reality check: if the "clean" thresholds are aligned but the dollar conversion shows wide differences, then the dollar conversion probably has not included adequate cost considerations, and if the impacts appear widely different when the true dollars are aligned, then perhaps the consequence metrics need to be reevaluated.

Geographically, the physical safe/clean boundary where the receptor would be located would likely be a Point of Compliance or (for active facilities) the facility boundary, the Site boundary or the boundary of the Exclusive Use Zone or Emergency Planning Zone. Although there is an apparent spatial correlation of dose-type envelopes, a geographic gradient probably does not directly apply to some of the socio-cultural and programmatic impacts, which may be adversely affected merely by the event occurring even without (or before) significant impacts to physical receptors.

4.2 Approach to Developing Risk Measures with Identified Constraint Limits

Step 1. Define the *categories of risk* (specific types of potential adverse impacts) that reflect evaluation requirements contained in regulations or frequently requested by decision makers, regulators, and/or stakeholders.

Categories of risk: Health, Environmental, Socio-Cultural, and Programmatic.

Step 2. Define *individual risk measures* (i.e., what are the scales) for each type of risk required or typically requested for analysis.

These consequence measures are stand-alone scales along which the severity of impacts can be plotted. They define what generally must be measured (e.g., worker dose) and the units of reporting (e.g., annual dose or lifetime cancer risk). They are independent of how frequently the causal event may occur. Starting points: regulations, TWRS values and measures studies, and other Hanford information.

Step 3. Describe *routine risk constraint/acceptance levels* (for routine operations and post-remedial conditions). These are the compliance-based "safe" and "clean" envelopes, conventional target risk ranges, or narrative descriptions of widely recognized acceptance criteria for each type of impact.

"Compliance" defines constraint levels for each measure in terms of regulatory or other conventional units; "being in compliance" itself is not a separate measure because each measure must ultimately be in compliance or be otherwise "acceptable." Some measures must be evaluated (by law), but no specific limits or reporting requirements are prescribed; for those, this report presents target ranges based on conventional negotiated ranges or actual Hanford information. *Note:* while alternatives initially may be evaluated for each measure without considering constraint levels (i.e., keeping the initial evaluation free of constraints), the preferred alternative(s) must be compared to compliance/acceptance levels fairly early in the decision process.

Step 4. Describe regulatory risk limits or DOE risk acceptability rules for *potential accident risks* for as many measures as possible (also part of the "safe operating envelope"). These limits reflect the amount of risk a program is willing to accept across the range of risk consequences, and also form part of the technical safety basis.

The severity of the consequences is independent of probability of the event, but "risk" includes both the expected consequence and the probability or estimated frequency of the event that could lead to those consequences.

Step 5. Because the proposed VOI methodology will not work without assigning a cost to the consequences, *costs per consequence* must be developed.

For this report, placeholder costs are included for some measures as an example of how this process might be used in a VOI analysis. For actual application to TWRS issues, the cost function will need to be addressed in more detail. This may be cone with varying degrees of precision depending on the decision needs; three examples with increasing precision are presented for consideration (Section 5).

4.2.1 Categories of Risk

Consequences in four basic risk categories might occur after a release of materials, and these constitute the four categories of risk described in this report: Health, Environmental, Socio-Cultural, and Programmatic. Both these risk categoriess and the measures in each category are based on Keeney and von Winterfeldt (1995)[2], the TWRS Risk Management List[3], the Risk Data Sheet activity, on other Hanford sources, on comments submitted by stakeholders over the years, and on values expressed by the Hanford Advisory Board and Energy Secretary O'Leary related to management of Hanford natural resources as a national resource (Hanford is a National Environmental Research Park). While most of the measures are directly traceable to individual regulations and/or widely recognized Site values, a few additional measures are included that are typically required by the program, decision makers, or the public and which, if omitted, have the potential to change decisions. Although these measures are broadly based on stakeholder values, neither the individual measures nor the acceptance criteria have been reviewed for this task by the major stakeholders. Stakeholder review of the measures, acceptance criteria, and especially the monetary valuation of the consequences will be essential to the successful application of VOI. Without active stakeholder participation in this process, the uncertainty about the ultimate acceptance of these

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RL Keeney and D von Winterfeldt, "Values-Based Performance Measures for the Hanford Tank Waste Remediation System (TWRS) Program," Nov 22, 1995.

Tank Waste Remediation System Risk Management List, WHC-SD-WM-RPT-201, October 16, 1995.

measures will remain high.

4.2.2 Individual Risk Measures

Individual risk measures are presented in Table 1 and Attachment 1. A total of 20 measures are spread among the four categories of potential consequences (Table 1). This proposed set of risk measures is longer than the Keeney and von Winterfeldt set because (1) the VOI approach must be applicable to both safe storage and disposal issues, while the Keeney and von Winterfeldt list applies mainly to disposal issues, and (2) the shorter set of measures is suitable for relative ranking of long-term risk, but not for demonstrating compliance or assigning monetary value to the full range of potential adverse consequences of a given event. The list in Table 1 may be considered for decisions in which demonstrating compliance is important or where it will be necessary to demonstrate that specific measures generally requested by decision makers, regulators and stakeholders have, in fact, been used in the decision process. The list in Table 1 may also be used as a menu from which to select relevant measures in those decision contexts where this is appropriate.

Table 1. Individual Risk Measures (See Attachment 1 for more detail)

CATEGORY: PUBLIC/WORKER HEALTH	CATEGORY: SOCIO-CULTURAL QUALITY OF LIFE
H1. Short-term public/worker radiological dose	S1. Community Quality of Life
H2. Short-term public/worker non-radiological exposure.	S2. Tribal Quality of Life
H3. Annual worker radiological dose	S3. Intra- and Intergenerational Equity
H4. Annual public radiological dose	S4. Impacts to cultural resources
H5. Annual population radiological dose	CATEGORY: PROGRAMMATIC
H6. Lifetime individual cancer and non-cancer risk	P1. Penalties for non-compliance
H7. Multigeneration risks	P2. Shutdown costs
CATEGORY: ENVIRONMENTAL IMPACTS	P3. Response and repair costs
E1. Contamination of environmental media	P4. Mission impacts
E2. Ecotoxicity and Habitat impacts	P5. Interprogram and Sitewide impacts
E3. Environmental disturbance during emergency response or remedial action	P6. Cost of stakeholder non-involvement

Within the Health Consequences, regulators, decision makers and stakeholders require or expect several different evaluations of health risks to distinct receptor groups. Therefore, the relevant health measures in Attachment 1 are presented in the format that is required for demonstrating compliance (e.g. annual public radiological dose) or a target risk range (e.g., lifetime excess cancer risk). While it is necessary to convert each of the health measures to a common metric for the VOI analysis itself (such as dollars or years of life lost), it will still be necessary in actual practice to be able to identify the individual risks that contribute to total risk. For example, annual dose limits and other compliance limits must be met by the selected technical options (or a waiver sought), and therefore these measures must be retained in their original units.

4.2.3 Risk Constraint Levels for Routine Operations and Post-Remedial Conditions (The Safe, Clean, Compliant and/or Acceptable Envelopes)

The program will have to demonstrate compliance/acceptance for the chosen alternative, and therefore the analysis must include measures in appropriate units (e.g. annual worker radiological dose in rem/yr). Figure 4 shows examples of constraint levels applied to two risk measures. For the health measure of annual radiological dose, the constraint levels are dose limits based on regulations and on WHC-CM-4-46. For the environmental measure of area disturbed, the constraint levels are based on the homerange of the loggerhead shrike (a Hanford Threatened or Endangered Species). As noted above, this measure is an example of constraint levels that are logical, but which have not been reviewed or approved by regulators or stakeholders.

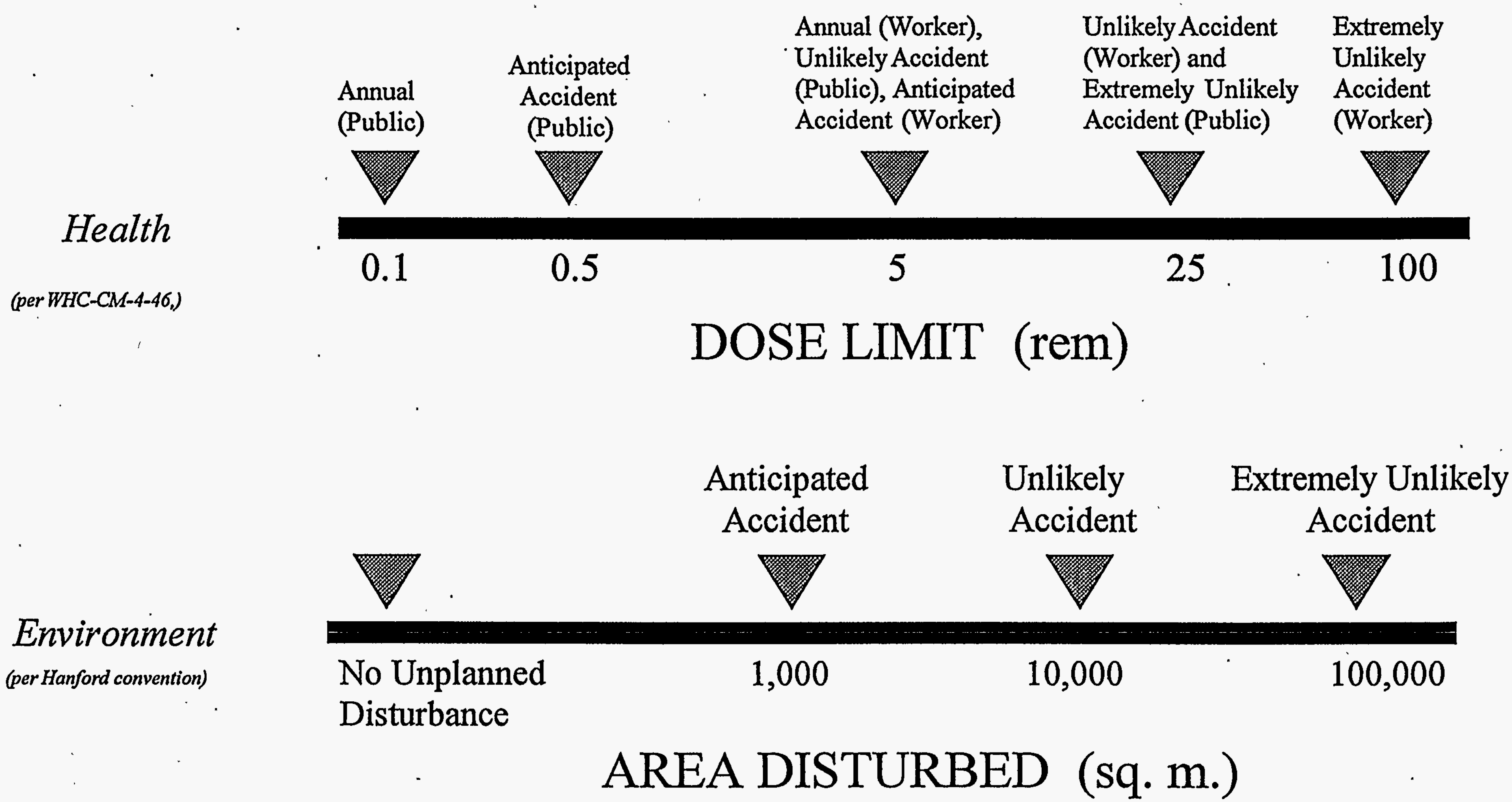
The application of the risk constraint levels needs to consider the level of aggregation within tank farms, tank types, or the entire TWRS program, dividing the dose and/or risk among potential risk sources or possible accident types, and so on. The approach used by NRC is termed "apportionment" where, for instance, no single source within a Site is allowed to exceed some fraction of the Site annual limit, or no single facility is allowed to exceed 25% of the public's annual dose limit. This is also relevant to TWRS because safety issues must be resolved on a single tank basis (or tank type, and so on), while closure occurs at the tank farm level, storage/disposal of processed waste occurs at a TSD (transfer, storage and disposal) facility level, and some of the regulatory standards apply to the entire Site as a single entity. (Note that TWRS shares some aggregate Site limits, such as the NESHAPs air quality limits, with all of the other Hanford programs.)

4.2.4 Risk Constraint Limits for Accidents

While no death or injury is acceptable, there is nevertheless a certain amount of risk that a program implicitly accepts regarding on-the-job accidents or accidental releases of hazardous materials. The amount of risk that a program is willing to accept for accidents depends on their estimated probability and on the estimated magnitude of the potential consequences. For routine (normal operations) events, the compliance envelope described in other sections of this report are applicable, thus in effect anchoring the 10^0 or anticipated annual frequency. The Safety Analysis Manual (WHC-CM-4-46, Rev. 4) provides guidance for extending the consequence versus

Figure 4. Sample Risk Measures with "Constraint Levels"

(Constraint Levels are identifiable points on risk scales that define "safe," "clean" (i.e. "acceptable"))



probability analysis to less-than-annual frequency events. However, this guidance is provided only for selected human exposure situations. Although the accident envelope is generally thought of only in terms of dose, the entire set of risk measures can be used in its definition (as described in Attachment 2 and shown graphically in Figures 5, 6a, and 6b). We have provided placeholder descriptors of severity classes (equivalent to accident frequency classes) for each risk measure; they are not intended as actual replacement risk acceptance guidelines at this time because they have not been reviewed by technical, regulatory or public stakeholders.

Good risk acceptance guidelines have some self-evident characteristics. They must be technically defensible, flexible, acceptable (i.e., reflect Site values), as simple as possible, and stable (not likely to change significantly after the decision is made or the facility built). They must also reflect risk aversion by providing some margin of safety. They must ultimately span the four categories of risk, rather than relying on a single proxy measure (typically, short-term human inhalation dose) that is currently the sole available method for performing safety analyses.

4.2.4.1 Status of Current Accident Risk Guidelines

The risk guidelines presented in the Safety Analysis Manual (WHC-CM-4-46, Rev. 4) have been challenged by DFNSB and are currently under review. Some of the accident-related risk limits were derived from siting criteria and were not intended to be used as operating guidelines. Other considerations, such as margin of safety (risk aversion) and apportionment might also need to be considered for accidents as they should be for routine operations. It is common sense that an event with larger adverse consequences is more acceptable if the frequency of occurrence is low, but the philosophy for setting protectiveness goals and allowable risk has not been clearly articulated.

The 25 rem (public) and 100 rem (worker) limits stem from various rules for emergency exposure situations where there is a need to perform lifesaving or protection of large populations (10 CFR 835: Occupational Radiation Protection). These limits are not discussed in terms of frequency or probability of occurrence. Other siting rules discuss these limits in terms of accident frequencies. Proposed rulemaking for 10 CFR 60 (Geologic Disposal of HLW) limits the annual public dose to 5 rem as the design basis for a repository for events estimated to occur at an annual frequency of from 10^{-9} up to or equal to 10^{-2}/yr. In 10 CFR 100 (Nuclear Reactor Siting), exclusion and low population (easily evacuated) zones are defined as zones where an individual would not receive a whole body dose in excess of 25 rem from nonseismic event initiators. The size of this zone has no relation to the facility boundary, and the rulemaking (Sept., 1995) specifically decouples siting criteria from reactor design and accidents that could occur within a typical 60-year facility lifetime.

Compliance dose limits are performance measures, not design criteria. As stated in NCRP 116 (p. 10), "the dose limit is the upper limit of acceptability rather than a design criterion. For example, it would be inappropriate to design a barrier based on criteria that would allow individuals to be exposed to the annual dose limit." For occupational radiological exposures, the dose limit is the maximum permissible dose limit to be received by a worker, so it is expected that the average dose is several fold less (NCRP 116, p. 14). For occupational chemical exposures, a somewhat more complex approach includes ceiling limits or time-weighted averages across specified exposure intervals. For environmental and socio-cultural risk measures, descriptors of what might constitute high, moderate, and low severity consequences are presented in Attachment 2. They can be envisioned graphically as scales that parallel the dose and toxicity scales (Figures 7-1 and 7-2 in WHC-CM-4-46, Rev. 4), such that the frequency intervals are aligned. These descriptors should be regarded as placeholders until they have been reviewed by regulators and stakeholders.

Figure 5 shows how the impacts of a hypothetical event might be mapped onto the set of severity classes or zones, which are defined by aligning the constraint levels for each risk measure. Then, an event frequency analysis determines which severity zone is applicable to any particular event so that the applicable severity interval can be examined to see how many risk measures have impacts that are severe enough to fall within that interval. In the hypothetical example shown in Figure 5, if the event has an expected frequency of between 10^{-4} to 10^{-6}/yr (assuming that the frequency "bins" used in WHC-CM-4-46 are still valid), then four risk constraint levels are exceeded, while if it has an expected frequency of between 10^{-2} to 10^{-4}/yr, then 13 risk constraint levels are exceeded. By plotting impacts for all relevant measures, a "risk portrait" can be visualized.

Three decision options thus become apparent from this hypothetical example. (1) the risk can be made "acceptable" by lowering the event's frequency, thus moving the severity zone of concern. (2) The risk can also be made acceptable by lowering the impacts, typically by reducing material that could be released, thus shrinking the size of the "risk portraits." (3) In some situations, it might be logical to reducing the impacts for only those measures exceeding their constraint levels for a given estimated frequency of occurrence. This might be done by improving emergency response time, and so on, but is likely to be less acceptable than addressing the material and its probability of release. The following section takes this conceptual model and suggests actual constraint-based definitions of the severity zones.

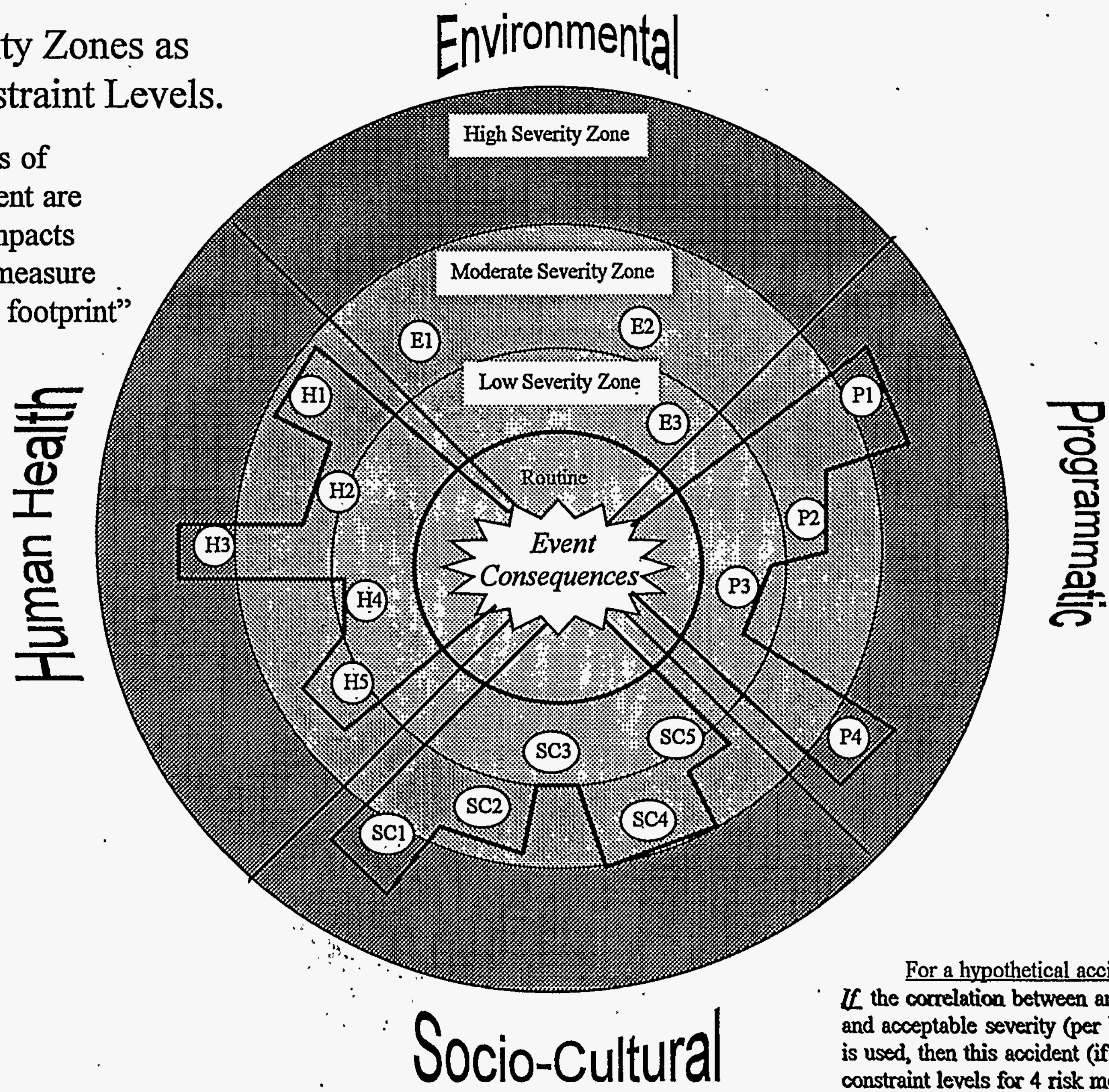
4.2.4.2 Suggestion for Accident Risk Guidelines Based on the Four Risk Categories.

The full set of risk measures may be used to evaluate accident risks, and a placeholder set of numerical or qualitative descriptions of severity class demarcations for each risk measure is presented in Attachment 2, with the caveat that they have not been reviewed by regulators or stakeholders. As with other risk evaluations, different sets of risk measures will be relevant to particular accident scenarios. The selection of risk measures to use for accident risk acceptance criteria will be context-specific. Again, a few test cases will serve to determine which "indicator" measures form a "least set" of risk measures for particular accident types and decisions types. For example, for a given accident scenario, a decision that involves ranking various hazards might require only human dose information, while decisions that involve using the cost of consequences might require the use of additional measures.

These constraint-based definitions of severity classes can be used to complement the conventional frequency-times-severity graph used at Hanford. Figure 6a is taken from WHC-CM-4-46 (Rev.4), and shows the annual offsite dose limits (however controversial) for the accident frequency classes. The inverse correlation between frequency class and severity class allows other impact scales to be developed using the same severity "bins" (Figure 6b).

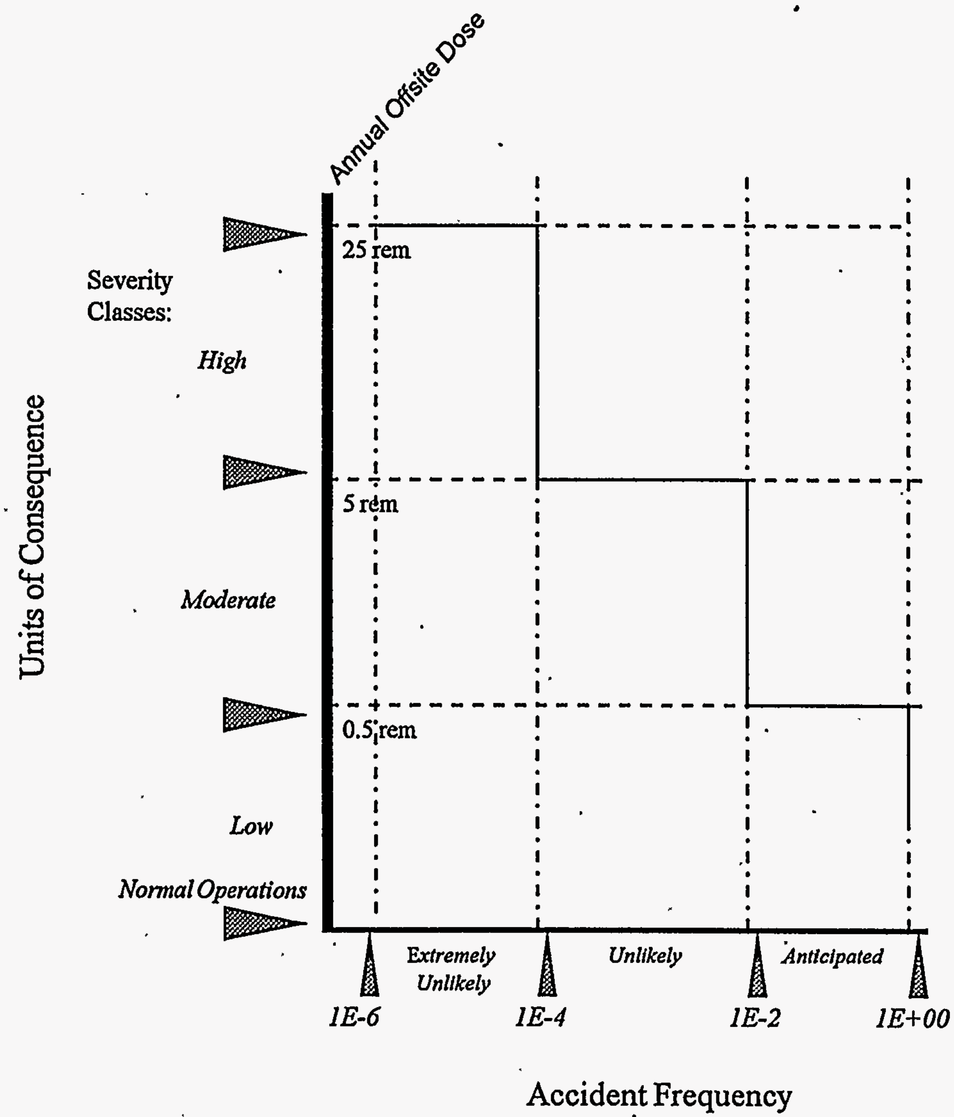
Figure 5. Severity Zones as defined by Constraint Levels.

The consequences of a hypothetical event are mapped by the impacts to each relevant measure to show the "risk footprint" for that event.



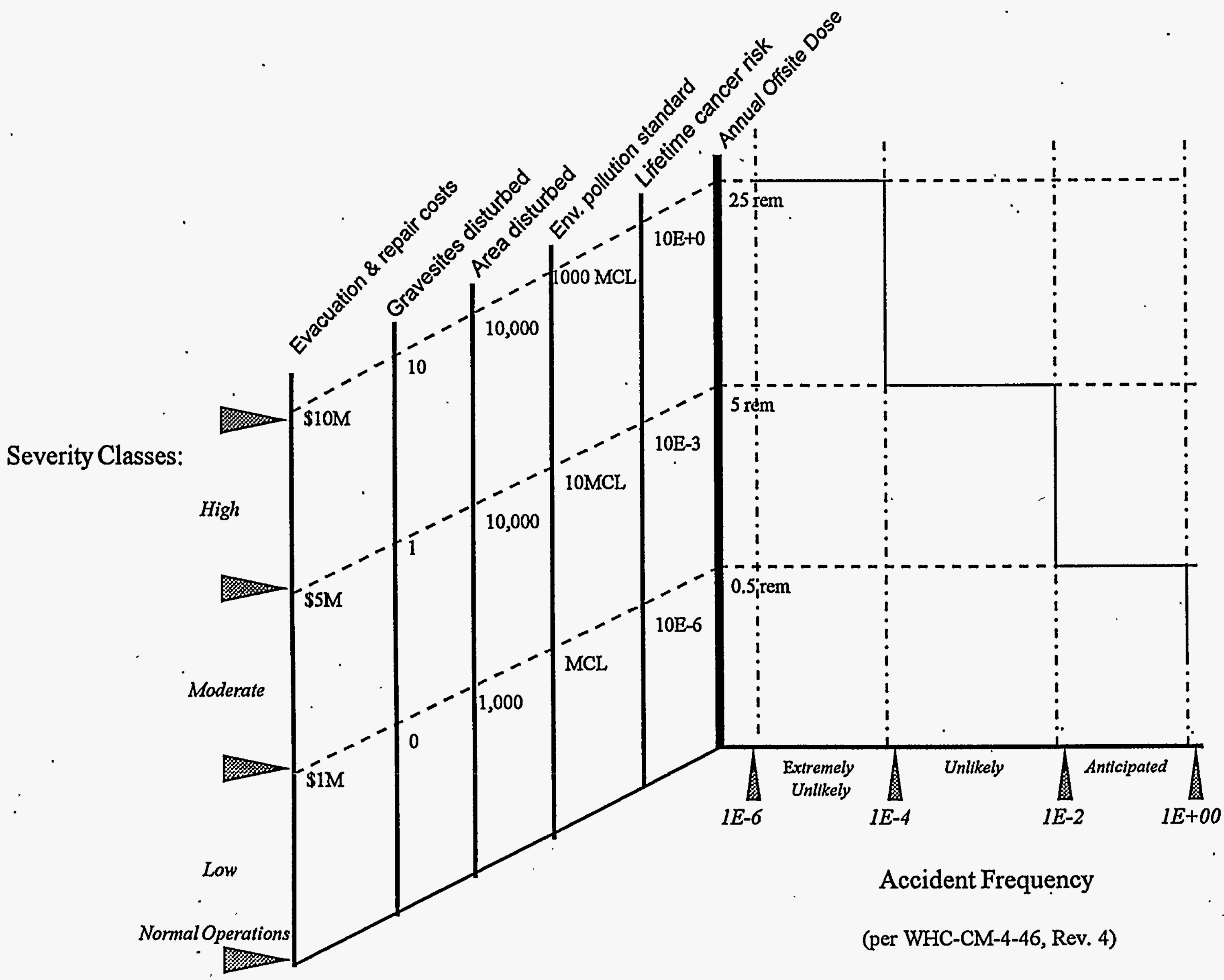
For a hypothetical accident scenario:
If the correlation between annual frequency and acceptable severity (per WHC-CM-4-46) is used, then this accident (if ≤1E-6/yr) exceeds constraint levels for 4 risk measures, and the same accident (if ≤1E-4/yr) exceeds constraint levels for 13 risk measures.

Figure 6a. Severity Scales for Annual Public Dose per Accident Frequency



(per WHC-CM-4-46, Rev. 4)

Figure 6b. Complementary Severity Scales for Additional Risk Measures per Accident Frequency



5.0 USING RISK IN VOI: COST PER CONSEQUENCE

In order to apply VOI in the situations described in this task's scope of work, the costs for each consequence measure must be defined. In practice, this can only be done with active participation of regulators, decision makers, and stakeholders, but for the purpose of demonstrating the proof of principle, placeholder costs are used here. For the purposes of demonstrating the utility of a risk-based VOI, an airborne release from a dome collapse in a flammable gas tank which releases 10 kg of material was selected as the test case.

SUMMARY OF DOME COLLAPSE COSTS: The costs are derived from dispersion/deposition models and maps showing contours of concentration and risk. The costs for this particular accident were developed from knowing the size of the area impacted, the degree and duration of the impact, and other measures. The material that was released from tank S-106 in this hypothetical case included both the respirable fraction (< 10 microns) and the total airborne release fraction (including particles > 10 microns) of four isotopes (see below), and a puff model ("GXQ") was used for the dispersion and deposition analysis to give contours of inhaled and deposited concentrations. From these contours, the following costs were estimated:

Health and Ecological Impacts:	= $ 6,040,000
Remediation costs:	= $ 35,085,000
Cultural/Historic Resources, and impacts to cultural access and use	= $ 20,000,000
Programmatic Impacts	= $426,503,000
Total	= $487,628,000

The costing of consequences may be approached in three ways, in order of increasing precision:

- Estimate an upper bound cost for cleanup for each event (with or without costs of health effects, remediation and restoration, food interdiction cost, shutdown costs, penalties, compensation for reduced quality of life, and so on);

- Estimate the magnitude of impact for each measure by estimating the severity class for each measure, then apply a constant cost-per-severity-class and sum the approximate costs.

- Select all individual consequence measures that could be impacted by an event and develop a cost estimate for each individual impact, then sum the costs.

  This approach requires an evaluation of existing risk assessments, safety analyses, and so on. The exact measures that are relevant to a particular decision depend on the material released, concentrations at various distances, the persistence of the contaminants, and the total area impacted (concentration isopleths). It is possible to approximate the true impacts by keying the measures to simple model outputs such as environmental concentration and (for example) farthest distance downwind at which particulate deposition results in food interdiction or marketability of produce. *It is absolutely essential to include both inhalation and deposition in the dispersion modeling, because deposited material accounts for most of the cost.* Attempts to "roll back" the evaluation from modeled environmental concentration to, for instance, material released or total tank contents and then keying the consequence measures directly to some of these "upstream" data results in simpler analysis but less precise results. This may be quite acceptable for ranking or screening applications but may be less acceptable when comparing relative (estimated) consequence costs to absolute (known) mitigation costs.

Valuation of specific measures has a long and controversial history and includes methods such as contingency valuation (willingness to pay), hedonic price estimates, and other means. The danger of discounting the worth of future generations or future harm still persists. The problem of attempting to use Multi-Attribute Utility Analysis to force a consensus among disparate value sets also persists; it is useful for achieving consensus within a single value set but often fails when used with multiple value sets. There is a philosophical problem with the apparent trading of information for lives, particularly when the payers and payees are different; even though the equivalent costs for the risk measures are used solely for decision purposes, it nevertheless implies that those are actual costs. Finally, there are several ways to value each measure (e.g., should environmental harm be valued by restoration costs per acre or cost of lost ecosystem functions and services?) A few examples of typical consequence costs will illustrate this.

The cost to avoid one rem of exposure per year has been estimated at $2000 (NUREG-1530). Using this estimate, the exceedance of a worker's annual 5 rem dose "costs" only $10,000, and achieving 100 mrem/yr (the annual offsite total dose allowance) is essentially worthless. In fact, using a cost-per-rem approach for valuation of radiation health effects prevents protection of worker and public health from being cost-effective until near-fatal doses are reached. Clearly, a single event that puts the entire Site instantly out of compliance for the entire year will be more expensive than this.

NCRP (#116) has estimated that a radiation cancer fatality results in an average 15 years of life lost (YLL), or 1 cancer risk = 15 YLL. An exposure that results in an increased lifetime cancer risk of 10^{-6} is therefore equivalent to 15 years/1,000,000 = 8 minutes of life lost. If one life is worth $10 million, then these 8 minutes are worth $2.14. Further, if a cancer actually occurs, the entire lifetime ($10M) is not the cost of the cancer, but only the lost 15 years ($2.14M). This example illustrates the problem with linear extrapolation from a full cost/life to a cost/minute of life.

Both of the above examples suffer from the problem of fractionalizing a human life. The general approach to regulating hazardous substances is not made on the basis of defining a level of clinically observable effects just barely below statistical significance (the Pareto principle). On the contrary, toxics are regulated using a precautionary approach (margin of safety). Dividing lives into minutes and optimizing across dollars per minute-detriments is analogous to removing the safety factors from protectiveness standards and thus results in an inappropriate comparison of costs.

Other thresholds in acceptance or cost likely will be discovered. For example, releases may occur that do not trigger surface soil removal or food interdiction, so those costs would be zero until a threshold concentration were exceeded, at which point costs would increase substantially.

5.1 Application to the Flammable Gas Safety Issue

The representative accident scenario selected as a test case was a dome failure (high severity). Three methods for assigning costs to the consequences of these two events are:

A. Total Estimated Cleanup Costs.
   A single (rough) estimated cost may be adequate in some decision contexts.

B. Estimated Cost per Measure by Severity Class.
   Estimate the number of measures adversely impacted for each of the two events, and assign costs on the basis of whether the event might cause high, medium, or low impacts. For this example, the impacts are placeholder examples and are not based on real data.

C. Estimated Cost per Measure with Environmental Modeling.
   If environmental transport modeling data are available for both inhalation and deposition (such as concentration at a single location at a single time point, or distance to the boundary of an emergency planning or exclusive use zone, etc.), the impacts to each measure can be estimated.

The first step is to estimate the amount and composition of material that might be released during an accident, and to identify the particle size. For this test case, the following information was used:

	Amount of material <10 microns released to air	Amount of material >10 microns released to air
Pu (ρCi)	1.2E+03	2.4E+03
Cs (ρCi)	1.8E+06	3.6E+06
U (ρg)	1.8E+07	3.6E+07
Sr (ρCi)	7.5E+05	1.5E+06
Size	RF = 1.0E+04 g	ARF = 2.0E+04 g
Note: Inventory and released fractions for Tank S-106 were obtained from S Agnew, personal communication.		

The second step was to apply dispersion and deposition modeling results to develop environmental concentration contours. The puff model ("GXQ") was used with Hanford meteorological data to develop one complete Hanford grid layout for each radionuclide. The exposed persons are assumed to either be exposed via inhalation for 1 hour during the initial event, or to be a farmer in residence on non-mitigated soil for the standard 30 years. Figures 7a and 7c show the total risk contours for inhalation and foodchain exposures, respectively, after the concentrations of individual nuclides are translated into individual risk contours and summed. Figures 7b and 7d show the dominant nuclides for inhalation and foodchain risks. Figures 7e and 7f show the inner set of concentration contours for the risk drivers (plutonium for inhalation risk and cesium for foodchain risks).

5.2 Total Estimated Cleanup Costs per Event

Table 2. Cleanup Costs per Event

	Dome Collapse
Total Cleanup Cost Estimate	$20M

For general estimation of consequence costs, several computer codes are available. The MELCOR Code[4] includes cost estimates for evacuation, decontamination and lost agricultural marketability. Updates of parts of this code also exist[5]. As an example of user-selected input parameters, evacuation costs can be selected from $0-1000/person-day and relocation costs can be selected, and from $0-1000/person-day to cover food, housing, transportation, lost income, and replacement of lost personal property. The duration of lost access to the land ranges up to 317 years. Decontamination costs range up to $100,000/hectare for farmland and $100,000/person for residential land. Costs for temporary or permanent relocation of people ranges up to $1M/person (also includes loss to the businesses impacted). Real estate costs include market value of agricultural land and its products and market value of non-farm land and its improvements. At Hanford, additional considerations of environmental and cultural resources will be important.

MELCOR Accident Consequence Code System (MACCS). NUREG/CR-4691, Volumes 1-3, 1990. Developed by D.L. Chanin, J.L. Sprung, L.T. Ritchie and H-N. Jow, Sandia National Laboratories. The purpose of this code is to simulate the impact of severe accidents at nuclear power plants on the surrounding environment. The phenomena considered in MACCS are atmospheric transport of radionuclides, mitigative actions based on dose projection, dose accumulation by a number of pathways including food and water ingestion, early and latent health effects from radionuclides, and economic costs. Data inputs include such items as percent evacuation, amount of farmland contaminated, percent success of farmland decontamination, length of growing season, and other variables related to evacuation/relocation costs, decontamination costs, and marketability of locally produced crops, meat and milk.

D.L. Chanin, "A New Emergency Response Model for MACCS" LA-SUB-94-6, November 1992 (improvements in flexibility in modeling the mitigative actions of evacuation and sheltering).
Also: D.L. Chanin and M. Young, Code Manual for MACCS2 (Beta test version), May 1995 (sponsored by DOE for application to diverse reactor and non-reactor DOE facilities. Includes a more flexible emergency response model, an expanded library of radionuclides, and a semi-dynamic food chain model.

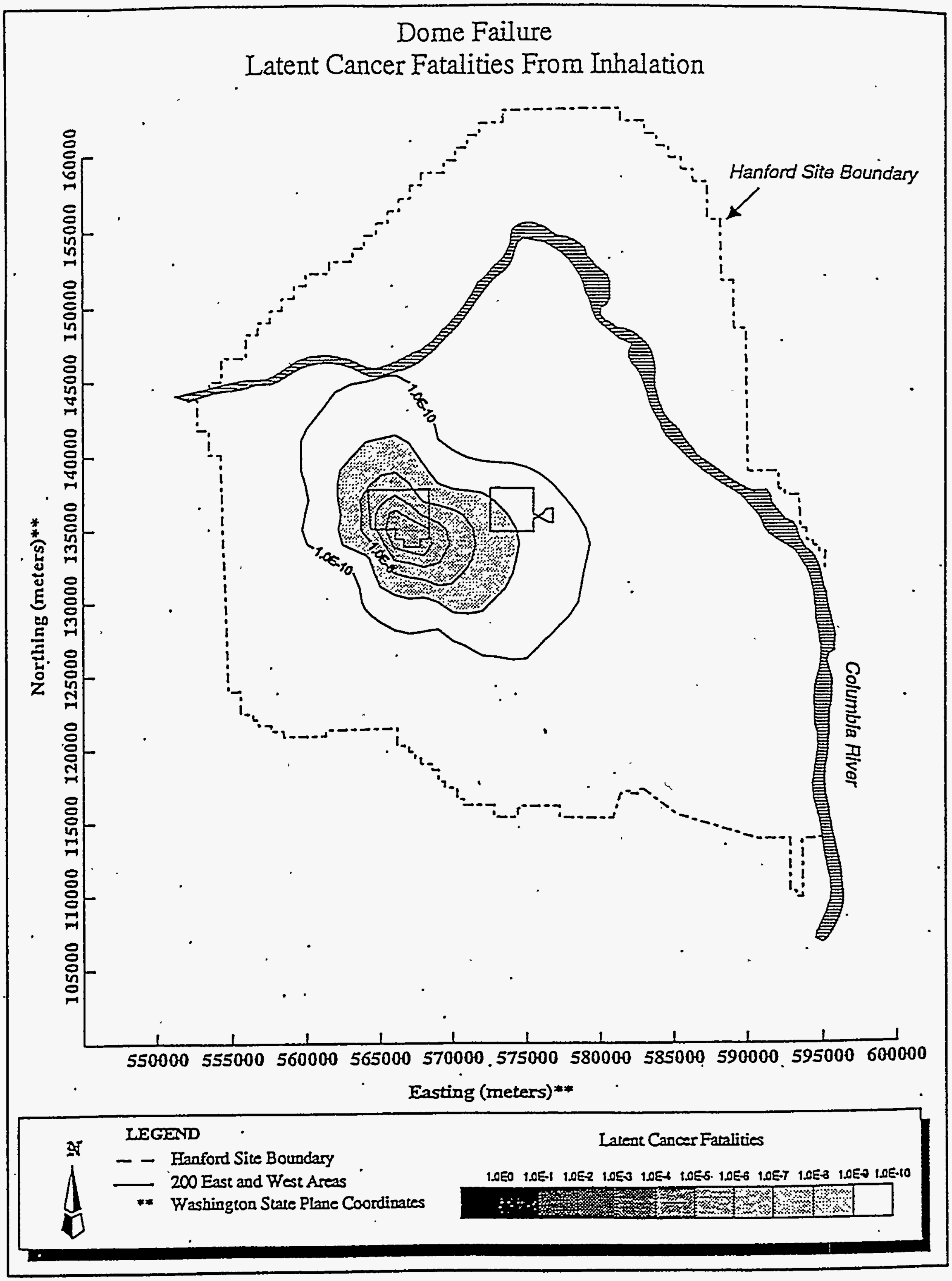


Figure 7a. Dome Failure Latent Cancer Fatalities From Inhalation

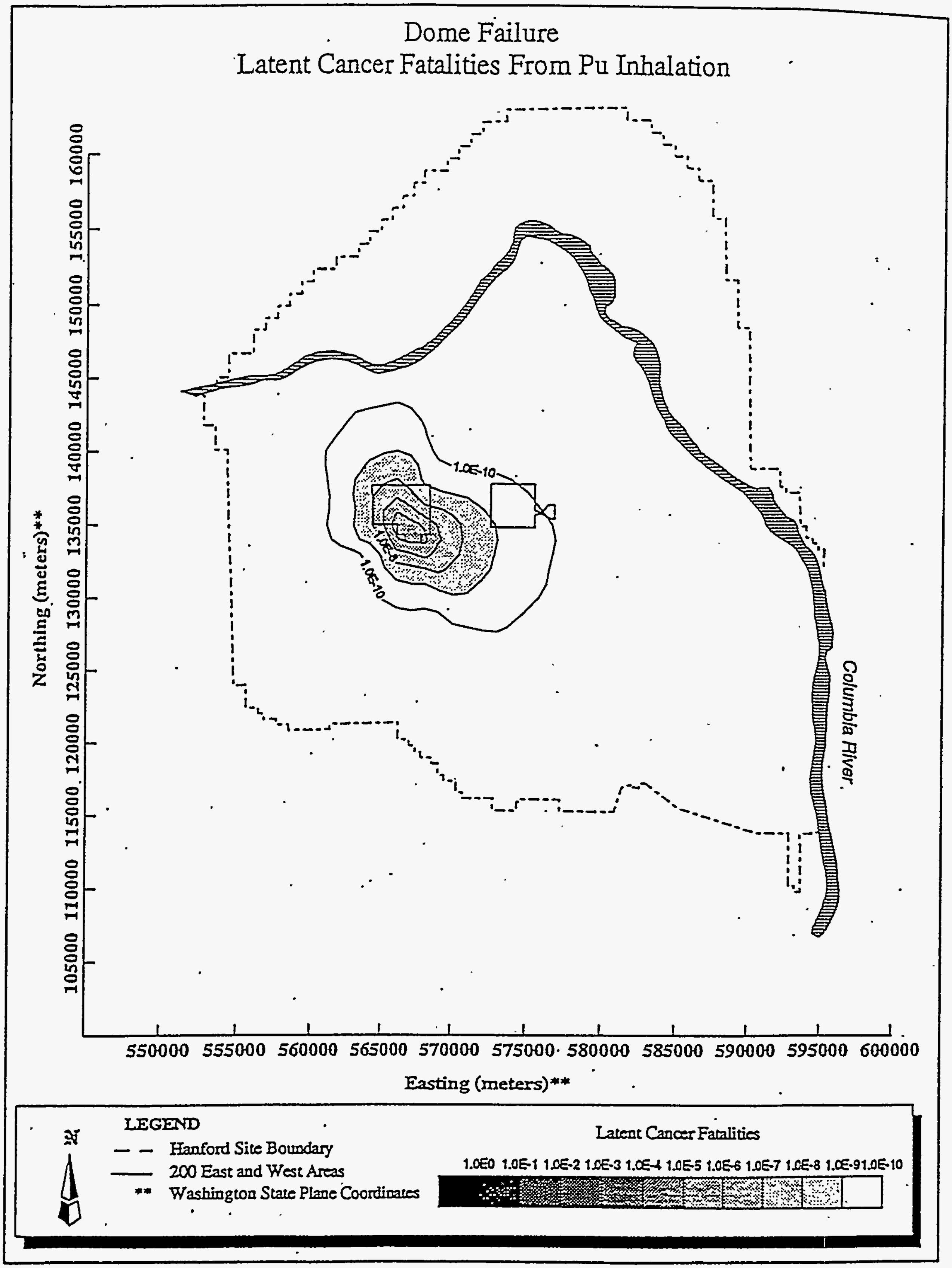


Figure 7b. Dome Failure Latent Cancer Fatalities From Pu Inhalation

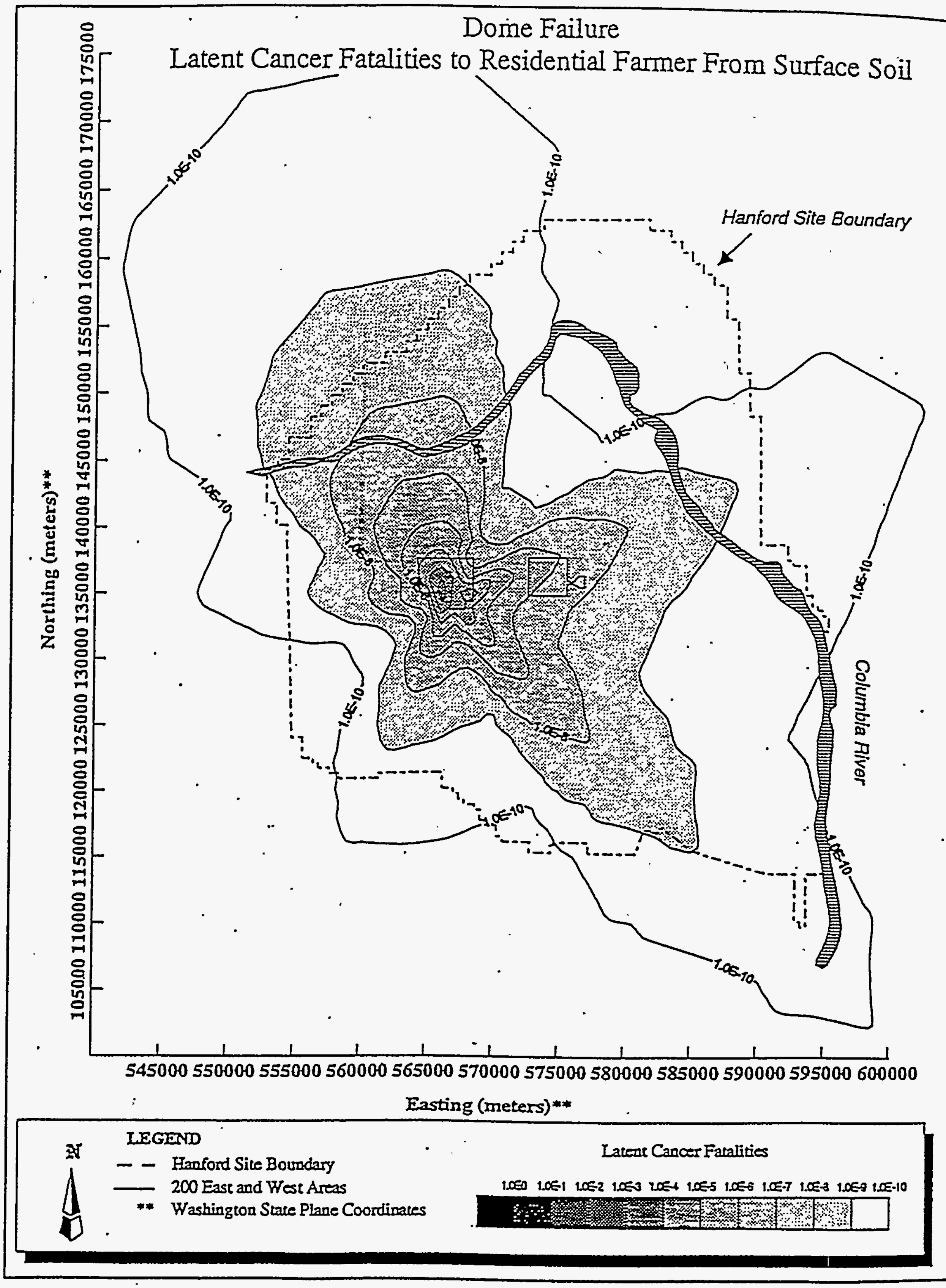


Figure 7c. Dome Failure Latent Cancer Fatalities to Residential Farmer From Surface Soil

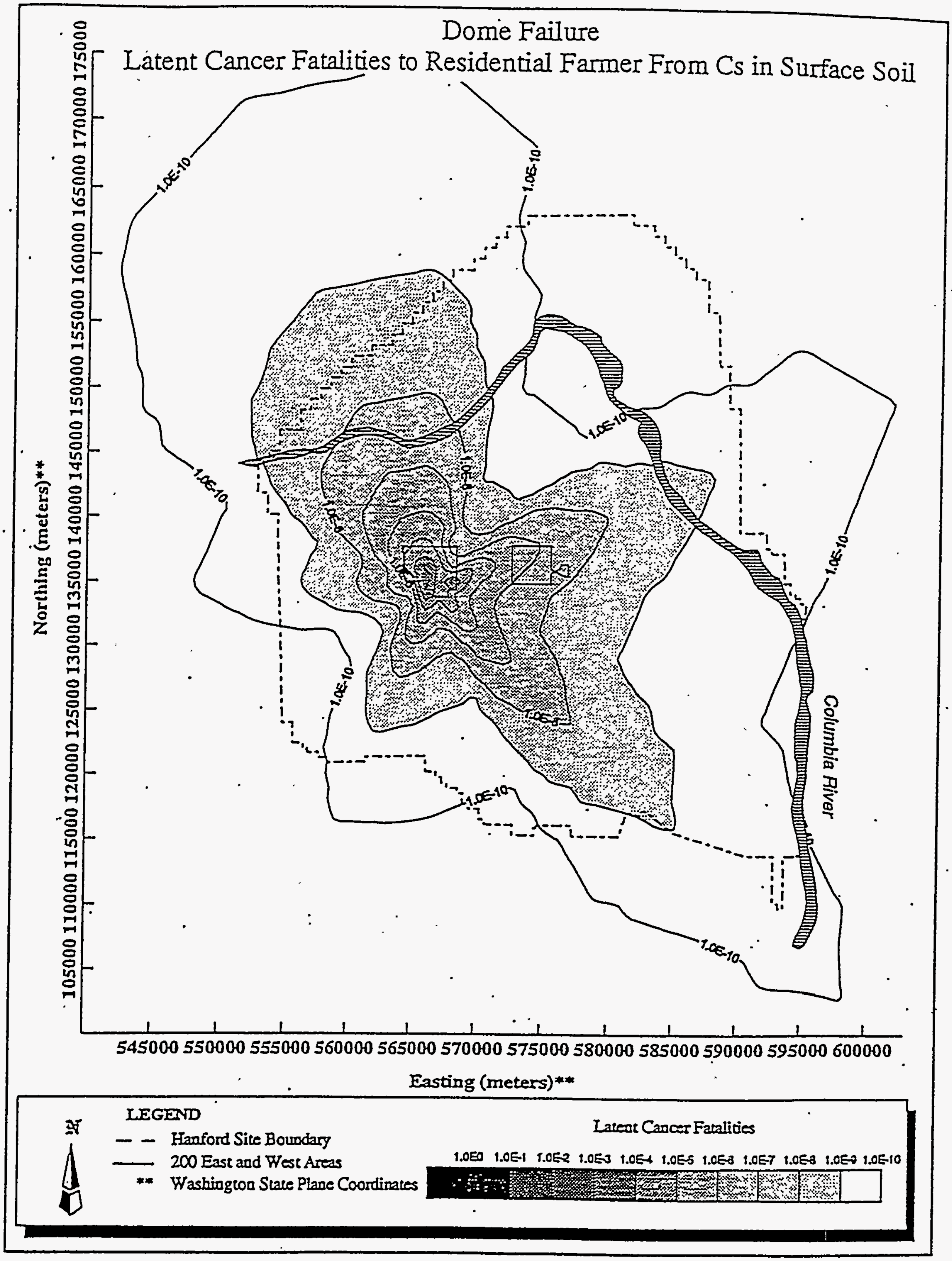


Figure 7d. Dome Failure Latent Cancer Fatalities to Residential Farmer From Cs in Surface Soil

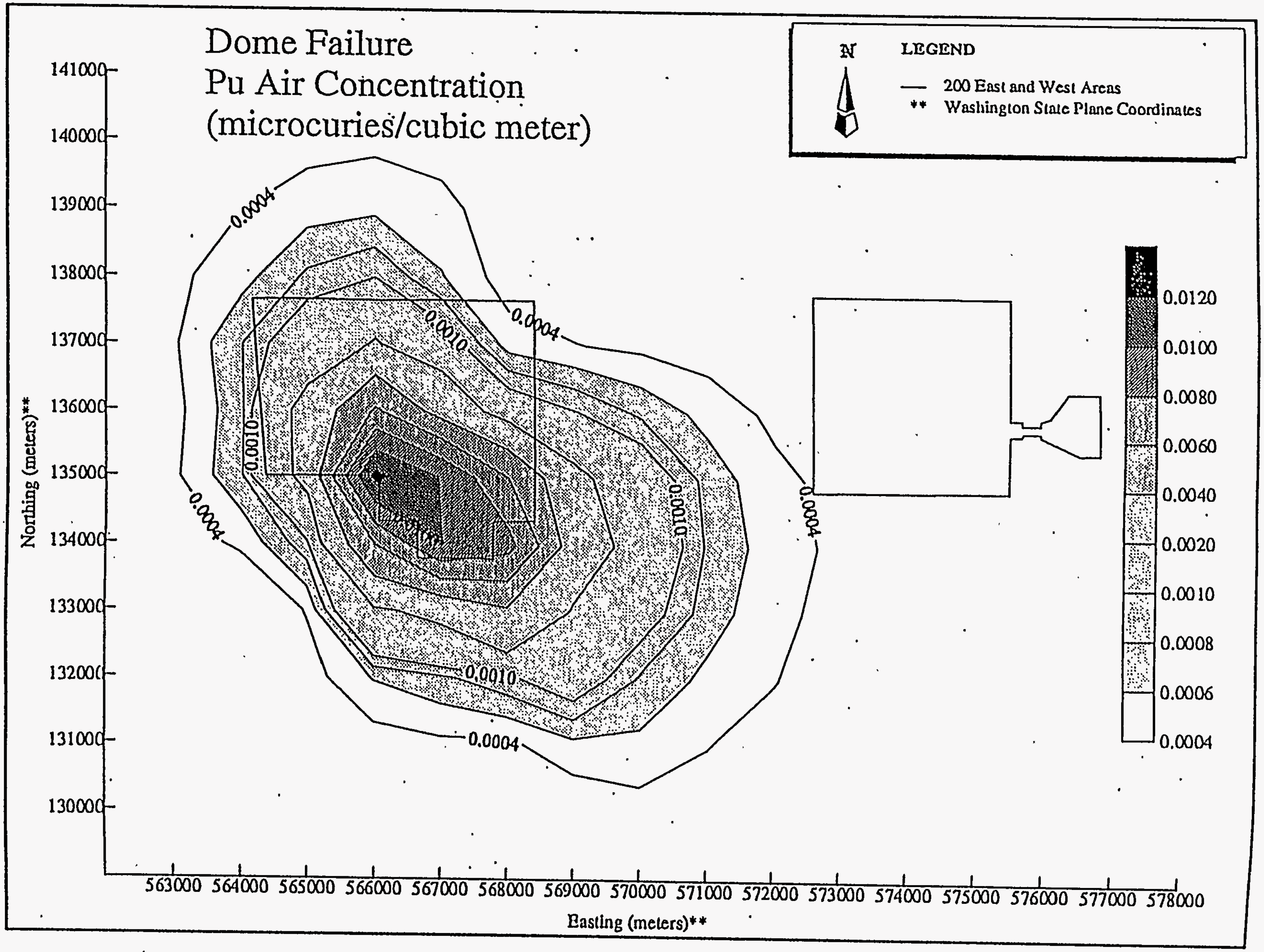


Figure 7e. Dome Failure Pu Air Concentration (microcuries/cubic meter)

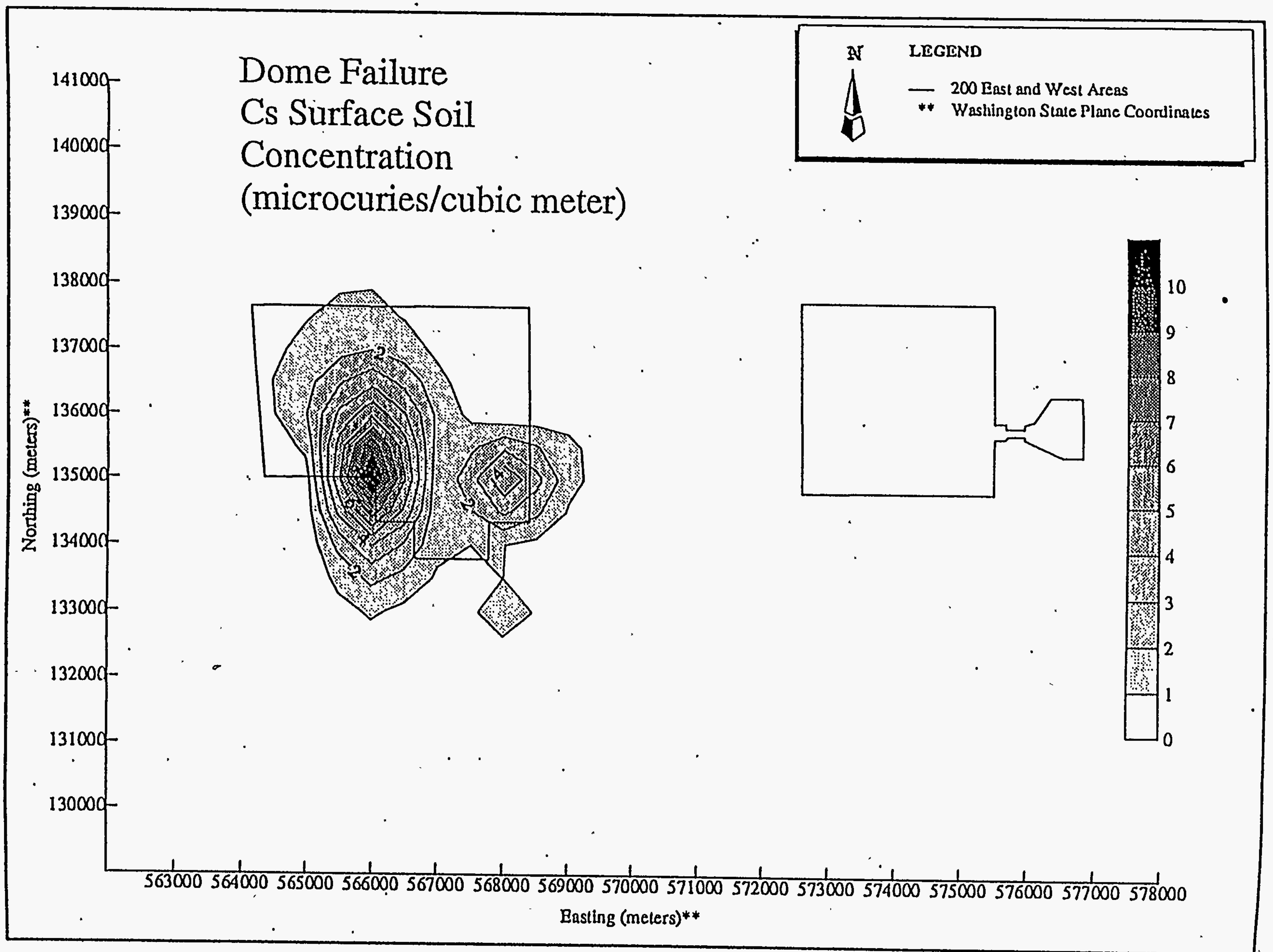


Figure 7f. Dome Failure Cs Surface Soil Concentration (microcuries/cubic meter)

5.3 Estimated Cost per Measure by Severity Class

For the purposes of this example, sample (unsubstantiated) estimates of the magnitude of impact for each measure are used, and a cost-per-severity (also unsubstianted) is assigned. If the impact to a given measure might be either not applicable or within the safe or clean envelopes, this is designated "-" and no cost is assigned. A hypothetical cost of $0.1M/measure is assigned to each low severity of impact, $1M/measure is assigned to each moderate severity of impact, and $5M/measure is assigned to each high severity (or catastrophic) impact. The principle behind this generalization of similar costs across all measures is predicated on the assumption that, for instance, the cost of a catastrophic impact on any measure might have roughly equal degrees of adverse impact and therefore equal degrees of cost. This hypothesis remains to be tested.

For the hypothetical example below, a high estimated impact represents the degree to which the measure exceeds the constraint level, without requiring calculation of the exact performance. For example, the worker dose might be very non-compliant, without defining exactly what dose range defines "very non-compliant."

Table 3. Hypothetical severity of individual impacts for the dome collapse

Measure	Dome Collapse
H1. Short-term public/worker radiological dose	H
H2. Short-term public/worker non-radiological exposure (relative to TWA or ERPG levels)	H
H3. Annual worker radiological dose (relative to 5 rem/yr)	H
H4. Annual public individual radiological dose (relative to 100 mrem/yr)	H
H5. Annual population radiological dose	TBD
H6. Lifetime individual MEI cancer and non-cancer risk (relative to cancer risk range of 10^{-4} to 10^{-6} and non-cancer hazard index $\geq$ 1).	M
H7. Multigeneration risks (sum of risk to all people ever exposed, including the present generation).	TBD
E1. Contamination of media exceeding environmental or health standard.	M
E2. Ecotoxicity and habitat impacts	M

E3. Environmental disturbance during remedial/emergency response	H
S1. Community Quality of Life	H
S2. Tribal Quality of Life	H
S3. Intra and Intergenerational Equity	H
S4. Impacts to cultural resources during remedial/emergency response	H
P1. Penalties (non-compliance, audits, treaty violation, trusteeship breach, etc)	H
P2. Shutdown costs (additional training, idle workers, etc)	H
P3. Response and repair costs (additional equipment, evacuation costs, etc.)	H
P4. Mission impact costs (rebaselining, refocusing, change orders, etc.)	H
P5. Interprogram and Sitewide Impacts (additional disposal, delays to other programs, Sitewide refocusing)	H
P6. Costs of inadequate stakeholder involvement.	M
TOTAL	_0_ Low x $0.1M = $0M _4_ Moderate x $1M = $4M _14_ High x $5M = $70M Total Cost = $74M

5.4 Cost per Measure with Environmental Modeling

This example shows how some of the costs for major health endpoints, environmental, socio-cultural and programmatic endpoints can be estimated. Both acute inhalation doses and long-term exposures from incorporation of nuclides into the foodchain are considered. The risks to the public were evaluated as if full access to the Site (but not to the 200 West Area) were allowed, as was done in the TWRS EIS. The single ecological toxicity endpoint used for this test case was radiation dose; ecological risk measures due to exposure of individual organisms will need to be reviewed during implementation of this process.

Note that if 10-fold more material were released than the nomical 10 kg amount, the 10E-6 risk isopleth would approach the Site boundary to the NW. Further, exposures and risks to Native Americans using the 100 Area would exceed 10E-5, since their exposures would be approximately 10 times higher than those of the residential farmer.

Table 4. Health Risks and Costs of the Dome Collapse

Risk Categories: Health and Ecological	Cost (10 kg release)
Dose to Involved Workers (dose to worker at 0m x 10 workers) x $2000/rem[a]	100 mrem x 10 workers = $2000 (use $1M for conservativism)
Dose to Non-involved Workers (dose to worker at 100m x 1835 workers) x $2000/rem[b]	10 mrem x 2000 workers = $40,000
Inhalation dose at 100m (public or worker); 1-hr duration[c]	0.01 mrem = $0
Inhalation dose at Site boundary[c]	$0
Excess lifetime cancer risk to a residential farmer located beyond the Central Plateau[c]	<1E-7 = $0
Public evacuation and relocation costs, offsite (onsite worker evacuation is a programmatic cost)[d]	$0
Cost of lost agricultural production offsite[e]	$0
Harm to biota (area exceeding 0.1 rad/day)[f]	Use $5M for conservatism
Total	$6,040,000

a) NUREG-1530 estimates $2000 to avoid one rem of exposure
b) Number of workers taken from the TWRS EIS
c) Based on $10M per life x 15 YLL per cancer (NUREG-1530)
d) From MELCOR, would use $1000/d for temporary relocation, $1M for permanent relocation, and $100,000/person for decontamination in non-farm areas if the doses were high enough to warrant these actions.
e) From MELCOR, would use $100,000/hectare to decontaminate farmland plus food interdiction costs TBD.
f) Habitat restoration = $50K/acre to restore (C Brandt, personal communication); costs to biota TBD, and other habitat and resource valuation TBD.

The dome collapse scenario includes an in-tank explosion which would crack the tank and result in a crater. The cost of remediating the crater includes the assumption that 13,000 cubic meters of contaminated material and soil would be excavated using remote technology (such as robotics). It also includes surface deconmamination of U Plant, which is directly downwind of Tank Farm S.

Table 5. Remediation Costs Near the Tank

Risk Category: Remediation, Restoration & Repair[a]	**Cost**
Remote excavation	$12,210,000
Demolish Tank	$19,600,000
Excavate under Tank (Level C protection)	$730,000
Disposal in ERDF	$1,080,000
Site restoration	$210,000
Surface decontamination of U Plant	$1,155,000
Off-Site non-farm soil decontamination	$0
On-Site decontamination to restore unrestricted access outside the Central Plateau (15 mrem oublic dose limit)	$0
Cost of environmental restoration after on-Site soil decontamination	$100,000
Total	$35,085,000

a) Decontamination costs taken from ARAM: $21K/cubic meter of high-pressure wash water, which must be collected and treated @ 0.125 gal/square foot, for a cost of $66 per square meter of external building surface. The surface area includes only U Plant, but other buildings would also need surface washing.

Impacts to cultural and historic resources and community impacts such as lost recreational use, lost access by tribal members to cultural areas, and lost use of tribal natural resources are examples of measures that would be included in a Cultural/Historic Impact section. For the present example, the size of the contamination footprint is relatively small, but there would be some direct impact to Gable Mountain, a traditional cultural property and sacred site. Placeholder costs for damage and lost access and use are included here, pending stakeholder involvement.

Table 6. Cultural/Historic Impacts and Costs

Risk Category: Cultural/Historic Impacts	**Costs**
Harm to historic buildings and cultural resources during emergency response	$10M
Lost recreational use along the river	$0
Lost use of natural and cultural resources	$10M
Total	$20M

There sould also be additional programmatic impacts, such as evacuation of workers, and various shutdown costs, as follows:

Table 7. Additional Programmatic Costs

Risk Category: Programmatic Impacts	**Costs**
Evacuation costs (workers) (2 days x 15,000 workers x $300/d)	$9,000,000
Shutdown and Inactive worker costs (TWRS plus other programs plus PR costs)	$313,000,000
Public releations impact (2 FTE plus other speakers, consultants)	$367,000
Health Professionals, screening costs	$2,160,000
Accident investigation	$1,800,000

SAR Reanalysis, modeling	$176,000
Hardware & procedural upgrades	$24,000,000
Impact on other Tanks and Facilities	$36,000,000
Impact on other DOE Sites as prevention	$40,000,000
Total	$426,503,000

6.0 CONCLUSIONS AND RECOMMENDATIONS

A number of lessons may be learned from this report:

•The risk assessor should be involved in the decision from the beginning, especially if risk-based data are used during negotiation (e.g., for seeking a temporary waiver of a standard in order to achieve a lower endstate risk).

•Stakeholders should also be involved in the steps involving selection of measures, setting constraint levels, and assigning costs, since they will also be party to negotiations and will need to see that specific measures have been used to support the decision.

- The actual decision process will probably be iterative, beginning with a values and constraints step, initial screening of alternatives for those which clearly will be unacceptable, selection of measures relevant to an event and its consequences and which will discriminate among technical alternatives, and a final screen to demonstrate with more precision that the preferred alternative meets acceptability limits.

- For practical application, the issue of "roll-back" (or tying consequences directly to antecedent information rather than performing a comprehensive risk assessment with environmental modeling and exposure pathway analysis) needs to be addressed. It is possible, for instance, to tie consequences to environmental concentrations at a single location at a single point in time, or (moving "upstream" in the risk paradigm shown in Figure 1) to the release fraction or even to material inventory. Each step further "upstream" increases the uncertainty of the data, but this may be acceptable for a particular decision. The combination of choosing only a few consequence measures and keying them all the way back to release fraction or material inventory results in the greatest degree of uncertainty, but even this amount of uncertainty may be tolerable in initial prioritization or screening analyses.

- At present, the set of risk consequence measures has constraint limits identified only for normal (routine) operations. Guidelines for human dose limits for excursions during normal operations and for more serious but less frequent accidents are also provided, but accident risk guidelines for all the other measures also need to be developed, either in parallel with current suggested frequency classes (per WHC-CM-4-46) or by general descriptors of consequence severity classes (what would constitute high-medium-low consequences for each measure, which could be matched to the frequency classes).

- The next step in operationalizing this report for TWRS characterization requires modularized environmental transport results (once for 200E and once for 200W), which then allows tank-specific release fractions to be incorporated as spreadsheets without having to re-model each accident scenario or each tank. The results of the transport model can be shown geographically, and the isopleths for contaminant concentrations can be converted to risk isopleths through linked spreadsheets that contain human exposure scenarios and similar factors for each of the proposed risk measures. These methods have been used for other Hanford applications, although the specific determinations of concentration-based impact levels for the proposed measures have not been done.

ATTACHMENT 1

RISK CONSTRAINT MEASURES FOR NORMAL OPERATIONS AND POST-REMEDIAL CONDITIONS

The Risk Constraint level is a level of risk (or dose, exposure or other impacts) above which some regulatory response, technical or scientific objection, or public protest is typically triggered. Examples include exceedance of a regulatory standard and/orguidance, an accidental release that requires some minimal level of emergency response, a significant likelihood of project delay and inquiry, or residual contaminant levels that invoke some level of restricted access or land use. The middle column in Attachment 1 (the constraint level for routine event or normal operations) may be thought of as things to minimize, avoid, or (in a few instances) goals to achieve. Before the Constraint Measures are used, they must be reviewed for verbal precision; for example, do the constraint levels define levels that must not be reached, or do they define the minimum level of impact that is likely to be acceptable? *Note that for more significant events, additional measures may need to be evaluated because there could be many more adverse impacts whose effects persist longer. The constraint levels in this Attachment are minimum-impact definitions.*

The human health portion of a full risk assessment may involve any or all of the pathways and effects in the table below, in addition to the comparison of individual doses to regulatory standards. This level of assessment is most likely only necessary for disposal and closure situations where perpetual safety must be demonstrated. For other decisions, a lesser subset of measures might be acceptable. Again, this is entirely dependent on the particular decision and on the approval by interested and affected parties, especially if there is a need to gain the most information from the least data.

The following table is presented to show the relation between the duration of the event and the duration of the health effects. The health measures in the attached matrix include this entire range.

Table A-1. Temporal relationships between duration of events and health effects.

Health Effects Description	Duration of Environmental Release	Duration of Exposure	Likely Human Exposure Pathways	Likely Health Effects of Primary Concern
Immediate (acute) non-cancer effects from either normal operations or accidents[1]	Short-term (generally airborne): puffs, fugitive emissions, accidents.	Hours to Days ("acute")	Inhalation, Immersion (external)	Acute effects from all constituents (carcinogens and non-carcinogens)

Latent cancer from short-term events	Same	Short-term inhalation exposure and long-term indirect exposure	Multi-pathway, typically after deposition from the air onto soil and plants	Increased cancer risk from short-term events and exposures
Chronic effects (cancer and non-cancer) from long-term releases	Long-term releases to any environmental medium	Chronic	Multi-pathway, both direct and indirect (foodchain)	All effects (cancer and non-cancer) in the present generation
Multi-generation and cumulative effects	Summed for both short-term and long-term releases	For as long as the agent persists (e.g. 10 half-lives)	Same as above	All effects, summed over all people ever exposed, including cumulative genetic impacts

(1) The short-term exposures for workers may be within acceptable short-term occupational limits (e.g., STEL: short-term exposure level, or PEL: permissible exposure level); for public exposures, analogous limits might be derived from occupational limits by using additional safety factors. The short-term limits might be exceeded for either duration and/or magnitude; both acceptable and unacceptable short-term exposures may be included in the evaluation. As benchmarks, ACGIH and AIHA have established IDLH (immediately dangerous to life and health) concentrations for many chemicals, and the NRC has developed emergency dose limits for radionuclides.

TABLE A-2. RISK CONSTRAINT MEASURES FOR ROUTINE OPERATIONS AND POST-REMEDIAL CONDITIONS

CATEGORY OF IMPACT	EXISTING REGULATION, GOAL, OR SUGGESTED "CONSTRAINT" LEVEL: May be keyed to a dose level, an exposure level, a risk level, an environmental concentration, or qualitative descriptor. Some of these levels are absolute thresholds, some are guidelines, and some are target ranges. In order to apply the proposed VOI methodology, each measure must eventually be converted to dollars. Note that in addition to the maximum dose limits below, the ALARA principle applies to all individual and collective worker and public radiological exposures from occupational sources (10 CFR 835/B2, DOE Order 5400.5).	Notes/Issues
CATEGORY: DOSES FROM ROUTINE EVENTS AND NORMAL OPERATIONS		
H1. Short-term public/worker radiological doses Compared to (as examples only) fraction of annual allowable dose (EDE in mrem/yr). Needs consideration of apportionment and additive probabilities of multiple events if source terms are aggregated.	WORKER: 0.05 Sv (50 rem) during emergencies involving lifesaving; otherwise, control to annual occupational limits (NCRP 116, p.44). Planned special exposure limits are given in HSRCM-1, DOE RadCon Manual, and 10 CFR 835. VISITORS and OFFSITE: temporary annual limit of 500 morem if pre-approved by DOE for an activity for infrequent exposures; otherwise limit visitor doses to the 100 mrem annual offsite public dose limit (Draft 10 CFR 834, NCRP 116, DOE RadCon Manual, HSCRM-1).	The short-term limits (H1 and H2) are defined as acceptable dose excursions when considered as part of total annual or lifetime doses. Issues: limits on the number of visits due to total annual dose limits; apportionment of dose by the number of visits; apportionment of dose over time or the facility life cycle.
H2. Short-term public/worker non-radiological exposures Compared to occupational standards (or a fraction thereof for public exposures). May consider multiple events and exposures from other Hanford and/or non-Hanford sources.	WORKER: Occupational short-term exposure standards (STEL, PEL, or other limits set by NIOSH, ACGIH or AIHA). PUBLIC: Some fraction of occupational limits	

H3. <u>Annual worker radiological</u> dose from all occupational sources	5 rem/yr (50 Msv) total effective dose <u>and</u> a cumulative lifetime EDE of 0.5 rem (10 Msv) x age (10 CFR 835, NCRP #116, ICRP #60). Exceedance of the DOE Administrative Control Level of 2 rem/yr requires preapproval (10 CFR 835/B2, HSCRM-1).	Annual event frequencies of 10^0 (i.e. anticipated to occur once per year) should be compared to annual dose limits and used to anchor the scale for less-than annual frequencies. Apportionment among risk sources should be considered.
H4. <u>Annual public (individual) radiological dose</u> Contribution ("apportionment") to the annual public MEI radiological *Hanford-wide* total dose and inhalation dose from routine (stack + fugitive) and unplanned releases. Includes consideration of tanks as point sources, privatized processing activities as contributing to Hanford air quality, etc.	Public MEI dose limit (TEDE) = 100 mrem/yr (1 mSv/yr), summed across all continuous or frequent exposures from all sources (for local compliance this is all Hanford sources combined), all pathways, and all radionuclides; 10 mrem/yr of this dose may be by inhalation (40 CFR 60 - NESHAPs; NCRP #116; 10 CFR 23; 40 CFR 191.04; DOE Order 5400.5; Draft 10 CFR 834). There are additional limits, such as 0.5 Msv/month (50 mrem/mo) for the embryo-fetus. Also: 25 mrem/yr (0.25 Msv/yr) (or 15 mrem/yr as cited by EPA in 40 CFR 191 for WIPP) whole body dose from a single source, termed "apportionment" (40 CFR 191, 10 CFR 61.41, 40 CFR 190; 40 CFR 191.03; WAC 173-480, NCRP #116). Draft 40 CFR 193 & 196 have limits of 15 and 75 mrem/yr, depending on "protection." For HLW storage: 15 mrem/yr for 10,000 yrs (40 CFR 191.15). Groundwater ingestion dose for an individual located offsite during facility operations and at 100m from the edge of the facility after the period of institutional control = 4 mrem/yr (DOE 5480.2A, 40 CFR 193 draft, Clean Water Act)	Same comment as above. Issue: current Hanford MEI locations may eventually move on-site to 100 m or at the 200 Area boundary. There are nuances in public dose limits for HLW/LLW storage, operational facilities, and so on.

H5. Annual population radiological dose.	TBD Collective EDE = 500 person-rem/yr (DOE 5820.2A; groundwater only?)	Issues: this measure may need to be applied to a subset of the general population which has high exposure through reasonably anticipated land uses.
H6. Lifetime individual MEI cancer and non-cancer risk Risk from radiological plus non-radiological chemicals, from routine and unplanned airborne releases plus routine and unplanned soil/groundwater releases and existing contamination, all exposure pathways. The MEI location and Point of Compliance location may change over time. Depending on the context, this risk may be per accident, per tank, per entire TWRS Program, or for the entire 200 Area or Hanford-wide aggregated source terms.	10E-6 lifetime increase in cancer risk is EPA's starting point or initial protectiveness goal for multiple contaminants or multiple exposure pathways, with the upper bound for risk allowed for individuals between 10E-4 and 10E-6 (55 FR 46, p. 8718 and 40 CFR 300.340.e.2.i.A.2). WA Dept of Ecology uses 10E-6 for individual carcinogens with the total for multiple carcinogens not to exceed 10E-5, all pathways (WAC 173-340, MTCARC Method B; WAC 173-303). Non-cancer target level is usually Hazard Index = 1, summed across pathways and contaminants (40 CFR 300.340.e.2.i.A.1 and WAC 173-340). After decommissioning, the annual limit from a site for an indefinite number of years is 15 mrem/yr assuming unrestricted use, with the decommissioning goal being fully met if the TEDE to an average member of the critical group does not exceed 3 mrem/yr (Draft 10 CFR 834). The critical group is defined therein as the group reasonably expected to receive the greatest exposure due to residual radioactivity, considering all reasonable potential future uses of the site. Residual contamination includes all radioactivity in structures, materials, soils, groundwater and other media but excludes background radiation.	Risk levels are coupled to environmental concentrations through the use of selected exposure scenarios, and largely depend on land use and/or human activity patterns. Issues: Target analytes and "comprehensiveness" of analysis; stakeholder approval of enabling assumptions; fragmentation of source terms and exposures (apportionment).

H7. Cumulative multigeneration MEI and population risks Risk integrated over time and risk during the maximum lifetime. All releases, all pathways and all contaminants over complete duration of contamination.	TBD NCRP 121 (p.60) uses a 7.3% health detriment/Sv of collective dose (fatal plus nonfatal plus genetic effects), or 1 year of lost life per Sv (100 rem) across a general population, provided that no individual's lifetime dose/risk is excessive. Also: 15 yrs of life lost out of a 70 year lifetime per fatal cancer (ICRP 60).	This measure may be thought of as a dose per collective gene pool at low dose rates over a long time period within a closed population such as local Indian nations. It includes everyone ever exposed from the event or source, whenever that exposure occurs. A proxy measure might be total mass (kg or Ci) released. Issues: receptor location, point of compliance, aggregate source terms. No discounting or dilution of dose across a population.
CATEGORY: ENVIRONMENTAL IMPACTS (due to any type of release and response to it)		
E1. Contamination of media Soil, groundwater, air, surface water concentrations relative to regulatory standard (various statutes) or antidegradation policies (e.g. GWPMS). May include provisions for multiple contaminants, aggregate area source terms (permitted plus unplanned releases), and multiple events/releases.	Avoid any release or exceedance of a regulatory standard which triggers program or regulatory response, Notice of Violation of an operating permit, land impoundment or food interdiction (by the WA Dept of Health), or new restriction on access due to exceedance of a regulatory standard.	Issues: Single or multiple contaminants; aggregation of source terms; dilution as the solution (acceptable concentration but diluted over a large area with a large total environmental contamination burden); definition of "degradation;" detection limits; definition of a "significant" duration of impact. Both the degree of exceedance and the duration of contamination are important to know.

E2. <u>Ecotoxicity and habitat impacts</u> Contamination of living natural resources (ecotoxicity) and/or impacts to ecosystem and habitat functions and services. Includes measures for reversibility, organism-population-community scaling, habitat and landscape functions, aesthetics, the potential for contaminant migration, foodchain biomagnification, population vitality, the impact on species' gene pools, additive effects with other stressors and other actions/releases, and interfaces between habitat types and trophic levels. Also includes consideration of meeting Trusteeship responsibilities. (General citations are given in this column because specific measures and reporting requirements are not specified: NEPA, NRDA - 42 USC 9601 Section 107.a.4.c, ESA - 16 USC 1531, 16 USC 661, 16 USC 668, 16 USC 703, 16 USC 1271, 16 USC 757a, 43 USC 1701.a.8)	Only localized (<1000 m^2) short-term effects (<1 yr or season) (worse: widespread short-term or widespread, long-term and/or irreversible). Only impacts on individual organisms of non-T&E species, but not on populations, communities or ecosystems. Dose to individual non-T&E organisms less than 1 rad/d. T&E species: no "taking" is allowed, including incidental taking via harassment or habitat disturbance. No or low potential for contaminant migration.	For a minimum level of impact, it is assumed that impacts to individual organisms would not result in substantive impacts to ecosystem functions and services. For more significant impacts, other measures of ecosystem functions and services need to be included. Issues: definition of baseline or optimal conditions; intermeshed spatial and temporal scales; overlapping transport and transfer pathways; selection of indicator or surrogate species; representativeness of simplified measures or biomarkers.
E3. <u>Environmental impacts from remediation or emergency response actions</u> Additional physical impacts from remediation or responding to an accident (including restoration costs, loss of future use and impaired aesthetics due to habitat loss, and permanent residual loss or reduction of resource services after restoration). Includes provision for adding impacts of multiple individual events, as well as for increasing remediation costs if release is not prevented, increasing physical remediation harm due to contamination spreading or plume mixing, and additional acreage needed for disposal needed above technical planning basis. (citations as above, plus cleanup regulations).	Removal or disturbance of surface soil <1000 m^2 required over the lifetime of the facility or the full remedial cycle.	Issues: effectiveness of restoration; how satisfactory is mitigation; condition of media (such as soil column profile) and biota after completion of action relative to target or optimal conditions; uniqueness and functional criticality of the area/habitat type.
CATEGORY: SOCIO-CULTURAL IMPACTS (due to environmental contamination, to physical responses to it, and/or to delayed milestones)		

S1. Community quality of life Impacts on quality of life and the economic base, or the demographic characteristics of the local community (NEPA - 42 USC 4321 et seq.; specific measures not specified). Includes benefits of an intact/uncontaminated environment, aesthetics, and recreational quality. (see footnote for additional measures).	< 5-10% adverse impacts on jobs, markets, the community or publicity. Perceptible loss of recreational opportunities and aesthetics or quality of experience.	These impacts must be included even if they occur in response to "perceived" risk to local quality of life. Community values are real things at real risk even from seemingly small occurrences. Issues: reversibility (i.e. duration of restricted access or environmental or aesthetic decrement); distribution of impacts versus benefits.
S2. Tribal quality of life Impacts to tribal culture, health, quality of and access to natural and cultural resources, quality of life and socio-economics. Includes benefits of an intact/uncontaminated environment, aesthetics and other measures (NEPA, Treaties with each American Indian Nation, Executive Order 12898, DOE American Indian Policy, DOE Order 1230.2, Acts listed under S4). (footnote)	No/minimal restriction on access, and no increased dose to tribal members over background if used. No key culturally-important resource or site whose character requires non-disturbance, non-defilement, or non-degradation is contaminated or physically harmed.	Other measures for assessing impacts to socio-cultural quality of life are also available. Issues: duration or permanence of harm; definition of cultural site (e.g. gravesite), traditional cultural property, culturally-important resources, and historically-important landscapes (see Park Service Bulletins); definition of harm (i.e. contamination versus physical disturbance).
S3. Intra- and inter-generational equity (What members of the present generation are at greatest risk of exposure and risk of effects, and why? Is the degree of health protectiveness evenly distributed across all reasonably expected exposed groups? Whose resources and activities are most likely to be harmed by releases and remediation? Is the cleanup/disposal burden postponed/imposed on future generations? Does a decision alternative result in essentially irretrievable waste forms, or does it decrease future land use options? Will the cleanup/disposal burden increase if not dealt with soon? Do management goals promote sustainability of the habitat, resources and uses?) (NEPA, Executive Order 12898, others)	<10% of the most-impacted significant Site user group is adversely affected. Contamination and harm is limited to the present generation. Minimally increased future long-term cleanup and monitoring costs. Minimally increased storage and disposal capacity and total quantity of waste left on Site; can be accommodated under current plans. (NEPA, Executive Order 12898)	Issues: intrusion safety at 100 and 500 years; whether to allow discounting of the worth of future generations.

S4. <u>Cultural resource impacts from remediation or emergency response actions</u> Additional physical disturbance of cultural, historic or archaeological resources during remediation or emergency response (NHPA - 16 USC 470, ARPA - 16 USC 470aa-470.11, AIRFA - 42 SC 1996, NAGPRA - PL 101-601, 16 USC 431-433, 36 CFR Parts 60, 63, 79, 800,).	No or minimal perturbation or disturbance of site(s) or resource(s) during response to the event. (NHPA - 16 USC 470, ARPA - 16 USC 470aa-470.11, AIRFA - 42 SC 1996, NAGPRA - PL 101-601, 16 USC 431-433, 36 CFR Parts 69, 63, 79 and 800).	Issues: mitigation versus protection.
CATEGORY: PROGRAMMATIC IMPACTS (of inadequate characterization, of accident, of environmental contamination)		
P1. <u>Non-compliance penalties</u> Potential for, and degree of violations, penalties, or threat of litigation due to non-compliance with statutes, orders, permits, treaties, Tri-Party Agreement, Trusteeship, or other.	Only marginal noncompliance (perhaps one violation/year) with orders etc or marginal administrative noncompliance without potential for fines, jail, permit denial or compensatory requirements.	
P2. <u>Shutdown costs</u> Shutdown/Standdown costs if safety issue not resolved, if accident occurs, if retrieval is impeded through inadequate characterization, etc.	< $0.5 Million (Risk Data Sheet guideline)	
P3. <u>Response and repair costs</u> Response and repair costs and scheduling impacts to reestablish or prolong MinSafe conditions during interim storage or retrieval/disposal.	< $0.5 Million (Risk Data Sheet Guideline)	
P4. <u>Mission goals and milestones</u> Impacts on the timely ability of the program or facility to meet its missions of safe interim storage, volume-based retrieval, waste processing/disposal, and clean closure.	Goals and milestones can be met with minor adjustments within the activity/facility.	

P5. Inter-program and Sitewide ramifications Scheduling impacts and ramifications for other activities or programs, including privatization and disposal, and effects on the ability of other programs/activities to meet their TPA milestones.	Goals and milestones can be met with minor adjustments within the program or between or among programs.	
P6. Stakeholder acceptance and implications to the program(s) Impact on implementation and credibility if stakeholders are not involved early and honestly in the decision process; risk of delay if stakeholders disagree with performance measures or retrieval strategy (this is not the same as "risk communication" or informational briefings, but assesses the true degree of cooperation, partnership, and co-decision making).	Stakeholders are an integral part of the decision process so assumptions are likely to be acceptable and the decision is likely to be durable.	

Notes:

For workers, a single uniform whole body dose of 1 Sv (100 mrem) = 4E-2 lifetime fatal cancer risk + 0.8E-2 severe genetic defects + 0.8E-2 non-fatal cancer risk = 5.6E-2 total lifetime detriment. (NCRP #116, p.30, 1993). For the public, 1 Sv (100 rem) = 5E-2 fatal cancer risk, 1.3 E-2 for serious genetic effects, and 1E-2 for non-fatal cancer, resulting in a total detriment of 7.3 E-2/Sv (NCRP #116, p. 51). The difference between the worker and public dose-to-cancer risk conversions are due to the age distribution in the worker versus the general population and also to the duration of the committed doses (50 yr for workers and 70 yrs for the public).

1 rem = 0.01 Msv; 1 mSv = 100 mrem; 1 Sv = 100 rem.

De minimis cancer risk levels are typically assumed to be 10E-6 or 10E-7 excess lifetime cancer risk due to the single source, depending on the Agency or situation. The radiological "negligible individual risk level" is defined as 1 to 5x10E-7/yr (equivalent to 0.01 mSv/yr or 1 mrem/yr) per source or practice (NCRP #116, p.52).

Note H1 and H2: When considering risk from acute exposures (or short-term visits), there may be a potential problem if an annual dose limit or a fraction thereof is used in a manner which restricts the number of visits allowed by a member of the public per year. In addition, if activities such as certain cultural practices require visits to a location that is within a partially restricted zone, the issue of whether there is a risk burden due to the probability of an event even if no event or no exposure occurs.

DOE-SEN-35-91 contains general risk goals relative to individual and population rates of other accidental and cancer deaths:

- The risk to an average individual in the vicinity of a DOE nuclear facility for prompt fatalities that might result from accidents should not exceed 0.1% of the sum of prompt fatalities resulting from other accidents to which members of the general population are generally exposed. For evaluation purposes, individuals are assumed to be located within one mile of the site boundary.
- The risk to the population in the area of a DOE nuclear facility for cancer fatalities that might result from operations should not exceed 0.1% of the sum of all cancer fatality risks resulting from other causes. For evaluation purposes, individuals are assumed to be located within ten miles of the site boundary.

Note S1 and S2: Additional Quality of Life measures:

- Economic well-being: community costs for services, effects on housing markets, income or tax or bankruptcy rates, net job differential, health care costs, lost productivity, well-functioning infrastructure, access to adequate education, costs of avoiding exposure or illness.
- Community well-being: good mental health, trust of governing institutions, access to reliable information, personal security, low stress levels, assurance for the well-being of future generations, funding stability, sustainable economic and environmental practices, capturing economic opportunity in the local community, shared decision-making power, equitable distribution of impacts and benefits, community cohesiveness, accountability of decision makers, connection to the land with local access to open space, protection of cultural and religious values, degree of ceremonial quality of the site/resource relative to optimal and adequacy of aesthetic buffer zones, quality of religious (or recreational) experience at an alternative site, cost and inconvenience of an alternative site or resource of equal quality, degree of spiritual integrity of the overall traditional/heritage area, individual and collective psycho-social well-being derived from membership in a healthy community with access to ancestral lands and heritage resources, degree (and effectiveness) of protection and preservation efforts being expended to maintain good conditions or restore lost quality and use, ability to satisfy the personal responsibility for maintenance of the spiritual quality of a site/resource/area and the responsibility to participate in traditional practices as a community member, quality of the socio-cultural and eco-cultural landscapes, intergenerational transfer of community educational and cultural knowledge

ATTACHMENT 2

RISK CONSTRAINT MEASURES FOR ACCIDENT CONDITIONS BY SEVERITY CLASS

This attachment assumes that there is an inverse correlation between event frequency and severity class. Descriptors for each measure are in terms of severity of impact. Some of the severity descriptions are numerical, while some are still in narrative form until numerical correlates can be developed jointly with reguators and stakeholders. For each application, the inverse correlation between event frequency and acceptable severity (per WHC-CM-4-46) may be used as a starting point for consideration of how to match frequencies and severities across each of the risk measures. This Attachment provides placeholder descriptors for each risk measure by severity class; they are not intended as actual replacement risk acceptance guidelines, and have not been reviewed by technical, regulatory or public stakeholders.

EVENT FREQUENCY (with Event Frequency Category from WHC-CM-4-46)	SEVERITY CLASS (with Hazard Category from WHC-CM-4-46, Rev.4)
Normal operations (10^0/year frequency of routine excursions)	Acceptable, or within the Safe or Clean compliance envelope (this report's definition)
10^{-2} to $<10^0$/year ("Anticipated")	Low (Category 3 Hazard: only significant localized consequences)
10^{-4} to $\leq 10^{-2}$/year ("Unlikely")	Moderate (Category 2 Hazard: significant onsite consequences)
10^{-6} to $\leq 10^{-4}$/year ("Extremely Unlikely")	High/Catastrophic (Category 1 Hazard: significant offsite consequences)
Note: The hazard category is used to apply a graded level of safety analysis and may not reflect the actual severity of unmitigated consequences (WHC-CM-4-46, Section 3.2) Note: While WHC-CM-4-46, Rev. 4 is the official DOE version, Rev.0 is also being used by TWRS at the time this report was written. Rev.0 and Rev.4 contain different dose levels per frequency class.	

RISK CONSTRAINT MEASURES (placeholders) FOR ACCIDENT CONDITIONS BY SEVERITY CLASS

	SEVERITY		
	High severity (Extremely unlikely event)	Medium Severity (Unlikely Event)	Low Severity (Anticipated Event)
CATEGORY: PUBLIC HEALTH IMPACTS			
H1. Acute exposures due to accidental radiological airborne releases (WHC-CM-4-46, Rev. 4)	WORKER: 100 rem (1000 mSv) PUBLIC: 25 rem (250 mSv)	WORKER: 25 rem (250 mSv) PUBLIC: 5 rem (50 mSv)	WORKER: 5 rem (50 mSv) PUBLIC: 100 mrem (0.5 mSv)
H2. Acute exposures due to accidental non-radiological airborne releases (WHC-CM-4-46, Rev. 4)	WORKER: ERPG-3 or IDLH PUBLIC: ERPG-2 or 5 x TWA	WORKER: ERPG-2 or 5 x TWA PUBLIC: ERPG-1 or 3 x TWA	WORKER: ERPG-1 or 3 x TWA PUBLIC: PEL-STEL
H3. Lifetime MEI cancer and non-cancer risk from radiological plus non-radiological chemicals, from routine and unplanned airborne releases plus routine and unplanned soil/groundwater releases and existing contamination, all exposure pathways.	HQ>1000 (placeholder; likely to be fatal) Cancer risk (rad + chem) > 1E+00	HQ between 10 and 1000. Cancer risk between 1E-2 and 1E+00	HQ between 1 and 10 Cancer risk between 1E-4 and 1E-2
H4. Cumulative MEI and population doses integrated over time and maximum lifetime exposure. All releases, all pathways and all contaminants over complete duration of contamination.	TBD	TBD	TBD
CATEGORY: ENVIRONMENTAL IMPACTS			

E1. Contamination of media	>100 x regulatory standard. Land impoundment or food interdiction likely.	10-100 x regulatory standard. Land impoundment or food interdiction possible.	1-10 x regulatory standard.
E2. Contamination of living resources (ecotoxicity) and/or impacts to ecosystem functions and services.	Widespread & long-term (>1 yr) or irreversible damage to habitat or wildlife. Major ecosystem population and community effects. High potential for contaminant migration if not remediated.	Wide-spread, short-term (<1 yr required for isotope decay or full recovery) or localized long-term effects. Effects on individual organisms and low to moderate population and community effects. Moderate potential for contaminant migration if not remediated.	Localized short-term effects. Impacts on individual organisms only. Low potential for contaminant migration if not remediated.
E3. Additional physical impacts from responding to the action (including restoration costs and permanent loss or reduction of resource services after restoration).	Removal or disturbance of surface soil >10,000 m^2 required.	Removal or disturbance of surface soil 1,000 to 10,000 m^2 required.	Removal or disturbance of surface soil <1,000 m^2 required.
CATEGORY: SOCIO-CULTURAL IMPACTS			
S1. Community quality of life	Significant adverse job/market/ community/publicity impacts. Permanent loss of recreational opportunities and aesthetics or quality of experience.	Modest adverse job/market/ community/publicity impacts. Moderate or short-term loss of recreational opportunities and aesthetics or quality of experience.	Minimal but noticeable adverse job/market/ community/publicity impacts. Minimal but perceptible loss of recreational opportunities and aesthetics or quality of experience.

S2. Tribal quality of life	Loss of access >10 yrs. (acreage TBD) Culturally-important resource/site contaminated or physically harmed irreversibly or irretrievably.	Lost access 1-10 yrs. Culturally-important resource/site contaminated or physically harmed significantly but not permanently.	No lost access, but increased dose if used. Culturally-important resource/site contaminated or physically harmed to any degree.
S3. Intra- and inter-generational equity	Proportion of most-impacted group adversely affected >25%. Temporal profile of contamination extends >1 generation, and distribution of remedial and residual doses is unevenly spread across the population. Significant long-term cleanup and monitoring requirements. Significantly increased long-term waste treatment, storage and disposal capacity needed and unlikely to be adequately met.	Proportion of most-impacted group adversely affected >10%. Temporal profile of contamination limited to present generation, but doses are unevenly distributed across non-worker populations. Moderately increased long-term cleanup and monitoring requirements. Increased waste storage and disposal needs can be accommodated only with difficulty, at great expense, or with significant increases in required acreage.	Proportion of most-impacted group adversely impacted 1-10%. Minimally increased long-term cleanup and monitoring requirements. Any increased storage and disposal needs can be met under current plans.
S4. Additional physical disturbance of cultural, historic or archaeological resources during remediation or emergency response.	No mitigation possible when responding, resulting in total loss of important site(s) or resource(s).	Partial loss or degradation of site(s) or resource(s) during emergency response of remediation.	Perturbation or disturbance of site(s) or resource(s) during emergency response or remediation.
CATEGORY: PROGRAMMATIC			

P1. Potential for penalties, etc.	High potential for fines, imprisonment, penalties, liability for significant damages, injunction, permit denial or compensatory requirements.	Low to moderate potential for fines, imprisonment, penalties, liability for significant damages, injunction, permit denial or compensatory requirements.	Marginal non-compliance with orders, directives, codes or standards, guidances, or marginal administrative non-compliance.
P2. Shutdown/Standdown costs.	>$ 5M total (over the lifecycle of the event, response and/or program)	$1-5M	< $1M
P3. Response and repair costs: evacuation and related plus re-establishment of MinSafe operating conditions.	> $5M total (lifecycle)	$1-5M	< $1M
P4. Impacts on the ability of the program to meet its mission.	Serious impact to overall performance evaluation or the ability to meet annual technical performance goals and milestones Program reorganization likely, with federal and state investigation and certainty audits; major rebaselining probably reburied. Significant violation of public trust and confidence. Threats to funding stability.	Moderate interruption where goals and milestones may still be met. Reorganization and audits possible; program evaluation efforts and increased scrutiny will occur. Significant erosion of image and credibility. Funding maintained but still at risk.	Goals and milestones can be met with minor adjustments.
P5. Schedule impacts and ramifications for other activities or programs, including privatization and disposal.	>10% chance of > 1yr increase in schedule or 1/1000 chance of > 10yr increase in schedule.	Milestone slips with some impact on other programs and activities, but overall Hanford schedule is maintained.	Milestone schedule is maintained by intra- and inter-program adjustments.

Notes:

Human Health: ERPG-1 = the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr without experiencing other than mild transient adverse health effects or perceiving clearly defined objectionable odor. ERPG-2 = the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action. ERPG-3 = the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr without experiencing or developing life-threatening health effects. PEL-STEL = permissible exposure level, short term (15 min) exposure level for occupational settings. PEL-TWA = permissible exposure level, time weighted average for occupational settings. IDLH = immediately dangerous to life and health.

Environmental Impacts: Effects on individual organisms might include a fraction of a lethal dose to one or more sensitive species or to threatened or endangered species. Effects on population vitality might include organism density relative to optimal density for that area. Community effects might include the structure and function of the community as well as the ability of the community to provide physical, eco-cultural or aesthetic functions and services. 10,000 m^2 is the homerange area of a loggerhead shrike.

ATTACHMENT 3

POST-RETRIEVAL AND POST-CLOSURE EVALUATION MEASURES FOR TANK RETRIEVAL DECISION LOGIC

(from: A Brothers and B Harper, "Tank Retrieval Decision Logic")

The following matrix was prepared as an example of what information might be needed at various retrieval decision levels. The retrieval milestone is expressed in terms of volume retrieved from each tank, and therefore the simplest information needed to demonstrate achievement is residual volume after retrieval. When moving from retrieval to closure, or from a volume-based retrieval strategy to a volume/risk strategy, however, it is likely that additional information would be needed. The possible measures below are ordered from simple to complex. It should be noted, though, that even as data needs increase in scope, the degree of precision needed for those data depend on the decision to be made. Thus, for some decisions, a wide range of data about consequences, for instance, might be either qualitative (if this is a prioritization decision) to probablistic (if this is a risk-based post-closure compliance demonstration). Note further that "risk measure" may be used as a generic title for measures that one may need to evaluate for internal tank conditions as well as for event tree analysis or consequence analysis. Ultimately, all of the measures are conditional on tank conditions, but the further one "rolls back" the measure, the less visible (and more approximate) the consequence becomes. Because different people use different definitions for risk, any "risk" measure must be clearly defined, since a risk-based evaluation might use measures ranging from volume to curies to health effects.

EVALUATION MEASURES FOR RETRIEVAL AND CLOSURE OF TANKS

Level of Data Complexity (least to most)	Measure[1]	Units	Information required	Comments
1	Residual Volume	Total gallons in Hanford tank farms; Gallons (or kg) remaining in each tank; Percent of original volume remaining	Retrieval (technology) effectiveness; Volumes remaining	Uncertainty about predicted effectiveness of each technology for different waste forms will decrease with experience. This is the sole TPA performance measure.
2	Residual Volume by Waste Type	Volume categorized by: Primary waste category (sludge, salt cake, solids, mixed) or DST waste type (DN, DSSF, DC, CC, PD, PT, NCAW, CP)	Retrieval effectiveness Total volume remaining Volume of each waste type in each tank and for all tanks	Basis for including individual tanks on the Watch List (e.g. high heat, hydrogen, organic) may crosscut waste form.
3	Residual Activity	"Gallons of what" Total Ci; Ci of each isotope/nuclide; (volume + amount = concentration of each nuclide, summed for each tanks or across all tanks)	Retrieval effectiveness Total volume remaining Volume of each waste type Heterogeneity of distribution of isotopes among waste types or forms; Totals of each substance in each tank stratified by waste forms.	Based on radioactivity only (non-radioactive material is considered below), even though "volume" includes rad + chem + matrix + solid items. Characteristics of individual nuclides (mobility, half-life) become important. Does not include non-rad substances for this particular example.
4	Radiation Dose Potential	Rad, rem-EDE, ALI (Allowable Lifetime Intake). (Dose per individual isotopes, or summed by isotope, by tank, or both)	Retrieval effectiveness Total volume remaining Volume of each waste type Total activity and isotope totals Distribution of isotopes in waste types Conversion factors (Ci to rad to rem);	Based on concentrations in tanks (i.e. no fate & transport modeling) Assumes 100% conversion of material to dose, i.e. complete ingestion etc. Could include assumptions about delayed exposure and isotope decay.

5	Consequences Health effects: radioactive and non-radioactive constituents; Environmental and Ecological; Socio-Cultural Programmatic	See Consequences Matrix	Retrieval effectiveness Total volume remaining Material totals (rad, non-rad) Distribution of materials among waste types and waste categories Source term information (release characteristics: mechanism, probability, medium, fraction released, release rate, etc.), added to existing soil and groundwater contamination Fate & Transport modeling Environmental concentrations at points in time and space Exposure pathway definition Cancer slope factors; Non-cancer Reference Doses; Radiation dose-to-risk conversion factors (internal, external). Other data to support the Consequences.	Based on concentrations in the environment. Can be modeled from estimated post-retrieval inventory or documented inventory; uncertainty is proportional to source term uncertainty plus modeling and dose-to-risk uncertainty. Requires many model assumptions. Partial modeling has been done already based on current inventory (pre-retrieval). Precision needs vary with the decision context; may range from qualitative to probablistic.

Notes:

1. These measures may by applied to individual tanks, to tank farms or to the entire Hanford Tanks Program.

ATTACHMENT 4

THE LINKAGE OF RISK MEASURES AND CONSTRAINTS TO THE

TRI-PARTY AGREEMENT (TPA)

The Hanford Federal Facility Agreement and Consent Order (Tri Party Agreement) states that its purpose and intent is to ensure population health, Hanford worker safety, and a pollution free environment. In addition, the TPA recognizes that social and cultural human values must also be free from the defacing impact of radiological and hazardous waste contamination. In particular, the TPA provides for the claims and negotiation rights of local Indian tribes whose cultural resources and values have been or may be impacted by Hanford waste products.

Most of the 20 risk consequence categories that document the potential Hanford adverse impact upon social and cultural values, human health, worker safety and the environment are recognized by one of the TPA Articles. These are further provided for in the Agreement's Action Plan and some are the reason for specific TPA Milestones.

For this reason, the 20 risk consequence categories have been chosen to align with TPA regulatory guidance, TPA published intention, and TPA specified direction. Because the TPA recognizes no minimum risk levels, and purposefully positions itself to provide maximum social, cultural, public health and environmental safety, it is essential for any Characterization Technical Basis to fully apprise itself of both the remotest possibilities of any endangerment as well as the more imminent ones. Specific points of TPA recognition for the risk consequence categories are shown in this Attachment.

ATTACHMENT 5

INTEGRATION AND IMPLEMENTATION PLAN

Figure 7 shows the major steps that will be needed when using the risk measures and their constraint levels in VOI-based decision making.

Stakeholder/regulator involvement is shown as a one-time event but it really involves ongoing participation, particularly with respect to selecting individual measures (and reporting units) that will be relevant to particular accident severity classes. Following this, the risk assessor and/or analytical team will need to prepare tables of contaminant-specific concentrations that determine which severity class(es) the impacts from a selected accident scenario fall into.

The analytical team will select the minimum set of risk measures that will help discriminate among technical options, and will also estimate the degree of potential impacts from current conditions (if no action is taken or if only minimum safety procedures are employed) and from the endstate conditions after the various potnetial mitigation/response actions are successfully completed.

The Structured Logic Diagram process will develop "source term" information for environmental fate and transport modeling. The source term is a general label for the materials that could be released and their release characteristics

These tables are used with decision rules about additivity of multiple contaminants, persistence, and distance to a defined toxicity-based boundary (such as the outer boundary of the Emergency Planning Zone) *or* the area impacted (concentration isopleths). The concentration isopleths are converted to risk isopleths by adding the impacts from multiple contaminants, and compared to the contaminant tables. At this point, a decision rule about using single versus summed contaminants will be needed, since the total impact from all contaminants is the information that is important to the decision. Many, if not most, of these data files have already been produced during preparation of the TWRS EIS and do not need to be repeated.

Figure 8. Integration and Implementation Steps