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SCOPE

Safety-Controls Optimization by Performance Evaluation: A Systematic Approach for Safety-Related Decisions at the Hanford Tank Waste Remediation System

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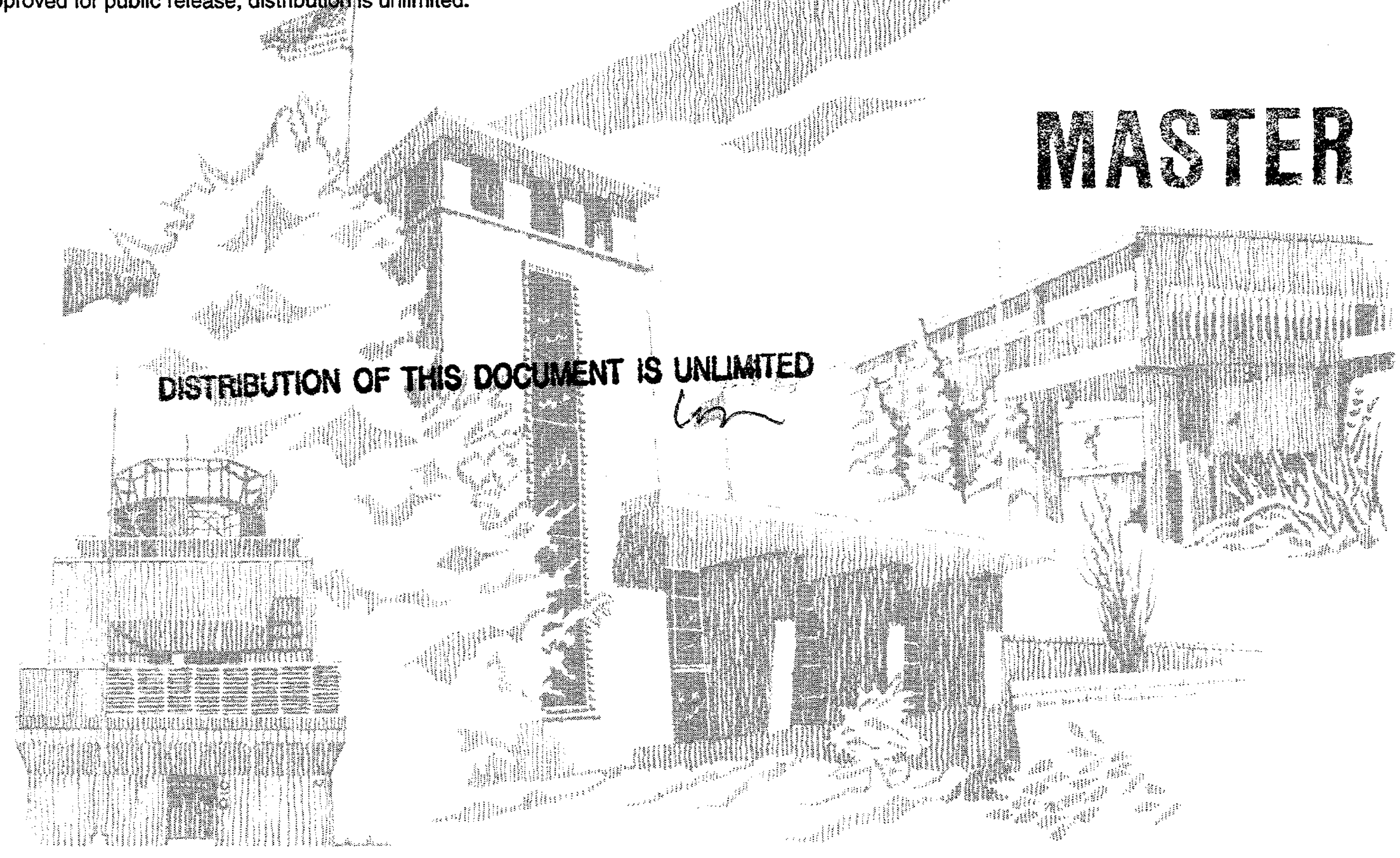

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Safety-Controls Optimization by Performance Evaluation:

A Systematic Approach for Safety-Related Decisions at the Hanford Tank Waste Remediation System

Phase 1 Final Report

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ABSTRACT
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ABSTRACT

The Department of Energy's Hanford Tank Waste Remediation system poses a significant challenge for hazard management because of the uncertainty that surrounds many of the variables that must be considered in decisions on safety and control strategies. As a result, site managers must often operate under excessively conservative and expensive assumptions.

This report describes a systematic approach to quantifying the uncertainties surrounding the critical parameters in control decisions (e.g., condition of the tanks, kinds of wastes, types of possible accidents) through the use of expert elicitation methods. The results of the elicitations would then be used to build a decision support system and accident analysis model that would allow managers to see how different control strategies would affect the cost and safety of a facility configuration.

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PREFACE

In May 1996, the Tank Waste Remediation System (TWRS) program at Westinghouse Hanford Company (WHC) asked Sandia National Laboratories (SNL) to explore the possibility that methods SNL had developed for other programs could be applied to hazard management at TWRS. These methods used systematic expert elicitation to deal with the phenomenological uncertainty embedded in the resolution of nuclear safety policy issues. With funding from WHC and the support of a team made up of SNL personnel, and personnel from WHC and its subcontractors, Sandia carried out such a concept study during the period June-September 1996. The concept that evolved from this study was named Safety-Controls Optimization by Performance Evaluation (SCOPE). The 4-month concept development effort was phase 1 of the SCOPE program. This report is the final product of phase 1 and in it the work needed to implement the concept in phase 2 is outlined.

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1.0 BACKGROUND AND OVERVIEW

1.1 Background

Managers of hazardous waste sites in the nuclear weapons complex are faced with public pressure and Department of Energy (DOE) requirements to prudently manage the health and safety risks attached to storing these wastes. The Hanford Tank Waste Remediation System (TWRS) presents one of the greatest challenges to managers responsible for cleanup. The approach that guided operations for decades was based on standards of safety assessment and documentation that were far less strict than today's. The problems are made especially challenging by the large quantity and variety of highly hazardous and radioactive wastes produced when the site was operational. Because of the hazards and the costs of in-tank measurements, the composition and configuration of wastes at the TWRS facilities is not always well characterized. In addition, the physical state of many of the facilities themselves is not fully known. Some of the facilities are being used well beyond their intended design life. These uncertainties have made closure of the flammable gas unreviewed safety question (USQ) elusive.

The topic of flammable gas hazards is persistent and is the motivating factor behind extensive safety analysis efforts, workshops, review committees, and other forums producing an array of disparate viewpoints. The lack of technical convergence has tended to steer analysts to clearly conservative assumptions in order to avoid controversy, but the implications of such analyses are themselves controversial as various groups debate the cost effectiveness of proposed controls or the tradeoffs of costs and productivity versus safety and prevention of low-frequency, high-consequence accidents.

Important progress is now being made in two areas: first, the DOE is developing more consistent high-level safety policy approaches for its sites and their operating contractors; second, there has been a rapid growth in the store of essential quantitative data and technical information about the physical state and behavior of the wastes. Despite this progress, however, practical decisions about appropriate safety systems and control strategies for specific facilities remain difficult. What is missing are practical methods that can use the newly available technical data to address specific operational issues in a manner that is consistent with the high-level safety policies. One of the principal barriers to consistent decision-making is unavoidable technical uncertainty about the physical behavior of the facilities and the wastes they contain.

Other fields of technology policy have been faced with the need to make concrete decisions in the face of high phenomenological uncertainty, and have used methods developed in the behavioral sciences to deal with this uncertainty. In particular, methods have been developed that use expert elicitation to quantify phenomenological uncertainty and incorporate the results into decision processes in a scrutable and defensible manner. For example, the U.S. Nuclear Regulatory Commission (NRC) used expert elicitation in a study of risk and uncertainty at commercial nuclear power plants.[1] In a quite different application, the DOE used expert elicitation to develop design requirements for the new production reactor (NPR) (before the NPR program was canceled).[2]

1.2 Overview of Approach

The objective of the SCOPE process is to develop ways to apply similar expert elicitation methods to uncertainties about the Hanford tanks. The initial application of SCOPE concerns the selection of controls to manage TWRS facility risks associated with flammable gas generated, stored, and released by high-level radioactive waste.

The overall goal is to provide hazardous site managers with a tool that will allow them to quantitatively predict the effects of control strategies on the safety of a facility configuration. To do this, expert elicitation methods would be applied to uncertainties about the Hanford tanks and the results integrated into a decision support system that will make decision-making about hazard controls for TWRS operations more consistent, defensible, and cost effective. The intent is not to create a "simulation code" for wastes, but to develop a tool that organizes and processes information in a clear and reviewable manner so that managers can see how different control strategies will affect operations.

The predictions of results would be approximate and reported in the form of metrics that are consistent with current standards for safe operation. For example, they could take the form of the expected radiological dose to an exposed worker 100 m from the facility as a result of a gas release with ignition sources. The metrics used in the SCOPE decision support system will be consistent with current approaches to risk guidelines. By developing a methodology that is based on broadly accepted results and conclusions, and metrics that take into account both real-world and regulatory requirements, it is hoped that SCOPE will lead to control decisions that have the support of public stakeholders as well as site management--and that reflect current perceptions about the acceptable degree of risk.

The goal of phase 1 has been to provide a preliminary overview of the approach and how it can be used to address Hanford's flammable gas problem. That overview is given in this report. In phase 2 this approach would be refined and reviewed in an iterative process to develop the SCOPE decision support system (DSS). This will include assembling panels of experts, training them in the elicitation process, and using the results to develop the DSS. The system is intended to provide a basis for making consistent and prudent decisions on modifications to installed equipment, work restrictions and control, engineering design requirements for new equipment, and protection against natural phenomena.

The first step in phase 2 would be a careful sorting of quantitative information that is relevant to the evaluations. This information would be organized into three categories: information or data that are low in importance or uncertainty, information that is high in uncertainty and importance, and information pertaining to the proposed control strategy that must be supplied by the user. Information in the first category will have values that have some degree of "pedigree"; the basis for the choices will be documented carefully. Information in the second category will be handled by the expert elicitation process. The third category will be specific to the decision under consideration (e.g., the tank designator or equipment specifications for different control strategies).

This information will be organized in a reviewable manner in a computerized system that will form the SCOPE analysis tool. This software will combine the data in a relatively simple computational process to obtain the desired metrics. These metrics will incorporate uncertainty, propagating the distributions supplied by the expert panels, so that the decision maker can use the information over a range of specified confidence levels. While the analysis tool will have a modeling framework that organizes and processes the information in a specific sequence, it is not a detailed simulation code--the "models" will be simple and noncontroversial methods for organizing the information.

In addition to the analysis tool software, in phase 2 the project team will provide documentation on the technical basis for the tool, guidance on its use, a process for adapting the tool to new information, and any other processes and procedures needed to support decision-makers at Hanford who must decide on control strategies.

1.3 Organization of the Report

This report is organized as follows: Section 2 discusses the use of expert elicitation methods in situations similar to those at Hanford and the experience of team members with applying expert elicitation to reactor safety issues. Section 3 describes the way SCOPE can be used, including the sources and kinds of information and metrics it will require, and how uncertainty will be captured in the parameters. Section 4 discusses our approach to designing the analysis framework for SCOPE; that is, the quantitative information needed to support safety control decisions and the processes for applying that information to produce the results for alternative strategies. The foundation for the SCOPE process -- the use of expert opinion -- is discussed in some detail in Section 5, which includes the selection of experts for panels and how expert elicitation works.

Section 6 discusses how SCOPE could be applied to specific problems at Hanford -- for example, achieving closure of the flammable gas USQ within the prescribed schedule -- and how it could be applied to other problems of hazardous waste. Section 7 briefly summarizes this report. Appendix A provides a preliminary reference library and Appendices B - F provide backup material on the methodology and operation of a prototype system.

References

[1]U. S. Nuclear Regulatory Commission, *Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants,* NUREG-1150, Washington, DC, 1990.

[2]K.D. Bergeron, S. E. Slezak, and C.E. Leach, *Heavy Water New Production Reactor Design Review Guidelines,* SAND92-2538, NPRW-DSAC91-5, Sandia National Laboratories, Albuquerque, NM, 1992.

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2.0 EXPERIENCE WITH SIMILAR APPLICATIONS

2.1 Origins of Formal Expert Elicitation Processes

The use of technical experts to help regulators and government officials make decisions on complex issues involving the public well-being and also a high degree of technical uncertainty is by no means a new phenomenon. Blue ribbon commissions, advisory panels, peer review groups, scientific advisors, and so on are traditional ways that public policy has been supported with scientific expertise. Panels of this type [e.g., the Defense Nuclear Facilities Safety Board (DNFSB)] are already available to provide guidance for DOE operations, and it is not the intent of the SCOPE project to add to them. Instead, the intent is to provide an analysis tool that will permit decision-makers to use careful expert evaluations of the impact of phenomenological uncertainties without the decision-makers themselves being experts in the disciplines involved and without forcing them to choose between competing claims of experts who do not agree.

Studies of judgment and decision-making under uncertainty in the social sciences (e.g., Kahneman[1]) have led to the development of methods for incorporating expert judgment in a controlled and documented fashion. Such methods have been successfully applied to complex technical issues that are in some ways comparable to the Hanford waste management problem. An important aspect of these methods is that they are structured so that:

- multiple experts in different fields can contribute
- the product is quantitative, and can be used "after the fact" within a range of anticipated uses
- consensus among the experts is facilitated but is not required to obtain a useful product
- the rationales for the technical analyses are well documented and reviewable.

Some additional details of how formal expert elicitation techniques will be used in SCOPE are given in Section 5 and Appendix D of this report.

Other areas of technology policy have been faced with the need to make concrete decisions in the face of high phenomenological uncertainty, and have applied expert elicitation methods to quantify phenomenological uncertainty and incorporate the results into decision processes in a scrutable and defensible manner. An example is the NRC's NUREG-1150 project,[2] an analysis of risk and uncertainty in risk at commercial nuclear power plants. A second and quite different example is the DOE's Deterministic Severe Accident Criteria (DSAC) project[3] that developed design requirements for the containment building of the new production reactor (before the NPR program was canceled). These two examples are sufficiently pertinent to the present problem that they are briefly reviewed here.

2.2 The NUREG-1150 Project

In the NUREG-1150 project, probabilistic risk assessments (PRAs) were performed for five nuclear power plants selected as representative of the major U.S. designs. The analysis was required to cope with uncertainties in many diverse areas, including accident initiation frequencies, phenomena governing core melt progression, containment loading and performance phenomena, and radionuclide releases. It was recognized that quantification of uncertainties in these phenomena was essential to permit realistic estimation of the uncertainties in the final risk estimates. Indeed, one of the most telling criticisms of the earlier Reactor Safety Study[4] was that inadequate attention had been paid to uncertainties and that the error estimates that were provided were undoubtedly too small.[5] The NRC recognized that the credibility of the NUREG-1150 risk assessments would stand or fall with the credibility of the treatment of uncertainty, and the focus of the project was on defining uncertainty ranges for the risk, rather than point estimates. The NRC and its contractors responded to this challenge by developing expert panel elicitation techniques that are in many ways similar to those proposed for SCOPE.

Six separate expert panels were used, each dealing with a separate subject area. The number of panels was dictated in part because too many uncertainity issues were involved to be amenable to treatment by a single panel, and in part because finding panelists with expertise in all the fields involved would have been virtually impossible. However, the range of phenomena requiring consideration by even a single panel was large. Good panelists are typically skilled generalists with a knowledge base that is broad as well as deep; the ability to integrate diverse phenomena into a coherent picture of a complex accident scenario is more important than the ability to perform cutting-edge research in a narrow specialty.

Figure 2-1 presents the results of a typical elicitation. This example presents uncertainty distributions elicited for containment pressure rise in a direct containment heating (DCH) event under specified conditions.* The elicitation takes the form of each expert providing the probability that the quantity of interest will be less than some value Y as a function of Y. The elicitations are given by the expert individually and the results are then combined to produce the aggregate curve that is actually used in the analysis (solid curve, Figure 2-1). Methods of aggregation are considered in Section 5.2 and Appendix C; for present purposes, the important point is that the aggregate curve can always be defined, even if the experts disagree more widely than was the case in this example. Thus the methodology does not require consensus in order to produce usable results.

Typically the issues considered by the panels were treated in series in the actual accident analysis; that is, the answers to issues addressed by one panel (such as in-vessel accident progression questions) would be required for the analysis of subsequent events (such as containment loads) that were addressed by a separate panel. An important difficulty in NUREG-1150 proved to be managing the information transfer at the interfaces. Mismatches sometimes existed between the output quantities supplied by an "upstream" panel and the information required by a "downstream" panel. Since the panels were sometimes required to consider a wide range of conditions, these ranges were typically subdivided into narrower ranges called "cases." Carrying out the complete analyses required evaluation of the

* DCH is a hypothesized severe accident scenario in which molten core material is ejected from the reactor vessel under high pressure when the vessel lower head fails. The ejected debris then interacts thermally and chemically with the containment atmosphere and the blowdown steam, transferring energy to the containment atmosphere and pressurizing the containment building.

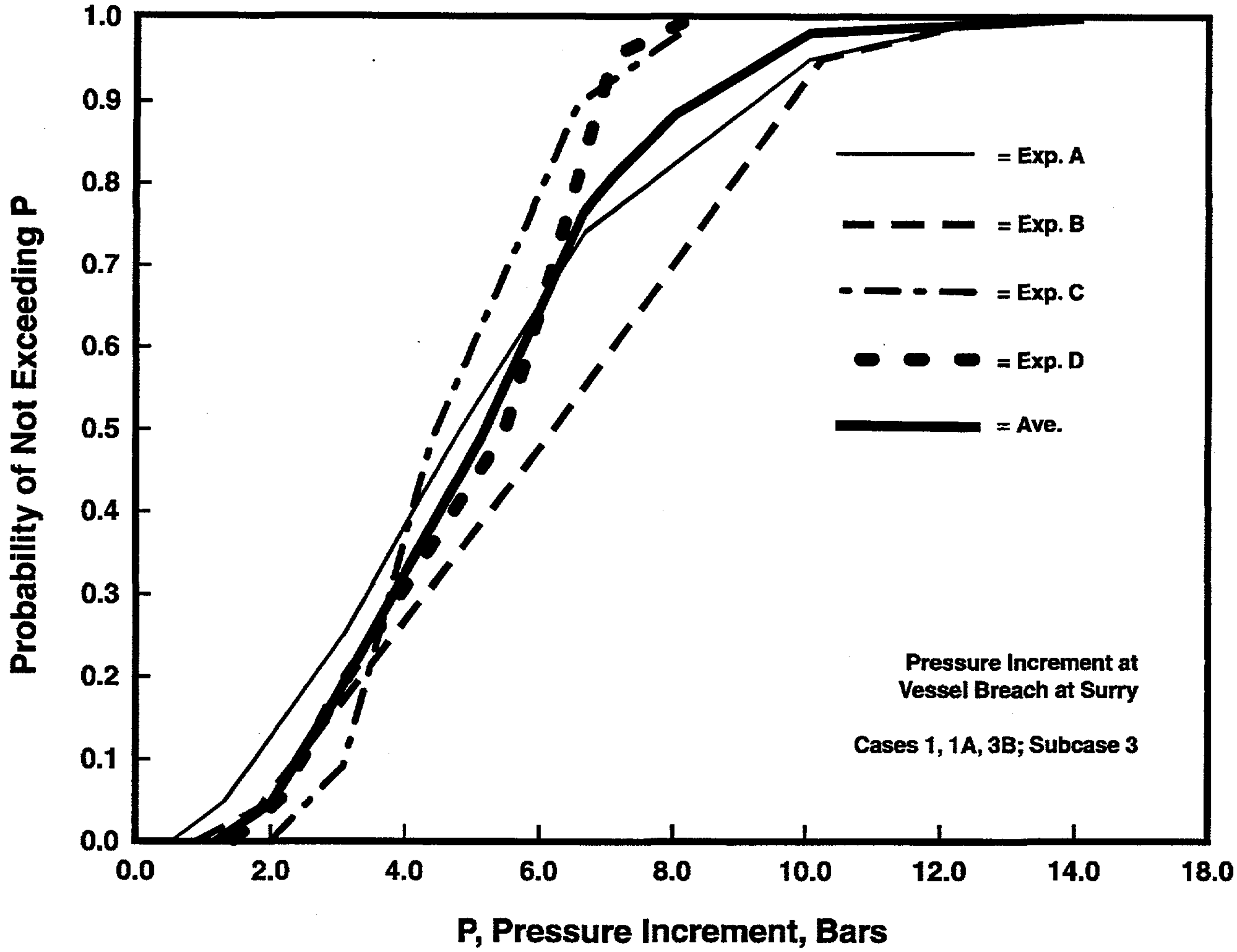

Figure 2-1. Example of NUREG-1150 elicitation results.

probabilities of the various cases, and these probabilities typically depended upon the results of elicitations for issues appearing upstream in the analysis. Mapping the upstream elicitation results into the cases used by the downstream panel was not always straightforward.

Obtaining risk estimates in NUREG-1150 required the definition of numerous conditional probabilities. Eliciting uncertainty distributions for these resulted in some confusion (e.g., concerning the intended meaning of "a probability of a probability"). This confusion may be minimized by defining problems so that the probability being elicited is clearly identifiable as a stochastic probability that can be interpreted as a frequency. This frequency is then treated as if it were a physical quantity such as a pressure or temperature, and the probability that the expert assigns to specific values in his elicitation is then interpreted as a degree of belief.

The elicitation structure for SCOPE is not expected to be as large and complex as that employed for NUREG-1150, but it is expected that multiple panels will be required and the flow of information across panel interfaces will require careful attention. Uncertainties in stochastic probabilities such as the frequency of gas release events (GREs) and ignition sources will also require consideration in order to provide decision makers with information concerning uncertainties in such SCOPE metrics as compliance with the risk guidelines (RGs). Lessons learned during the NUREG-1150 effort will be helpful in dealing with these potential difficulties.

2.3 The DOE's New Production Reactor DSAC Project

Like current Hanford waste management efforts, the DSAC project took place in an environment set by the evolution of a DOE safety culture determined to meet the demanding standards that have been defined for the commercial nuclear power industry. The guiding principle was to be that NPR safety should be equal or superior to that of commercial nuclear power plants. Since the DOE had not constructed major nuclear reactor facilities for many years, existing DOE precedents were not fully adequate. NRC experience and standards were not fully applicable because of the large technical differences between the NPR and commercial nuclear power plants. What was required was a means of capturing the essential philosophy underlying NRC requirements in the regulation of commercial power plants and implementing this philosophy in a manner technically suited to the characteristics of the NPR. The DSAC project represented an effort to achieve this goal in the area of containment design for the NPR. In much the same way, SCOPE seeks to assist in implementing modern nuclear safety philosophy in the management of risks associated with flammable gas generation in the Hanford tank systems.

In some ways, the DSAC project was simpler than NUREG-1150. The number of cases elicited, and the range of phenomena of concern, were sufficiently limited that a single expert panel could be used. Even so, the range of phenomena considered was sufficiently wide that the success of the effort hinged upon choosing panelists who were skilled in integrating diverse phenomena.

The elicitations were conditional upon the occurrence of specified accident scenarios called representative conservative accident scenarios (RCASs). Each RCAS was a specific scenario intended to represent a broader class of accident scenarios, and to provide a reasonably conservative (though not necessarily bounding) representation of that class. It was also intended that each RCAS provide the experts with a well-defined problem for analysis. An initial set of RCASs was proposed by the DSAC project technical staff, but the experts had the final judgment as to how the RCASs were to be defined.

The quantities elicited were physical parameters such as a particular type of energy release that might result from an RCAS. These parameters were defined in such a way that, given the value of the parameters, it would be relatively straightforward to calculate the resulting load on the containment. The containment designer was then required to demonstrate that the containment could survive the calculated loads that corresponded to a specified percentile of the parameter uncertainty distribution.

Unlike the NUREG-1150 project, the DSAC project was intended to aid in the design of a plant that did not yet exist and for which relevant design information was not complete. It was therefore essential that the DSAC project provide a product that could be applied in a straightforward manner to judge the adequacy of a variety of containment designs that the plant designers might wish to consider. This application was to take place "after the fact," i.e., after the expert panels had rendered their judgments. It was also necessary that the DSAC product be useful for designers who were not themselves experts in reactor severe accident phenomenology, and who could not and should not be expected to assess severe accident phenomenological uncertainties in their analyses of containment adequacy. These requirements have clear parallels for the SCOPE-DSS: the methodology must be sufficiently flexible to be applicable to control systems, equipment, and tank farm operations that were not necessarily explicitly evaluated in detail by the experts; and users of the SCOPE-DSS cannot be expected to be experts in the phenomenologies governing flammable gas risks.

References

[1]Daniel Kahneman, Paul Slovic, and Amos Tversky, Eds. *Judgment Under Uncertainty: Heuristics and Biases*, Cambridge University Press, Cambridge, UK, 1982.

[2]U.S. Nuclear Regulatory Commission. *Severe Accident Risks: An Assessment for Five U. S. Nuclear Power Plants,* Final Summary Report, NUREG-1150, Washington, DC, 1990.

[3]K. D. Bergeron et al. *Heavy Water New Production Reactor Design Review Guidelines,* NPRW-DSAC91-5, SAND92-2538, Sandia National Laboratories, 1993.

[4]U.S. Nuclear Regulatory Commission. *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants* WASH-1400, NUREG-75/014, Washington, DC, 1975.

[5]U.S. Nuclear Regulatory Commission. *Risk Assessment Review Group Report to the U.S. Nuclear Regulatory Commission* NUREG/CR-0400, Washington, DC, 1978.

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3.0 SCOPE DECISION SUPPORT SYSTEM

3.1 Intended Use

The SCOPE decision support system would provide the overall framework (or system) for evaluating the efficacy of control strategies and their compliance with respect to risk guidelines and other metrics. The SCOPE analysis tool (AT) is a composite accident analysis model for computing quantitative metrics in the DSS so that control strategies can be compared and evaluated.

Information about tanks, waste, and accident phenomena would be divided into three general categories of information sources for the SCOPE analysis tool: reference information specifying the particular control strategy and TWRs facility, phenomenological information that is fairly well characterized or relatively unimportant for accident consequence analyses, and highly uncertain information that strongly influences consequence calculations and risk estimates. Data in this last category are usually the source of disparate perceptions about the risk associated with waste storage and tank farm operations (Figure 3-1). The SCOPE process will use technical experts to provide quantitative judgments on the appropriate values and the degree of uncertainty that should be associated with these parameters. These, along with data from the other two categories, will become inputs to phenomenological models for calculating accident source terms.

In designing the DSS, every effort will be made to ensure that it is a self-sufficient system that will not require reconvening experts in the future as knowledge changes. Parts of the DSS will also be flexible so that the users can, to some extent, change models and input values as desired to compare how results differ from the benchmark results and how reducing uncertainties may affect the risk estimates.

The analysis tool would be assembled from phenomenology-specific models that have already been developed. These models would be reviewed by the technical experts to identify any limitations. The project team and the expert panels would then work together to ensure that there are appropriate elements of expert elicitations within the overall calculation framework, so that the uncertainties due to the model's limitations would be captured in the overall output of the analysis tool. It is important to emphasize here that SCOPE would assess only the current state of knowledge; it would not develop new information.

There are practical limits to the number of parameters that a team of technical experts can quantify. Consequently, there will inevitably be less-important or less-uncertain parameters that are not quantified by the experts but which have an impact on computed metrics. These parameters will be assigned nominal values based on the best information available. The basis for each assignment will be clearly documented (for that reason, this category of low uncertainty or low importance parameters is sometimes called "pedigreed" in this report). For special applications, the user may override the baseline values for these parameters.

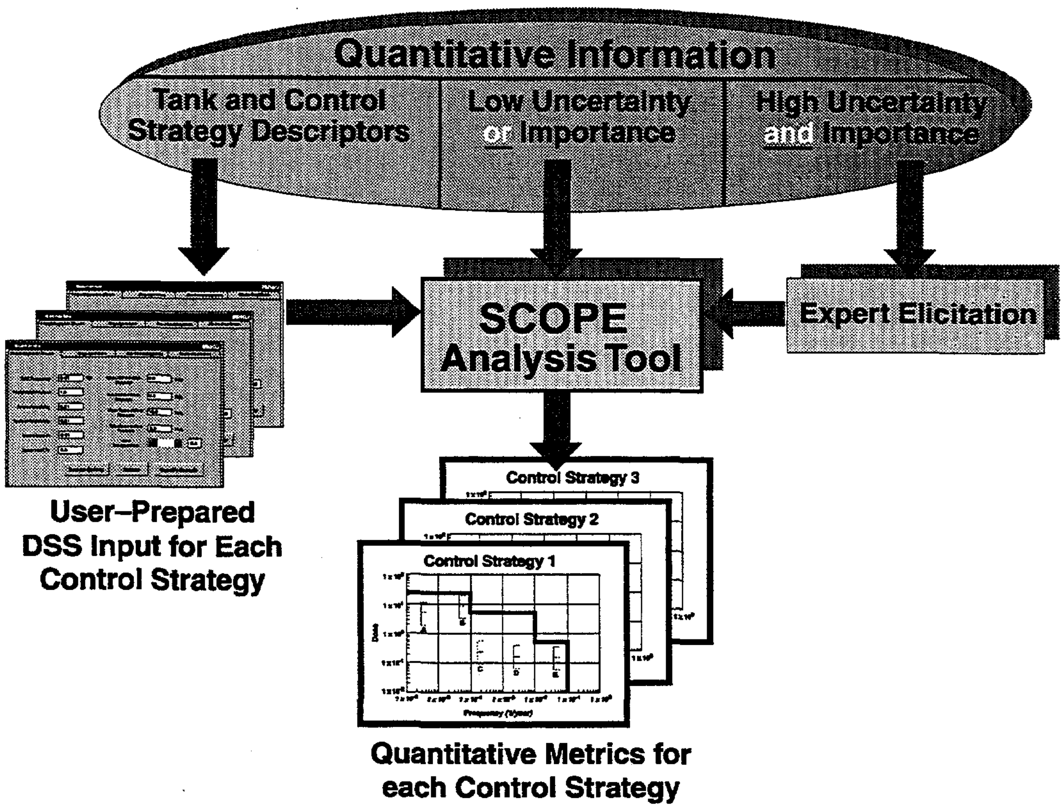

Figure 3-1. Conceptual diagram of SCOPE decision support system.

The SCOPE analysis tool would be structured like an analytical "black box" in that the user would provide a set of input parameters, including control requirements and equipment specifications, and the AT would produce a variety of metrics, such as dose, that could be compared with guidelines. By comparing the results for different sets of input parameters, the user could determine a number of things that can aid decisions.

For example, assume one is considering imposing requirements for newly installed equipment to be certified as National Electrical Code (NEC) Class 1 Division 1 (i.e., for operation in explosive atmospheres). Imposing the requirement would affect the frequency of sparks from the equipment, which affects the frequency of potential ignition of flammable gas, but not necessarily the expected magnitude of an accident. Two specific cases, which differ only in the expected ignition frequency from new equipment, would be run through the analysis tool. Specific frequency versus consequence distributions would be computed for each case. Some possible results that would affect decisions are:

1. The ignition sources from operating older equipment that is not Class 1 Division 1 and static sparks caused by intrusive activities, lightning, etc. would not be affected by the control on new equipment. Thus the absolute change in risk may be calculated to be insignificant because the frequency of accidents is dominated by these other ignition sources and the consequences are unchanged. In this case one may decide that the relative reduction in risk is too small to justify the costs associated with imposing the control, independent of the estimated value of the absolute risk from operations.

2. The absolute risk for both cases (with and without the new controls) may be calculated with high confidence to be far inside the risk guidelines. One may thus decide that, independent of the amount of relative risk reduction estimated, operations are acceptably safe without the control.

3. The absolute risk for both cases may be calculated with high confidence to be far outside the risk guidelines. However, the results may show that the control results in a significant reduction in relative risk because sparks from operating new waste retrieval equipment strongly dominate the potential for ignition. From this result, one may decide to impose the control in addition to other controls so that the combined impact of all of the controls brings the estimated risk well within the risk guidelines.

4. The expected frequency for accidents may be substantially reduced by the control, but the risk estimates may indicate that the expected consequences are virtually unaffected because the probability of failure of high-efficiency particulate aerosol (HEPA) filters is very low for both cases. With this result, the control might still be implemented because of a policy decision to avoid accident initiators, even if the risk guidelines are met and any anticipated radiation releases and dose consequences are negligible, since there are concerns about political and administrative consequences and negative publicity associated with any flammable gas explosions.

From the above example it is clear that changes in absolute risk, relative risk, and event frequency can all be important influences on decisions. For this example, the particulars of the models used to determine the impact of changes in equipment sparking frequency were the same for both cases and thus of low importance to calculations of relative risk.

Among the key metrics that the DSS would generate to assess the impact of controls are radiation source terms. Past accident analyses have generally shown that offsite consequences for most likely and unlikely accidents are small and health risks to the public are low. However, the computed consequences for worst-case "bounding" scenarios are often unacceptably large, even for beyond-credible accidents, and attempts to tie these consequences to event frequencies are widely criticized. Because the DSS contains uncertainty information and SCOPE seeks endorsement of the process before any results are computed, the estimates for frequencies computed for extreme consequence events using the SCOPE DSS should not be contentious. For comparatively high-consequence events, source terms are appropriate metrics because methodologies for estimating the dose consequences from source term data are well established. Some methodologies have been endorsed by the NRC for reactor accident analyses. For more likely events that have negligible offsite consequences, source terms are still valuable for estimating the risk to onsite workers. Even if controls and accident response training result in small dose consequences to onsite workers, source term data are still valuable for indicating the anticipated amount and location of contamination that would affect operations at the remaining tanks in a farm or at nearby facilities. Finally, using source term information as a metric provides a means to compare the overall severity of accidents with each other and with risk guidelines.

The specific details of the SCOPE analysis framework, i.e., how existing phenomenological models would be assembled into the SCOPE analysis tool and what parameters will be quantified by the technical experts, are not presented here. The development of these details is a large and important part of the second phase of the SCOPE process. However, the considerations that will drive the design process are discussed in Section 4.

3.2 Approach to Phenomenological Uncertainty

The inhibiting effect of uncertainty about such phenomena as flammable gas combustion on decision making at TWRS has been identified above. In this section, the general approach toward phenomenological uncertainty that is planned for SCOPE is described. The motivation for that approach is also discussed, as well as the way that its success can depend on the nature of the larger decision-making environment in which the SCOPE process would function.

3.2.1 The Need for a Systematic Approach to Phenomenological Uncertainty

The issue of the effect of uncertainty on decision-making at TWRS has at its core the conflict between the need for a certain level of confidence that public and worker safety is adequately protected, and the reality that the current state of understanding and knowledge is insufficient to provide that confidence in a straightforward manner. Traditional ways of dealing with such a conflict are not well suited to the Hanford situation:

- It is not realistic to suspend operations pending the resolution of this conflict, and to do so is widely judged as inconsistent with the long-term well-being of the public.

- Another traditional approach is to deal with the uncertainty by postulating conservative assumptions about the uncertain phenomena and providing safeguards that can demonstrably deal with the resulting scenarios. In the case of the TWRS, the resulting compounding of conservatisms has led to hypothetical hazards for which practical control strategies are either impossible or so expensive as to be judged unwarranted by many responsible observers who believe the scenarios to be unrealistic in the extreme.

- The reduction of uncertainty through research and characterization should be an important element in any approach to resolving this conflict, but the cost of even small amounts of relevant information can be extremely high at the TWRS because of the hazards themselves, and the value of this information can be quite limited because of the complexity and diversity of conditions in the facilities. Resolution through research and characterization alone is therefore widely believed to be an unachievable goal.

3.2.2 Advantages of Quantitative Treatment of Uncertainty

The existence of technical uncertainty is not necessarily an absolute barrier to effective decision making about safety, and other solutions exist besides reducing the uncertainty to some specified acceptable level. Part of the problem is that the degree of uncertainty is not well characterized, with the result that decision-makers have difficulty finding a basis for making judgments in the face of uncertainty.

A way out of this quandary can be suggested by a hypothetical illustration. Consider a safety analyst carrying out a typical conservative hazard analysis for some particular facility. This analyst postulates several hypothetical events that range from "anticipated" to "extremely unlikely" and develops an approach for calculating the consequences of each postulated event. A standard frame of reference for the results of such calculations is a set of risk guidelines, such as those discussed in the WHC *Safety Assessment Manual.*[1] Now, hypothetically again, these results are reviewed and commented upon, and the analyst is asked to use more conservative assumptions for part of the analysis. This can continue until approval occurs, which encourages the analyst to use increasingly more conservative (even beyond bounding) assumptions.

Imagine now that unbeknownst to this analyst, there are hundreds, even thousands of safety analysts who have been given the same assignment, who choose the same descriptions of a hypothetical event, carry out their independent analyses, and iterate them within their own isolated approval chains with similar outcomes. If all these results get collected and plotted as in Figure 3-2, it is interesting to speculate how a decision-maker faced with all this information would react. The spread of results, both in terms of consequence ("dose" in Figure 3-2) and frequency, reflects the uncertainty in the situation and the effect of differing individual judgments about how to bound the uncertainty. An enlightened decision-maker would see the information portrayed in Figure 3-2 as more useful for decision making than just one set of points from one analyst, because in some sense the uncertainty range is portrayed.

This is an important point: specific information about the range of uncertainty inherent in safety analyses might assist decision making about safe operations. On the other hand, the meaning of the "cloud" of points shown for each event in Figure 3-2 is ambiguous because there was no established, quantitative characterization of what "conservative" or "bounding" meant among the mythical population of analysts that contributed to the results shown in the figure.

In contrast, Figure 3-3 shows one of the ways that the SCOPE analysis tool would display results. It is premature at this point to explain why the format is envisioned as shown, or what other ways of displaying results might be possible, but this figure can suggest the benefits of quantitative representations of phenomenological uncertainty for decision making about safety. Instead of a cloud of points, there is a "bar and whisker" representation of the statistical distribution of results that might be possible. The median value of dose is shown, as are the values at the 5th and 95th percentiles. The distributions that these values refer to are not characteristic of a mythical analyst population, but are instead representative of the "degree of belief" that a certain small group of experts has assigned to the various elements that enter into the overall phenomenological uncertainty. Clearly, the information shown in the figure, supplemented by other data such as system costs, would greatly assist a decision-maker in choosing between two alternative control strategies.

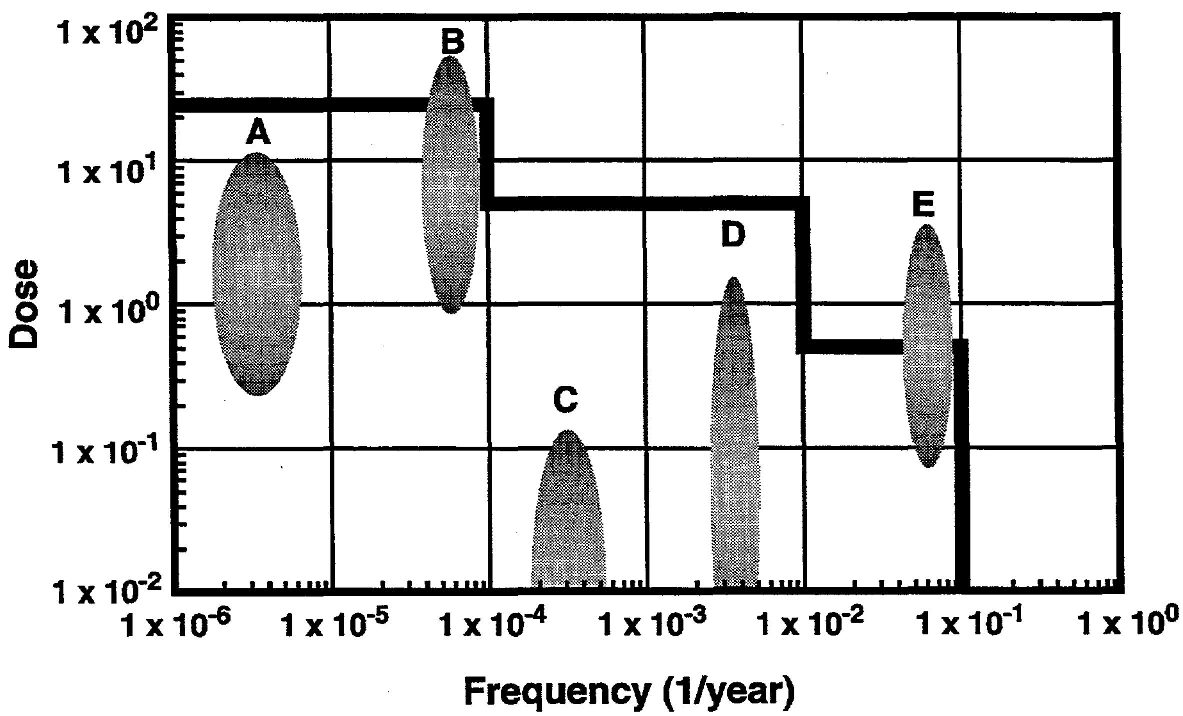

Figure 3-2. Hypothetical results from thousands of analysts.

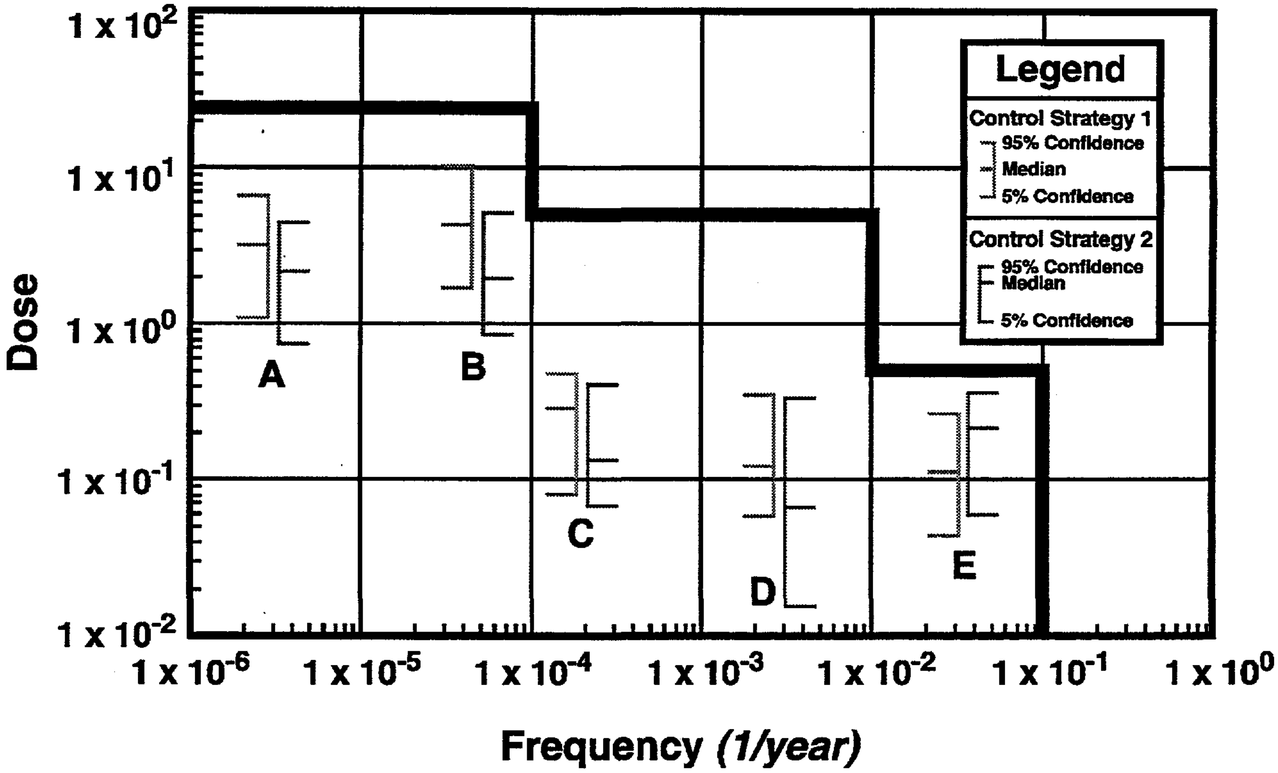

Figure 3-3. Example of how SCOPE could be used to compare alternative strategies.

The results provided by the SCOPE process, such as those shown in Figure 3-3, will greatly facilitate a broad range of difficult decisions and tradeoffs needed about public and worker safety. The process is not intended to eliminate or even reduce technical uncertainty. Rather, it is intended to provide decision-makers and stakeholders with specific, quantitative information about uncertainties, and to do so in a manner that is reviewable and defensible. The result should be a decision environment that is much more amenable to timely and cost-effective approaches to safety controls.

3.2.3 Identifying the Key Sources of Uncertainty

In a strict sense, all quantified information is subject to uncertainty, including prosaic quantities like measurements of air temperature and wind speed at a site. The SCOPE approach begins with the understanding that the uncertainty related to safe operations is driven by a spectrum of uncertainties in phenomenology. The magnitude of the uncertainty in various quantities varies greatly, as does the impact of the particular uncertain variable on quantities of interest for the safety analysis (e.g., the safety metrics). Since quantitative evaluations of uncertainty are time consuming and expensive, it would not be practical to apply the systematic methods envisioned to all uncertain quantities. Therefore an essential first step in the SCOPE process is to sort all the quantities that affect the calculation of safety metrics into two categories:

a. quantities that have relatively low uncertainty, or whose uncertainty does not contribute very much to the uncertainty in the metrics of interest

b. quantities whose uncertainties are both high and important contributors to the uncertainty in the metrics

Only category (b) will be the subject of expert elicitation, the process described briefly in Section 2. Therefore, only the uncertainty in the metrics that is due to category (b) will be displayed in results like those shown in Figure 3-3.

There are two ways that uncertainty from category (a) can be handled. First, defensibly conservative values can be assigned by safety analysts, in the process discussed in Section 3.1; this approach would be followed for quantities (which we will categorize as a1) whose uncertainty is of intermediate importance. Second, nominal values would be assigned to other quantities (in category a2) whose uncertainties are very small contributors; this would include reasonably accurate measurements of tank and waste properties. The impact of the residual uncertainty due to parameters in category (a) on the results of the SCOPE analyses will make the "bar and whisker" indicators (as well as other modes of display) somewhat conservative because of category (a1) and somewhat uncertain because of category (a2).

It is natural to ask how greatly the two effects of category (a) might affect the results. A key underlying assumption for the SCOPE process is that stakeholders and decision-makers will be able to carry out their responsibilities effectively without a precise answer to that question. The success of this approach depends not only on the skill of the project team and the expert panels in choosing the quantities for category (b) so that the analysis framework can be developed in a reasonable time and for a reasonable budget, but also on the willingness of decision-makers and stakeholders to accept the residual category (a) uncertainties and their implications. The next subsection discusses the latter issue.

3.2.4 Requirements for Success

The discussion above, and experience in other programs, indicate clearly that there are important benefits that can accrue from the use of systematic expert elicitation methods for dealing with safety issues in the face of technological uncertainty. These methods offer a path for achieving closure and regulatory stabilization without excessive conservatism and wasteful expenditures. However, the success of the SCOPE approach cannot be guaranteed independently of conditions in the institutional environment in which it is utilized.

As suggested at the end of Section 3.2.3, unquantified uncertainty is not eliminated by this approach. Possibly even more important, the quantified part of the phenomenological uncertainty will likely be unpleasantly large. Moreover, the expert elicitation process, while systematic, is not "scientific" in the sense of postulating theories and taking measurements to confirm or refute them. In fact, subjective opinion is often viewed as the antithesis of scientific methods, but in the SCOPE process subjective opinion is at the center of the resolution process.

A process like SCOPE can be seen to be a path to success only if it is viewed in the larger context of societal decision making. In Section 3.2.1 we discussed the conflict between the need for assuring public safety versus the absence of adequate knowledge to provide assurance. The resolution of that conflict is partly technical and partly political (in the traditional sense of the way different groups and institutions come to mutually acceptable public policy decisions). Consequently, the success of the process proposed here is dependent on the conditions in the institutional environment associated with oversight of the Hanford site.

The DOE has the principal responsibility for both operations and safety at Hanford. However, as an agency of the federal government, the DOE has important responsibilities to ensure that its oversight is consistent with the interests and wishes of a wide range of stakeholders. These include other federal agencies, such as the Environmental Protection Agency (EPA), and also agencies of the states that might be affected by a release. In addition, the DOE must weigh the interests of the public in general, not only as taxpayers but also as people whose safety is being considered. At other governmental levels, Congress and the judicial branches of the federal government can be included as stakeholders. There are also interest groups that have been formed to represent certain aspects of the public welfare, as well as the companies and workers who have been charged with managing the site and disposition of the waste.

Recent history has made it clear that no one agency or group can unilaterally define standards for success in such a complex institutional environment. It is for that reason that the SCOPE process will include early and meaningful involvement of the key stakeholders. More in that regard will be seen in Section 5.4 when we discuss the opportunity that will be made for a wide variety of input from stakeholders concerning the selection of technical experts and the core technical information base. More relevant to the current discussion is the fact that a process like SCOPE can succeed only if the key stakeholders are motivated to achieve resolution and have a certain minimal openness about how it is achieved. In particular:

- The conceptual legitimacy of using expert opinion to achieve closure on controversy must be accepted; this includes accepting results that are different quantitatively than if only one stakeholder or interest group could impose its views.

- A certain degree of imprecision in this method must be accepted; while SCOPE goes farther than most approaches in assigning numbers to uncertainty ranges, it would be a mistake to equate it to a scientific measuring process. There is a kind of risk associated with accepting this imprecision-- a risk that cannot be borne only by the site contractor, or the DOE field office, or any other single entity. A cooperative atmosphere in which all key stakeholders understand and share that risk is essential.

Thus, early stakeholder involvement is important not only to obtain input from the key players, but also so that the process of developing the analysis framework is one that is well informed about the degree of risk that the key stakeholders are willing to accept. If, for example, the DOE field office has a strong desire to ensure that any conceivable controversy is captured in the expert elicitation process, the analysis tool would include a larger category (b) and a larger and more expensive SCOPE process. Conversely, if the DOE were willing to deal with some of the controversies outside the formal elicitation process (e.g., through position papers or review groups), a more focused category (b) could be developed with a correspondingly more manageable analysis framework and SCOPE implementation program.

3.3 Sources of Information

Since March 1990 when the flammable gas issue in Tank 241-SY-101 became public knowledge, a large amount of information has been generated. Indeed, the number of reports, letters, and data that have been published in the past 6 years on safety issues concerning the Hanford tanks is overwhelming. However, the quality of the work ranges from excellent to questionable; the documents often contradict each other (albeit new information can invalidate older presumptions), and the sources range from field measurements to physically impossible assumptions used for convenience in bounding calculations. Information management is thus an important part of the SCOPE process.

There are several different sources of information important to the Hanford tanks. Published documents are only one source of data. The historical information resident in the experiences of the waste tank operators and chemical process engineers for Hanford is another valuable source. Similarly, the various engineers and scientists who have studied Hanford safety issues have important knowledge that is not found in the published reports. The general industrial experience for comparable operations at other sites (e.g., Idaho, Savannah River, Oak Ridge, and the chemical industry) is also important in assessing hazards associated with flammable gas generated in waste. The SCOPE process will tap into all of these sources by involving experts from inside and outside Hanford to review both written and verbal information from a range of technical specialists.

Tank-specific data that are relatively incontrovertible, such as the location and size of risers, the location and types of installed equipment, and engineering drawings and photographs, have been compiled into tank data files. Some of this information, such as the volume and general category of waste in each tank,[2] surface level history,[3] and temperature history,[4] has been compiled and published in reports. The tank-specific data are a historical reference library that is important to a general understanding of Hanford tank waste behavior. This information is data that will affect the calculations of metrics for assessing the impact of proposed controls on a specific tank, but it is generally not the source of technical uncertainty in the results.

The technical uncertainty that fuels controversy over Hanford tank safety issues arises from incomplete information on both the waste and how relevant physical processes interact with each other. To fill the gaps in information, many laboratory and analytical modeling efforts have been done. However, to date these studies have not been able to resolve many issues because of questions regarding conditions different from actual waste in the tanks, the validity of assumptions and input values in analytical models, and conflicting findings from different studies. The SCOPE process will attempt to isolate the key contentious parameters that most strongly affect the calculations of metrics of the proposed controls. SCOPE will use the expert panels to evaluate the various studies; to make judgments about their quality, relevance, completeness, etc.; and to obtain elicitations to quantify the uncertainty associated with those parameters. The elicitation results can then be used as input to existing models to produce estimates of consequences and frequencies (and thus risk) with quantified uncertainty levels.

Clearly the spectrum of contentious parameters for calculations of metrics is a continuum from critical to inconsequential. SCOPE will attempt to evaluate the most important parameters, but the process must balance the effort to quantify additional parameters with the diminishing impact of those parameters on the metrics. The experts will have much influence on where the line is drawn between elicitation parameters and pedigreed parameters. The assessment of the available information and the selection of parameters for elicitation will be systematic and well documented, but there is no single "optimal" set of elicitation parameters and no clear division between what is essential for the experts to elicit and what is not.

SCOPE will be designed to assess the current state of knowledge and develop expert judgments based on that knowledge--it will not be designed to generate new information. The SCOPE process must make the information available to the experts for them to assess and minimize any influence on their thinking by providing only selected reports and presentations by selected technical specialists. This has to be balanced against the overwhelming amount of material that is available. To make the SCOPE process timely, some filtering of information is essential. Appendix A contains an initial list of documents that the SCOPE management team would assemble and make available to each of the panel experts. These documents are those that are frequently referenced in reports on flammable gas issues, that contain substantial compilations of relevant tank data, and/or are particularly relevant to the topic. No attempt is made to evaluate these reports--that is the role of the experts. The list is sure to grow as future reviewers and participants bring other documents to the attention of the SCOPE management team.

These reports form the common database from which the experts would operate. Panel members are certain to request additional documents as they pursue their individual interests and develop their opinions about elicitation parameters. Some flexibility is built into the panel meetings to allow additional presentations by technical specialists as requested by the panel. Because presentations by specialists involve the entire panel, these will be limited to those requested by the entire panel. Panel members of course will be free to have lengthy detailed discussions with the specialists outside of the formal meetings.

The SCOPE process will require the panel members to document the basis for their elicitations. This will produce a record of why each expert discounted some information sources and relied on others. If the experts discount much of the information relevant to a parameter, then their elicitations should have large uncertainty bands for that parameter. If future information shows that the discounted information was accurate and the elicitation uncertainty bands were not wide enough to encompass the discounted data, the documentation provides a basis for reevaluating the consequence metrics with new values for one or a few parameters without invalidating the SCOPE results or reconvening the panelists.

3.4 Quantitative Metrics

3.4.1 Selection Criteria

The consequence metrics that would comprise the output of the SCOPE-AT would be based on existing regulatory risk criteria and the potential level of detriment to facility operations. Established approaches will be used to calculate these metrics. It is not within the scope of the

SCOPE-AT to provide a detailed representation of the physics of environmental transport for each postulated source term or a comprehensive analysis of the potential human health and environmental impacts.

The risk metrics will be selected for both radiological and toxicological release scenarios according to existing DOE and site contractor risk guidelines. In addition, consequence and dose metrics used by the EPA and the NRC will be reviewed to evaluate their potential application to this project. The regulatory basis for the metrics to be used in the SCOPE-AT is discussed at the end of this section.

3.4.2 Recommended SCOPE-AT Consequence Metrics

The focus of the SCOPE-AT is the development of technically defensible risk metrics that can be used to select among alternative tank controls and operations. The consequence metrics should allow comparison with risk guidelines, provide a measure of the impact on facility operations, and provide data that can be applied in cost-benefit analyses.

The consequence metrics recommended for the SCOPE-AT for radiological releases are the following:

1. 100-m effective dose equivalent (EDE)
2. Site boundary EDE
3. Compliance factor at 100 m for released particulates, corrosives and irritants, and toxic chemicals
4. Compliance factor at site boundary for released particulates, corrosives and irritants, and toxic chemicals
5. Tank confinement failure (HEPA or dome failure)
6. Total activity of radionuclides released
7. Population dose (EDE) within 50 miles of the release site

The WHC *Safety Analysis Manual*[1] provides risk guidelines for three levels of postulated event frequencies. The radiological consequence metrics used by WHC to assess the acceptability of the risks of Hanford site operations are the 100-m and site boundary EDE. The 100-m dose is typically included in DOE facility safety analysis reports as a measure of the potential onsite worker dose. One hundred meters is generally considered to be the very minimum distance at which simple Gaussian dispersion analysis is used to calculate air concentrations downwind from a release. The site boundary dose is used by both the NRC and the DOE to assess the safety basis of facilities.

The WHC document, WHC-SD-WM-SARR-016, Revision 2, *Tank Waste Compositions and Atmospheric Dispersion Coefficients for Use in Safety Analysis Consequence Assessments*,[6] provides conversion factors that simplify the onsite and site boundary dose calculations for Hanford waste tank atmospheric releases at ground level.

The compliance factor is a term developed by the WHC to provide a measure of compliance with WHC risk guidelines (RG) for releases of particulates, corrosives and irritants, and toxic chemicals. This term will be discussed in more detail in Section 3.4.4.

The frequency applied for the comparison of the calculated 100-m and site boundary metrics to the WHC RGs will be the frequency calculated by SCOPE-AT for the release scenario.

In addition to RG metrics, it is necessary to define metrics that can represent the potential impact to tank facility operations for release events that are within the RGs. A tank confinement failure could significantly affect tank facility operations because of the potential political ramifications of such an event independent of whether RGs are exceeded. An example of tank confinement failure would be the failure of the HEPA filter. In postulated cases of tank containment failure that do not result in 100-m or site boundary doses that exceed the RGs, the total activity released can provide a useful comparison measure.

The population dose (person-rem) has a long history of application by the NRC in cost-benefit analyses. This metric can be combined with cost data provided by the user to obtain a cost per person-rem avoided. The cost estimates developed by the user could include the costs associated with the maintainability, labor requirements, and job performance efficiencies of alternative operations.

3.4.3 Radiological Dose Calculations

The WHC has developed a unit liter dose (ULD) methodology for tank farm safety analyses. It provides a simple and efficient method for calculating 100-m and site boundary doses that can be compared with the RGs. Radiological dose conversion factors per liter of tank waste released have been developed. These are multiplied by the release magnitude and tabulated atmospheric dilution factors to obtain the 100-m and site boundary doses for comparison with the RGs.

The atmospheric dilution factor is expressed as χ/Q' values.* The tabulated χ/Q' values represent the 95th percentile direction-independent or 99.5th percentile direction-dependent meteorology as specified in NRC Regulatory Guide 1.145.[5] Site boundary distances for each wind sector are defined as the smallest distance from any tank to the site boundary for that wind sector. All releases are assumed to be ground-level nonbuoyant releases. ULD conversion factors are provided for 12 waste composites:

- all liquids
- all solids
- all single-shell tank (SST) liquids
- all SST solids
- all double-shell tank (DST) liquids except aging waste facility (AWF) tanks
- all DST solids except AWF tanks
- AWF tank (Tank Farms 241-AY and AZ) liquids

* Q' represents the initial source strength of the released waste expressed as a release rate and χ represents the downwind air concentration at a specified location.

- AWF tank (Tank Farms 241-AY and AZ) solids
- SST flammable gas watchlist liquids and solids
- DST flammable gas watchlist liquids and solids
- SST liquids excluding six noninterim stabilized tanks (C-106, C-107, T-104, U-105, U-107, U-109) and one interim stabilized tank (AX-102)
- tank C-106 solids

Waste compositions and ULD conversion factors are provided for mean, 50th, 90th, 95th, 99th, and the 100th percentile composites. The ULD methodology is described and the tank waste compositions, ULD conversion factors, and χ/Q' values are provided in Ref. 6. The tabulated ULD conversion factors and χ/Q' values provide the factors required to calculate the 100-m EDE, site boundary EDE, and the 50-mile site radius population dose. The 100-m EDE includes only the dose received from inhalation of the passing plume. The site boundary EDE includes inhalation of the passing plume and the dose received from ingestion, resuspension inhalation, and groundshine during the 24-hr period following the release.

The unit liter of isotopes suspended in the headspace is estimated using a "partition fraction." The partition fraction developed for the worst-case liquid waste tank, 1E-8, is applied to all tanks. The partition fraction is multiplied by the volume of the headspace to obtain the number of liters of waste suspended in the headspace.

The inhalation dose (sieverts) is calculated using the following equation:

$$\text{Dose} = Q \bullet \frac{\chi}{Q'} \bullet R \bullet ULD$$

where:

Q = Liters (L) respirable tank waste released, activity mass aerodynamic diameter (AMAD) = 1 μm
χ/Q' = Integrated atmospheric dispersion coefficient (s/m^3)
R = Breathing rate (m^3/s), 3.3E-4 m^3/s for 100-m and offsite dose calculations for release durations of less than 1 week for 100 m and less than 1 day for offsite; 2.7E-4 m^3/s is to be used for release durations of 1 week or greater for 100-m dose calculations, and for release durations of greater than 24 hr for offsite calculations
ULD = Unit liter released dose conversion factor (Sv/L)

The dose (sieverts) received at the site boundary from ingestion, inhalation resuspension, and groundshine during the 24-hr period following the release is calculated by:

$$\text{Dose} = Q \bullet \frac{\chi}{Q'} \bullet ULD$$

where:

Q = Liters (L) tank waste released, AMAD = 1 μm
χ/Q' = Integrated atmospheric dispersion coefficient (s/m^3)
ULD = Unit liter released dose conversion factor (Sv/L)

3.4.4 Assessment of Compliance with Chemical Release RGs

Unit liter released conversion factors have also been developed for WHC Tank Farms chemical release consequence assessments. Chemical releases must be evaluated in terms of compliance with RGs associated with:

- total particulates released
- corrosive and irritants
- toxic chemicals

Unit liter constants have been developed and tabulated which, when multiplied by the liters of waste released, provide a measure of compliance with the RGs. Constants have been developed for particulate, toxic, and corrosive material releases. The 100-m and site boundary air concentration is calculated for particulate, toxic, and corrosive material. The RGs are exceeded if the product of the magnitude of the release and the unit liter constant is greater than one. Composites and unit liter constants for the particulate, toxic, and corrosive material content of waste have been developed for the following waste types:

- SST liquid
- SST solid
- DST liquid
- DST solid
- headspace gas, worst case
- headspace gas, steady-state sample data
- flammable gas watchlist liquid and solid
- 50 % NaOH solution
- All liquids and solids
- C-106 solids

The chemical compositions developed for each waste type represent the highest concentration found in the sample data for each analyte of concern.

Chemical release constants are based on air concentrations calculated for continuous, puff, and gaseous releases. The air concentrations for continuous toxic solid and liquid chemical releases were calculated using the following equation:

$$C = Q' \bullet \frac{\chi}{Q'}$$

where:

C = Concentration at the maximum onsite/offsite individual (mg/m^3)
Q' = Toxic material release rate (mg/s)
χ/Q' = Integrated atmospheric dispersion coefficient (s/m^3)

Air concentrations calculated for instantaneous toxic solid and liquid chemical releases were calculated using:

$$C = Q \bullet \frac{\chi}{Q}$$

where:

C = Concentration at the maximum onsite/offsite individual (mg/m^3)
Q = Toxic material released (mg)
χ/Q = Puff release atmospheric dispersion coefficient ($1/m^3$)

Air concentrations from gaseous toxic chemical releases were calculated using:

$$C = \left(\frac{\frac{\chi}{Q'}}{1 + V' \bullet \frac{\chi}{Q'}} \right) \bullet S \bullet V'$$

where:

C = Concentration at the maximum onsite/offsite individual (mg/m^3)
S = Gaseous toxic material source concentration (mg/m^3)
χ/Q' = Integrated atmospheric dispersion coefficient (s/m^3)
V' = Volume release rate of gaseous source (m^3/s)

The air concentration for total particulates of puff releases is calculated using:

$$C = \rho \bullet 10^6 \bullet Q \bullet \frac{\chi}{Q}$$

where:

C = Concentration at the maximum onsite/offsite individual (mg/m^3)
Q = Release amount (L)
χ/Q = Puff atmospheric dispersion coefficient ($1/m^3$)
ρ = Density of source material (g/cm^3); densities of 1.6 g/cm^3 and 1.1 g/cm^3 are assumed for tank solids and liquids respectively

The air concentration for total particulates of continuous releases is calculated using:

$$C = \rho \bullet 10^6 \bullet Q' \bullet \frac{\chi}{Q'}$$

where:

C = Concentration at the maximum onsite/offsite individual (mg/m^3)

Q' = Release amount (L/s)

χ/Q' = Puff atmospheric dispersion coefficient (s/m^3)

ρ = Density of source material (g/cm^3); densities of 1.6 g/cm^3 and 1.1 g/cm^3 are assumed for tank solids and liquids respectively

An extensive discussion of the above calculations, chemical composites of the waste types, the unit liter constants, and χ/Q' and χ/Q values applied in the above chemical release calculations may be found in the WHC document, *Toxic Chemical Considerations for Tank Farm Releases.*[7]

3.4.5 Definition of the SCOPE-AT Consequence Analysis Input

The SCOPE-AT would produce the following input to the ULD calculations for each release scenario modeled:

- chemical and radiological waste composite types released to the atmosphere
- liters of 1-µm AMAD waste particles released for each radiological composite type
- total liters of each radiological waste composite type released
- for chemical waste types -
  - solid or liquid toxic chemical release rate for continuous releases (L/s)
  - solid or liquid toxic chemical released for puff releases (L)
  - volume release rate for gaseous toxic chemical releases (m^3/s)

3.4.6 Uncertainty in Atmospheric Dispersion Calculations

There are a number of uncertainties inherent in the calculation of the dose consequences of the release of hazardous materials to the atmosphere. The current approach in the SCOPE project is not to use expert elicitation for these uncertainties but rather to use standard methods. One dominant source of uncertainty for consequence calculations is the uncertainty in predicting weather conditions at the time of a postulated accidental release. The methodology specified in NRC Regulatory Guide 1.145 addresses this uncertainty by specifying that the dose compared with the site boundary dose criteria must be that dose which is exceeded only 5.0% of the time for the overall site or 0.5% of the time for a specific wind direction, whichever provides the highest dose estimate.

The release height and the heat of release are two additional source term parameters that will affect the magnitude of the 100-m and site boundary dose calculations. The assumptions for the SCOPE-AT dose calculations are that all releases will occur at ground level with zero heat of release. Both of these assumptions are typically conservative for the 100-m and site boundary dose calculations and appropriate for the comparative assessments to be performed using the SCOPE-AT.

3.4.7 Regulatory Basis of the SCOPE Consequence Metrics

3.4.7.1 DOE Radiation and Toxicological Risk Guidelines

The Nuclear Safety Policy of the DOE states that the general pubic shall be protected so that no individual incurs significant additional health or safety risks as a result of operations at DOE nuclear facilities.[8] The policy further states that the additional risk of early fatalities or cancer fatalities incurred by an average individual as a result of DOE operations should not exceed 0.1% of the sum of the risks from other causes.

DOE-STD-3009 provides guidance for the preparation of DOE nonreactor nuclear facility safety analysis reports (SARs)[9] and suggests binning postulated accident scenarios according to the likelihood of the release and the severity of the consequences. Evaluation guidelines (EGs) are provided in a 1995 draft of Appendix A to DOE-STD-3009.[10] DOE-STD-3009-94 provides the following definition of EGs:

> *Hazardous material dose/exposure values that the safety analysis evaluates against. The intention is that theoretical individual doses/exposures exceeding the Evaluation Guideline should not occur at a given point, unlike other values, such as emergency planning thresholds. Offsite Evaluation Guidelines are established for the purpose of identifying and evaluating safety-class structures, systems, and components. Onsite Evaluation Guidelines are not required for adequate documentation of a safety basis utilizing the overall process of this standard.*

The Appendix A draft specifies that the EGs represent a maximum theoretical dose to an exposed individual located at the centerline of a plume of released material. The dose calculations are to include only the dose received from direct exposure to the passing plume. Measures would be taken to protect the public from other dose pathways such as long-term exposure to significant levels of ground contamination or the ingestion of contaminated agricultural products.

The 1995 draft also specifies the radiological EG as 25 rem total effective dose equivalent at the site boundary. It is generally accepted that a dose of this magnitude would not result in significant health effects. The toxicological EG represents the dose at which an individual could be exposed for up to 1 hr without experiencing or developing serious health effects or symptoms that could impair the ability to take protective action.

The draft standard recommends the use of the Emergency Response Planning Guidelines (ERPGs) published by the American Industrial Hygiene Association (AIHA). The air concentration specified as ERPG-2 is identified as an appropriate EG for toxicological releases. Craig[11] provides the following definition of ERPG-2: The ERPG-2 value is the maximum airborne concentration to 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. Individual sites are required to develop EGs for chemicals for which ERPGs are not available.

3.4.7.2 Federal Radiation Dose Guidelines

The site boundary dose metric specified in DOE-STD-3009 draft Appendix A was derived from commercial reactor siting criteria specified in 1962 in 10 CFR 100, which states that an individual located on the outer boundary of a commercial reactor exclusion zone should not receive, from a 2-hr exposure after a design basis accident, a *whole body dose* in excess of 25 rem or a thyroid dose in excess of 300 rem. The 25-rem limit was judged to represent a one-time emergency dose that would have no detectable health impact. The 25-rem whole body dose was defined as the external whole-body exposure at a tissue depth of 1 cm and does not include the dose received from radionuclides that are inhaled and deposited within the body.

Currently, the *effective dose equivalent* is the most common measure used to specify radiation dose limits. The EDE was originally proposed by the International Commission on Radiological Protection (ICRP) in 1977 and was updated in 1990.[12,13] The EDE is a whole-body dose measure that can be used to calculate stochastic health risks. It is not appropriate to use the EDE to calculate acute health effects. Calculations of acute health risks are based on doses to specific organs.

A 1994 NRC Policy Issue Document recommended replacing the 10 CFR 100 25-rem whole body and 300-rem thyroid dose limits with a 25-rem *total effective dose equivalent* (TEDE).[13] This is the sum of the effective dose equivalent from external exposure and the 50-year dose from inhaled radionuclides.

The TEDE dose measure is used by the EPA to specify doses for protective action guidelines for the public and for workers during nuclear incidents.[15] The TEDE measure is also specified in federal radiation protection guidance for the prevention of stochastic health effects. The federal guidance also provides an organ dose limit for the prevention of acute health effects.[16]

3.4.7.3 Federal Residual Contamination Standards

Site remediation is considered complete under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) when the cancer fatality risk from residual contamination is less than 10^{-6} cancer fatalities per year. This risk level cannot be translated into a single ground contamination activity level for all radionuclides because health risks will vary depending upon the specific radionuclides present. In addition, the cancer fatality risk for natural background levels of some radionuclides is greater than 10^{-6} fatalities per year. It is the policy of the DOE Office of Environmental Management that cleanup standards are to be defined on a case-by-case basis, depending upon such factors as site cleanup costs and land-use decisions.[17]

3.4.7.4 NRC Cost-Benefit Metrics

The regulatory framework of the NRC requires that radiation doses to individuals not exceed federal radiation dose limits and that radiation exposure below the regulatory limits be kept as low as reasonably achievable (ALARA). Cost-benefit analyses have been performed to assess the value of actions implemented under the ALARA framework. The expression of the potential benefit (i.e., dose averted) of a regulatory requirement in the same units as the potential cost of the requirement allows benefits and costs of alternative courses of action to be compared. In 1975, the NRC first recommended the use of a person-rem conversion factor for translating person-rems averted into units of cost and, in addition, recommended a $1000 per person-rem value for the conversion.[18] In December 1977, the NRC issued value-impact guidelines for evaluating regulatory requirements (SECY-77-388A). These recommended the implementation of a conversion factor and the $1000 per person-rem value.

U.S. NRC Regulatory Guide 1.110, *Cost-Benefit Analysis for Radwaste Systems for Light-Water-Cooled Nuclear Power Reactors*, specifies $1000 per man-rem as a cost-benefit criterion. In addition, Regulatory Guide 1.110 specifies that the dose is to be calculated for the population within 50 miles of the reactor. The conversion factor was also used in the prioritization of generic safety issues.[19]

A January 27, 1994 *Draft Federal Register Notice (FRN) for Proposed Dollar per Person-Rem Conversion Factor* recommended that the conversion factor be increased to $2000 per person-rem. Consistent with past guidance, the draft FRN stated that the conversion factor applies only to stochastic health effects and should not be applied to deterministic effects. The $2000 per man-rem conversion factor is the product of an assumed $3 million statistical value of life and the ICRP 60 recommended cancer risk coefficient of 7.3E-4 per rem for doses to the general public. The ICRP 60 recommended risk coefficient (7.3E-4 per rem) applies only to the risk of latent cancers (fatal and nonfatal) and severe hereditary effects; consequently, this conversion factor applies only to stochastic health effects. This risk coefficient is defined in units of ICRP 60 effective dose.

3.4.7.5 WHC Radiation and Toxicological Risk Guidelines

The binning scheme applied in the Westinghouse Hanford Company's nonreactor facility *Safety Analysis Manual*, which provides risk guidelines for three levels of postulated event frequencies, is consistent with DOE-STD-3009 and the DOE Nuclear Safety Policy.[20]

Westinghouse has published a number of versions of the RGs. Current DOE guidance requires that Revision 1 of the radiological RGs be used for the TWRS basis for interim operations/final safety analysis report and project safety analyses started after April 4, 1996. The toxicological risk guidelines are currently based on Revision 4 of the WHC RGs.[21]

The radiological RGs provided in the WHC *Safety Analysis Manual* Rev. 1 are plotted in Figure 3-4 and listed in Table 3.1. The radiological RGs are defined in terms of effective dose equivalent. The onsite and offsite doses and their associated frequencies are within the risk guidelines if they fall under the curves in Figure 3-4. Table 3-2 lists the WHC *Safety Analysis Manual* Rev. 4 toxicological risk guidelines. The offsite risk guidelines for toxicological releases are expressed in terms of the ERPGs and the permissible exposure limit-time-weighted average (PEL-TWA). The onsite guidelines are expressed in terms of the ERPGs.

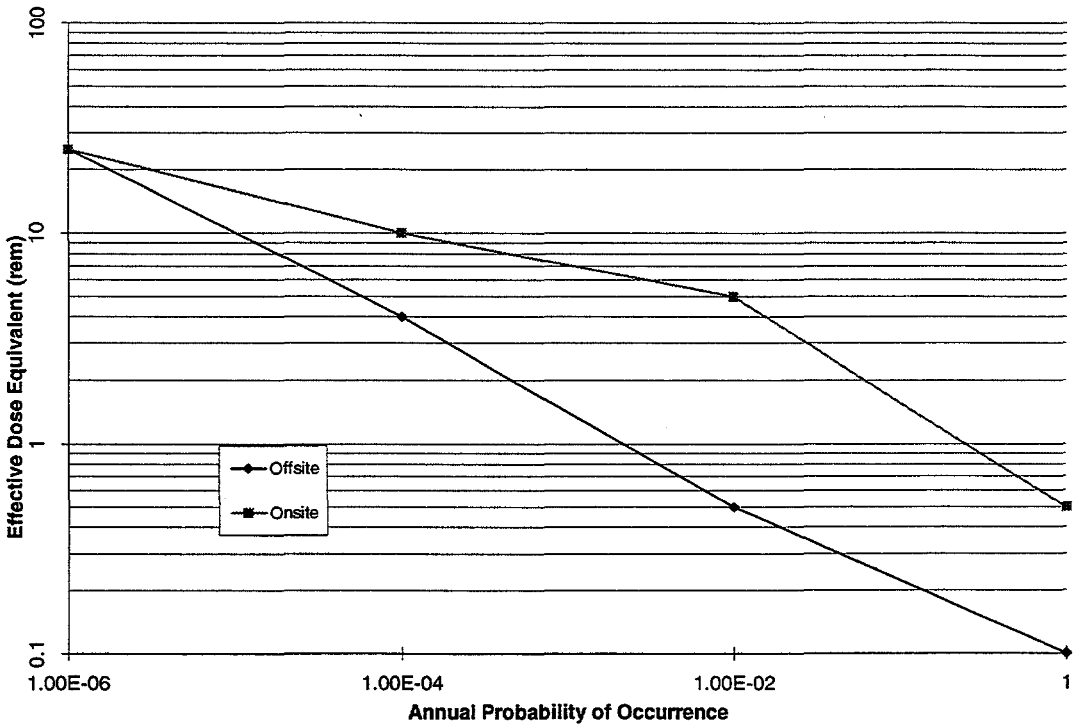

Figure 3-4. WHC radiological risk guidelines.

Table 3-1. WHC Rev. 1 risk guidelines for radiological releases

		EDE	
Event Frequency Category	Event Frequency (yr^{-1})	Onsite (rem)	Offsite (rem)
Anticipated	1 to 10^{-2}	0.5 - 5	0.1 - 0.5
Unlikely	10^{-2} to 10^{-4}	5 - 10	0.5 - 4
Extremely Unlikely	10^{-4} to 10^{-6}	10 - 25	4 - 25

Table 3-2. WHC Rev. 4 risk guidelines for toxicological releases

	Concentration		
Event Frequency Category	Event Frequency (yr^{-1})	Onsite	Offsite
Anticipated	1 to 10^{-2}	≤ERPG-1	≤PEL-TWA
Unlikely	10^{-2} to 10^{-4}	≤ERPG-2	≤ERPG-1
Extremely Unlikely	10^{-4} to 10^{-6}	≤ERPG-3	≤ERPG-2

The RGs are used in safety analysis reports and safety analysis documents to provide a basis for evaluating the safety of facilities. Facility risk is generally considered acceptable if the radiological doses and the toxicological air concentrations are within the RGs for the defined event frequencies.

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4.0 SCOPE ANALYSIS FRAMEWORK

4.1 Introduction

If SCOPE is to generate quantitative metrics to assist decision makers in judging the need for and relative benefits of hazard control strategies at TWRS, then at some point quantitative information about waste and the systems that contain it must be processed to generate the metrics. The general way that input information is organized and processed to produce output metrics is called the analysis framework (see Figure 4-1). A critical element of the SCOPE program is the design of this framework. As discussed earlier, it is not the role of phase 1 of the SCOPE program to develop this framework in any detail; rather it is a major task in phase 2. However, much is understood now about what the requirements will be for the design process for the analysis framework. In this section we describe (sometimes at a somewhat abstract level) how the development of the analysis framework in phase 2 will proceed.

There are five principles that will guide the development of the analysis framework:

1. Economy of Analysis. The goal of SCOPE is to bring information to bear on a defined range of decisions about safety controls at TWRS and to gather, generate, and analyze only that information that is essential to those decisions. For that reason, it is important to decide in advance what metrics are to be used for these decisions, and what degree of precision is needed in generating the metrics. In developing the method for calculating these metrics, there will be a need for a great many decisions about where to obtain data, how accurate it must be, and how to manipulate the quantitative information to produce a result. All these decisions must be guided by a clear understanding of the range of decisions that are targeted for SCOPE and the degree of precision that is required. By constantly focusing on these requirements, we can avoid the tendency to blindly pursue technical information and physical understanding about any and all aspects of the TWRS systems and its components.

2. Building on Existing Knowledge. Whenever possible, information that is already available concerning TWRS should be used in the analyses for SCOPE. As will be seen below, there are many ways that existing data and analyses can be used. An important challenge, of course, is that the volume of information currently available for TWRS is rather overwhelming, and consequently a systematic review and selection process is an important preliminary step in the process (as discussed in Section 3.3).

3. Establishing a Reviewable Decision Basis. The way that information is selected and processed, and the reasons for the numerous decisions about selection and processing, must be clearly documented. A particular reviewer in the future may disagree with one or another decision, but at least the basis must be well documented so that a meaningful review is possible.

4. Limiting the Number of Elicitation Parameters. The principal barrier to efficient and cost-effective decisions about operations at TWRS is the high degree of phenomenological uncertainty in a few key areas. In other words, relative to the large amount of information that is known about the waste and the systems that contain it, there are a relatively small number of

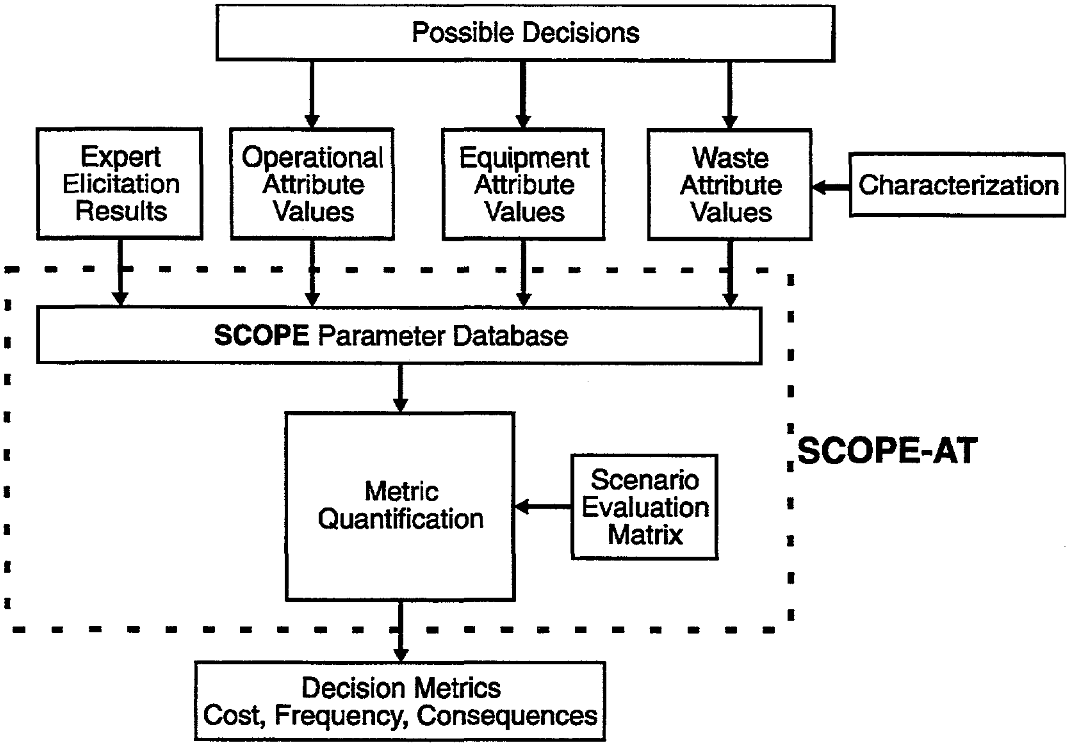

Figure 4-1. Simplified diagram of information flow in the analysis framework. SCOPE-AT is the analysis tool that will be used to support decisions about safety controls at the TWRS.

quantities whose values are uncertain and which are highly important to evaluations of hazards. Expert opinion processes will be brought to bear on these key uncertainties, but they can only be effective if the number of elicitations is not excessive. This concept may be somewhat unclear at this point, but will be explained in more detail in the remainder of Section 4.

5. Iteration of the Analysis Framework with the Expert Panels. It would be difficult to have meaningful input from the experts on the panels if they did not understand or agree with the way their input was to be used. While complete concurrence about all details among all experts would be impossible, it is essential that they have an opportunity to identify significant defects in the framework, or to suggest important ways it could be improved. In designing the framework, some thought must be given to ensuring that the system can be modified or adapted to respond to significant criticisms. For example, alternative ways of doing parts of the analysis might be considered in the development process and be ready for presentation to the experts if there is a need.

The remainder of this section provides additional details about the resulting structure of the analysis framework, focusing specifically on hazards associated with flammable gas.

4.2 The Scenario Evaluation Matrix

SCOPE's evaluation of specific hazards related to flammable gases and the effect of safety controls on those hazards begins with the observation that one can categorize the scenarios that give rise to significant threats into four types:

- gas release event in tank headspace
- gas buildup in equipment
- flammable gas outside headspace
- subsurface gas burn

As the full development of the analysis framework proceeds, it may be that one or more of these scenarios is not of concern, but at present these four cover the full range of operational safety issues concerning flammable gas that have been identified at the site.

Assessment of the flammable gas hazard requires estimation of the source term to the environment (the release of radiological or toxicological material into the atmosphere). The calculation of the consequences of a release was discussed in Section 3.4.

For any event in one of the four scenarios, the calculation of the source term can be divided into four steps:

- frequency of the event
- probability of flammable gas ignition, given the event
- damage freqency, or the conditional probability of certain damage levels (such as HEPA failure) being achieved
- release frequency, or the probability of a source term being of a given magnitude

This structuring of the possible pathways for hazardous events will allow a systematic evaluation of what information should be collected, and how it should be manipulated to calculate safety controls metrics. Table 4-1 shows how the scenarios and four analysis steps combine to form the SCOPE scenario evaluation matrix.

Every matrix element represents a large number of decisions on where to obtain information and how to manipulate it and pass it down to the next step. The intent of the SCOPE phase 1 project is not to fully develop the analysis framework, but rather to illustrate the nature of the design process that will be required in phase 2. Some elements of the scenario matrix will be discussed in more detail in Section 4.3 to illustrate the considerations that enter into decisions about data and information processing.

Table 4-1. SCOPE scenario evaluation matrix

SCOPE DSS Evaluation Matrix for Flammable Gas Issue				
	Scenario			
	Headspace Burn	Burn in Equipment	Exheadspace Burn	Subsurface Burn
1. GRE Frequency P(GRE)	• Intrusive equipment • Rollover GRE • Nonrollover GRE • Earthquake	• Drill string	• Tank pit • Vent system	• N/A
2. Ignition Frequency P(burn/GRE)	• Spark frequency in headspace • Spark location	• Interior ignition frequency	• Ignition frequency per location	• Frequency of subsurface ignition
3. Damage Frequency P(damage/burn)	• Burn completeness • Pressure rise • HEPA fragility	• Pressure rise • Equipment Fragility	• Burn completeness • Pressure rise • Location fragility	• Amount of gas burned • Headspace pressure rise
4. Release Frequency P(release/damage)	• Release from tank and waste surfaces • HEPA leading	• Ejected waste	• Release from surfaces	• Ejected waste entrained extank

4.3 Specific Design Issues for Analysis Framework

In this section, specific aspects of the logic and information flow associated with one portion of the scenario matrix are explored to provide a more concrete sense of what factors will enter into the many decisions required for the design of the analysis framework. The example studied will be the first column of the matrix, i.e., the headspace burn scenario. Before beginning, it is essential to understand that the point of the present discussion is *not* to *define* that portion of the analysis framework that deals with the headspace burn scenario. Instead it is only to illustrate the kind of information that needs to be defined and the decisions that need to be made in order to develop this portion of the analysis framework. The actual development of the analysis framework will be a major task for phase 2, a task that cannot be fully completed until it has had the benefit of review by the expert panels themselves.

Here we walk through the major analysis steps (i.e., down the first column of the scenario matrix), identifying some of the major information needs and decision requirements at each step. For some steps, these illustrative examples are described at a very high level of generality only; however, somewhat greater levels of detail are used for definition of the GRE parameters and the pressurization resulting from gas headspace burns. This greater level of detail is introduced to give a somewhat more realistic picture of what will actually be required of all the steps. The order of presentation is the order in which the steps occur in an actual physical event, which is also the order of information flow in the calculation. However, this is not necessarily the order in which the events must be considered for planning purposes. Often the information required for the later stages of the sequence of physical events dictates what must be done in analyzing the earlier stages, as will be illustrated later in this subsection. The design of each step of the analysis framework must take into account the requirements of the entire framework.

4.3.1 GRE Frequency and Magnitude

Figure 4-2 illustrates the logical flow of information through the calculation steps of the matrix. The sequence of events starts with the occurrence of a GRE. A key branch between plumelike behavior and well-mixed behavior is shown in the figure, but for this discussion, only the branch on the left is discussed. Appendix D discusses the case for a plume. It is necessary to consider both the frequency and the magnitude of the GREs in order to perform the analysis. The next step is to assign this information requirement to one of the three basic categories: user-defined, pedigreed, or elicited. The expected choice for the GRE volume and frequency is elicited, at least in most cases.

It is not possible to obtain meaningful elicitations on as vague and general a subject as "GRE frequency" and "GRE volume" without saying anything about what waste characteristics, release mechanisms, etc., are being assumed. It is therefore necessary to narrow the problem by specifying values for some of the governing parameters, or ranges for some of these parameters. This process is called "conditioning." (Conditioning and several other principles important for the design of the elicitation process are discussed further in Section D.2 of Appendix D.) Thus each elicitation is conditional upon some combination of parameter values or ranges of values. The specific combination used for any given elicitation is called a case. Deciding upon the conditioning parameters that define the various cases, and deciding on the appropriate ranges for these parameters, are among the decisions that must be made in defining the analysis framework.

As noted in Section 4.1, it is important to control the number of elicitation cases. A maximum of 200 to 300 cases is considered feasible, but it is to be hoped that the actual number can be kept smaller than this. It is obvious that each tank cannot be considered individually: simply eliciting GRE volume and frequency for one release mechanism per tank would exhaust the total allotment of elicitations. Hence it will be necessary to "bin" the tanks into groups that are similar in terms of characteristics that are believed to control GRE behavior. To be useful, the binning parameters must represent quantities that are known for the various tanks (pedigreed data), supplied by other elicitations, or provided by the user.

As an example, one important parameter is waste rheology, which might be coarsely binned into three categories: salt-well pumped single-shell tanks, unpumped SSTs, and double-shell tanks, which have substantial supernatant overlying the solid wastes. Different GRE mechanisms most likely need to be considered separately, e.g., rollover GREs, spontaneous nonrollover GREs, and GREs induced by waste-intrusive activities (which actually might be further subdivided according to the type of intrusive activity). Other waste parameters important to GREs include thickness of the solid layer, waste porosity, and the density difference between the liquid and solid phases. These are continuous variables and definition of cases requires subdividing the full range; in a coarse binning, the full range might be divided into only three subranges for each parameter. Assuming only one frequency and one volume elicitation for each combination of the five conditioning parameters defined here, we now have $2 \times 3^5 =$ 486 elicitation cases. Again, we have substantially exceeded the maximum allowable for the entire SCOPE project, yet we have not completed the first box of the scenario matrix.

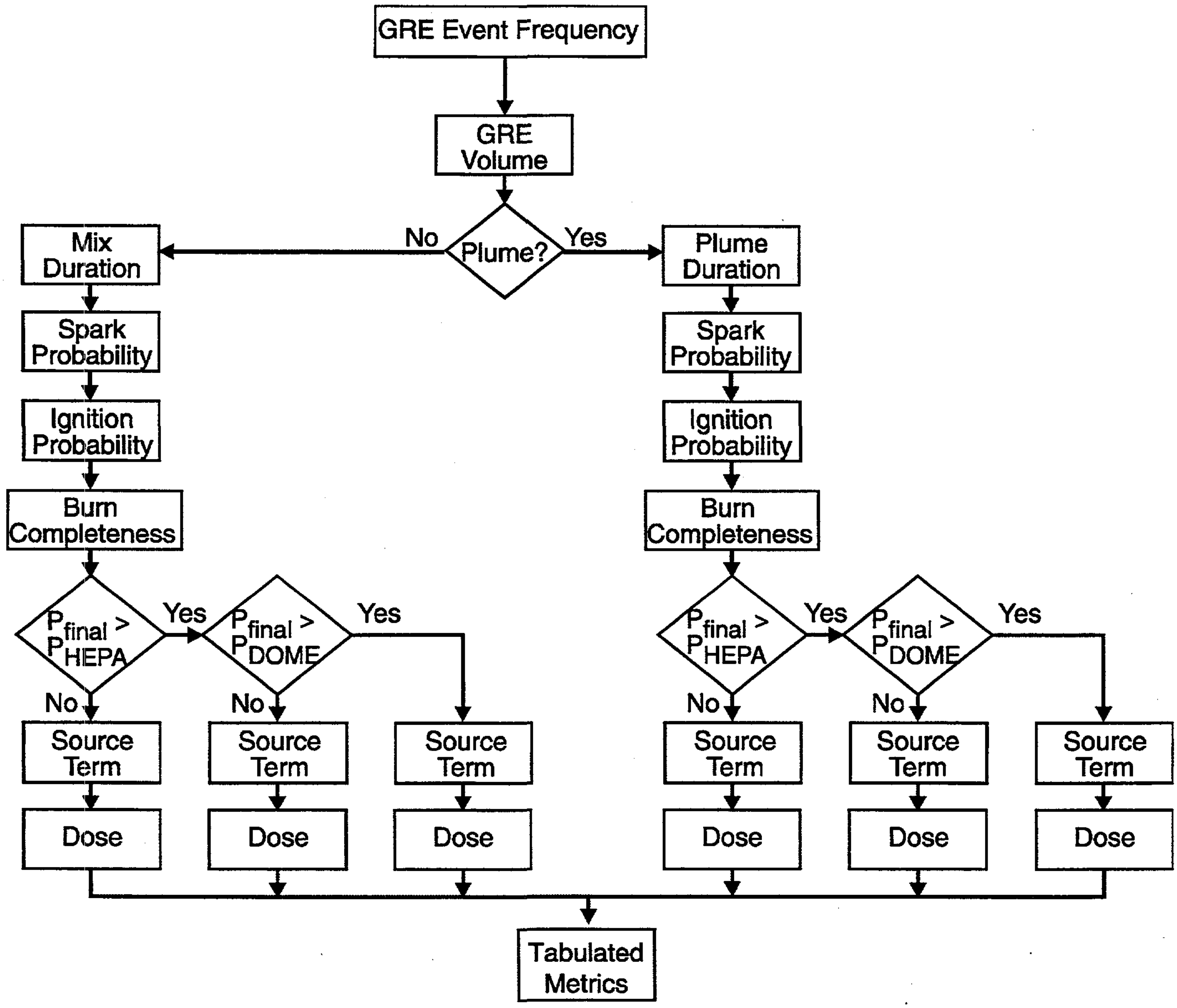

Figure 4-2 Flow of information in SCOPE matrix.

This example illustrates the ease with which the number of elicitation cases can get out of hand. It is obviously necessary to be "smart" in defining elicitation cases, taking advantage of what is known to eliminate unnecessary cases. For some parameter values, behavior can be insensitive to certain other parameters; e.g., the SSTs include little free liquid and hence rollover GREs and the liquid/solid density difference need not be considered. It may also be true that elicitations are not needed in all cases. For example, it has been suggested that the historical record might be used to define uncertainty distributions for rollover GRE frequencies and/or magnitudes in some cases (pedigreed data source). If a relationship between the amount of gas released and the amount of waste disturbed in waste-intrusive operations can be defined, it may be possible for users to provide reasonable estimates of the amount of waste disturbed for some operations.

In Appendix D, a very preliminary "strawman" structure of elicitation cases is defined. Though far from bounding, this definition was intended to be conservative with respect to the level of detail and number of elicitations considered in order to provide guidance as to feasibility of the work required for SCOPE phase 2. A total of about 230 cases were defined, which is near the upper limit for SCOPE success. Fortunately there is reason to believe that this preliminary elicitation structure can be simplified and that the total number of elicitations is more likely to decrease than to increase in later refinements. Some reasons for this belief are also summarized in Appendix D.

For spontaneous GREs, most controls would not influence the GRE parameters, but exceptions will exist in special cases, e.g., installation of mixing pumps as in Tank 241-SY-101. For induced GREs, controls may be introduced to reduce GRE likelihood or magnitude. Some possible controls take the form of restricting the nature of permitted waste-intrusive operations. It is then necessary to decide how the impact of the control will be reflected in the analysis framework. For sufficiently important controls identified before or during the expert panel meetings, elicitations specific to the particular control may be used, but the number of such cases must be kept small. Controls may be binned into a small number of groups so that controls within a group may have similar effects.

Controls may also be defined through input, e.g., through a user-specified upper limit to the amount of waste that can be disturbed in an intrusive operation. Parameters that describe the effect of a control then become design or performance requirements for the control and therefore should be chosen carefully.

4.3.2 Ignition Source Frequency

The next step in working down the first column of the scenario matrix is to consider frequencies of sparks and other ignition sources. Sparks may result from the operation of electrical equipment, electrostatic discharges not related to electrical circuits, or mechanical impact of surfaces (equipment banging against other equipment, etc). Sparks or other ignition sources may arise either at random with respect to GRE occurrence or as a result of a common cause; e.g., an earthquake may trigger a GRE and at the same time result in sparking from damaged electrical equipment or from the banging of mechanical equipment.

Spark frequencies will be a strong function of the types of equipment and types of operations involved. Decisions must be made whether available information on spark frequencies is adequate. The National Fire Protection Association (NFPA) category of equipment may provide considerable guidance; however, much equipment currently in use is not designed to NFPA specifications and it may be difficult to provide acceptable pedigreed data for spark frequencies except by adopting excessively conservative values in order to avoid controversy. Elicitations for spark frequencies may be needed in such cases, since a basic purpose of SCOPE is to minimize the need to choose between excessive conservatism versus risking excessive delay owing to controversy over assumptions in the safety analyses.

One of the most common forms of controls requiring consideration by SCOPE are various measures to reduce spark probabilities. These may take the form of restrictions on operations, requirements for what equipment can be used, or both. If equipment is installed as part of a control measure, it is more likely to meet NFPA specifications than is the case for existing equipment; i.e., meeting a particular NFPA specification may be part of the control. Available data on equipment meeting these specifications may obviate the need for elicitations in some cases, but this probably will not always be the case. In sufficiently important cases, the effect of a control on spark frequency may be elicited directly. Alternatively, controls may be binned into groups and the effect of each group defined using either pedigreed data or an elicitation, depending upon whether the available information is adequate to justify defining pedigreed data for the control. The SCOPE user may also define the effect of the control through input, in which case the input chosen by the user becomes a design specification for the control, as was discussed previously.

4.3.3 Damage Frequency and Magnitude: Combustion Analysis

Given an ignition source at a time and location where flammable gas exists, a burn will likely occur. The next step in the analysis is to evaluate the damage to tank features that are important to confinement such as HEPA filters or basic tank structures such as the dome. This damage is a function of the pressure rise (and possibly temperature rise) resulting from the burn and also depends upon the fragility curves for the tank features of interest. The fragility curves have been the subject of considerable prior study, including evaluation by expert panels. At present it is believed that these prior results can be provided as part of the pedigreed database without additional elicitations and that effort in SCOPE can be focused on analyzing the pressure rise from the burn.

In designing the analysis framework, it is frequently necessary to make decisions concerning the level of detail involved and whether a particular effect can be calculated with a phenomenological model versus elicitations being required. The gas burn analysis provides a good illustration of this point. For example, the following three options are possible:

1. It can be assumed that all flammable gas released will burn completely with no mitigation by atmosphere-structure heat transfer, with the constant-volume pressure rise being calculated from the resulting energy release. This is the adiabatic isochoric complete combustion (AICC) model and provides the simplest treatment. The calculation is simple, with little modeling uncertainty, and thus there should be no controversy concerning modeling uncertainty. Likewise, there should be no controversy as to adequate conservatism because the model is bounding for all deflagrations. The difficulty, of course, is that the model may be excessively conservative.

2. At the opposite extreme with respect to complexity, any of various phenomenological models for gas combustion may be used to estimate the amounts and rates of gas combustion and the burn completeness. Models for combustion of a well-mixed headspace and combustion of flammable gas plumes are available, and mitigation by atmosphere-structure heat transfer can also be modeled. These models could substantially reduce or eliminate the excessive conservatism that can result from the first option. Unfortunately, the available models are far from perfect and there is substantial uncertainty in their predictions. Their use without allowing for this uncertainty would undoubtedly generate much controversy. A possible approach is to use a set of agreed-upon models together with

a parametric representation of the uncertainty in the models, and perform elicitations on the parameter(s) that represent the modeling uncertainty.

3. As a compromise, the AICC pressure might be calculated as in the first option, and elicitations then used to define an uncertainty distribution for an efficiency factor ε_P such that the actual pressure rise is obtained by multiplying the AICC pressure rise by ε_P. At a minimum, ε_P will depend upon the magnitude of the GRE. A case structure with GRE magnitude as a conditioning variable might therefore be defined.:

   - GRE magnitude is small enough that, after mixing through the tank headspace, the flammable gas concentration, $X(FG)$, is $< 25\%$ of the lower flammability limit (LFL) for upward flame propagation. Either no burns are possible at all or else only small plume burns in the vicinity of the release point may occur in this case.

   - $25\%\ LFL \leq X(FG) \leq 100\%$ LFL. Larger plume burns may occur prior to the gas becoming well mixed in the tank headspace, but no burns can occur once the gases are well mixed.

   - $X(FG) > 100\%$ LFL. Global headspace burns can occur after the gases become well mixed, and large plume burns may occur prior to complete mixing.

The gas combustion analysis can also be used to illustrate the point made earlier, that the treatment of a later stage of analysis can affect the information requirements of a previous stage. For any of the above options, GRE magnitudes are obviously needed; these are supplied by elicitations, as discussed previously. However, gas composition is also needed. Elicitations might be used to define uncertainty distributions for composition variables as part of the GRE analysis treatment. Alternatively, a conservative composition based upon available tank data might be used. Note, however, that no one composition is conservative in all contexts. For example, maximizing the hydrogen content is conservative with respect to the LFL, but maximizing the methane content is conservative with respect to tank pressurization because the molar heat of combustion of methane is about 3.3 times that of hydrogen. A decision will have to be made as to whether the approximation inherent in specifying a single "conservative" composition is acceptable.

Calculation of $X(FG)$ also requires the free headspace volume for the tank. Headspace volumes that are of adequate accuracy are known for all tanks and this information can be incorporated into the pedigreed database for each tank, as can other known tank data required for the SCOPE analysis.

The above information requirements apply to all three options for the burn treatment summarized above, but there may be other requirements that depend upon the option chosen. For example, the plume combustion models used in the second option will require as input information on gas release rate and the area of waste surface over which the release occurs. Additional elicitations in the GRE analysis would likely be required to define uncertainty distributions for these parameters. On the other hand, if the first option were to be used, this information would be totally irrelevant because all gas is assumed to burn with 100% efficiency, independently of release rates or release areas.

In the third option, the release area and rate information is not explicitly required by the structure of the analysis framework itself, and hence formal elicitation of uncertainty distributions for these parameters is not required. However, the experts most likely will want to consider these parameters in developing their elicitations for the efficiency factor ε_P. In the technical workshops preceding the elicitations, information on release rates and areas might be discussed and plume combustion model calculations illustrating predicted sensitivity to these parameters might be presented by the technical specialists (see Section 5.2 for more detailed discussion of the role of the technical information exchange workshops). Unlike the first option, in which these parameters could be completely ignored, the third option requires their consideration as input to the experts for their efficiency elicitations, but there is no need to actually elicit these parameters as most likely would be the case in the second option.

In keeping with its general approach of providing a conservative estimate of SCOPE complexity, Appendix D assumes that elicitations for gas composition as well as quantity will be required and it is also assumed that Option 2 will be used for the burn analysis. However, the treatment does invoke the simplifying approximation of neglecting mitigation by atmosphere-structure heat transfer.

4.3.4 Release Frequency and Magnitude

Given that a burn of sufficient intensity to damage tank confinement systems does occur, the last of the four scenario matrix analysis steps is to quantify the consequences in terms of radiological and toxicological releases. This requires the information on confinement damage and tank pressurization generated in the preceding analysis step. It also requires information on the various factors controlling the amounts of waste resuspended and the particle size distribution of the resuspended waste, since health effects are largely governed by the respirable aerosols released. These questions will not be considered in detail here, since doing so would illustrate no major new principles of analysis framework design.

We can use the release analysis to illustrate another type of decision that must be made regarding the analysis framework design, which concerns the relative priority that should be assigned to different parts of the analysis. The mathematical definitions of risk (sum over frequency-consequence products) is symmetric with respect to frequencies and consequences. It provides no basis for considering precision in quantification of frequencies to be more important than precision in quantifying consequences, or conversely. However, this symmetry does not entirely apply to the intended use of SCOPE, which is to assist in the selection of appropriate controls for managing flammable gas risks. The large majority of controls being considered are designed to reduce the frequencies of combustion events, not reduce consequences given that a combustion event occurs. Given that the event occurred anyway, the presence or absence of the control typically does not have a large effect on the source term. Hence *relative* comparisons of different controls, or of controls with the no-action alternative, may be made even if the source term estimate is quite crude. This argument may justify focusing less attention on magnitudes of releases than on the analysis of event frequencies. The experts may, for example, decide that it is acceptable to represent releases in terms of conservative stylized scenarios and models, with only a minimum of elicitations being required.

This argument should not be carried too far, however. The effectiveness of a control may be a function of event magnitude; for example, a system designed to rapidly detect dangerous levels of flammable gas and trigger automatic shutdown of certain equipment might reasonably be expected to function more rapidly and more reliably for large GREs than for smaller ones. It thus might be more effective in preventing severe combustion events with high consequences than in preventing events with lower consequences. If SCOPE cannot provide a reasonable representation of this difference in consequences, it will underestimate the benefit resulting from such a control.

Another, more important, reason why consequence estimates deserve attention is that some potential applications of SCOPE will require absolute estimates of risk or consequences, not merely relative measures. Often the best possible control will be significantly more expensive than some alternative that is less effective. Deciding whether the cheaper alternative is good enough, or applying a cost-benefit criterion to choosing between the two, will require absolute risk metrics, and hence absolute consequence estimates. Likewise, comparisons with risk guidelines require absolute estimates of consequences.

Despite the preceding caveats, it remains true that SCOPE could be routinely applied to assist choices among alternatives that differ primarily in terms of the frequencies of adverse events, rather than in terms of the consequences resulting if the adverse events do occur. This fact most likely will justify some simplifying approximations in those features of the analysis framework that involve estimation of consequences, provided these approximations are introduced with sufficient attention to their impact on the planned spectrum of SCOPE applications.

4.4 SCOPE Analysis Tool Prototype

Phase 1 of the SCOPE program was a brief (4-month) but intensive effort to evaluate whether and how expert elicitation methods that had succeeded in other fields could be applied to problems at the Hanford site. It was also intended to provide a basis for estimating resources and schedule for implementing the process, once the range of questions to be addressed was defined. Because of the complexity of the issues involved, there was some concern on the part of the project team that if phase 1 stayed at too high a level of abstraction, it would not achieve its goals. In other words, "the devil is in the details," or could be.

For that reason, part of the phase 1 effort was to pursue an approach familiar in modern software development and manufacturing design--rapid prototyping. The idea behind rapid prototyping is to construct a rough model for the final product that captures the essence of those features that can be specified early in the design process, but uses artificial and simplistic substitutes for other features that would take a lot of time to specify. The approach is useful in many ways, if it is not misused or misunderstood. For example, a product that will be used long after a significant development investment has been made should be designed with the ultimate users' needs in mind; a prototype allows those needs to be addressed in concrete terms, feeding back into the design process early, when accommodation is easy, rather than late, when a great deal of expensive re-work would be needed.

What is true of manufacturing and software development is also true of a process like SCOPE. Planning and implementation of a major process of this nature would benefit from a "zero'th order" walkthrough of what such a product would look like even if the representation of the product is sketchy, and even if it incorporated features that were more or less invented to fill in knowledge gaps.

This strategy was a very successful element of the phase 1 SCOPE project. Throughout phase 1, the prototype exercise served as a "reality check" on the more abstract conceptual development. It also provided a basis for some quantitative estimates of the resources that might be required for a specific implementation of SCOPE (e.g., the estimate of the number of experts and expert panels needed that is presented in Appendix D).

Appendices B, E, and F contain the principal results of the prototype exercise. Appendix B contains a list of specific TWRS hazard control questions that might be addressed by an analysis tool developed with the SCOPE process. Appendix E provides an outline of the calculation process that could produce estimates of source terms due to the postulated events in the SCOPE scenario matrix. (Given a source term, various dose metrics would be calculated by the methodology described in Section 3.4.) Here, the product being prototyped was the SCOPE analysis tool, which is the SCOPE product that is most directly connected with assessments of specific TWRS facility issues. Appendix F describes a software prototype that reflects the structure of the calculation process, though not precisely. The emphasis in developing this software was to visualize the interaction between the SCOPE-AT and the intended user. Part of that interaction is the graphical user interface (or GUI) and one of the reasons that this software development task was feasible in a project with limited time and budget is that commercial software for developing GUIs for PCs has in recent years become very powerful and inexpensive.

As stated earlier, rapid prototyping can be a powerful tool for product development, whether the product is software, a manufactured item, or a decision support system. However, it is important to recognize the limitations of the resulting prototype. The project team combined (in decreasing order of validity) factual knowledge, informed decisions, educated speculation, and pure invention, in order to create a complete but sketchy picture of what the products of SCOPE would look like. The resulting prototype products were very useful for achieving the phase 1 goals, but should not be scrutinized too closely as a true representation of what the final product of SCOPE would be.

5.0 USE OF EXPERT OPINION

5.1 General Approach

The use of panels and review boards composed of acknowledged experts is widespread in government agencies that must deal with complex technical questions that have high public import. Some function at the highest level; e.g., the DNFSB reviews nuclear safety issues involving the weapons complex and makes recommendations with which the DOE and its contractors strive to comply. Some function in a narrower context; e.g., the Chemical Reaction Subpanel of the Technical Advisory Panel for High-Level Nuclear Waste Tanks exercises technical oversight specific to the flammable gas problem and other potentially hazardous chemical reactions at the Hanford tank farms. The role of such groups is to bring the best available technical information and understanding to bear on the subject of interest, to evaluate the existing situation and future needs, and to make recommendations as to how to proceed.

The role of the SCOPE decision support system would be quite different from that of advisory panels in that its purpose would not be to make policy or programmatic recommendations, or to propose new standards for operational compliance. Instead, its role would be to bring the best available technical information to bear on the effort to implement policies and programs established elsewhere, and to comply with existing standards. The core of the SCOPE-DSS would be a calculation tool, the SCOPE-AT, which is designed to evaluate the effectiveness of control strategies in meeting applicable safety goals and regulatory standards. What this project has in common with advisory panels is that the SCOPE-DSS must be perceived by the broader technical community as incorporating the best available technical information into its analyses.

The SCOPE-AT is not intended to be a simulation code for facility or waste behavior. Such simulation codes can be useful for many purposes, but they are inevitably dependent upon modeling assumptions made by their developers concerning uncertain phenomena. Relying exclusively on such tools typically generates controversy, especially when phenomenological uncertainty is large and difficult to assess. What is needed is a more direct way of representing the best available technical understanding in a way that clearly quantifies the uncertainties and that directly reflects the views of a reasonably broad and representative cross section of the technical community involved. The SCOPE project seeks to achieve this goal by relying *primarily* upon the judgments of suitably defined expert panels for the quantification of the dominant uncertain phenomena that control flammable gas risks in the Hanford tank facilities. The intent is to *minimize* reliance upon modeling assumptions made by the SCOPE project itself.

In order to achieve this goal, the expert panels must provide quantitative representations of the major uncertain phenomena in a way that permits the results to be combined for calculation of the various output metrics of interest to users of the SCOPE-AT, and in a way that permits quantification of uncertainties in the output metrics. Methods of organizing the information required for achieving this goal are discussed elsewhere in this report, as are methods for selecting panels to obtain optimal acceptance by the major stakeholders involved in management of the flammable gas question. What is of interest here is the progress made in the social sciences in developing techniques for the elicitation of expert opinions in a way that yields quantitative results with a reduction in the unconscious biases and underestimation of uncertainties that have been shown to afflict many expert judgments obtained under less carefully controlled conditions.[1] We describe some details of these techniques in the following subsection.

5.2 Proposed Process for Expert Elicitation

In this subsection, we start by summarizing the expert elicitation process proposed for SCOPE, and then discuss certain features of the process in more detail. The process includes the following steps:

1. Specialists in the required technical fields are identified, selected, invited, and assembled into the panels.
2. A technical information base is developed that forms the documented core literature for the panels.
3. A "strawman" proposal is developed for the structure and phrasing of the questions to be posed to the panels and the way the results will be combined to calculate metrics.
4. The panel sessions are convened. In large measure, they take the form of a series of workshops that include the following activities:
   - Through presentations and physical documentation, the experts are exposed to the technical information base. The panel members share opinions and viewpoints throughout to benefit from the perspectives of their peers on the panels.
   - Recommendations from the panels on the structure and phrasing of elicitation questions, as well as recommendations concerning the analysis tool calculation process, are accommodated in a revised version that becomes the basis for the formal elicitations.
   - The panels are convened in a format that is conducive to sharing of viewpoints among the members and also with topical experts requested by the panel. Consensus development is encouraged and facilitated, but not required.
   - The workshops include training the technical experts on the use and mechanics of expert elicitation methods. The trainers are social science professionals involved in the development and use of formal expert elicitation techniques (referred to as "normative experts").
5. The experts provide their formal elicitations on probability distributions for the uncertain quantities of interest under a range of specified conditions, following the structure and phrasing of the elicitation questions agreed upon in advance. The elicitations are conducted by the normative experts.
6. The results of the experts on a given panel are aggregated (i.e., averaged) into a single curve that reflects the input of each individual. The quantitative results are incorporated into SCOPE-AT.
7. The experts document the rationales for their elicitation results in some detail, and the normative experts conducting the elicitations also document the technical experts' rationales from their perspective. This documentation is an important part of the formal documentation of the SCOPE-DSS project and is essential for the scrutability and reviewability of the results.

The first step, selection of the expert panel, is discussed in Section 5.4 of this report. The second step, compiling a technical information base, is one of the major tasks that the SCOPE project must undertake prior to the onset of the panel workshops (see Section 3.3). This compilation will constitute a large part of the common information pool that will be presented to the experts in step 4. Among other things, ensuring that all the experts have a common information base to work from helps to bring about consensus when initial differences of opinion merely reflect differences in factual knowledge, rather than differences of opinion about the meaning of the information.

The third step refers to preparation of a "strawman" proposal for the questions to be presented to the experts. The term "strawman" is used because the experts must be allowed to have considerable control over the questions upon which they will be elicited. It is not reasonable to expect them to address questions that they consider to be ill posed or to be based upon false assumptions. At the same time, the SCOPE project must take responsibility for ensuring that the set of elicitation questions as a whole meets the needs of the project. The final set of elicitation questions is arrived at as a result of discussions among the experts and SCOPE project staff that take place in the course of the workshops of step 4.

The fact that the term "strawman" is used in connection with step 3 does not mean that this compilation can be viewed as a hurried task that does not really count. On the contrary, it is one of the most important tasks of the project and requires much care. The basic structure of the SCOPE-AT calculations must be defined and the information required identified in order to ensure that this information will be available; elicitations must be defined to supply this information if it is not available from the established database of accepted ("pedigreed") technical information. The controlling parameters may vary over wide ranges among the many tanks, waste types, tank farm operations, and control options that must be considered; this wide range of parameters must be broken down into specific cases so that each case presents a well-posed problem for elicitation without the total number of elicitation cases becoming excessive.

In preparing the strawman elicitation cases, it is essential to give careful attention to the information flow between the topics that are treated by different panels. Typically, the information generated will be used sequentially in the SCOPE-AT calculations; for example, information provided by the panel elicited for information on gas release events will be required for the evaluation of gas combustion. It is therefore necessary that the case structure for the GRE elicitations be designed to include information required by the combustion analysis. This does not mean that the combustion elicitation will require the actual numerical information elicited from the GRE experts. However, the types of information that can reasonably be obtained from the GRE elicitation need to be considered in defining the case structure for the burn completeness elicitations, and the information required for the burn completeness elicitations needs to be considered in defining the case structure for the GRE elicitations.

Additional discussion of the general principles underlying design of the elicitation process is given in Appendix D. This appendix also presents a very preliminary but still relatively detailed strawman proposal for the SCOPE elicitation case structure. This preliminary case structure would require substantial additional work before it would be ready for presentation to the SCOPE expert panels.

After the workshops are complete and the elicitation questions have been defined, the elicitations themselves take place. The information provided by the experts can take a number of forms, but the most common is for each expert to provide a cumulative probability distribution $P_<(Y)$ for some scalar quantity so that $P_<(Y)$ represents the expert's degree of belief that the value of the quantity will be less than Y. An example elicitation taken from the NUREG-1150 study was given in Figure 2-1. For each elicitation, the expert is requested to provide the complete curve, from a minimum Y value [defined by $P_<(Y_{min}) = 0$] to a maximum value [defined by $P_<(Y_{max}) = 1$]. Several experts will be elicited on each question, and the results of the individual expert elicitations aggregated by averaging the values of $P_<$

given by each expert for a given value of *Y*. Appendix C has some additional discussion of the aggregation method.

The "probabilities" represented by the uncertainty distributions $P_<(Y)$ may be thought of as numerical representations of the experts' degrees of belief concerning uncertain phenomena. This concept should be kept separate from the concept of stochastic probabilities that represent expected mean recurrence frequencies in the limit of an extremely large number of trials. Although the distinction between these two concepts is not always completely clear-cut in practice, it is nonetheless useful and it helps to avoid confusion in cases when the quantity elicited is itself a stochastic probability that can be interpreted as a recurrence frequency, e.g., the frequency of a GRE or of a spark ignition source. Additional discussion of stochastic and phenomenological probabilities, and of how uncertainties can be represented in the SCOPE-AT output, is given in Appendix C.

Scientists and engineers are typically trained to estimate uncertainty through so-called "objective" techniques such as experimental error analysis and error propagation theory. However, when the information available suffices for the application of such techniques, it is usually unnecessary to convene an expert panel of the type considered here. For many scientists and engineers, the concept of representing uncertainty estimates using something as seemingly subjective as a numerical degree of belief is unfamiliar and even alien. Hence an important part of the workshops of step 4 includes training conducted by experts in decision analysis (sometimes referred to as "normative experts") who are professionals specializing in the techniques of eliciting expert opinion. This training familiarizes the technical experts with the concepts involved and provides them with opportunities to perform example elicitations. Another important goal of the training is to improve awareness of the various sources of unconscious bias that can degrade the quality of expert judgments. The technical experts are also provided with examples warning them against the very common tendency of experts to be overconfident concerning their knowledge, and to underestimate uncertainties.

Each technical expert provides his or her elicitation in the presence of a normative expert who guides the process. The other technical experts are not present; there is no peer pressure to conform to an artificial consensus. However, the information exchange in the workshops preceding the elicitations, and the controlled process of elicitation itself, can encourage convergence to an approximate consensus when the available information justifies a common understanding. An example of this tendency toward convergence is shown by the comparison of the NUREG-1150 elicitation of Figure 2-1 with results obtained by the expert group called the Containment Loads Working Group (CLWG), which considered the DCH question a few years before the NUREG-1150 evaluation of the issue.[2] Meetings that included technical information exchange were held, but this exchange consisted of each investigator presenting whatever he considered pertinent (usually his own work) without an independent centralized effort to bring together all relevant information for all members to consider. At the end of the effort, the participants were polled to provide their "low," "medium," and "high" estimates of what they thought DCH loads could be. There was no formal elicitation, no participation by decision analysts, and no training in expressing uncertainties as numerical degrees of belief.

Figure 5-1 represents the result of the CLWG assessment of DCH in a form qualitatively similar to the Figure 2-1 representation from NUREG-1150. A considerable amount of interpretation is required to represent the CLWG results in this form because complete $P_<(Y)$ curves were not defined and even the

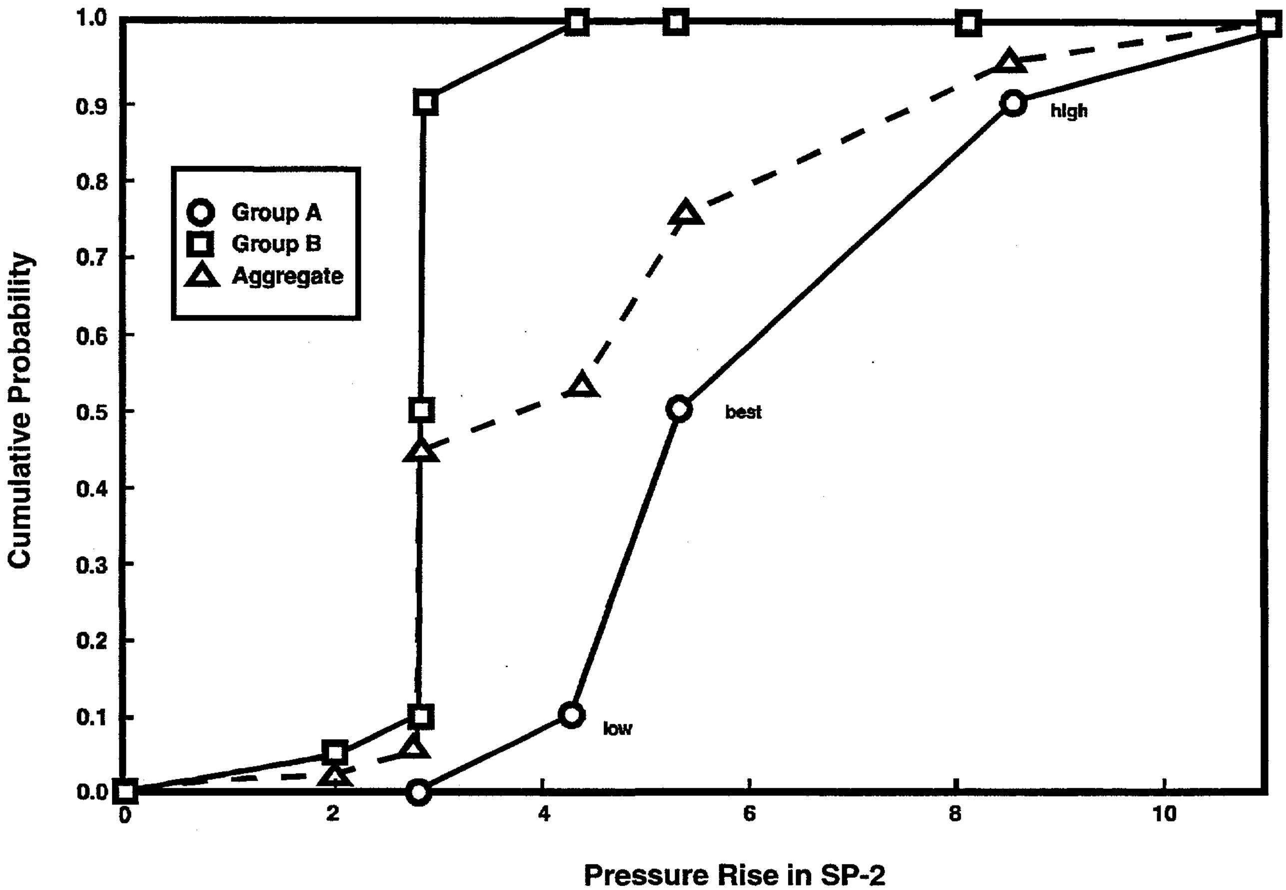

Figure 5-1. Results of poll of Containment Loads Working Group experts.

"low-medium-high" points were not defined quantitatively. A noteworthy feature of the results is that the CLWG was split into two groups, with "Group A" believing that there was virtually no chance that DCH could result in a pressure rise greater than a few bars while group B considered substantially greater pressure rises to be relatively plausible. This situation may be contrasted with Figure 2-1, in which the curves provided by the individual experts are fairly similar.

In part, the improved consensus in the NUREG-1150 assessment reflected the improved information base that had been developed by the NRC severe accident research program during the intervening years. However, the consensus did not consist of agreeing that the uncertainties were small; all the curves in Figure 2-1 represent a substantial uncertainty range. Instead, the consensus was more in the nature of agreement as to what the issues were and what their importance was. The organized and structured information exchange together with the formal elicitation process probably deserves at least some of the credit for this convergence in viewpoints on the DCH issue.

The report summarizing the CLWG work was forced to conclude that no consensus could be reached on the issue. With the present methodology, however, it is still possible to define an aggregate curve even in this case (dashed curve, Figure 5-1), just as it was when better agreement was obtained in

Figure 2-1. This aggregate is seen to give substantial weight to the more pessimistic group in that it still allows for significant probabilities of a large pressure rise, although these probabilities are not quite as large as believed by Group B. The aggregate curve may seem unsatisfactory to Group A, who would have ruled out any possibility of the more severe results. However, the aggregate curve does conform to what should be expected of a prudent decision-maker who cannot and should not attempt to decide for himself between the competing claims of experts in conflict. The decision-maker would have little choice but to give substantial weight to the experts who believed the pressure rise might be large, given that Group B does indeed consist of bona fide experts whose competence and objectivity are not seriously questioned.

As Figure 5-1 suggests, the aggregate curve spans the full range of uncertainties acknowledged by all the experts. No value, either high or low, that is considered credible by even one expert is assigned a zero probability in the aggregate curve. Again, this inclusivity feature is sometimes criticized by those who believe the uncertainty distributions should be narrower. However, experience shows that experts commonly underestimate uncertainties, and the inclusivity feature helps to guard against this tendency. Figure 5-2 provides an example of overconfidence cited by Kahneman et al.[3] in which seven "internationally known" geotechnical engineers were asked to estimate the height at which an embankment would fail, and to provide 50% confidence intervals for their estimates. The actual measured failure height does not fall within the uncertainty ranges estimated by *any* of the experts, but it does fall within the range of the ensemble. Evidently a decision-maker would have been better served by assuming that the range spanned by the ensemble provides a better measure of the true uncertainty than the uncertainty estimate given by any one of the experts.

The final step in the expert elicitation process is the documentation of the experts' rationales for their elicitations. It is essential to allow adequate time and resources for this step if the final product is to be reviewable and scrutable to the extent required for concerned stakeholders to have faith in the process. In the DSAC project, the experts themselves provided detailed explanations of their rationales. In addition, the normative experts conducting the elicitations summarized the technical experts' rationales from the perspective of the normative experts. This dual perspective helps to clarify the reasoning processes underlying the quantitative results presented in the elicitations.

5.3 Number and Types of Expert Panels Needed

An important question that must be addressed in planning for phase 2 of SCOPE is the makeup of the expert panels required. In this section we consider the factors that will determine the number of separate panels, the type of expertise on each panel, and the number of experts on each panel.

The number of expert panels will be governed primarily by the number of disciplines involved. The phenomenology governing the release of gases from the waste is quite different from that controlling the hydrogen burns and deflagration to detonation transition (DDT) issues; hence, these would probably represent separate panels. Resuspension might require a third panel, although there is some overlap in the expertise involved with that of the GRE panel. If elicitations are required for sparks or other ignition sources, this may require an additional panel. Hence, as many as four panels might be needed. However, there is sufficient overlap between panel disciplines that some panels might be combined. For

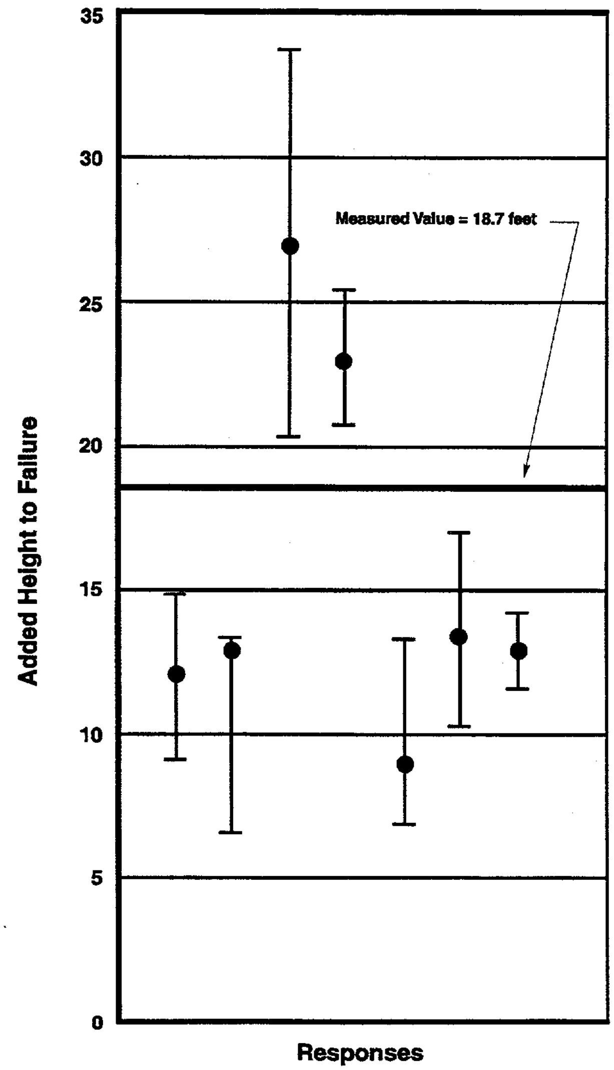

Figure 5-2. An example of overconfidence in expert judgment, as represented by the failure of error bars to contain the true value. The data represent estimates by seven "internationally known" geotechnical engineers of the height at which an embankment would fail. (From H. Hynes and E. Vanmanke, "Reliability of Embankment Perf. Predictions," in *Proc. of the ASCE Eng. Mach. Div. Specialty Conf.* Waterloo, Ont. Univ of Waterloo Press, 1976.)

example, some experts on flammable gas hazards in industrial settings may also be sufficiently familiar with spark ignition hazards that a single panel could suffice for both the combustion phenomenology and the ignition source elicitations.

The number of experts will be determined by (a) the minimum number of elicitations required for each case in order to obtain a reasonable sample of expert opinions, and (b) the maximum number of cases each expert can reasonably be expected to handle. Appendix J of Bergeron et al.[4] indicates that three to six experts should consider each case; for planning purposes we assume five experts will consider each case.

A conservative estimate of the number of experts and panels needed is given in Appendix D. This estimate is believed to be too conservative for several reasons. One is that it was based upon the DSAC project, which was implemented on a very compressed time scale that reduced the number of elicitation cases each expert could reasonably be expected to handle. In addition, Appendix D was largely written before the phase 2 project plan had evolved to the point where it became clear that SCOPE would be implemented in two stages, with only issues required to address flammable gas risks for SSTs considered in the first stage. This division reduces the number of experts required because this number is governed by the size and diversity of the elicitation task in each stage, not in the total SCOPE project.

An approximate estimate taking into account these factors is that three panels will suffice, with each panel consisting of six to eight members. The three panels would address GRE issues, gas combustion (including ignition sources), and resuspension and release following a burn.

5.4 Approach to Selection of Experts for Panels

The selection of the individuals who will serve as panel members and quantify the elicitation parameters is very important to the overall success of the SCOPE process. Several factors must be considered. They include the technical capabilities of each expert, technical biases they may have, organizations they are associated with, how they interact with other panel members and technical specialists, and support from stakeholders.

A number of stakeholders outside of the management and integration contractor have become involved with the safety issues associated with the Hanford tanks. Some of the most obvious are the Tri-Party Agreement participants--the DOE, the State of Washington Department of Ecology, the Environmental Protection Agency--and the Defense Nuclear Facilities Safety Board. Technical staff from Pacific Northwest National Laboratory (PNNL) and Los Alamos National Laboratory (LANL) have also been involved in studying phenomenology important to the safety issues and in preparing safety assessments for key activities. Other stakeholders include the National Research Council's Board on Radioactive Waste Management, the Chemical Reaction Subpanel of the Technical Advisory Panel to DOE, the Native Americans from surrounding tribes, the State of Oregon, and numerous public groups from the Tri-Cities.

Because the various stakeholders often operate independently of each other, and because they often have different motivations (regulatory, financial, safety, technical, etc.), different stakeholders sometimes take conflicting positions on some issues. The SCOPE process will be most effective if the panel members are selected from a broad range of experts because the differing views can provide a better representation of the extent of technical uncertainty. Thus SCOPE inherently could and should be used to involve many different stakeholders early in the process. When done properly, the SCOPE process could develop consensus among stakeholders on issues where consensus is possible. If consensus is not possible, SCOPE could act as an arbitrator with agreement that the results of the process will be used to make decisions and proceed with activities.

The aggregation process described in Appendix C will preserve the input from all participants in the elicitations. Unlike the judging of Olympic events where the high and low scores are thrown out, the aggregation process would include the "outlier" data in the final results. That is why SCOPE can act as an arbitrator--every expert's opinions would be incorporated into the result. On some issues one expert may provide an input that may be described as extremely optimistic, while another expert may provide an extremely pessimistic input. The differences in perspective will be represented in the final result as a high degree of uncertainty associated with the "best estimate" value; i.e., the probability is high that "true" or "actual" values may be very different from the averaged value. This is exactly what one would qualitatively expect on issues where technical experts do not agree. The SCOPE process would quantify the degree of uncertainty into values that are amenable to mathematical calculations.

The members of the expert panels must be technically knowledgeable about the phenomena involved with the flammable gas issue. Not all stakeholders have members who are suitably knowledgeable. However, most stakeholders can be expected to consult with technical experts that they trust. These stakeholders will be asked to provide lists of experts that they believe are technically qualified and would like to see involved in the SCOPE elicitation process. These nominations can aid the SCOPE management team in locating the appropriate experts while simultaneously promoting "buy-in" from the stakeholders.

Technical expertise will be the foremost consideration in selecting panel members and technical specialists. It is not possible to locate experts who are truly experts on all of the topics that affect considerations for resolving flammable gas issues. Therefore, it is important for the panels to be teams of experts who collectively cover a broad range of important skills and knowledge. The experts do not have to have extensive direct experience with the Hanford tank issues, but they do need to at least have experience in areas that can be directly applicable. Experts who are highly specialized with deep knowledge of only one or two important areas are best involved as technical specialists that provide topic-specific information for the panel members to consider. The best panel members are so-called "renaissance" men and women who have a broad range of relevant experience. Individuals who have worked as industrial accident investigators, for example, could bring valuable expertise to the panel without necessarily having direct experience with the Hanford tank flammable gas issue.

The technical expertise that is desired goes beyond the obvious areas of chemistry, radiolysis, thermodynamics, heat transfer, combustion, mass transport, etc., that are involved in models relevant to the flammable gas issue. Field experience with the tank farm operations will be important, so the management and integration contractor may have members participating as panelists. PNNL has done extensive chemical analysis and small-scale testing of Hanford tank waste, and LANL has done extensive accident analysis work on Hanford tank operations, so both laboratories might supply panel members. However, these panelists would not be expected to have experience with a broader scope of waste issues and other industrial operations outside of Hanford. This type of expertise should be provided by the DNFSB, the National Academy of Sciences, and others who are familiar with operations and accidents across the DOE complex and industry in general.

It has been emphasized that the SCOPE process will promote consensus on technical issues where possible, but does not require it. SCOPE could quantify for the decision-makers the degree of uncertainty in those areas where consensus is not possible. Where consensus is possible, it can help the decision-makers to know that a considerable degree of confidence exists on key technical points. The panel members will spend a considerable amount of time discussing technical issues, so personality conflicts can arise independent of technical conflicts. Thus the personalities of the members are not a minor consideration because they can influence the panelist's support for the entire process and the degree to which consensus can be reached. It is important to weigh technically autonomous independence against the need for a smoothly functioning panel--sometimes the former may be more important than the latter.

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[2]U.S. Nuclear Regulatory Commission. "Estimates of Early Containment Loads from Core Melt Accidents," Draft Report for Comment of the Containment Loads Working Group, NUREG-1079, Washington DC, 1985.

[3]*Op.cit.*

[4]K. D. Bergeron, et al., *Heavy Water New Production Reactor Design Review Guidelines*, NPRW-DSAC91-5, SAND92-2538, Sandia National Laboratories, Albuquerque, NM, February 1993.

6.0 ROLE FOR SCOPE

The Defense Nuclear Facilities Safety Board has emphasized the importance of an integrated safety management system for each DOE site.[1] Such a system for TWRS would include the safety authorization basis as well as the processes currently being developed and exercised to manage TWRS safety. SCOPE could play a role in both of these areas (see Figure 6-1), but it can also provide a means for arriving at defensible safety management strategies when traditional evaluation and documentation approaches prove to be unsuccessful or unsatisfying to all stakeholders. This is typical of situations where technical uncertainty is sufficiently high that consensus positions or even majority positions do not exist.

The initial application of SCOPE concerns the selection of controls to manage TWRS facility risks associated with flammable gas generated, stored, and released by high-level radioactive waste. The intended roles of SCOPE in this context include the following:

- The TWRS Final Safety Analysis Report (FSAR) under development makes no claim to close the flammable gas unreviewed safety question. Its analyses are broadly believed to be conservative and bounding with respect to the baseline risk posed by flammable gas in the TWRS facilities. The SCOPE process may augment the FSAR risk baseline analyses by providing a defensible alternative means of selecting representative, unique, and bounding scenarios, as well as values for highly uncertain input parameters. This would be a key step toward the closure of the flammable gas USQ.

  Once the flammable gas hazards have been thoroughly identified and the baseline risk has been quantified via defensible analysis, control strategies may be proposed for risk management. The SCOPE process could provide the means to quantify the relative value of various control strategy proposals. This exercise would include considerations related to:

  - the need for gas monitoring
  - the role of ventilation in flammable gas risk management
  - electrical equipment requirements
  - nonelectrical equipment requirements
  - specific work control and field practices
  - the means and value of attempting to anticipate waste behavior

- Once the bases for the control strategies are established and the associated benefits are quantified and documented in the Justification for Continued Operation (JCO) and the Basis for Interim Operation (BIO) per the requirements of DOE Order 5480.23, the possibility would exist to close the USQ. The anticipated role of SCOPE in this process would be to produce defensible consequence analyses that portray the managed flammable gas risk (i.e., with mitigation and prevention features in place) to be acceptable to DOE.

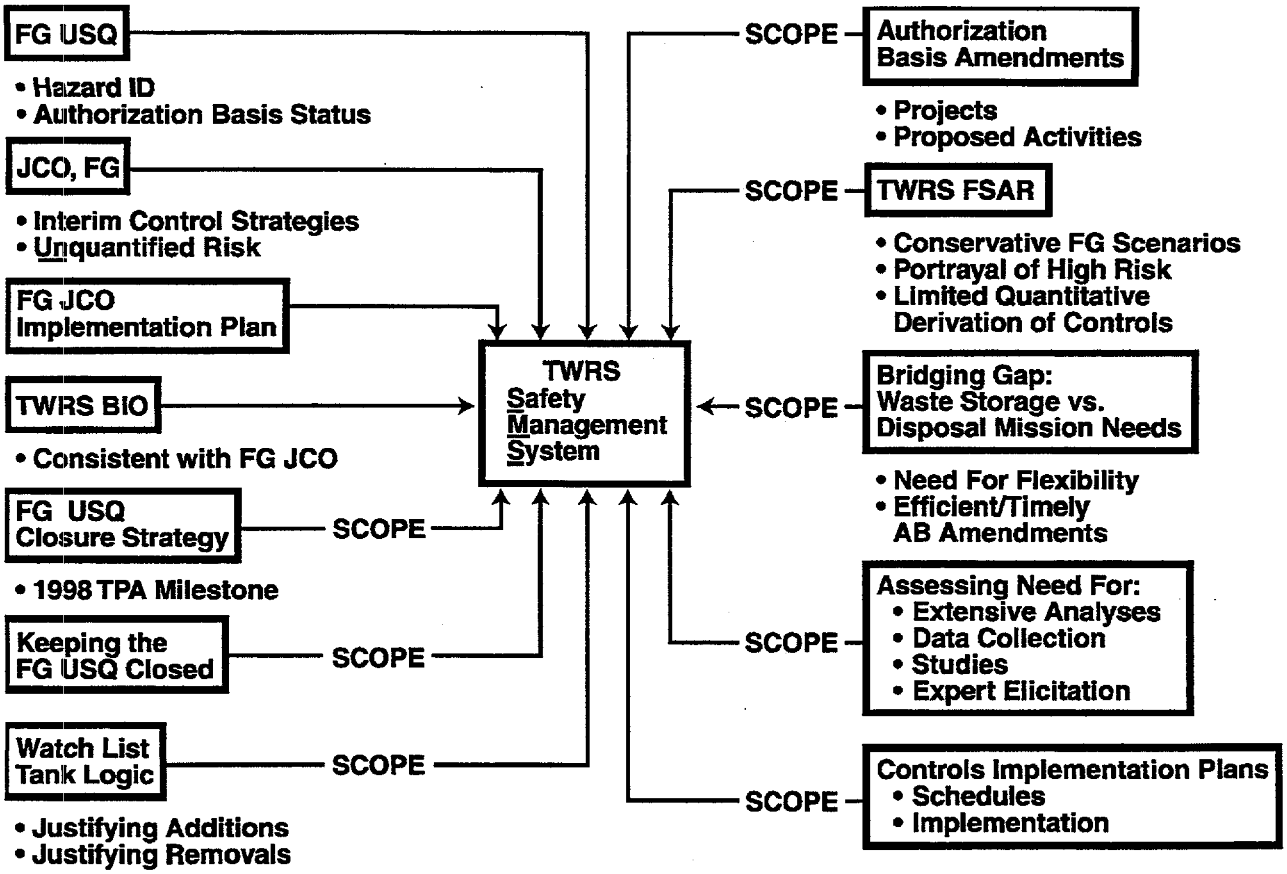

Figure 6-1. Potential roles for SCOPE in TWRS Safety Management System.

- SCOPE is also expected to help bridge the diverse opinions that hinder the progress of individual amendments to the TWRS authorization basis in support of specific projects and field activities.

- Because the rationales for all control strategy decisions associated with SCOPE are captured by the SCOPE-DSS, SCOPE will be a useful tool for the USQ process. The framework for evaluating perturbations to field conditions and proposed changes will be established and available.

- SCOPE could also be used to perform sensitivity studies examining the impact of a broad range of assumptions for uncertain parameters. This application of SCOPE may provide insight into the value of research, data collection, or additional expert elicitation.

Reference

[1]Defense Nuclear Facilities Safety Board Recommendation 95-2 (60 FR 54065) October 19, 1995.

7.0 SUMMARY

While it is clear that the health and safety risks of DOE hazardous waste sites need to be prudently managed, the best way to achieve this is not always clear. The Hanford TWRS flammable gas hazard is a particularly difficult problem because of the large quantities and varieties of wastes produced over the years, and incomplete information on the physical nature of the hazard.

The approach to developing the decision support system proposed here would make it possible to choose optimal and cost-effective control strategies for the Hanford TWRS and to defend these decisions. By having experts in specific areas provide quantitative judgments on the value and degree of uncertainty attached to important parameters involved in such decisions, it would provide a well-documented, systematic way to deal with safety and health issues. What is equally important is that it would also provide a way to involve key stakeholders by obtaining their input on the selection of technical experts and the information base for the decision support system. The result would be better overall acceptance of the control strategies chosen.

The values obtained through the expert elicitation process would be used in phenomenological models for calculating accident source terms. These would then be used in an analytical tool that would produce defensible metrics, such as dose, that could be compared with risk guidelines or other safety criteria. Thus site managers would be able to review a variety of control scenarios, examine their effect on facility safety and operating costs, and make an informed choice of strategy. Given an institutional environment that encourages resolution of the flammable gas issue, this approach offers a way to achieve regulatory compliance and public acceptance without excessive conservatism and wasteful expenditure.

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APPENDIX A

PRELIMINARY TECHNICAL LIBRARY

The following is a list of reports that are particularly relevant to assessing the flammable gas issue. These reports would be made available to panel members for their review of work to date and for them to assess the assumptions and conservatisms noted in many of these documents. Acronyms: PNL - Pacific Northwest National Laboratory; WHC, Westinghouse Hanford Company; LA, Los Alamos National Laboratory; ANL, Argonne National Laboratory.

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APPENDIX B

QUESTIONS POTENTIALLY ADDRESSABLE BY SCOPE

In this appendix we list a broad range of questions that a system like SCOPE might be called upon to evaluate. While it is not exhaustive (since it is not possible to anticipate every possible control approach), it is extensive, more so than any initial implementation of SCOPE would encompass.

Ventilation Performance Requirements (Relative to Flue Gas Control)

Q.1 Would augmented passive ventilation (e.g., improved convective ventilation on SSTs via better chimneys) significantly reduce steady-state or GRE risk during normal operations?

Q.2 Would augmented passive ventilation (e.g., improved convective ventilation on SSTs via better chimneys) significantly reduce steady-state or GRE risk during global waste disturbing activities?

Q.3 Would active ventilation on currently passively ventilated SSTs significantly reduce steady-state or GRE risk during normal operations?

Q.4 Would active ventilation on currently passively ventilated SSTs significantly reduce GRE risk during global waste-disturbing activities?

Q.5 Would modifying active ventilation inlet geometries (e.g., extending inlet risers, adding spargers) improve plume dispersion and significantly reduce risk?

Q.6 Would upgrading active ventilation systems to increase tank vacuum significantly reduce GRE risk by preventing flammable condition in ex-tank regions?

Q.7 Would upgrading active ventilation systems to increase tank ventilation flow rate significantly reduce GRE risk by dispersing plumes and diluting dome space more quickly following a large GRE?

Q.8 Can current active ventilation systems be optimized (vacuum vs flow rate) to reduce steady-state and GRE risk? (Answer questions 1.6 and 1.7 together, given the constraint of using the current ventilation systems.)

Q.9 Would bleeding fresh air into ventilation system upstream of heaters, fan and instrumentation reduce risk of deflagrations in the ventilation systems (i.e., by diluting gases prior to reaching possible ignition sources)?

Q.10 Would more reliable active ventilation systems (e.g., backup train) significantly reduce steady-state or GRE risk? What should maximum allowed outage time be? How should a nonoperating ventilation system be restarted?

Ignition Source Controls

Q.1 Should a given piece of equipment have electrical circuits or materials upgraded to meet National Electrical Code (NEC) Class I, Division 2 criteria? Or Division 1 criteria? Pertinent equipment is listed in Table B-1.

Q.2 Should equipment materials be upgraded to be spark resistant? Pertinent equipment is listed in Table B-1.

Q.3 For electrostatic spark prevention:

A. Should bonding be required for objects inserted into the ex-tank location during work activities? All or some? Into the dome space during work activities? All or some?

B. Should nonconductive polymers continue to be used for equipment bagging and temporary confinement during work activities?

C. Should polyvinylchloride riser liners used with FIC level gauges be replaced or modified?

For flammable gas monitoring:

A. Can gas monitoring and equipment shutdown be adequately substituted for other ignition source controls during work activities (ex-tank, dome intrusive, waste disturbing)? Normal operations (ex-tank, dome intrusive, waste disturbing?) If so, what monitoring set points should be used?

B. Should gas monitoring and equipment shutdown be performed in addition to ignition source controls during work activities (ex-tank, dome intrusive, waste disturbing)? Normal operations (ex-tank, dome intrusive, waste disturbing?) If so, what monitoring set points should be used?

Changes to Operating Procedures

Q.1 Is use of spark-resistant tools during riser removal a significant risk benefit?

Q.2 Is bonding of riser covers to risers during removal a significant risk benefit?

Q.3 Is gas monitoring during work activities a significant worker safety benefit (entry sniffing, intermittent ongoing monitoring, continuous monitoring)? If so, what set points should be used? What actions should be followed? Should monitoring be required in ex-tank locations on actively ventilated tanks?

Table B-1 Equipment Considered in SCOPE Questions
A. Candidate Equipment for NEC Upgrades
DST Waste High Level Detectors DST Pit Leak Detectors DST Transfer Pump Motors DST Mixer Pump Motor DST or SST Video Camera and Lights DST Ventilation System Heaters DST Ventilation System Instrumentation (pressure transducers, switches, etc.) DST Ventilation System Damper Valve Motors DST Ventilation Stack Radiation Monitor Components (vacuum pump/motor, pressure transducers, switches, radiation detectors, etc.) SST pit leak detectors SST Active Ventilation System Heaters SST Active Ventilation System Fans SST Active Ventilation System Instrumentation SST Active Ventilation System Stack Radiation Monitors SST Saltwell Pump Jet Pump Motors SST Saltwell Pumping System Transfer System Components (pressure transducers, valve actuators and motors, valve position limit switches, etc.) SHMS Cabinets
B. Candidate Equipment for Spark-Resistant Materials
Submersible pump rotors/stators Mixer pump rotors/stators Core drill sampler casing Core drill sampler components Auger sampler guide tubes T/C trees (new - to be installed) T/C trees (old - remove and install new ones) pumps (new - to be installed) pumps (old - remove and install new ones) saltwells (new - to be installed) other instrumentation/samplers (new to be installed/used temporarily)

Q.4 Is gas monitoring (sniffing) of liquid observation wells (LOWs), thermocouple (T/C) trees, etc. during entry into this equipment a significant safety benefit?

Q.5 Do sealed pits and risers present a risk that warrants special spark controls and monitoring?

Q.6 Should Core Sample Truck #1 continue in use without drill string purging?

Q.7 Should vehicle access be restricted around tank openings? How close is too close (18 opening diameters, 15 ft.)?

Q.8 Should people access be restricted around tank openings (static discharge potential)?

Q.9 Should operations and activities be stopped (immediately, after a grace period) if active ventilation shuts down?

Q.10 Should "windows" (i.e., a time of low retained gas or unlikely GRE) be established for performing work activities? Operations (e.g., waste transfers)?

Waste Management Options to Reduce Flammable Gas Risk

Q.1 To limit gas generation rates:

A. Should tank farms continue to saltwell pump SSTs (reduces water, radioactive cesium, soluble organic compounds that generate flammable gases)?

B. Should double shell tank/aging waste facility (DST/AWF) waste content allowables (i.e., heat load, average TOC, waste levels) be limited to limit gas generation rates?

C. Can generation rate inhibitors be added to DST/AWF wastes to reduce generation rates? If possible, is this a good idea?

To control GREs:

A. Can/should sludge be separated from supernatant to reduce rollover GRE likelihood and magnitude?

B. Can/should supernatant density (specific gravity) be limited to reduce rollover GRE likelihood or magnitude?

C. Should mixer pumps be installed and operated in tanks to mitigate possible GREs (or only when other mitigation methods are not practical)?

Q.3 To mitigate flammable conditions, should tank headspaces be inerted? Although inerting may not be able to eliminate all deflagration scenarios, inerting may significantly reduce overall risk by mitigating some of the most likely or severe scenarios [i.e., large, hydrogen-laden GRE that could cause the entire dome space to exceed the lower flammable limit (LFL) if mixed with dome space air].

Protection Against Natural Phenomena Hazards

Q.1 What is the risk of lightning-induced deflagrations and what lightning protection measures can significantly reduce risk in a cost-effective manner?

Q.2 What is the risk of seismic-induced gas releases and ignition? What measures can be taken to significantly reduce risk in a cost-effective manner?

Deflagration Mitigation (Can Accident Consequences be Reduced?)

Q.1 Would stronger HEPA filters significantly reduce risk (i.e., filter blowout would require a larger deflagration event than with current filters)?

Q.2 Would limiting HEPA filter material accumulation (shorter changeout intervals) significantly reduce risk?

Q.3 Would flushing/cleaning out ventilation system ducting and de-entrainers, and tank walls significantly reduce deflagration material releases and thus dose consequences?

Q.4 Would the installation of rupture disks or "blow-off" riser covers significantly reduce the risk of tank structural damage and possible large consequence events?

Q.5 Would wetting down the waste surface to reduce deflagration-induced waste entrainment significantly reduce material releases and thus dose consequences?

Q.6 Would adding a layer of inert material (e.g., sand) on top of SST wastes significantly reduce deflagration-induced waste entrainment and thus significantly reduce material releases and dose consequences?

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APPENDIX C
TECHNICAL ASPECTS OF THE APPROACH TO UNCERTAINTY

C.1 Introduction

A basic difficulty that complicates management of the Hanford flammable gas problem is the high degree of phenomenological uncertainty that characterizes the analysis of the potential hazards involved. A fundamental purpose of the SCOPE Decision Support System (SCOPE-DSS) is to provide defensible metrics that decision-makers can employ in choosing among possible control options despite this uncertainty. However, it is essential to recognize that the SCOPE-DSS is not a "silver bullet" that somehow eliminates this uncertainty. Hence the phenomenological uncertainties underlying the analysis necessarily manifest themselves as uncertainties in the metrics provided by the system. It is therefore necessary that the decision-maker be provided with measures of the uncertainties in the metrics, rather than simply point estimates of the metrics. If, for example, the best estimate is that the risk guidelines (RGs) will be satisfied by a factor of 2, this may be quite comforting if the uncertainty in the estimates is ±10%; it may be less comforting if the uncertainty is an order of magnitude.

In this appendix, we consider the representation of uncertainty in the metrics provide by the SCOPE Analysis Tool (SCOPE-AT). As elsewhere in this report, many of the specifics are subject to change and are introduced, in part, to illustrate more general concepts. The SCOPE-AT metrics, like the RGs themselves, are necessarily probabilistic in nature, and discussion of uncertainties in these metrics can invite confusion concerning such concepts as "the uncertainty in the uncertainty" if care is not used in terminology. Hence, in Section C.2, we distinguish two different concepts of uncertainty, which we refer to as stochastic uncertainty and phenomenological uncertainty, that we will use in subsequent discussion. In Section C.3 we review the reasons why most SCOPE-AT metrics, at least, will be probabilistic in the stochastic sense, and Section C.4 summarizes how the uncertainty distributions elicited from the experts will be used to evaluate uncertainty in the metrics that result from the phenomenological uncertainties. The experts' uncertainty distributions used in Section C.4 will be obtained by aggregating the distributions provided by each of the individual experts; Section C.5 summarizes the aggregation method of choice for the SCOPE-AT.

C.2 Stochastic and Phenomenological Concepts of Uncertainty

In discussing uncertainties in the SCOPE metrics, it is necessary to distinguish two different concepts of "probability" and corresponding meanings of "uncertainty." The first is stochastic probability that can be interpreted as an average frequency in the limit of a very large number of trials; e.g., what is the probability that a toss of an honest coin will come up heads? In this example, the probability (1/2) is known with high precision, while the outcome of any one toss of the coin remains uncertain. It is this type of uncertainty that we refer to as stochastic uncertainty: the outcome of a single event is uncertain even though the average outcome, or distribution of outcomes, for a large number of similar events may be known. Despite the uncertainty afflicting predictions of individual events, decisions sensitive only to the average behaviors can be made with confidence in this situation; insurance companies and gambling casinos have grown wealthy applying this principle. A number of inputs to the SCOPE-AT can be interpreted as stochastic probabilities. Frequencies (i.e., probability per unit time) of a gas release event (GRE) or a spark ignition source are examples.

The second concept of probability is used to represent degrees of belief about uncertain phenomena: i.e., instances in which we would expect a series of identical trials to yield the same result, but we are uncertain as to what this result would be. If we assign a probability to a particular assumption about this result, we are providing a numerical representation of a degree of belief concerning the outcome, not making a prediction about the frequency this result would arise in a series of identical trials. In a case of pure phenomenological uncertainty, the average outcome of a large number of trials is as uncertain as the outcome of an individual event.

The uncertainty distributions provided by the expert elicitations will generally take the form of cumulative probability distributions in which the experts provide the probability (i.e., the expert's degree of belief) that the value of a quantity will be less than a specified value, X, as a function of X; an example might be to estimate the probability distribution for the gas volume released in a spontaneous GRE. The probabilities so defined will be treated as degrees of belief concerning uncertain phenomena. Propagating these uncertainty distributions through the SCOPE-AT model will generate distributions in the output metrics. It is these distributions that will provide uncertainty measures for the output metrics (Section C.4).

Just as a physical quantity may be uncertain, so may a stochastic probability or frequency be uncertain. Consider, for example, a common thumbtack, which can rest on a solid surface in either of two stable configurations. In the first configuration, the thumbtack rests on its head, with the point sticking up. In the second, it rests on its side, with the point and the rim of the head in contact with the surface. If we toss the tack in the air and let it fall on the surface, it will come to rest in one of these two positions. However, it might be difficult to predict, *a priori*, what the probability that a single toss will yield the point-up configuration will be. Though the probability is uncertain, it is in principle a well-defined number; it could, for example, be determined experimentally by tossing the tack a very large number of times. Hence we view this as an example of an uncertain stochastic probability.

Just as uncertainty distributions for physical parameters can be elicited, uncertainty distributions for stochastic probabilities (typically expressed as frequencies) will be elicited from the experts when necessary. Spontaneous GRE frequencies and spark frequencies are examples.

In order to avoid confusion in what follows, "frequency" should always be understood as being related to a stochastic probability. "Uncertainty" and "uncertainty distribution" are to be understood as representing phenomenological uncertainties, and the associated probabilities represent numerical representations of degrees of belief. It is admitted that the distinction between these two concepts of "probability" are not always as clearcut as implied here, and no one terminology for these concepts is universally accepted. However, if some such distinction between stochastic probability and phenomenological uncertainty is not maintained, it becomes very difficult to meaningfully represent uncertainty in metrics which themselves include probabilistic concepts in the stochastic sense. Hence we maintain this distinction in the discussion in this Appendix.

Notation and Terminology. Before continuing to discuss the probabilistic properties of SCOPE-AT metrics, it will be useful to define some notation and terminology. We assume that we are interested in a quantity, x, which may either assume certain discrete values or which may be continuously distributed. If the quantity assumes only certain discrete values, we let p_i represent the probability it will assume the *i*th value, x_i. For a continuous variable, we let p(x)dx be the probability that the value of some quantity x will lie on the interval (x, x+dx), and define p(x) to be the probability distribution function (PDF) for x. We define the cumulative probability distribution, $P_<(x)$ and the complementary cumulative distribution function, $P_>(x)$, by

$$P_<(x) = \int_0^x p(x')d'x; \quad P_>(x) = 1 - P_<(x), \tag{C-1}$$

where we assume that x is a quantity (e.g., radiological dose) that is constrained to be ≥ 0. Eq. (C-1) can still be used to define $P_<$ and $P_>$ for the discrete variable case with p(x) represented as a sum of δ functions, $p(x) = \Sigma_i p_i \delta(x_i)$.

The mean or "expectation value" of *x*, which we denote by <x>, is given by

$$\langle x \rangle = \int_0^\infty xp(x)dx = \int_0^\infty P_>(x)dx, \tag{C-2}$$

where the second form of Eq. (C-2) can be obtained by integrating the first form by parts and using the relation $P_>(x) = 1 - P_<(x)$. For the discrete variable case, the mean can also be represented as

$$\langle x \rangle = \sum_i x_i p_i. \tag{C-3}$$

For the sake of clarity, we will use the term "expectation value" when averaging over stochastic PDFs and use the term "mean" to refer to an average over the phenomenological uncertainty distributions provided by the expert elicitations, even though the mathematical definitions are of the same form. One SCOPE-AT metric is the population dose, which can be used to guide cost-benefit judgments; the population dose is actually the expectation value as defined by Eq. (C-2) or Eq. (C-3). Other metrics are expressed in terms of doses at specified locations. For example, the probability that a dose will equal or exceed a value specified in a regulation, D_r, is given by $P_>(D_r)$ in this notation.

C.3 Probabilistic Nature of SCOPE Metrics

In order to appreciate the probabilistic nature of the information that the SCOPE-AT can provide, it is helpful to consider what the output would be if there were no phenomenological uncertainties at all. In the absence of phenomenological uncertainties, all magnitudes (GRE volumes and compositions, etc.) and frequencies (GRE frequencies, ignition frequencies, etc.) would be known. Even in the absence of phenomenological uncertainty, stochastic probabilities make up an important part of the SCOPE-AT input. These may involve frequencies (i.e., probability per unit time) of an event such as a spontaneous GRE, or they may involve the probability of one event given that another event has occurred (e.g., the probability that a particular waste-intrusive activity will trigger a GRE). Another important example is the probability that a spark will provide an ignition source during the time that flammable gas compositions are present. Propagating these probabilities through the SCOPE-AT model provides probabilities for certain outcomes that are used to define the SCOPE-AT metrics.

If there are frequency distributions input to the calculations, or included internally, frequency distributions can be generated in the output. For example, consider the scenario in which a GRE results in flammable conditions developing and a random spark provides an ignition source at some time while flammable conditions still exist. Even given that ignition of a combustible plume does occur, there is still random variability in the timing of the ignition. The burn completeness (hence the pressure rise) will depend upon when the ignition source occurs. This variability leads to a PDF for the extent of tank pressurization and hence a PDF for the source term and the resulting doses. Since the spark timing is assumed to be random, this variability can be treated as a stochastic uncertainty. Hence PDFs are generated for the output metrics even if there is no phenomenological uncertainty.

Since the SCOPE-AT model includes frequency and PDF information, it cannot predict specific values of doses or radionuclide releases, even in the absence of phenomenological uncertainty. Instead, it generates information about the probabilities of certain outcomes. Although the output could include complete PDFs for doses, this might be more complex than typical SCOPE users will desire, especially once phenomenological uncertainties are taken into account. In the absence of phenomenological uncertainty, possible output metrics include:

- Probability of HEPA filter failure
- Probability of exceeding the maximum tank design pressure
- $P_>(D_r)$, where D_r corresponds to various dose limits of regulatory significance; e.g., 0.5 rem to the maximally exposed offsite individual (MEOI) or 5 rem at a distance of 100 m
- Population dose [more precisely, the expectation value of the population dose as defined by Eq. (C-2)]
- Information on total radionuclide release

"Information on total radionuclide release" requires some explanation. This information is of interest because it can be very important to integrity of the Hanford site mission and would control site cleanup costs. There is not necessarily a close correspondence between total release and radiological dose measures because the latter tend to be dominated by the respirable fraction, which may be different for different accident scenarios. However, the SCOPE-AT will not predict a single release value; instead, it can only generate PDFs for the releases of the various radionuclide releases of interest. As in the case of radiological doses, one could report probabilities of exceeding certain threshold values; however, release thresholds of regulatory significance are not as well established for radionuclide release as they are for radiological dose. Standards for contamination levels requiring cleanup exist in some contexts, but it is not intended that the SCOPE-AT will provide the kind of detail required to generate contamination isopleths that would permit a full analysis of the cleanup implications of a major release. Hence simpler metrics are required. Some possibilities include:

- Complete release PDFs for curies of the major radionuclide species
- Radionuclide release expectation values
- Radionuclide release expectation values conditional upon occurrence of certain events, together with the event frequencies.

For the third metric, the "certain events" might correspond to a combustion event together with loss of specific confinement features (HEPA failure, breach of DST primary containment into the secondary annulus, tank dome failure, etc).

Comparison with the Risk Guidelines. An especially important metric involves comparison with the RGs, which are widely used in managing the risks of Hanford site operations. The guidelines specify an upper limit on dose that shall not be exceeded in events of a given frequency, with the upper limit depending upon the event frequency. The intent is that, if analysis shows that the guideline limits are exceeded, safety enhancements are warranted that reduce the event consequences, the event probability, or both.

Several revisions to the RGs have been issued. Current usage favors Revision 1 and we assume its use here; however, the approach used by SCOPE is independent of the specific numerical values of the risk guidelines and the system can easily accommodate any future revisions to the RGs. The Revision 1 guideline limits are given in Table C-1. The offsite RGs are expressed in terms of the MEOI, and the onsite guidelines are expressed in terms of the dose received by a worker at 100 m from the release point. For events with probabilities other than those given in the table, linear interpolation on a log-log representation is to be used.

Often safety analyses express event frequencies in terms of the broad probability categories "anticipated" (probability 1.0 to 10^{-2}/yr), "unlikely" (10^{-2} - 10^{-4}/year), "extremely unlikely" (10^{-4} - 10^{-6}/yr), and "beyond extremely unlikely" ($<10^{-6}$/year). When this is done, the applicable dose limit is that specified for the high end of the frequency range of the probability category, except that no specific guidelines are given for "beyond extremely unlikely" events. We consider here only the off-site RG, but compliance with the on-site RG can be assessed in the same manner.

Table C-1. Radiological Risk Guidelines		
Frequency (yr^{-1})	Onsite Dose (rem)	Offsite Dose (rem)
1	0.5	0.1
10^{-2}	5	0.5
10^{-4}	10	4
10^{-6}	25	25

The off-site RG is plotted in Figure C-1. The four curves labeled "S1", "S2", etc., represent hypothetical values of $P_>(D)$ for the four accident scenarios considered by SCOPE; i.e., for tank head space burns, ex-tank equipment burns, burns within waste-intrusive equipment, and subsurface burns within the waste. These curves are not the result of any analysis and are purely synthetic, provided for illustrative purpose only.

The curve labeled "total" is calculated from

$$P_{t,>}(D) = \sum_{i=1}^{4} P_{i,>}(D), \qquad \text{(C-4)}$$

which corresponds to summing the probabilities at a given dose level. Strictly speaking, this would be correct only if the four accident scenarios were independent and mutually exclusive. In reality, this is not entirely true. For example, a burn in ex-tank equipment may propagate back into the tank headspace. In the SCOPE-AT this possibility will be taken into account when evaluating the frequency of head space burns, but not all the interrelationships between the scenarios will be considered in the SCOPE-AT. As noted in the main report, it is not intended that the SCOPE-AT will be a complete simulation code for all aspects of tank behavior.

From curves such as those in Figure C-1, it would be immediately obvious whether the RGs are satisfied. In the hypothetical example, it is apparent that the total risk does not satisfy the RGs at the low-frequency end of the range, and the culprit is S_1. S_1 might, for example, represent a rollover GRE with headspace ignition occurring with a probability ~0.04/yr that fails the HEPA, but the release is still within the RGs; however, there is also a small probability ($\sim 4 \times 10^{-6}$) of tank dome failure that results in a large release exceeding the RGs. Were it not for S_1, the RGs would be satisfied. Hence mitigative efforts could be focussed on S_1.

Another metric that could be reported is the "compliance factor" C_F, defined by the relation $P_{C,>}(D) = P_>(D)/C_F$, where $P_>(D)$ is the actual complementary cumulative probability distribution

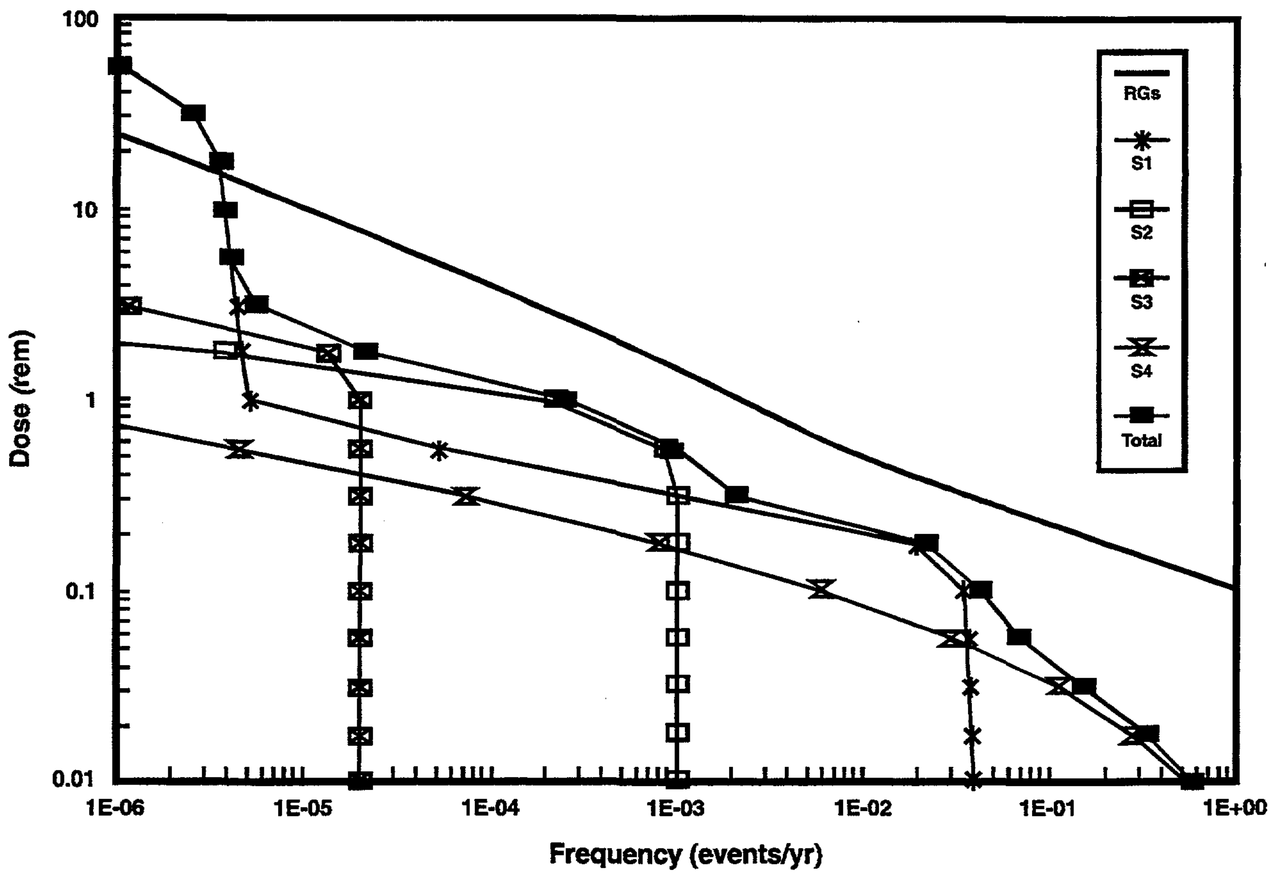

Figure C-1. Relationship to risk guidelines without phenomenological uncertainty. S1...S4 represent different threat scenarios (see text).

and $P_{C,>}(D)$ is the same distribution with doses multiplied by a factor of $1/C_F$ such that it just touches the RG line but nowhere exceeds it. $C_F \leq 1$ represents compliance with the RGs while $C_F > 1$ represents exceeding the RGs. C_F can be defined for the scenarios individually as well as for the curve representing the total. Note that, since the RGs themselves are probabilistic, the SCOPE-AT can give an unambiguous answer to the question of whether the RGs are satisfied in the absence of phenomenological uncertainty.

As they have been described here, all probabilities and frequencies involved are considered to be stochastic; no phenomenological uncertainty has been allowed for. We consider the representation of uncertainty in the next section.

C.4 Representation of Uncertainties

The SCOPE-AT output as described in the previous subsection represents what one would obtain if all phenomenologically uncertain variables (frequencies and magnitudes) were held fixed at specific values. In reality, it is necessary to factor into the analysis the uncertainty distributions elicited from the experts for the uncertain inputs. In the SCOPE-AT this will be done by repeatedly evaluating the SCOPE-AT model using values that are selected by random sampling from the aggregate uncertainty distributions provided by the experts. Each evaluation of the SCOPE-AT model will be performed with fixed values of the uncertain variables that are selected by the sampling scheme. Each such calculation, which will be referred to here as a "sample member", will yield results qualitatively similar to those described in Section C.3. By repeatedly sampling the uncertainty distributions provided by the experts, a corresponding uncertainty distribution is built up for the SCOPE-AT output metrics that were described in Section C.3.

Sampling of the uncertainty distributions could be done using simple Monte Carlo methods. However, the SCOPE-AT will use Latin Hypercube sampling, which is considerably more efficient in that it gives statistically stable results with a smaller sample size than Monte Carlo sampling. Latin Hypercube sampling was used in the NUREG-1150 study[C-1] and it was found that good results could be obtained with sample sizes as small as 200.

It is possible that the SCOPE-AT technical project staff will define uncertainty distributions for some uncertain parameters that are not elicited. This will be done only for uncertainties that are considered to be less important than those which are elicited, or for uncertainties in which prior work has established distributions with an adequate pedigree. The distributions for these parameters would also be sampled.

Uncertainty in the SCOPE-AT can be represented by the percentiles of the distributions generated by sampling the uncertainty distributions. For example, one metric might be the probability that the MEOI dose will exceed 0.5 rem, $P_>$(MEOI=0.5 rem). The 5th and 95th percentiles of the values of $P_>$(MEOI=0.5 rem) obtained by sampling the elicited uncertainty distributions could be reported as representing the uncertainty range. The 5th and 95th percentiles can also be interpreted as representing 5% and 95% confidence limits for the results. In addition, the median value and arithmetic mean value can be reported. The mean value is the arithmetic mean of all the values of $P_>$(MEOI=0.5 rem) obtained by sampling the input uncertainty distributions.

For the metrics that were discussed in Section C.3 without uncertainty representations, the corresponding results reported with uncertainty included are:

- Median, mean, 5th and 95th percentiles for the probability of HEPA filter failure

- Median, mean, 5th and 95th percentiles for the probability of exceeding the maximum tank design pressure

- Median, mean, 5th and 95th percentiles for the $P_>(D_r)$, where D_r corresponds to various dose limits of regulatory significance; e.g., 0.5 rem to the maximally exposed offsite individual (MEOI) or 5 rem at a distance of 100 m

- Median, mean, 5th and 95th percentiles for the population dose

For the information on radionuclide release, possible metrics include:

- Median, mean, 5th and 95th percentile release PDFs for the major radionuclide species
- Median, mean, 5th and 95th percentiles for the radionuclide release expectation values
- Median, mean, 5th and 95th percentiles for the radionuclide release expectation values conditional upon occurrence of certain events, together with the median, mean, 5th and 95th percentiles for the event frequencies.

Compliance with RGs. Since each sample member will generate a set of curves such as those given in Figure C-1, displaying all of them would be hopelessly messy. One method of display is to include a "bar-and-whisker" display of selected percentiles of the dose that corresponds to specified frequencies. This is done in Figure C-2. The short horizontal lines ("whiskers") represent the doses corresponding to the 5th, median (m), and 95th percentile doses at a given frequency on the horizontal axis. The mean (M) is also displayed. Results are given for each decade of the frequency range.

Figure C-2 is intended to correspond approximately to the case given in Figure C-1 under the assumption that Figure C-1 represents a sample member at or somewhat above the median of the uncertainty distribution. At a frequency of 10^{-6}/yr, even the median and mean doses lie above the RG line and only the 5th percentile lies below it, corresponding to the assumption that most sample members predict a dome failure frequency > 10^{-6} and that dome failure usually results in exceeding the RGs. However, less than 95% of the sample members predict dome failure probabilities > 10^{-6} and thus the 5th percentile dose is still quite small at the 10^{-6} frequency. The reverse is true at the 10^{-5} frequency: most sample members do not predict dome failure but over 5% do, and the 95% dose at the 10^{-5} frequency point is still very high. Because the arithmetic mean is somewhat sensitive to the minority of sample members that predict dome failure and high doses, there is a greater separation between the mean and the median at the 10^{-5} frequency point than for other frequencies. For frequencies > 10^{-4}, no dome failures are assumed to occur in this example (at least at the 95% confidence level) and the uncertainty ranges are smaller. The mean and median values satisfy the RGs at all the higher frequencies, but the 95th percentile exceeds the RGs by a small amount in some instances. This means that even completely eliminating dome failure would not assure satisfying the RGs at the 95% confidence level. Note also that at the 1.0/yr frequency point, the 5th percentile, median, and mean results are all off the bottom scale, and only the 95th percentile and the mean is visible on the plot.

The SCOPE-AT will have the ability to store the complete results obtained from evaluating any given control option. It will be able to display the results obtained for two or three different options at the same time. This is illustrated for a hypothetical case in Figure C-3. Bar-and-whisker representations are given for each of the three options, designated A, B, and C. At a given frequency, the displays for the three options must be slightly displaced horizontally from one another for clarity; it should be understood that they actually correspond to the same frequency.

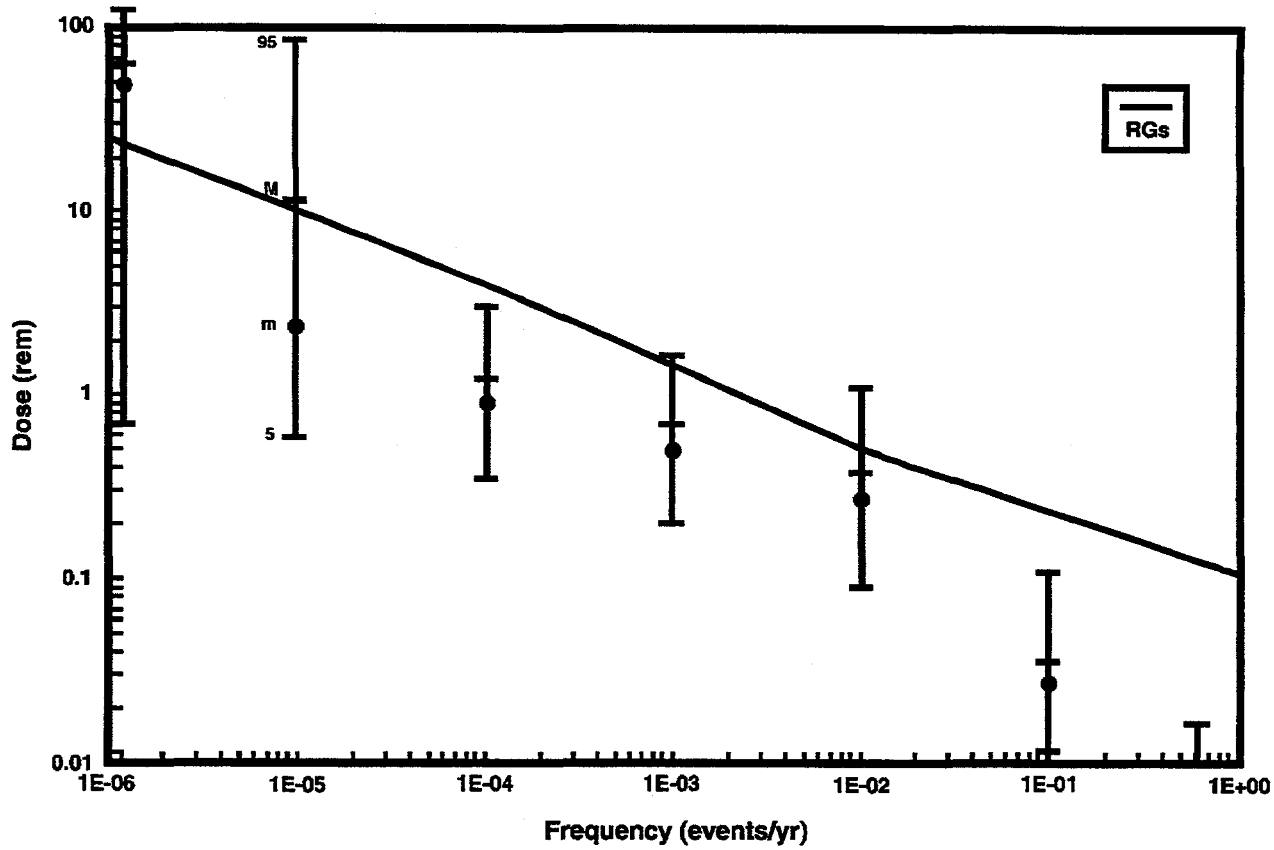

Figure C-2. Relationship to risk guidelines with phenomenological uncertainty.

Option A is the same as Figure C-2; it may be taken to be the "no action" option. Option B is assumed to be very effective in preventing the dome failure scenario but to do nothing to mitigate the higher-frequency, lower-consequence end of the range. Option C mitigates the entire range but is somewhat less effective than B in preventing dome failure. Thus both Options B and C result in median and mean releases satisfying the RGs over the full range, but neither assures full compliance at the 95% confidence level. They fail to achieve 95% confidence of compliance in quite different ways; i.e., in Option C failure is associated with the residual risk of a large-consequence event resulting from dome failure while for Option B the failure is related to lower-consequence, higher-frequency outcomes.

For reasons of clarity, the displays considered in Figures C-2 and C-3 do not include the results for each of the four individual scenarios as well as the total as was done in Figure C-1. However, results for the four individual scenarios will be readily available. Another metric that can be provided is the 5th percentile, 95th percentile, median, and mean for the compliance factor C_F defined in Section C.3. The SCOPE-AT will possess considerable flexibility with respect to output metrics and methods of displaying them. Default representations will be chosen after experience has been gained as to what best meets the needs of the SCOPE-AT customers in routine applications.

Figures C-2 and C-3 are purely synthetic examples constructed to illustrate the kinds of results that might be obtained using the SCOPE-AT and how they might be displayed. They were constructed to illustrate how the system can provide a substantial information helpful in choosing among different options and provide insights into what the controlling factors are. At the same time, the examples are constructed to illustrate that there is no pretense that the SCOPE-AT can eliminate the need for judgment in managing tank operations. In the example, both Options B and C offer substantial improvement but do not provide complete satisfaction of the RGs at the 95% confidence level; deciding upon the appropriate level of confidence for demonstrating RG compliance is a regulatory decision outside the domain of the SCOPE project. Furthermore, it is not immediately obvious whether Option B or Option C should be preferred in this example. Costs of the options also need to be determined and some of the factors involved are not included in SCOPE.

Despite the limitations that were deliberately built into these examples, the SCOPE-AT as described here provides at a glance a great deal of information about the risks and the effects of the options analyzed. The controlling scenarios can be quickly identified in at least a general sense, the status with respect to RG compliance is displayed at a glance, and the magnitude of the uncertainties is displayed. In many examples, of course, the ambiguities with respect to Options B and C that were built into this example will not be present, and the decision-maker's task might be simpler than in this example.

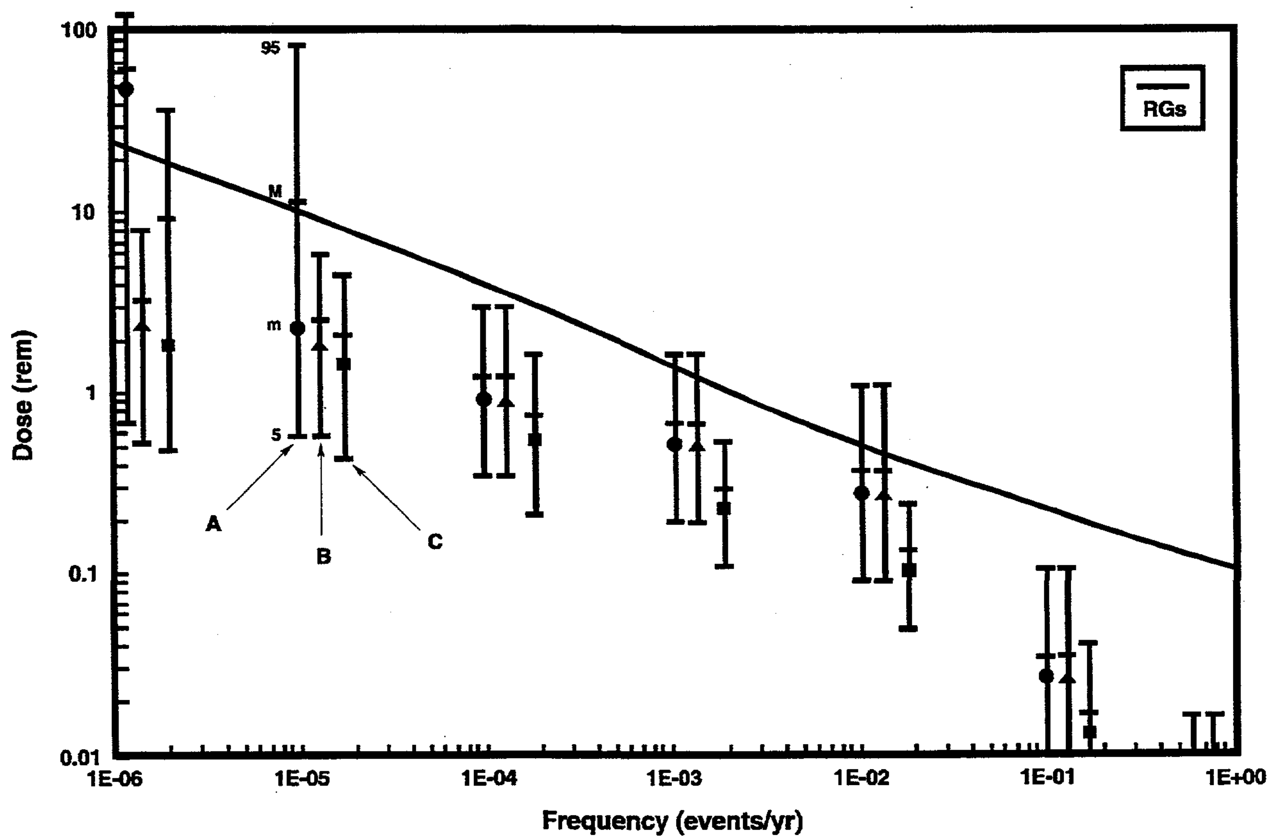

Figure C-3. Relationship to risk guidelines with phenomenological uncertainty.

C.5 Aggregation of Elicitation Results

Uncertainty distributions for uncertain parameters input to the SCOPE-AT are based upon the expert elicitations. Since several experts (typically ~5) are elicited on each issue, the uncertainty distributions provided by the individual experts must be aggregated in some manner for use in the SCOPE-AT. Aggregation is carried out using the formula

$$P_{<}(Y) = \frac{\sum_{i=1}^{N} P_{i<}(Y)}{N}, \qquad \text{(C-5)}$$

where Y is the elicited quantity, $P_{<}$ is the aggregate cumulative probability distribution, $P_{i<}$ is the distribution given by the *i*th expert, and N is the number of experts. This corresponds to taking an unweighted average of the experts' probabilities corresponding to a given value of Y.

It is a feature of this method of aggregation that the aggregated distribution spans the full range of values considered credible by *any* expert. No value to which even one of the experts has assigned a nonzero probability is completely excluded from the aggregate distribution. This inclusivity feature is helpful in obtaining buy-in by the stakeholders represented by the experts. It also provides at least a partial defense against the well-established tendency of experts to be overconfident in their judgments and underestimate uncertainties.[C-2] More fundamentally, it is the aggregation method with the most theoretical support and that has been the most widely used; see, for example, Appendix J of Reference C-3. This approach was used in both the NUREG-1150[C-1] and the DSAC[C-3] studies.

This aggregation method is sometimes perceived as causing a problem if one expert is an "outlier" in the sense that he or she considers certain outcomes to be much more probable than do the others. The problem is most evident when one elicits directly on the probability of high-consequence events that have very low probabilities. Suppose, for example, that four of five experts believe the probability of a certain high-consequence event is in the range 10^{-8}-10^{-7}, while the fifth considers the probability to be about 10^{-4}. The aggregate is then 2×10^{-5} and is essentially controlled by the fifth expert. Those who believe the smaller numbers are appropriate are naturally concerned about using a result that is dominated by the "outlier" whom they consider to be excessively conservative.

It is the present view that this problem is more apparent than real. If one out of five highly knowledgeable and respected experts carefully considers the available information and then concludes that some catastrophic event has a nonnegligible probability of occurring, it seems prudent that decision-makers should take this into account in some degree. Of course it is assumed here that the fifth expert is a highly competent and reasonably unbiased investigator. If this individual actually is strongly biased by ulterior motives in favor of an extreme result, or is simply incompetent, the situation might better be viewed as a panel selection problem, not a problem with the aggregation method.

It is expected, but not certain, that the SCOPE-AT will not be very sensitive to the outlier problem even if it should arise. One reason is that normally no one issue will overwhelmingly dominate the calculated release metrics. Release magnitudes and probabilities will be controlled by several disparate issues (GRE frequencies and magnitudes, burn efficiencies, spark frequencies, resuspension fractions, respirable fractions, etc). No one panelist will be elicited on issues in all of these areas because of the disparate areas of expertise involved. It should also be remembered that each expert will be required to document the rationale for his or her elicitations.

Various methods have been considered to address alleged limitations of the simple averaging aggregation technique. These include assigning different weights to results given by different experts, and eliminating the highest and the lowest elicitation for each issue. It has also been proposed that one average the Y values for a given probability rather than the probabilities for a given value of Y; e.g., the 95th percentile given by each expert would be averaged and this would correspond to the 95th percentile of the aggregate. This method gives narrower distributions than Eq. (C-5) and has the appearance of reducing the outlier problem somewhat, but it is difficult to justify theoretically and it can be shown to give unreasonable results in some instances (Appendix J, Reference C-1).

In general, the alternatives to Eq. (C-5) that have been proposed introduce at least as many problems as they solve, and most are difficult to justify in any theoretical sense. Hence Eq. (C-5) will be used for the SCOPE-AT.

References

C-1. U. S. Nuclear Regulatory Commission, *Severe Accident Risks: An Assessment for Five U. S. Nuclear Power Plants,* Final Summary Report, NUREG-1150, Washington, DC, December 1990.

C-2. Daniel Kahneman, Paul Slovic, and Amos Tversky, Eds., *Judgment Under Uncertainty: Heuristics and Biases,* Cambridge University Press, Cambridge, UK, 1982.

C-3. K. D. Bergeron et al., *Heavy Water New Production Reactor Design Review Guidelines,* NPRW-DSAC91-5, SAND92-2538, Sandia National Laboratories, Albuquerque, NM, February 1993.

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APPENDIX D
BASIS FOR THE STRAWMAN SCOPE ELICITATION STRUCTURE

D.1 Introduction

A fundamental goal of the SCOPE Analysis Tool (SCOPE-AT) is that it provide quantitative estimates of the risk metrics (including quantitative uncertainty measures) with as little dependence as possible upon uncertainties in various modeling assumptions made by the SCOPE Project staff. Ideally, treatment of uncertain phenomena would depend exclusively upon the elicitations given by the expert panels, not modeling assumptions made by the SCOPE project or assumptions made by the user concerning uncertain input. Unfortunately, meeting this ideal would require elicitations for every uncertainty that might possibly affect the results, which would require an excessively large number of elicitations if it could be done at all. Hence the actual SCOPE elicitation structure reflects a compromise between the goal of representing all important uncertain phenomena with elicited results versus the need to keep the number of elicitations required tractable. This appendix summarizes a strawman elicitation structure and the rationale for this structure.

The strawman elicitation structure outlined in this appendix is not intended or expected to be "the" elicitation structure on which the experts will provide specific inputs. It will undergo substantial review and revision early in phase 2 of the SCOPE project, and the expert panelists themselves will make additional modifications to the elicitation structure before providing their results. This preliminary strawman elicitation structure was outlined to:

- provide a conservative estimate of the number of elicitation cases required to quantify the flammable gas risk in order to evaluate if the flammable gas issue was manageable using the SCOPE process
- provide a starting point for defining an elicitation structure that can be presented to the experts in phase 2
- provide initial guidance as to which phenomenology is largely independent of proposed controls and can be handled with representative stylized models
- provide a structure for evaluating how the impact of proposed controls may be logically tied to the risk guidelines without performing a detailed probabilistic risk assessment
- estimate the number of experts and expert panels that would need to be involved
- identify potential trouble spots that will require careful attention
- estimate the project resources required

It is vital to understand that this compilation is preliminary and is subject to substantial change. A major reason for the complexity of the elicitation task is the large variety of relevant parameters (properties of the tanks and their contents, equipment, operations, etc.) that must be considered. To keep the number of elicitations under control, these parameters must be "binned" into specific cases. Optimum binning will require careful review and systematization of a very large amount of data concerning Hanford tanks and their wastes, equipment, and possible operations. Performing this task will be an important activity in phase 2, as time and resources have permitted only a high-level overview in phase 2, and completion of this task is expected to result in substantial revision to the elicitation structure described here. Equally important, even this revised elicitation structure will itself be only a strawman for presentation to the experts, who will undoubtedly wish to make further changes. Hence the structure defined must be sufficiently flexible to accommodate changes late in the process.

The number of elicitation cases required to treat the parameter ranges of interest is estimated here, but the exact values of the conditioning variables that delineate the various elicitation cases are not given in most cases. This level of detail is not needed to estimate total number of elicitation cases or estimate other parameters required to allocate resources.

It is estimated that approximately 230 elicitation cases would be required to develop the information required for the SCOPE-AT if the elicitation structure were used as it is defined here. Of these, about two-thirds would be required to address scenarios involving gas combustion in the tank head space. The number of elicitations for these scenarios, in turn, is dominated by the elicitations of gas release events (GRE) because of the large number of waste states that must be considered in order to encompass the contents of all the tanks. Modeling of ex-vessel burns requires fewer elicitations, in part because the GRE elicitations for the in-tank burn scenarios define the gas releases that drive the ex-vessel scenarios also. Burns within intrusive equipment require fewer elicitations because there is less variety in the release mechanisms than for the in-tank GREs and because combustion in complex plume geometries need not be considered. A number of ways that the elicitation structure might be simplified to reduce the number of cases are outlined at the end of the description of the strawman structure (see Section D.9).

One source of uncertainty in the number of elicitation cases is that there are a number of scenarios that have been discussed whose credibility is in doubt. In some instances, we have made the judgment that these scenarios are not credible and have set the number of elicitation cases for these issues to zero. We include them in the overall structure, however, in order to assure that the experts at least consider whether these scenarios are credible and define cases to treat them if the experts feel they are needed. It is also likely that the experts will delete cases that we have assumed to be needed and that they will add cases we have not considered at all.

Notation and Terminology. In this appendix, elicited quantities will be assigned names consisting of all capital letters; e.g., VGRS refers to the volume fraction of gas released in spontaneous gas release events (GREs). The number of elicitation cases for a quantity is represented by N with the quantity name as a subscript; e.g., N_{VGRS}. The variables or characteristics used to define the elicitations will be referred to as the "conditioning variables"; that is, the elicitation for a specific case will be conditional upon particular values, or ranges of values, of the conditioning variables. The conditioning variables will be assigned lower-case names and the number of cases defined to cover the full range for a particular variable will be represented by N with the characteristic name as a subscript. Thus the void fraction is one of the conditioning variables for spontaneous GREs and N_{void} is the number of cases defined based upon different values of the void fraction.

D.2 General Considerations for Elicitation Design

Based, in part, upon lessons learned from the NUREG-1150[D-1] and DSAC[D-2] projects, it is possible to define some general requirements that should be met in the design of the SCOPE-AT elicitations. These requirements apply to all the elicitations; additional considerations that depend upon the specific subject matter of the elicitation are considered in subsequent sections of this Appendix. Some of the subjects discussed here are treated in more detail in Reference D-2, especially Appendix D of this reference.

D.2.1 Conditioning

Experts cannot be expected to develop uncertainty distributions for general or vague questions such as, "How much gas will be released in a GRE?" The combination of circumstances posed by the various tank conditions and gas release mechanisms are too diverse to permit a meaningful answer to such a question to be developed. It is necessary to narrow the problem by specifying a particular set of initial and boundary conditions, e.g., by specifying important waste properties such as rheology parameters and porosity. It may also be necessary to narrow the problem further by specifying the particular processes or phenomena assumed to be controlling; e.g., specification of a rollover GRE versus nonrollover GRE, etc. In this way the problem is narrowed to produce a well-posed problem that the experts can analyze and provide meaningful results in their elicitations. The results given are then conditional upon the parameters specified in the problem definition; hence, the process of defining problems suitable for elicitation is sometimes referred to as "conditioning." Experience has shown that failure to provide well-conditioned problems can result in poor elicitations that are difficult to incorporate into the overall analysis. The experts may, for example, have different perceptions of what the problem to be solved is, and their answers in effect correspond to answers to different problems.

In the SCOPE-DSS elicitations, conditioning is achieved in part by the definition of the various cases to be considered for elicitation and the specification of the parameter(s) for which uncertainty distributions are to be elicited. Both must be unambiguously defined, and the parameters must be such as to readily lend themselves to numerical representation. Thus "gas release volume" might be a suitable elicitation parameter, but "gas composition" would be more difficult: there are several components in the released gas and the composition would require specification of the mole fractions of all of them. Elicitation of the constituents individually, and elicitation of the correlations between them, is potentially intractable; some simplifications in representing the gas composition have been accepted in the case structure defined here (Section D.3.2).

D.2.2 Internalization of Uncertainties

The practical necessity of keeping the number of elicitation cases under control means that each case must represent a substantial range of conditions. This fact conflicts in some degree with the conditioning requirement summarized above. One approach is to ask the experts to take into account the range of conditions represented by a case when developing the elicitations and treat this range as part of the problem to be solved, a process sometimes called "internalization" of the uncertainties. It is the preferred approach when feasible; however, if the range of conditions spanned by the case is too broad, it is likely that at least some of the experts will be uncomfortable treating it in this way.

If necessary, the need for internalization can be reduced by defining the problem more narrowly in the conditioning step, and treating the narrow problem as being representative of the broader case. Doing this tends to narrow the uncertainty distributions developed. If the representative case is defined to be a "best" or central estimate of the broader case, narrowing the distribution can have the effect of underestimating the probability of low-probability, high-consequence events, which are typically controlled by the tails of the probability distributions. This problem is reduced in the "representative conservative accident scenario" (RCAS) approach that was adopted in the DSAC project[D-2], in which the narrowed problem is defined to be a conservative representation of the broader case. However, the RCAS approach introduces an additional conservatism into the overall results that is not quantified, which compromises the ability to use the results for cost-benefit tradeoffs and comparisons among competing options. Other means of defining the representative case might include defining it to correspond as closely as possible to assumptions made in the FSAR or in the JCO, which might be expected to yield results qualitatively similar to the RCAS approach.

In the above discussion, "internalization" was used to refer to incorporation of allowance for uncertainties in the problem input parameters into the overall uncertainty distribution generated by the elicitation. The term has also been used to refer to the expert's attempt to adjust his distributions to allow for uncertainties in the *downstream* analysis that uses his distributions as input, so that the downstream analysis will yield results the expert considers more reasonable. For example, if an expert providing gas release information believes the hydrogen burn treatment will underestimate tank pressurization, the expert may feel a temptation to increase his gas release estimates in order to obtain pressure results he considers more reasonable.

It is the present view that the internalization of downstream uncertainties should be minimized. In addition to the intrinsic difficulty of attempting to adjust the elicitation in this way, the gas release expert is in effect passing judgment on hydrogen burn phenomenology, a subject in which he may have less expertise. In this example, internalization of the downstream uncertainties should not be necessary because uncertainty in the burn modeling will itself be the subject of expert elicitation. The preferred approach would be for the gas release expert to make sure his concerns were properly understood by the combustion experts and allow them to incorporate this information into their elicitations as they see fit. However, cases may arise in which uncertainties in the downstream analysis are not the subjects of separate elicitations and are not explicitly taken into account by the analysis in any other way. In this case, internalization of the downstream uncertainties might be defended as being better than simply ignoring them.

D.2.3 Representation of Dependencies upon Important Parameters

In many instances it will be known that certain parameters are likely to be important to the outcome of an issue that is the subject of an elicitation. If values of these parameters are available, either as input or as the results of upstream elicitations, it is desirable to preserve the dependence upon these parameters in the output. That is, one would not want to provide elicitations that average over these parameters, as in the case of internalization, because it would result in a loss of resolution, e.g., the ability to distinguish different tanks or the ability to distinguish different GRE magnitudes.

Two methods will be used to represent important parameter dependencies in the SCOPE-AT. The choice depends upon the degree of understanding concerning the parameter dependence of interest. The first method involves simply defining additional elicitation cases, with each case considering only a subrange of the full parameter of interest. For example, the dependence of GREs upon waste porosity can be handled by subdividing the full porosity range spanned by all the tanks into subranges. In this method, the experts themselves effectively define the dependence of the results upon the parameter of interest, through the difference between the results for the different cases. The method imposes no external assumptions upon the parameter dependencies defined by the experts, and is therefore used when understanding of the parameter dependencies is poor. However, it is expensive because it increases the number of elicitations. Complexity can quickly get out of hand when a number of independent parameters must be considered simultaneously, since an n-dimensional matrix would be needed to consider n parameters in the general case.

If there is substantial, but still imperfect, physical understanding of the problem, the parameter dependency may be captured to lowest order by a physical model for the phenomena of interest. The experts are then elicited on a measure that reflects their assessment of the uncertainty in the model predictions. The method is attractive when several parameters must be considered. Assuming the model does treat all the parameters, the large number of parameters does not necessarily add complexity to the elicitations, since it is still just the model uncertainty for which elicitations are taken. Conceptually, the simplest approach might be to elicit uncertainty distributions for the error in the model; e.g., for the ratio (model prediction)/(reality) or for the difference (model) - (reality). However, it may be possible to define a parameter with a physical interpretation related to a dominant uncertainty in the model, and elicit uncertainty distributions for this parameter. This approach is used in developing uncertainty distributions for the hydrogen burn completeness question; see Section D.4 for details.

For the sake of completeness, we note that at the two extremes with respect to physical understanding, no additional elicitations may be needed to treat the parameter dependencies involved. When understanding is sufficiently high, a validated model may be used to represent the parameter dependencies with the modeling error being small in comparison with other uncertainties. On the other hand, if understanding is very poor, with even the direction of the effect being unknown, defining separate cases for elicitation may be pointless because the experts would have little basis for defining different results for the different cases.

D.2.4 Commensurability

The elicitation results provided by the experts will be aggregated as described in Appendix E to define a composite distribution, and it is the composite distribution that will be incorporated into the SCOPE-AT. It is very important that the quantities for which experts provide uncertainty distributions correspond to the same physical quantity. Otherwise the aggregation step requires the averaging of apples and oranges. This problem may seem trivial when the elicitation parameter is a simple variable such as gas volume released, but cases can arise in which it is nontrivial. For example, in the NUREG-1150 study, the expert panel for in-vessel accident progression was to provide information on the composition as well as mass of molten material present in the vessel lower head at vessel breach. However, the experts did not provide the composition information in terms of the same parameters in all cases, which caused some difficulties for both the aggregation process and the use of the results in the downstream analyses requiring these results as input.

D.2.5 Decomposition

Even after conditioning as described above, the experts will typically find the problem too complex to analyze without additional decomposition. The expert may find it useful to divide the given case into subcases. In addition he may find it useful to identify a number of processes that control the results of interest and treat these processes individually. The expert may provide uncertainty distributions for individual components of the decomposed problem; if so, it is necessary that either the expert or the project be able to re-integrate the results to obtain uncertainty distributions for the complete problem. Otherwise, the expert's elicitation will not be commensurable with those of other experts. Although the possibility of having all the experts use the same decomposition is sometimes discussed, it is usually necessary to allow each expert to find the method of decomposition that best fits his understanding of the problem.

Another benefit of decomposition is that it can aid in the review of the work performed. An important purpose of controlled expert elicitation processes is to provide reviewable and scrutable rationales for the expert judgments used in the analysis. Well-conceived decompositions can contribute to clarifying the rationales for the experts' judgments by breaking down their arguments into steps reviewers find more understandable.

D.2.6 Technical Information Exchange and Panel Meetings

A large body of information relevant to the Hanford tank combustible gas problem has been generated by work performed at Westinghouse Hanford Corp., Los Alamos Scientific Laboratory, and elsewhere. The phenomena involved are quite diverse; it cannot be expected that any one expert will be familiar with all the relevant information. Technical information exchange is an essential part of the process. SCOPE-DSS project staff will bear much of the responsibility for collecting this information and making it available to the experts. The experts themselves will also play important roles in the information exchange and need to be free to request any additional information that is available.

Although much of the information may be available as reports that can be sent out in advance of the panel meetings, presentations by technical specialists at panel workshops represent a very important part of the process. It is vital that supporting arguments on all sides of any controversial issues be presented to the experts. Discussions among the experts play an essential role in developing common perspectives as to the problems to be solved. However, there is a delicate balance between the desire to achieve consensus and the need to preserve independence of judgment. As in other scientific discourse, the spirit of this balance should be that of objectivity, rational skepticism, and openness to dialogue. The goal should never be to force a consensus among the experts; on the contrary, the process needs to be designed to preserve differing opinions on how the available data concerning uncertain phenomena should be interpreted. The information exchange should, however, reduce differences among the experts that result from differences in factual knowledge about specific issues that each expert may possess prior to the information exchanges.

Panel meetings serve other purposes in addition to technical information exchange (e.g., training in expert elicitation processes), but the technical exchange is a very important part of their purpose. The time and resources allocated for panel meetings must not be underestimated. In the DSAC project, which was on a very tight schedule and involved only a single panel, there were three separate meetings, each lasting three days to one week, and each separated by about two weeks in order to allow the experts time to assimilate information received at the meetings. Even this schedule resulted in extreme time pressures on some of the experts. More time will be allocated in the SCOPE-DSS effort.

D.2.7 Uncertainty Assessment Versus Issue Resolution

Despite the preceding caveat concerning allowing sufficient time, it is probably inevitable that some experts will always express frustration about not having as much time as they desire. One reason for this frustration is that the experts may not be clear as to the intended purpose of the process: it is only to *assess* the current state of knowledge and quantify the uncertainties involved; it is not to *resolve* the uncertainties. It is only natural for the experts to feel that they could resolve some question if only they were allowed sufficient time to do some additional analysis or to refine a model. Although a rigid distinction between "assessing the current state of knowledge" and "resolving" an issue cannot always be drawn, it is important for the experts to understand (and accept) that the purpose of the present effort is principally the former. Advancing the state of the art, however worthy a goal, is outside the scope of the current effort.

D.2.8 Interfacing

Serious difficulties can arise at the interfaces between the different steps of the analysis unless careful attention is paid to avoiding these difficulties. Two-way information exchange between the panels is required in order to assure that the upstream analysts know what is required by the downstream analysts, and that the downstream analysts know what information can and will be provided by the upstream analysts. Otherwise the information provided by the upstream elicitations may not conform closely to the parameters that define the cases considered by the downstream panels.

SCOPE-DSS project staff will inevitably be required to assume much of the burden of assuring that the required information exchange takes place. An additional approach that will be considered is to have at least some of the panel technical information exchange meetings take place jointly. In this way, all panelists would be exposed to the technical discussions and would gain improved understanding of what was required by the other panels, and what could be provided by the other panels. One drawback is that the increased meeting size would be more cumbersome than meetings of the individual panels. Larger meetings may also increase the risk that the discussion may be dominated by a few of the most assertive experts, with others who may have equally valuable insights contributing less to the discussion. A judicious combination of joint meetings and single-panel meetings may be considered.

D.2.9 Modifications by the Expert Panels

From the preceding, it should be apparent that a great deal of work must be done by the SCOPE-DSS project technical staff in advance of the first expert panel meetings. They must define well-posed problems for elicitation that also fit the needs of the project. However, it cannot be expected that the experts will always be satisfied with the case definitions presented to them. They must be allowed to modify the cases, add cases, or delete cases if they judge that the initial case structure provided does not fit their perceptions of physical reality. It is, however, necessary that the experts agree on the changes to the extent required in order to assure that they are all evaluating the same problem. The need to provide the information that is required for the complete analysis also imposes some constraints on the changes that are allowable.

D.2.10 Role of Decision Analysts

An essential feature of both the NUREG-1150 and the DSAC expert panels is that the expert panels were provided with training by decision analysts who were specialists in expert judgment processes. They provide general information on controlled expert elicitation processes, since some of the panelists may not be familiar with the concepts involved. They provide some guidance on how to develop decompositions that will help the experts in their elicitations. They also provide training that familiarizes the experts with the tendency of experts to overestimate the certainty of their knowledge, and with the various sources of bias that can affect expert judgment processes. The decision analysts also conduct the actual elicitations of uncertainty distributions.

In addition to these direct contributions to the process, the role of the decision analysts has proven important in achieving the "pedigree" required for general acceptance of the results. For example, the final draft of NUREG-1150 was preceded by an earlier attempt in which expert elicitations were informal with no decision analyst participation. The lack of formality and control in the use of expert opinion was one of the major criticisms made of this earlier work.

D.2.11 Documentation of Expert Rationales

It should be understood at the outset by all concerned that the experts will be required to document the rationales for their elicitations and that this documentation will be part of the published record of the project. Inadequate documentation of the experts' rationales was also a major criticism of the initial NUREG-1150 effort alluded to above. In NUREG-1150, there was some experimentation with having the documentation of the rationales prepared by knowledgeable third parties who attended the elicitation sessions. This did not prove very satisfactory and the experts were required to provide their own documentation in subsequent efforts and in the DSAC project. In the latter project, the decision analysts also provided documentation of the elicitations from their perspectives. Funding for the experts' time required to document their rationales must be allowed for in the budget and documentation requirements need to be noted in the contracts with the experts.

D.2.12 Anonymity

The names and qualifications of the experts are necessarily part of the public record, but it is not necessary to identify which expert gives which elicitation. In NUREG-1150, the elicitations were only identified as being given by "Expert A," "Expert B," etc. In the DSAC project, the expert elicitations were identified individually. Anonymity is sometimes advocated as protecting the expert from pressure to bias his or her results in inappropriate ways; however, it is not clear that it is effective for this purpose. It may be best that experts who feel serious concern that providing "politically incorrect" elicitations can result in retaliation excuse themselves from participation.

It is sometimes proposed the experts be allowed to decide the anonymity question themselves. If this is done, it must be understood that anonymity applies to all members of the panel if even a single member requests it. Whatever the policy on anonymity, it should be clearly specified at the outset, in order to avoid false expectations concerning the question.

D.3 GRE Volumes and Frequencies

Before starting, we note that a GRE is of concern only if it is sufficiently large that combustion of the released gas could trigger failure of a HEPA or other tank features important to providing confinement, since both radionuclide and toxic releases are very small if the HEPA filters survive intact. Reference D-3 indicates that, for tank 241-SY-101, no HEPA filter failure would be expected for combustion of $\leq 2\ m^3$ of hydrogen. The reference also indicates that combustion of relatively small gas releases is not expected to be complete, and the actual flammable gas release would have to be larger than this. Reference D-3, for example, cites calculations indicating that a release of $9.6\ m^3$ of hydrogen over a two minute period would result in a maximum of $2.8\ m^3$ of hydrogen being present in those regions of the plume which are flammable. It appears, therefore, that releases of several m^3 may be required to threaten the HEPA filters, at least for this tank. It would be desirable to form estimates of the minimum amount of hydrogen that must burn to threaten HEPA integrity in other tanks.

In what follows, references to "GREs" refer to events sufficiently large to exceed the threshold for HEPA damage; we assume that smaller events may be neglected. For illustrative purposes, it will be assumed here that this threshold exceeds $1\ m^3$ for all tanks, but this number cannot be used for actual safety analysis without additional supporting analysis.

A wide range of waste characteristics must be accommodated by the SCOPE-AT. For gas release phenomena, it is judged that understanding is insufficient to permit reliance upon a model; hence a case structure must be defined to accommodate the range of conditions expected.

The number of elicitation cases required for GRE volumes and frequencies may be represented as

$$N_{GRE} = N_{QGW} + N_{XGW} + N_{VGRS} + N_{FGRS} + N_{VGRI} + N_{VWDI} + N_{VBGBL} + N_{CAGR} + N_{TGR} + N_{VGEQK} + N_{RGSS}. \qquad (D\text{-}1)$$

Here the Ns are the number of cases required to address the categories indicated by the subscripts, the subscripts QGW and XGW refer respectively to the quantity of gas retained in the waste and the composition of this gas, subscripts VGRS and FGRS refer respectively to volume fraction of gas released in GREs and the frequency of release occurring in spontaneous GREs, VGRI refers to the volume fraction released in a GRE triggered by waste-intrusive operations, VWDI refers to the volume of waste disturbed by waste-intrusive operations, VBGBL refers to the volume of gas released from hypothesized "big bubbles" as a results of waste-intrusive operations, CAGR is the parameter representing uncertainty in the waste surface area over which a GRE occurs, TGR refers to the time duration of the GRE, VGEQK refers to the volume fraction of gas released in a GRE triggered by an earthquake, RGSS refers to the long-term fractional rate of gas release at steady state or quasi-steady state. The meaning of some of these quantities should become clearer in the following discussion.

D.3.1 Quantity of Gas Retained in the Waste (QGW)

The elicitations on GRE magnitudes to be described in Section D.3.3 and D.3.4 are in terms of gas release fractions or amounts of waste disturbed, respectively; they are not in terms of actual gas release volumes. Hence information as to the amount of gas retained in the waste per unit volume of waste is required (waste volumes are generally known because levels are known). Information on the amounts of retained gas is available for some tanks, but there is substantial uncertainty in the amounts of gas for most of the tanks. It is proposed to group the tanks into "bins" depending upon what is known about the wastes they contain, and perform elicitations for each bin. The bins into which the tanks are grouped define the elicitation cases.

Although the chemically reactive gas components are principally of interest for combustion analysis, the total gas release is also of interest because it determines the extent of tank pressure rise in the absence of combustion; among other things, this pressure rise is needed in order to determine whether flammable conditions may develop within some of the ex-tank equipment. Hence the elicitation variable is the total volume of gas retained per unit volume of waste, and composition is considered in the next subsection.

In the present evaluation, it is assumed that $N_{QGW} = 5$ will provide adequate coverage.

D.3.2 Gas Composition (XGW)

Gas composition poses a more complex problem than gas quantity because there are several constituents and, ideally, the mole fractions of all of them would be specified. Measurements of gas composition within the waste are very sparse.[D-3] For a number of tanks, gas compositions in the head space have been measured; this gives data on H_2, N_2O, and CH_4 but no meaningful data on N_2, O_2, etc., owing to dilution with atmospheric air. Data on NH_3 are reportedly difficult to interpret owing to its strong tendency to absorb on surfaces and/or dissolve in tank liquids. In Reference D-3, head space gas compositions were converted to slurry gas composition estimates by assuming 0% nitrogen and 15% NH_3 for all cases. The remaining gases (H_2, CH_4, and N_2O) varied over a wide range and were all significant in at least some cases.

Where head space gas composition data are available, estimating slurry gas composition as in Reference D-3 may be adequate; composition data may then be input to the SCOPE-AT from a data file. For the other tanks, elicitation cases may be defined based upon what is known about the tanks. The number and complexity of the elicitations required depends upon whether correlations among the gas constituents are sufficiently important that they need to be taken into account.

The correlation question is examined in Figure D-1, in which the ratio $CH_4/(H_2+CH_4)$ is plotted against the ratio N_2O/(total RG), where "RG" represents total chemically reactive gas (H_2, N_2O, CH_4, and NH_3; other reactive species such as CO are assumed to be negligible). Data are taken from Table 5 of Reference A-5 and include the assumption that NH_3 is 15% in all cases. There appears to be a weak negative correlation between $CH_4/(H_2+CH_4)$ and N_2O/RG. However, a least-squares analysis indicates that this correlation explains only ~7% of the total variation in $CH_4/(H_2+CH_4)$ (i.e., $R^2 \approx 0.07$), which is not statistically significant. Hence we assume correlations may be neglected for present purposes.

As the figure shows, N_2O content varies from negligible to > 50% of the RG, and the $CH_4/(H_2+CH_4)$ ratio varies from negligible to ~0.5. The properties of these gases differ substantially from one another: N_2O is an oxidizer while the other RG constituents are fuels, and the molar heat of combustion of CH_4 is about 3.3 times that of H_2. Hence it would not be a good approximation to neglect these variations in composition.

The approach currently proposed is as follows:

1. Define "reactive gas" (RG) to be H_2, N_2O, CH_4, and NH_3; other species (N_2, CO_2) are "nonreactive" (it is assumed that any other reactive species such as CO are negligible).

2. Adopt the assumption of Reference D-3 that NH_3 is about 15% of the RG.

3. Elicit the nonreactive gas fraction and two other independent composition variables for the RG fraction (together with the assumption that the RG is 15% NH_3, determining two other independent RG composition variables is sufficient to fix the RG composition).

Possible elicitation variables could be independent ratios such as those plotted in Figure D-1. Eliciting individual gas compositions may be less satisfactory because these are not mutually independent; i.e., all the constituent mole fractions must sum to unity. Hence there is necessarily a negative correlation between the individual mole fractions because, if one mole fraction is large, others must necessarily be small. Allowing for this requirement could complicate the elicitation process.

For planning purposes, it is assumed that three elicitation cases will be defined, based upon categorizing the waste according to properties known to affect gas composition. Since there are three composition variables to be elicited per case, $N_{XGW} = 9$. Obviously, this number could change. The number of elicitation cases could be either increased or decreased once an improved systematization of available information on gas composition as a function of known waste properties is available. If no useful systematization is found, it might be decided that basing uncertainty distributions on an updated version of the data in Reference D-3 is as good an approach as any, in which case elicitations might not be needed.

An alternative approach would be to attempt to define a conservative gas composition that would be used for all tanks with unknown gas compositions. One problem with this approach is that no one assumption is "conservative" in all contexts. Assuming 100% H_2 is conservative for comparisons with the LFL, while assuming high CH_4 content is conservative in calculating tank pressures following a burn. Assuming $N_2O/RG \approx 0$ is conservative for calculating tank head space burns, in which atmospheric oxygen supplies ample oxidizer; it would be nonconservative for evaluating subsurface burns or burns in inerted waste-intrusive equipment, since atmospheric oxygen is not available in these scenarios and burns can occur only if N_2O is present.

D.3.3 Release Fractions and Frequencies in Spontaneous GREs (VGRS, FGRS)

For spontaneous GREs, it is necessary to consider both uncertainty in the quantity of gas released and uncertainty in the frequency of release. Quantities of gas released are expressed in terms of the fraction of the retained gas that will be released rather than in terms of the actual volume in m^3 that is released. This fraction multiplied by QGW (Section D.3.1) and the known waste volume in the tank then gives the actual volume released. At present we assume that it will be acceptable to elicit the magnitudes and the frequencies of the releases separately. If the experts reject this assumption, it will be necessary to define a more complex elicitation structure, e.g., one with different frequency uncertainty distributions for releases of different magnitudes.

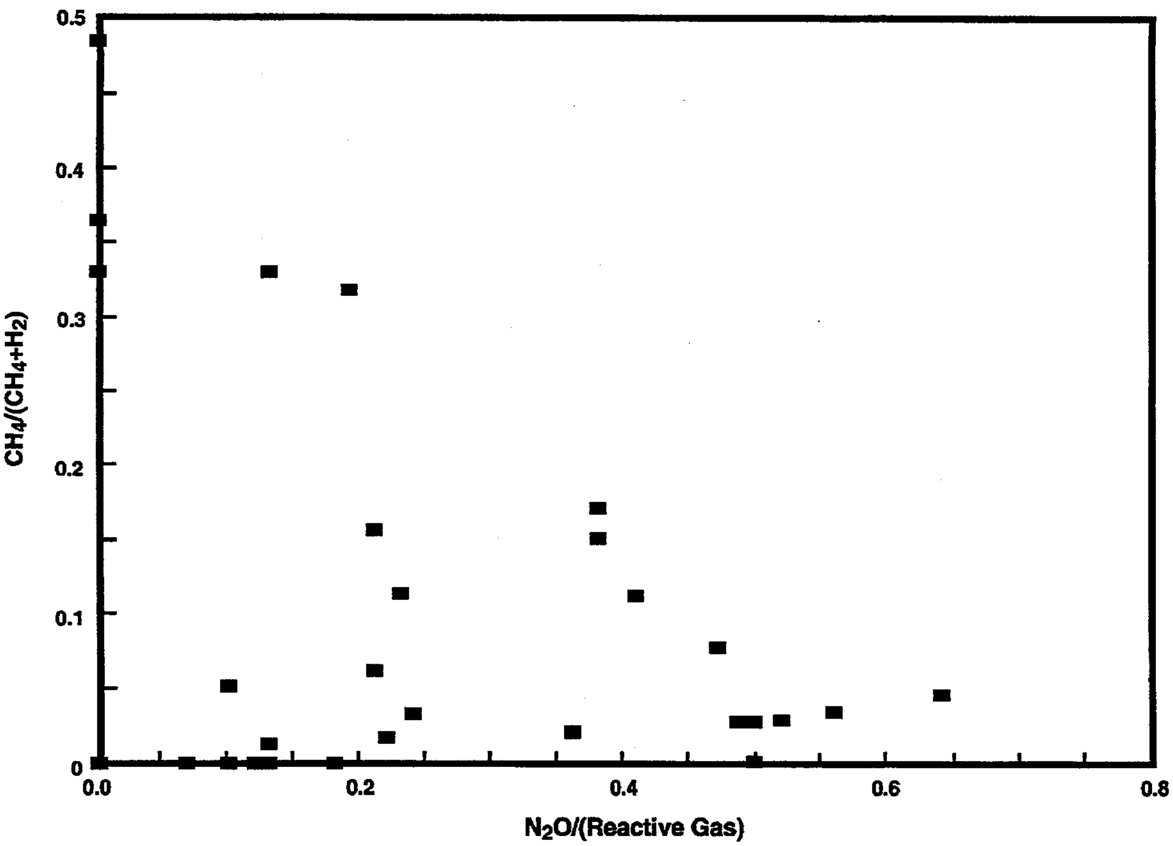

Figure D-1. Ratio of $CH_4/(H_2 + CH_4)$ to N_2O/(total RG).

Gas Release Fractions (VGRS). The quantity to be elicited is the fraction of the retained gas that is released given that a GRE does occur. Because of the different waste rheologies, release mechanisms are different for the SST and the DST and they will be considered separately. Spontaneous release mechanisms for the SST are not well defined, but factors considered to be important are the rheology (i.e., salt-well pumped or not pumped) and the void fraction in the waste. The fraction of retained gas that is released is thought likely to increase with increasing void fraction, since the amount of interconnected porosity is likely to be greater when the void fraction is large. We therefore assume the conditioning variables to be rheology and void fraction. Three cases are considered adequate to span the range of void fractions of interest ($N_{void} = 3$). The number of elicitations for VGRS in the SSTs is then

$$[N_{VGRS}]_{SST} = N_{rhe} N_{void} = (2)(3) = 6. \tag{D-2}$$

Spontaneous rollover GREs are an important concern for the DSTs, since all major gas releases observed to date fall in this category. All DSTs are considered to have the same basic "rheology"; i.e., solids overlain by liquid supernate. However, void fraction and the thickness of the solid waste layer are considered important and these are therefore selected as the conditioning variables in defining the case structure. Three cases each are considered adequate for the void fraction and the thickness parameters.

If spontaneous nonrollover GREs are deemed credible for the SSTs, it may be that such events need to be considered for the DSTs also. Even if this is the case, it does not necessarily follow that separate elicitations are required to include the nonrollover GREs. For example, the experts may conclude that the nonrollover events can be combined with the rollover events, and a single set of elicitations provided that includes both rollover and nonrollover GREs. In the present analysis, we assume that this will be the case, but continue to carry the nonrollover GREs in the case structure representations in order to indicate that the question must be considered by the experts.

The case structure for DSTs is then represented by

$$[N_{VGRS}]_{DST} = N_{v'oid} N_{thick} + N_{nr,spon} = (3)(3) + (0) = 9. \qquad \text{(D-3)}$$

The first term represents rollover events and the second term represents any additional elicitations required to account for spontaneous nonrollover GREs.

Including both the SSTs and the DSTs, a total of 15 elicitations are required for VGRS.

Spontaneous GRE Frequencies (FGRS). It is assumed that an uncertainty distribution for the GRE frequency will be elicited for each of the cases defined for the release magnitude. Hence the case structure is assumed to be the same for FGRS as for VGRS, and $N_{FGRS} = N_{VGRS} = 15$.

Discussion, Spontaneous GREs. The preceding accounting yields a total of 30 elicitation cases to quantify gas releases and release frequencies for spontaneous GREs. There are several points at which the evaluation of this case structure by the experts could either increase or decrease the number of elicitations. In the direction of increased complexity, the experts could decide that $N_{nr,spon} > 0$ is required. More fundamentally, the experts may conclude that additional variables need to be taken into account in the case structure. For example, the difference in density ($\Delta\rho$) between the solid and liquid layers in the tanks is thought to be important for determining rollover behavior, and the experts may conclude that $\Delta\rho$ needs to be explicitly represented in the case structure for DSTs. Significant increases in complexity could then result.

Counterbalancing simplifications may also be possible. For example, if the experts concluded that $\Delta\rho$ required explicit representation in the case structure, it might also be concluded that the effects of void fraction were then adequately represented in the effects upon $\Delta\rho$ and the case structure did not need to explicitly include void fraction. Other reasons might be found for believing that the *fraction* of the retained gas that is released might not be sufficiently sensitive to void fraction and/or solid waste thickness that explicit representation in the case structure is required. (Note that, since elicitations are in terms of fraction of retained gas that is released, a first-order dependence upon both void fraction and waste thickness is already built into the system). It is also possible that release frequencies for rollover GREs could be based at least in part upon the historical record, which could reduce the number of elicitations required for rollover frequencies.

D.3.4 Induced Releases (VGRI, VDWI, VBGBL)

For releases induced by waste-disturbing intrusive operations, release is elicited on a "per event" basis rather than on a per unit time basis as in the case of spontaneous releases. Intrusive events are generally planned operations and the user will normally specify event frequencies. Frequency elicitations are therefore not included for induced releases.

Three mechanisms for GRE induction by waste-disturbing intrusive operations may be considered:

1. In DSTs, disturbing the waste may trigger a rollover GRE.
2. At least some of the gas in waste that is physically disturbed is likely to be released.
3. Intrusion may result in release from a single large bubble (the "big bubble" hypothesis).

One reason for explicitly distinguishing these cases is that the elicitation variables are not the same (i.e., they do not have the same units) and therefore must be entered as different variables in the SCOPE parameter database and used in different ways in the SCOPE-AT.

Induced Rollover GREs (VGRI). Waste-intrusive operations in a DST may trigger a rollover GRE that is large in comparison with the amount of gas that would be released from only the waste that is directly disturbed by the intrusion. The magnitude of a release of this type might not be sensitive to the amount of waste disturbed in the operation that triggered the release. However, the magnitude could depend upon the same parameters that control the magnitude of spontaneous rollover GREs. Hence the elicitation case structure is the same as the rollover contribution to VGRS, i.e.:

$$N_{VGRI} = N_{void} N_{thick} = (3)(3) = 9 \qquad \text{(D-4)}$$

The elicited variable is the volume fraction of the retained gas that is released in the event.

Release from Disturbed Waste (VWDI). Even if no rollover GRE is triggered, waste-disturbing operations are expected to release some or all of the gas from waste that is actually physically disturbed. This release is expected to be approximately proportional to the amount of waste disturbed. The elicitation variable is therefore taken to be the effective volume of waste that is disturbed per operation. By "effective" is meant that it will be assumed that all gas in disturbed waste will be released. This will actually be a good approximation for some types of waste disturbance but not all; where the experts consider this assumption to be overly conservative, they can take this into account by reducing their estimates for the effective volume disturbed.

For the SSTs, conditioning variables are taken to be the waste rheology types (i.e., salt-well pumped and not pumped) and the nature of the operations being performed. For the DSTs, the conditioning variable is the nature of the operations being performed. It is assumed that five categories of operation will be considered for SSTs and also 5 for DSTs. Hence the number of elicitations required for VWDI is

$$N_{VDWI} = [N_{rhe} N_{ops}]_{SST} + [N_{ops}]_{DST} = (2)(5) + (5) = (15). \qquad \text{(D-5)}$$

"Big Bubble" Releases (VBGBL). It has been suggested that the wastes may contain large bubbles such that all the gas in the bubble will be released if the bubble is penetrated, almost independently of the amount of waste disturbed. The elicitation variable is the actual volume of the bubble. This scenario is of interest only if the bubble is large enough that combustion of the released gas could result in threats to HEPA integrity, which requires volumes > 1 m^3 as noted above. It is our expectation that the experts may consider this scenario implausible and we therefore assume $N_{VBGBL} = 0$ in estimating the total number of elicitations. We retain the issue in the overall structure, however, in order to bring it to the attention of the experts.

Discussion, Induced Releases. The case structure defined here requires 24 elicitations to assess gas releases induced by waste-intrusive operations. As in the case of spontaneous releases, future refinements could either increase or decrease the number of elicitations required. Although the frequencies of intrusive events are user input rather than elicited, it could be decided that the probability of a rollover event given an intrusive operation should be elicited, in addition to the magnitude of the event. The same may be true for the "big bubble" events if these are considered credible. On the other hand, it may be that the effective volume of waste disturbed can be sufficiently well defined for many intrusive events that elicitations are not needed, in which case N_{VWDI} may be decreased.

D.3.5 Area and Duration of Gas Releases (CAGR, TGR)

The combustion completeness analysis (Section D.4) requires as input the area of waste surface from which a GRE occurs and the time duration of the release.

Release Area (CAGR). It is assumed here that the release area will tend to be proportional to the volume fraction of the waste released. One rationale is that, for large fractional releases, gas must be released from waste corresponding to a large fraction of the waste surface area in the tank. Release from a small release point would require the gas to flow through the waste for long distances through interconnected porosity. It seems questionable whether large-scale interconnected porosity is sufficiently great to permit this to occur, especially for relatively rapid releases. For small releases, the variations in amount may reflect variations in the depth over which waste releases its gas as well as in the area over which release occurs, and the proportionality between release area and release fraction is less clear.

Since the proportionality relationship is uncertain, an uncertainty distribution will be elicited for the proportionality constant. In particular, we assume

$$A_f = CAGR * V_f, \qquad \text{(D-6)}$$

where A_f is the fraction of the waste surface over which release occurs, V_f is the volume fraction of the release, and CAGR is the proportionality constant that is elicited.

The relationship between A_f and V_f likely depends upon the release mechanism. At this point we define three cases ($N_{CAGR} = 3$) corresponding to rollover GREs, barometric nonrollover GREs, and other nonrollover GREs. Barometric nonrollover GREs refers to the enhanced gas release rates that have sometimes been observed during periods of low barometric pressure associated with the passage of weather systems. Note that separate cases have not been defined for spontaneous versus induced GREs. For some intrusive operations, the areas of the disturbed surface may be reasonably well defined, in which case the user may specify the area through input.

Duration of Release (TGR). TGR is the characteristic time over which the release occurs. Together with the amount of release, TGR is used to determine release rates. TGR will be elicited directly, using the same case structure as for CAGR; hence $N_{TGR} = 3$. Note, however, that historical data for TGR are available in some instances, and these data may be used to supplant elicited values.

D.3.6 Earthquake-Induced Gas Release (VGEQK)

Substantial gas release may occur during and immediately following an earthquake. Elicitation requirements have not received detailed study and it is currently expected that there will not be a strong initial focus, at least, on earthquakes in Phase 2 SCOPE. For present purposes we assume three cases ($N_{VGEQK} = 3$) based upon the three basic waste rheologies adopted in this work; i.e., salt-well pumped SST, unpumped SST, and DST.

D.3.7 Steady-State and Quasi-steady Release Rates (RGSS)

In all the events considered up to this point, it has been implicitly assumed that the gas release is in the form of discrete events that occur sufficiently rapid that the integral release is the most important parameter. However, it is known that tanks release gas continuously at a slow rate independently of the discrete GREs. These releases continue over time periods long compared with the characteristic ventilation times for the tanks, even for tanks with passive ventilation only. Release rate rather than total release then determines the gas concentrations. Hence the steady state release rates are needed for a variety of purposes, such as estimating flammable gas concentrations in passively ventilated tanks and estimating conditions following ventilation outages in actively ventilated tanks.

The elicitation parameter is the fractional release rate. Five elicitation cases are defined ($N_{RGSS} = 5$). These correspond to the following:

1. DSTs;

2. SSTs w/o saltwell pumping;

3. Late stage, saltwell pumped SSTs;

4. Early stage saltwell pumped SSTs (release from saltcake); and

5. Early stage saltwell pumped SSTs (release from sludge)

By "late stage" is meant tanks for which pumping began sufficiently long ago that little or no additional liquid is being removed or that the amount of liquid removed has reached a steady state with respect to any inflow; and conversely for "early stage" pumping. For early stage pumping, the rate of gas release is expected to be related to the rate at which liquid drains from the solid wastes. This rate is expected to be quite different for the saltcake and for the sludge components of the waste, and separate elicitations are therefore provided.

D.3.8 Total Elicitations for Gas Release

As analyzed here, the number of elicitations required for the gas release parameters totals 82. Future refinements may change this estimate in either direction.

D.4 Gas Combustion

For a well-mixed head space, the fraction burned will vary from ~0% to ~100% as the hydrogen mole fraction increases from about 4% to about 8%. For intermediate values, the completeness is a strong function of the mole fraction and also depends upon ignition location. For many scenarios, the well-mixed combustible mole fractions may be below the LFL, but compositions may be combustible in the plume that exists during and immediately after gas release, before the entire head space becomes well mixed. If an ignition source (spark) exists within the flammable volume, a plume burn may occur.

Plume combustion can have a complex dependence upon a number of parameters, and defining elicitation cases to reflect all these dependencies would be difficult. However, plume dependencies are sufficiently well understood that available models capture a large part of the dependency. Hence it is planned to use combustion models to make a zero-order prediction of the combustion completeness. The experts will then be elicited on measures of the uncertainty in the model rather than on the burn completeness directly.

As an example of the role a combustion model can play, we note that Reference D-4 describes a simple model for incomplete combustion in mixed layers that could be directly applied to the well-mixed case, and the model can provide a reference point for plume or layer cases. The model considers the concentrations of fuel and inertants, which influence flame speed, and the geometry, which influences the ultimate fraction of a region that is entrained into the burned gases. A commonly used parameter known as the flame flux multiplier is employed in the model to subsume uncertainty in the combination of flame morphology, flame speed, turbulence, and the density of entrained gases[D-5].

Since the model can encompass a large dynamic range of independent parameters such as gas composition, headspace height above the ignition point, tank radius, and turbulence, it is logical to elicit opinion on the efficacy of the model. This can be implemented as either elicitation on the uncertainty in the correct input value of the flame flux multiplier or as elicitation of a correction factor for the output combustion completeness (or pressure rise). The choice of which elicitation is used may be guided by preliminary sensitivity runs to determine which would yield the best fidelity to known experiments, e.g., if a simple systematic variation in one parameter is possible while no pattern is apparent in another.

Burn Completeness (FBRN). The burn completeness is the fraction of the total GRE that actually burns. As noted above, this fraction is not the actual elicitation parameter; the elicitation parameter is either a correction factor to be applied to the model prediction or else the flame flux multiplier. In either case it is a dimensionless number. The case structure is assumed to be given by

$$N_{FBRN} = N_{scen} N_{level}, \qquad \text{(D-7)}$$

where N_{scen} refers to the number of qualitatively distinct scenarios considered, and N_{level} is the number of cases defined for each scenario based upon the ranges spanned by the dominant parameters.

Three basic scenarios ($N_{scen} = 3$) are considered. These are:

1. Well-mixed head space gas;

2. Buoyant gas release with plume rising to the tank upper head space; and

3. Nonbuoyant gas release stratifying in the lower part of the tank head space, or initial phases of a buoyant release before substantial plume rise occurs.

It is not expected that a single elicitation will be adequate for the full ranges of conditions that can arise within these general scenarios. Hence N_{level} cases are allowed for within each scenario to account for additional variations that are important, especially the large variation in gas release quantities and rates that may be possible. $N_{level} = 5$ is assumed to be adequate here; hence $N_{FBRN} = 15$.

<u>Tank Ventilation Rates (RVNT and/or TAUXC)</u>. Elicitations described in Section D.3 will define most of the input required for the hydrogen burn models such as gas release quantities, compositions, release rates, and the waste surface area over which the release occurs. One other parameter that can be important is the tank ventilation rate. The ventilation rate controls the duration of the burn "window," i.e., the length of time following a GRE that conditions remain flammable within the tank. Together with RGSS (Section D.3.7), the ventilation rate controls the steady-state gas concentrations in SSTs. When ventilation rates are sufficiently large, they can also affect the rate at which a plume becomes well mixed with the entire tank head space.

For some tanks, ventilation rates may be well established, in which case they will either be provided by user-specified input or incorporated into the SCOPE parameter database. However, ventilation rates are not well established for all tanks and provision is made for elicitation of ventilation rates. For the SSTs, ventilation is currently limited to passive ventilation by natural processes while active ventilation is provided for the DSTs. It is estimated that 5 elicitation cases will be needed, with 2 cases being allocated to the SSTs and 3 cases to the DSTs. For the passively ventilated tanks, the elicitation parameter may be either the ventilation rate (RVNT in m^3/s) or the characteristic time to exchange out the tank headspace gas (TAUXC in s), depending upon which will give the simplest systematics. For the actively ventilated tanks, RVNT would be elicited. With the ventilation cases included, 20 elicitation cases are required to define the tank headspace burn behavior.

<u>Calculation of Pressure Rise</u>. A major purpose of the burn analysis is to calculate the pressure rise resulting from the burn. Given the gas release quantity, composition, and completeness fraction, the adiabatic pressure increase can be calculated using simple models. If mitigation by atmosphere-structure heat transfer during the burn is to be taken into account, the calculation is more complex and a number of uncertainties would require consideration. The adiabatic approximation is always conservative in this context but the degree of conservatism is usually not excessive; that is, mitigation by heat transfer during the burn is normally not a very large effect. Hence the adiabatic approximation will be used to calculate the pressure rise in the SCOPE-AT.

D.5 Deflagration to Detonation Transition (DDT)

Tieszen et al.[D-6] have reviewed the factors that control whether DDT is likely to occur. DDT tends to be favored by 1-D or 2-D geometries involving passages that are long compared with their width, with walls that prevent pressure relief by lateral expansion. There are strong dependencies upon other geometrical features, including especially the presence of obstacles that promote turbulence, which greatly increases the likelihood of DDT. The sensitivity of a gas mixture to DDT is also a very strong function of the gas composition. This sensitivity is represented by the detonation cell size, λ; small values of λ correspond to high sensitivity. Detonation cell size is plotted as a function of gas composition for air-hydrogen-steam mixtures in Figure D-2, which is taken from Reference D-6. The cell size is large for marginally detonable concentrations and is a minimum for gas mixtures near the stoichiometric composition. For otherwise-similar geometries, a good scaling parameter is the ratio λ/L, where L is a characteristic dimension of the volume of interest (diameter for a tube, width for a duct, etc.) DDT is considered to be at least marginally possible when $\lambda/L \leq \pi$ and strongly favored if $\lambda/L \ll 1$ when other geometrical details are favorable.

The detonation cell size λ can be estimated reasonably well from models such as those cited in Reference D-6, and L is known for any specific volume of interest. Hence elicitations are not considered necessary to define the scaling parameter λ/L, assuming the gas composition can be adequately defined from the upstream analysis of gas release and gas plume behaviors. However, λ/L is only a scaling parameter for relative sensitivities; even given the geometry there is considerable uncertainty as to whether DDT will occur for a given case and the likelihood of DDT can be very different for different geometries. Hence elicitations are needed to define the probability of DDT as a function of λ/L.

Separate cases are defined to take into account the different geometric configurations potentially of interest. The potential for DDT inside equipment is generally assumed to be much greater than for the tank head space, but the latter will still be included in the case structure offered to the experts. The quantity to be elicited is the probability of DDT (PDDT) and the currently proposed case structure is

$$N_{PDDT} = N_{head} + N_{pp} + N_{xtduct} + N_{intreq} \tag{D-8}$$

Here the subscripts refer, respectively, to DDT in the tank headspace, the pump pit, ex-tank ducts and/or pipes, and waste-intrusive equipment.

DDT in the tank headspace seems implausible because concentrations achievable in the head space are normally no greater than the threshold at which DDT is remotely possible, and the geometry is not favorable. Hence we assume $N_{head} = 0$, but leave it in the case structure for the expert panel to consider.

DDT in the pump pit may also be implausible because of marginal concentrations and a 3-D geometry; however we do not rule it out because L is large and obstacles are present. We allow $N_{pp} = 2$ for planning purposes. Ducts and piping in ex-tank equipment and waste-intrusive equipment present more favorable geometries for DDT than the tank head space, and DDT in waste-intrusive equipment is more likely than in ex-tank equipment because gas concentration can be higher in the waste-intrusive equipment. We allocate 2 cases for ex-tank ducts and pipes and 4 cases for waste-intrusive equipment; hence N_{PDDT} totals 8.

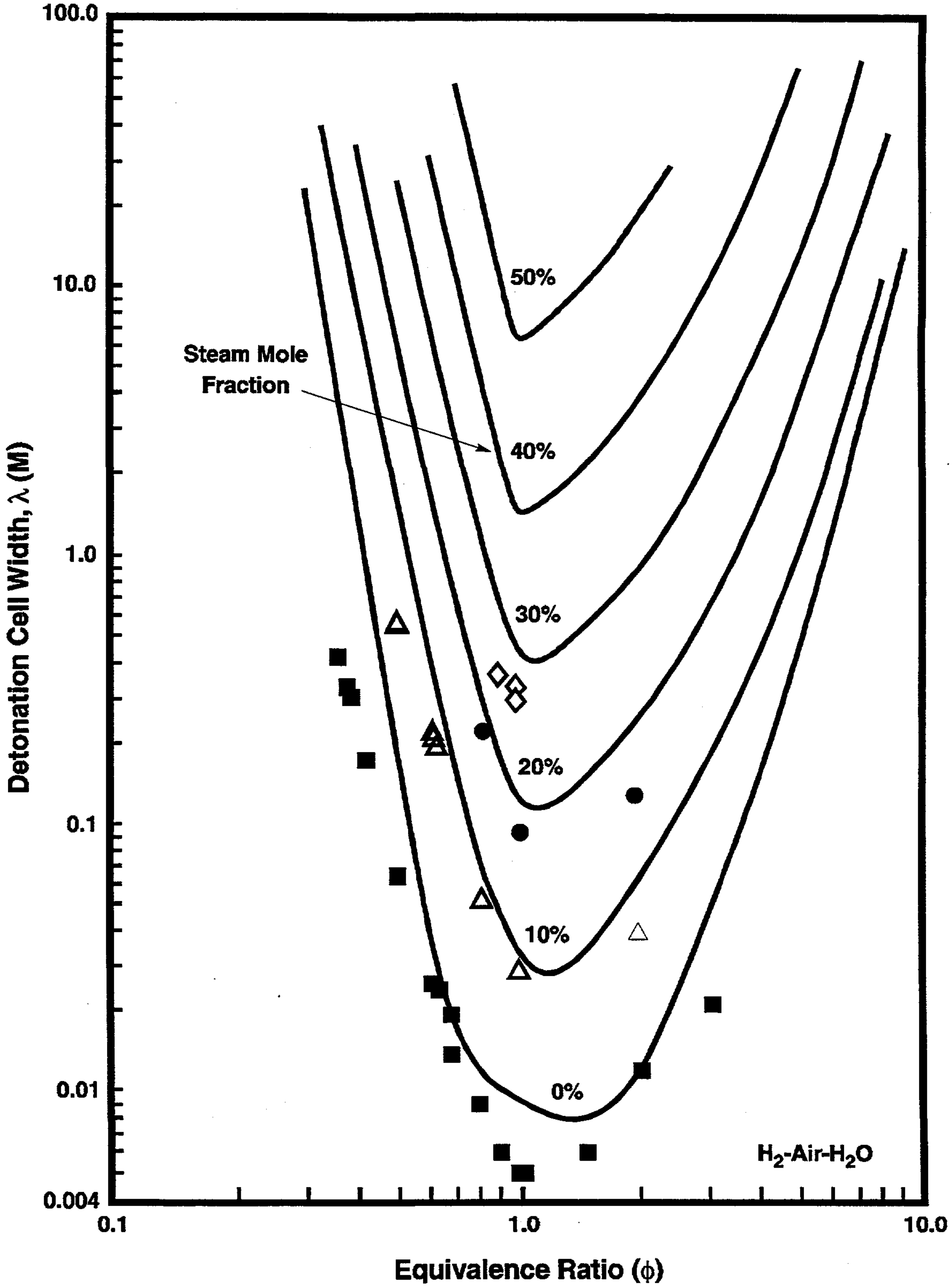

Figure D-2. An example of detonation cell width data and predictions. (H_2, air stream; ρ_{air} - 1.184 kg/m^3, T = 100°C for data, T = saturation for prediction) (from Ref. D-6.)

The preceding discussion assumes the gas concentrations in the regions of interest are known. For the waste-intrusive equipment, these concentrations should be defined by the elicitations for intrusive operations (Section D.7.2). Gas concentrations in the ex-tank equipment will be driven by the releases to the tank headspace. Ideally, the information obtained from the gas release analysis and the plume modeling used to support the combustion analysis would be sufficient to define the range of gas compositions that must be allowed for. For example, the elicited information in Sections D.3 and D.4 together with a plume model could be used to predict the gas concentrations at the points where the head gases enter exit paths to external equipment. If this representation of the composition is considered adequate, additional elicitations may not be needed. However, it seems more likely that there will be a need to elicit an uncertainty distribution for a dimensionless correction factor, CCOMP, to be applied to the concentrations predicted by the model. Two cases are allowed for (N_{CCOMP} = 2) in the present review, which brings the total number of elicitations required for the DDT analysis to 10.

D.6 Released Waste Mass Due to Headspace Burn

If there is a headspace burn, waste can be resuspended from either the waste surfaces or the surfaces of contaminated structures; the amounts are quite uncertain and elicitations are needed to evaluate the quantities that become airborne. Furthermore, some waste may become resuspended as a result of the GRE itself. The amounts resuspended by the various mechanisms will likely be sensitive to the intensity of the driving burn and it is doubtful that models for resuspension are adequate to capture this dependence reliably; hence the dependence upon burn intensity should be reflected in the case structure. The loadings on contaminated surfaces are also uncertain and may have to be considered by the experts, and release from the HEPA filter (which will have failed in the scenarios of interest) needs to be assessed. Given the amount of waste airborne and the extent of tank pressurization (from Section 4.3), the amount released to the environment may be calculated to a reasonable approximation without additional elicitations provided certain approximations are accepted. Finally, aerosol size information is needed to calculate the consequences of the release. These issues are discussed in more detail in the present section.

There are many complex issues involved in estimating resuspension, and defining an optimum decomposition will require considerable study of the available information as part of phase 2. For present purposes, we assume direct elicitation of the mass resuspended from the surface of the waste (MRES) and elicitation of the fraction resuspended (FRES) from contaminated surfaces and from failed HEPA filters. In future refinements, it is possible that models will be defined for at least some of these resuspension processes and elicitations performed on the uncertainties in the model predictions, instead of eliciting the quantities directly.

Mass Resuspended from the Waste (MRES). We consider resuspension from the waste surface resulting from the GRE itself and resuspension resulting from the combustion event; the masses resuspended by the two processes are additive. The elicitation variable is the actual mass resuspended. For resuspension by the GRE, possible conditioning variables include the waste surface character (liquid versus solid) and GRE parameters (magnitude, rate, type of GRE). For resuspension resulting from the burn, the conditioning variables are waste surface character and burn intensity as represented by the burn pressure rise, ΔP. The case structure assumed is

$$N_{MRES} = N_{wsurf}(N_{gre} + N_{\delta p}), \qquad \text{(D-9)}$$

where the subscripts "wsurf," "gre," and "δp" refer respectively to the waste surface character, GRE parameters, and burn ΔP.

For surface character, we distinguish liquid versus solid waste surfaces, giving $N_{wsurf} = 2$. For present purposes we assume $N_{gre} = 3$ in order to allow some representation of the range of GRE cases that must be considered. Note that Eq. (D-9) as written implies three GRE cases are considered for tanks with liquid waste surfaces and three for tanks with solid waste surfaces; actually there is no reason that these numbers of cases must be equal.

For the burn ΔP parameter, one case is assigned to burns sufficiently severe that the tank dome fails. The other burns of interest are those that fail the HEPAs or other tank features essential to confinement but do not fail the tank dome. Since this range may be rather wide, it is subdivided into two cases. Events insufficiently severe to fail the HEPA do not require detailed consideration. Hence $N_{\delta p} = 3$ is assumed. If DDT in the head space is considered credible, a fourth case might be required to treat resuspension by detonations.

With these assignments, $N_{MRES} = 12$.

Fraction Resuspended from Structures and the HEPA (FRES). The elicitation variable, FRES, is the fraction of the waste loading on contaminated surfaces (or the HEPA) that is resuspended. For FRES, one conditioning variable is the burn intensity as represented by ΔP, which is treated as before. For resuspension from surfaces, location and nature of the surface can be important in determining the resuspension fraction; we allow for specification of three cases in order to obtain a coarse representation of these variations. For the fraction released from the HEPA, it is not clear what conditioning variables should be specified in addition to the burn intensity. The decomposition and the number of cases proposed is then

$$N_{FRES} = N_{\delta p}(N_{ssurf} + N_{hepa}) = (3)[(3) + (1)] = 12, \qquad \text{(D-10)}$$

where the subscripts "ssurf" and "hepa" refer to structure surfaces and the HEPA filter, respectively.

Structure Surface and HEPA Loadings (SLOAD, HLOAD). Since resuspension from contaminated structure surfaces and from the failed HEPA is to be expressed in terms of the fraction resuspended, it is necessary to define the waste loadings on the contaminated surfaces and the HEPA filters. Only limited information is available concerning these loadings and some elicitations should be allowed for in order to develop uncertainty distributions for these quantities. Case conditioning variables have not yet been defined but it is expected that more than one case will be needed. For SLOAD, the elicitation variable could be either the loading per unit area (kg/m^2) or the total load (kg); for HLOAD, the elicitation variable is the total load (kg). For the present scoping exercise, we assume $N_{SLOAD} = 4$ and $N_{HLOAD} = 2$.

Particle Size Distribution Parameters (MMD, SIGG). Consequences of a release of waste depend heavily upon the particle size distribution for the resuspended waste. For health effects, the inhalation dose is usually assumed to dominate and for inhalation, the amount released as respirable aerosols is controlling. (The respirable release may be much smaller than the total release in some cases.) Site contamination is controlled principally by the larger particles, especially close to the release point. The amount of waste reaching the site boundary is also affected by the size distribution; this transport can include particles larger than the maximum respirable size but the largest particles released may not transport that far.

For many particle production mechanisms, the resulting size distribution is approximately lognormal. Lognormal distributions can be represented in terms of their mass median diameter (MMD) and the geometric standard deviation (σ_g in the usual notation; called SIGG in what follows in order to maintain notational consistency with usage elsewhere in this appendix). We specify three cases ($N_{MMD} = N_{SIGG} = 3$) in order to allow for a crude representation of dependencies upon parameters considered important for determining particle size such as burn intensity or nature of the surface from which resuspension occurs.

Alternative means of representing size distribution information are possible. For example, the fraction in the respirable range could be elicited directly; only one elicitation per case would then be required, but the ability to assess site contamination would be somewhat impaired because of the less detailed size distribution information available. If only health effects are of interest, the amount resuspended as respirable aerosol might be elicited directly, rather than eliciting total waste resuspended and size distribution information separately; i.e., MRES and FRES could be redefined to represent the amounts of waste resuspended that is in the respirable size range. This would eliminate the need for separate elicitations for the particle size. One price paid would be that the total release would not be obtained, and total release likely will be what drives ground contamination and cleanup costs. These parameters are important to the mission integrity question. Furthermore, it is not clear that eliminating the explicit size distribution elicitations will save much effort, because the experts might need to decompose the respirable release question into a total resuspension question and a respirable fraction question anyway. Hence it is currently expected that the size distribution elicitations will be retained.

Evaluation of Releases from the Tank. Given the postburn pressure, it is simple to evaluate how much of the resuspended material is released if one assumes that the tank head space is well mixed and the tank depressurizes adiabatically; that is, that the flow out of the tank is the only depressurization mechanism. Gas then flows out of the tank until the tank pressure reaches the ambient pressure. If P_{max} is the peak tank pressure resulting from the burn and P_a is the ambient pressure, the fraction of the airborne material within the tank that is released, F_r, is given by

$$F_r = 1 - \left(\frac{P_a}{P_{max}}\right)^{\frac{1}{\gamma}}, \qquad \text{(D-11)}$$

where γ is the ratio of specific heats of the tank gas. The adiabatic assumption is conservative because atmosphere-structure heat transfer will also act to reduce tank pressurization and thus reduce the amount of outflow that occurs before pressure equalization. Failure of the well-mixed assumption could either increase or decrease releases.

Treating the nonadiabatic effects would complicate the analysis substantially and any treatment of departures from well-mixed conditions would be very uncertain. The SCOPE-AT will therefore use the adiabatic model to calculate the releases. It is possible that detailed analyses could be used to justify alternative treatments in specific cases and the SCOPE-AT input will therefore include an option that multiplies the calculated release by a user-specified factor. It would, of course, be up to the user to justify the value chosen for this parameter.

Radiological and Toxicological Content. The elicitations and analyses described in this section leads to estimates of releases in terms of mass of waste released. It is not expected that waste and structure surfaces will become sufficiently hot that volatilization will contribute substantially to resuspension; hence, resuspension is principally the result of mechanical processes. The resuspended waste will therefore have compositions approximately the same as the composition of the waste reservoirs from which it was resuspended.

Radiological and toxicological releases will be evaluated using the "unit liter release" methodology developed at Hanford. This methodology is based upon compilations of the radionuclide and toxicological contents of various waste categories and evaluating the doses that result from release of one liter of waste in a given category. The categories are defined in terms of the specific tank or tanks of interest and whether the wastes involved are liquids or solids. Since the tank(s) of interest will be specified by the SCOPE-AT user and the resuspension scheme described above does distinguish between resuspension from liquid versus solid waste surfaces, much of the information required to assign the releases to the appropriate Hanford unit liter release categories will be available. However, the composition of material deposited on contaminated structure surfaces and HEPA filters may differ from the composition of the bulk waste materials in the tank; e.g., residues from evaporated liquids may be more concentrated than assumed in the standard liquid categories. The significance of the uncertainties associated with this question will be assessed in Phase II and, if necessary, elicitations will be defined to address them.

Total Elicitations for Resuspension. With the case structure considered here, a total of 36 elicitations are required to define the amounts of waste resuspended in head space burn scenarios. This estimate does not include any additional elicitations required to address uncertainties in the composition of wastes on contaminated structure surfaces and HEPA filters.

D.7 Other Combustion Scenarios

With the exception of DDT, which applies principally to burns within equipment, the discussion in Sections D.2-D.6 have emphasized scenarios involving burns in the tank head space following a GRE. Attention has been focussed on this scenario because it is the most complex and largely controls the total number of elicitations needed. However, other scenarios must be considered in order to complete the assessment of the SCOPE-AT elicitation requirements. These scenarios include ex-tank burns within equipment, burns within waste-intrusive equipment, and burns beneath the surface of the waste. These scenarios will be briefly discussed here, although not at the level of detail that was given for the tank headspace burns.

D.7.1 Ex-Tank Burns in Equipment

If flammable gas compositions develop at the various locations at which flows exit the tank, flammable compositions may develop in pipes, ducts, and other equipment downstream of the tank exit points. If surfaces in these regions are contaminated with waste, ignition of the flammable gases could resuspend some of the waste and release it to the atmosphere.

Since flammable gases exiting the tank headspace are the source of flammable conditions developing in the ex-tank equipment, the elicitations and supporting analysis required for defining GREs and plume behavior for the headspace analysis should provide most of the information needed to assess flammable gas accumulation in the ex-tank equipment spaces without additional elicitations. Uncertainty in deriving ex-tank equipment gas compositions from the in-tank analyses was considered in connection with DDT in Section D.5 and may suffice to address uncertainties in ex-tank concentrations in the present context, since the modeling issues involved are basically the same. A small number of elicitations may be needed to address composition questions specific for particular ex-vessel equipment volumes, however.

Elicitations and supporting analysis for resuspension from structure surfaces within the tank will also provide some information needed for analyzing resuspension from ex-tank surfaces. It is likely that not all the required information will be so provided, because of the differences in structure geometries and flow velocities. A few elicitations may be required. Similar considerations apply for estimating the aerosol size distribution information.

It is estimated about 2 elicitations may be needed for the gas composition questions pertaining to the ex-tank analysis. Resuspension and particle size distribution are each estimated to require 4 elicitations specific to the ex-tank scenarios. About 3 elicitations may be needed to define the amount of contamination present on the ex-tank equipment surfaces when data are not available. These estimates imply that the total number of additional elicitations for the ex-tank scenario, $N_{ex\text{-}tank}$, is about 13.

Under certain conditions, a burn initiated in the ex-tank volume may propagate back down into the tank, initiating a burn there. This will be assumed to occur if the flammable gas concentration in the connecting pathway exceeds the downward LFL. This assumption is believed to be reasonable provided the ex-tank equipment volumes do not pressurize significantly with respect to the tank interior. Should pressurization occur, flow back into the tank could carry the flame front into the tank even if flammable gas compositions were too low to permit downward propagation through a static gas mixture. Pressurization is not considered likely because of the geometries involved. Given these assumptions, no new elicitations are required to address the propagation question.

D.7.2 Burns in Waste-Intrusive Equipment

Waste can release gas directly into waste-intrusive equipment, and gas concentrations in the waste-intrusive equipment are therefore independent of those in the tank headspace and may be higher than in the headspace. Waste can also enter the waste-intrusive equipment, and its possible ejection by a burn needs to be considered. Unlike the ex-vessel scenarios, most of the required information cannot be inferred from the tank headspace analysis except that the quantity and composition of gas retained in the waste will be available from the elicitations for QGW and XGW described in Sections D.3.2 and D.3.3. Questions that need to be considered include:

- Amounts of waste that enter the equipment
- Gas release from the waste within the equipment, and amounts of gas (if any) that enters the equipment from waste that remains in the tank
- Flammable mixture compositions that can develop within the equipment
- Ignition of flammable mixtures, and the intensity of the resulting combustion events
- Efficacy of inerting strategies for waste-intrusive equipment
- Extent of ejection of waste from the equipment into the environment
- Aerosol size distribution information for the ejected waste (respirable fraction, etc.)
- Effects of burns within the equipment upon the tank (disturbing waste, igniting headspace gas, etc.).

In some cases, analysis of the various waste-intrusive operations and the characteristics of the equipment involved may suffice to give some of the information needed. In other cases, uncertainties are substantial and elicitations will be needed. Burns in waste-intrusive equipment represent a more complex problem than the ex-vessel burn scenarios, in part because they are less dependent upon the information already obtained for tank head space burns. On the other hand, the waste-intrusive burn problem is not as complex as the tank head space burn scenario because the variety of release mechanisms is smaller and complex flammable gas plume phenomenologies need not be considered.

The waste-intrusive operations and associated equipment have not been evaluated in sufficient detail to permit defining all details of the case structure for the elicitations. The summary that follows is tentative and subject to substantial change.

Quantities of Waste Entering Waste-Intrusive Equipment (QWINT). In some cases, the quantity of waste entering the waste-intrusive equipment may be determined from the nature of the operations, but it is not expected that this will always be the case and about 3 elicitations will be needed to address this question ($N_{QWINT} = 3$). Operations will be grouped according to their characteristics that govern the extent of waste intake, and these groupings will constitute the "conditioning variables." The elicitation parameter, QWINT, is the mass of waste entering the equipment.

Gas Released to Waste-Intrusive Equipment (GRINT). Some or all of the gas in waste that enters the equipment can be released to the equipment. In addition, it may be possible that some of the gas in disturbed waste in the vicinity of the equipment may enter the equipment even though the waste does not. The elicitation parameter may be the fraction of the gas in the involved waste that is released to the equipment but it is not clear that this will be optimum in all cases. Possible conditioning variables include the waste-intrusive operations groupings defined previously and the waste characteristics that can affect gas release. Six elicitations are allowed for ($N_{GRINT} = 6$).

Burn Completeness (FBINT). If gas distributions are uniform within a well-defined volume inside the waste-intrusive equipment, burn completeness can probably be predicted sufficiently well that elicitations are not needed. However, there may arise situations in which more complex gas distributions within the equipment complicate assessment of burn completion, or burn completeness may be difficult to estimate for other reasons. Three elicitations are allowed for in order to estimate burn completeness ($N_{FBINT} = 3$).

Efficacy of Inerting (FINRT). Some waste-intrusive equipment (e.g., some drill strings) is inerted as a defense against gas combustion events. In the future, inerting may require consideration as a control strategy for other operations in which inerting is not currently employed. It does not necessarily follow that inerting will be completely effective in preventing combustion of gas entering waste-intrusive equipment because the entering gas may itself include an oxidizer. The oxidizer may be N_2O generated within the waste and/or atmospheric oxygen that has penetrated the interstices within the waste. For wastes saturated with liquids, penetration by atmospheric oxygen is considered implausible and is not treated here. However, for saltwell pumped SST wastes, oxygen ingress is not ruled out.

The extent of a burn, if one can occur at all, would depend upon the relative rate of oxidizing gas ingress versus the rate of flow of the inerting gas. It is possible that detailed consideration of these and other controlling parameters will lead the experts to conclude that no burns are credible within inerted equipment, in which case elicitations will not be needed. For present purposes, however, we assume $N_{FINRT} = 4$. The elicitation parameter is the fraction of the combustible gas entering the equipment that burns.

Waste Ejection (FDINT). If a burn occurs within the equipment, some waste will be resuspended from contaminated surfaces and ejected from the equipment. The elicitation parameter will be the fraction of the waste that is within the equipment that is ejected. Two cases may be distinguished based upon the topology of the gas versus the waste. If some of the gas that burns is "upstream" of the waste contained within the equipment, relief of the pressure produced by the burn may require forcible ejection of waste slugs that block flow out of the equipment. This process could result in quite efficient ejection of the waste from the equipment. On the other hand, if the gas that burns is "downstream" of the main mass of waste, the waste ejected is limited primarily to waste that is resuspended from contaminated surfaces.

The elicitation parameter is the fraction of the waste at risk that is ejected. Conditioning parameters include the waste topology as defined above and the burn intensity. The latter includes whether DDT occurs. Six elicitation cases are allocated to the waste ejection question ($N_{FDINT} = 6$).

Particle Size Distribution (MMDI, SIGGI). Particle size distribution will be assumed to be approximately lognormal and characterized by the mass median diameter and the geometric standard deviation. Two elicitation cases are assumed necessary for each parameter ($N_{MMDI} = N_{SIGGI} = 2$).

Probability of Propagation Back Into the Tank (PPROP). At this point, it is not clear whether propagation of a burn from waste-intrusive equipment back into the tank to initiate a subsurface burn or a headspace burn should be considered credible. For present planning purposes it is assumed that one elicitation will be designed to address this issue for subsurface burns and one for head space burns ($N_{PPROP} = 2$). The elicitation variable is the probability that propagation will occur, given that a burn in the waste-intrusive equipment occurs. If propagation does occur, it is treated as an addition to the ignition probabilities allowed for the in-tank combustion events.

Elicitation Total for Waste-Intrusive Equipment. With the case structure outlined here, a total of 28 elicitations are required to treat burns within waste-intrusive equipment.

D.7.3 Subsurface Burns Within the Waste

It has been suggested[D-3] that bubbles within the waste that contain flammable gas mixtures might ignite under certain circumstances. If this happens, questions exist as to whether combustion could spread to other gas bubbles within the waste, whether a GRE to the headspace could be triggered, and whether ignition of headspace gases could occur. The amounts of aerosol resuspended and its size distribution will be needed if pressures sufficient to fail the HEPAs develop.

For tanks in which the solids are saturated with liquids, it is considered implausible that there will be sufficient penetration of atmospheric oxygen below the surface to permit combustion. Except for saltwell pumped tanks, therefore, the subsurface burn scenario can only arise in tanks which generate sufficient N_2O that the subsurface mixture is flammable. For saltwell pumped tanks, drainage of liquids from the solids may permit sufficient ingress of atmospheric oxygen to allow combustion even if little or no N_2O is produced within the waste. Hence one conditioning variable is the distinction between saltwell pumped and unpumped tanks.

Questions have been raised as to the credibility of the subsurface burn scenario for any tank, and it is possible that the experts may dismiss it as being too implausible to require treatment. For planning purposes, we assume 10 elicitations are needed ($N_{sub\_srf} = 10$). This is admittedly a compromise; if the scenario does require detailed evaluation, it is likely that more than 10 elicitations will be needed. The specific quantities that would be elicited, if any, have not yet been defined.

D.8 Spark and Ignition Frequencies

Ignition frequencies will be considered here because they have not been addressed in connection with the various scenarios. It has sometimes been argued that no elicitations will be needed for the frequencies of sparks or other ignition sources, on the grounds that NFPA category and other equipment information will suffice to define the spark frequencies adequately. However, spark frequencies could be the focus of controversy in some cases. For example, if certain equipment does not meet the requirements for any specific NFPA category and yet it is judged that spark frequencies are low, failure to take credit for the low frequency could be unnecessarily conservative while taking credit for it could be controversial if no elicitation is available to support it. A basic purpose of the SCOPE-AT is to minimize the need to choose between accepting excessive conservatism versus risking excessive delay owing to controversy over assumptions in the safety analyses. Hence the present recommendation is to include an allowance for elicitation of ignition source frequencies in planning for phase 2.

If elicitations are needed, it will be necessary to bin equipment and operations according to features relevant to sparking, in order that every conceivable combination need not be considered individually. NFPA category assignments will obviously help, but more resolution is needed than the NFPA categories provides. This is especially true since the majority of equipment now in use has not been designed to NFPA specifications at all.[D-7]

Ignition sources can be divided into two categories: chance sources whose occurrence is not correlated with the gas release event, and common cause ignition sources for which the cause of the ignition source is related in some way with the gas release event. For the first type of ignition source, the ignition source may be one that can occur at any time, in which case the elicitation parameter could be the frequency of an ignition source per unit time. Examples include sparking from equipment that operates continuously. Certain natural events, notably lightning, also fall in this category. In other instances, the ignition source is the result of a specific operation, but not an operation capable of triggering a GRE. In this case the elicitation parameter could be the probability of an ignition source per operation.

For common cause ignition sources, the elicitation parameter could be the probability of an ignition source given that the event causing a GRE occurs. No comprehensive review of common cause ignition sources for the SCOPE-AT has yet been attempted. Some examples include:

- Sparking of waste-intrusive equipment. Depending upon the ignition source location, the result could be a head space burn, a burn within the waste-intrusive equipment, or a subsurface burn.

- Sparking resulting from other activity within or close to the tank that is related to the waste-intrusive operation.

- Sparking from equipment banging that results from an earthquake that also triggers a GRE, or sparking from equipment malfunctions caused by the earthquake.

- Sparking from equipment banging that can result from a rollover GRE (some video evidence indicates that this is credible).

In evaluating spark probabilities, it is necessary to consider sparking associated with electrical circuits, sparking that results from electrostatic discharge, and sparking resulting from mechanical impact of one surface on another.

For planning purposes it is estimated that two elicitation cases will be used to define lightning-related ignition sources, two for equipment banging that results from a GRE, and four for equipment banging or equipment failures associated with an earthquake that triggers a GRE. The largest number of elicitations would be required to deal with the ignition sources associated with equipment and tank operations, and about 20 elicitations are required for these. This corresponds to a total of 28 elicitations, which we round up to 30 ($N_{spark} = 30$).

D.9 Potential Elicitation Structure Simplifications

No attempt has been made at this point to try to simplify the strawman elicitation structure described here because, as stated in Section D.1, one purpose for this exercise was to provide a conservative estimate of the number of elicitation cases potentially required. It was felt that the SCOPE process could be successfully applied if the first-cut estimate of the number of required elicitations did not exceed 200 to 300 cases. Experience from the NUREG-1150 and DSAC projects indicated that later stage simplifications to the elicitation structure and winnowing of cases by the experts would then reduce the final number of cases to a tractable amount. However, discussions prompted by the strawman have pointed out several areas where the experts might conclude that the structure could be simplified, such as:

- the retained gas and release gas fraction elicitations may be combined into a single elicitation on the total gas release for spontaneous GREs
- a representative gas composition, based on tank measurements, may be suitable for defining a more stylized assessment of ignition risks and consequence evaluations
- the existence of very large bubbles and the potential for subsurface burns may be considered too unlikely to require inclusion in the structure
- Nonrollover GREs induced by waste-intrusive operations may be more efficiently treated by eliciting the gas volume released directly, rather than by eliciting the effective volume of disturbed waste and combining with the elicitation of the amount of gas retained in the waste as suggested in Section D.3
- steady-state and quasi-steady-state conditions may be considered unimportant for elicitations based on the recent evaluation of the recommendation to add tanks to the flammable gas watch list based on surface level rise and barometric pressure response measurements for trapped gas[D-8]
- the ventilation rate may be considered as characterized well enough to be used as a fixed tank parameter
- ongoing experiments on the pressure rise resulting from the ignition of gas mixtures representative of tank conditions may be considered acceptable for direct input to the consequence analyses instead of using elicitations to quantify that parameter.

Additional simplifications may be identified by the experts. The review and revision of the elicitation structure scheduled for the initial stages of phase 2 may also result in some simplification of the strawman elicitation structure submitted to the experts; however, it is important that simplification of the structure be primarily the product of the experts' judgments, not something imposed by the SCOPE project. Note also that the experts probably will identify some instances where additional elicitation cases are needed in order to treat adequately some of the issues involved.

D.10 Number and Size of the Expert Panels

The SCOPE process is able to achieve timely and cost-effective results because of the way in which the experts are managed. The experts are divided into two categories: (1) panel members who are elicited for inputs and (2) technical specialists who present summary information to the panel members before the elicitation sessions. In this section we consider primarily the structure and the number of the panels, as panel makeup and structure is vital to the success of the process and must be planned well in advance.

The number of expert panels is governed primarily by the number of disparate disciplines involved. The phenomenology governing, for example, the release of gases from the waste, the ignition and combustion of the gases, the structural response of the tank and associated structures, and the suspension and transport of waste are quite different from each other. Thus, different experts should be expected to participate in discussions on these topics. As evident from the material in this Appendix, the phenomenology important to the flammable gas issue are diverse and an evaluation of the risk is complex. Consequently, any process that attempts to quantitatively characterize an issue as complex as the risk from flammable gases in Hanford tanks must involve a broad range of experts and these experts will be grouped into more than one panel.

The diversity of the phenomena that must be considered is also one of the factors that controls the total number of panelists involved in the process. In addition, this number is determined by (a) the minimum number of elicitations required for each case in order to obtain a reasonable sample of expert opinions, and (b) the maximum number of cases each expert can reasonably be expected to handle. Appendix J of Reference (D-2) indicates that 3 to 6 experts should consider each case; for planning purposes we assume five experts will consider each case.

Consideration of past experience with the NUREG-1150 project[D-1] and the DSAC project[D-2] provides some guidance as to the panel makeup and structure that will be appropriate for SCOPE. In the NUREG-1150 project 53 experts were divided among six panels, with 6 to 11 members on each panel. To a certain extent, the panels were specialized to specific phenomenological areas, but these individual areas were still quite broad. For several panels, different experts were elicited on different questions, with no one expert being elicited on all the questions considered by his panel as a whole. This was done partly to control the work load imposed on individual panelists. In addition, this division of the work load permitted panelists to choose issues with which they were most familiar.

In the DSAC project the experts were grouped into a single small panel of 6 members. A single panel could be used because the range of issues dealt with was considerably narrower than the NUREG-1150 range; e.g., all the issues involved quantifying the various energy releases possible in a severe accident. Nonetheless, the topics of interest were sufficiently broad that no one panelist could be a specialist in all of them. Each member was broadly knowledgeable on all of the topics and had a detailed understanding of some of the topics. Over two dozen technical specialists made detailed presentations to the panel on specific key phenomena, which was a major factor in permitting the panelists to cope with any limitations in their specialized knowledge on a specific issue prior to initiation of the DSAC process.

The elicitation structure outlined in this appendix, together with the DSAC experience, may be used to estimate a conservative limit to the number of experts and expert panels required. Phenomenology governing the release of gases from the waste is quite different from that controlling the hydrogen burns and DDT issues; hence, these might reasonably represent separate panels. Resuspension also involves many issues distinct from gas release issues and combustion issues and might therefore be assigned to a third panel. Phenomena governing sparking and other ignition sources are again sufficiently distinct from the areas of the first three panels as to suggest treatment by a separate panel. Hence a total of four panels could be justified by the breadth of the technical issues requiring treatment.

To estimate the total number of panelists, we assume each case will be elicited by five panelists as noted above. The decision analysts supporting the DSAC project recommended that each expert should not be expected to treat more than about 20 cases (Appendix J, Reference D-2). In the DSAC study, there were 15 RCASs, with each RCAS being split into two subcases, one for protected and one for unprotected accidents, giving 30 cases in principle. However, the experts could and did eliminate some RCASs as not being needed owing to their beliefs that some RCASs were redundant or bounded by other RCASs. (As the DSAC project was set up, it was not necessary for the experts to completely agree on which cases to elicit.) It is reasonable to suppose that individual experts will similarly prune the complete case structure as defined here. Hence, for present purposes, we assume that each expert will be able to treat 30 cases as defined in the complete case structure.

The number of experts needed on a panel is equal to $N_{case}\ N_{exp/case}/N_{case/exp}$, where N_{case} is the number of cases treated by the panel, $N_{exp/case}$ is the number of experts who will consider any one case (5 in our planning example), and $N_{case/exp}$ is the number of cases one expert can consider (30). Grouping the various cases defined in this appendix among the four panels defined above, and applying this formula to each group, results in an estimate of about 16 experts for the GRE panel, 8 for the gas combustion panel, 10 for the waste resuspension and transport panel, and 5 for the ignition source panel.

Although this estimate is significantly smaller than the NUREG-1150 elicitation effort, it would still represent a major expert elicitation project that would be difficult to execute within the constraints of the SCOPE schedule and budget. Fortunately, this estimate is almost certainly too conservative for several reasons:

- As noted in Section D.9, it may prove possible to simplify the preliminary elicitation structure presented in this appendix.

- This estimate was based upon the DSAC project which was implemented on a very compressed time scale that reduced the number of elicitation cases each expert could reasonably be expected to handle.

- The elicitation structure defined here was largely developed before the phase 2 project plan had evolved to the point where it became clear that SCOPE would be implemented in two stages, with only issues required to address flammable gas risks for Groups 3A and 3B to be considered in the first stage. This division reduces the number of experts required because this number is governed by the size and diversity of the elicitation task in each stage individually, not in the total SCOPE project.

- In the NUREG-1150 elicitations involving containment loads, some of the experts nominally treated an order of magnitude more cases than in the DSAC project. This proved possible because the cases were organized into a few large groups such that the many cases within each group were very similar in structure, and differed only with respect to the specific values assigned to one or two of the conditioning parameters. This feature permitted the experts to develop shortcuts for defining uncertainty distributions for all members of a group once a base case had been defined for that group. The elicitation structure defined for SCOPE in this Appendix appears to include some qualitatively similar opportunities for shortcuts, although these opportunities are not nearly as extensive as was the case for the NUREG-1150 containment loads panel.

Assuming that it is possible to relax the constraints imposed above by the number of elicitation cases, some more qualitative guidelines based in part upon prior experience with elicitation projects are helpful in defining a less conservative or "best" estimate of the panel requirements. Concerning the number of panels, we may note that some experts on flammable gas hazards in industrial settings may also be sufficiently familiar with spark ignition hazards that a single panel could suffice for both the combustion phenomenology and the ignition source elicitations. In addition, waste resuspension and transport has some areas of commonality (e.g., waste properties) with gas release phenomenology and combining these panels is at least conceivable. Hence reducing the number of panels to three seems plausible, with two being a bare minimum.

In general, it is considered desirable that panels consist of no more than 12 members, because larger panels become too cumbersome and the group discussions may be overly dominated by a few outspoken panelists, with the views of less assertive (but equally competent) panelists not being adequately heard by their fellow panelists. On the other hand, a minimum of 6 members per panel appears to be dictated by the following considerations:

- Too small a panel is excessively vulnerable to the unanticipated absence or withdrawal of one or two of the experts on the panel. Note that it is extremely difficult to replace a panelist on short notice because the new member would have missed much of the technical information exchange and/or the training in expert elicitation processes.

- If we accept the assumption there should be five elicitations on each case, a small panel means that each expert must accept being elicited on every case addressed by the panel as a whole; i.e., if some experts pass on some cases, there will be too few elicitations for those cases unless the panel size is larger than five. When the range of issues to be addressed by a panel is phenomenologically diverse, it is not likely that all panelists will feel comfortable being elicited on all the issues.

The constraint noted in the second bullet obviously increases in severity as the diversity of the issues treated by the panel increases. If only two panels are used, the diversity and number of issues to be treated probably rules out panels as small as six or seven members. Our current best estimate, therefore, would be that SCOPE would utilize three panels with 6 to 9 members on a panel, or two panels with 8 to 12 members on a panel.

Choosing between fewer but larger panels versus the converse involves a number of tradeoffs. The experience from the NUREG-1150 project highlighted that substantial effort is required to integrate the results from separate panels (see Section D.2.8). This consideration favors minimizing the number of panels. A reasonably large panel also helps to ensure that the results represent a sufficiently diverse range of opinions.

A factor favoring multiple panels is that, with several panels, sensitivity to results provided by any one panelist is reduced. For example, if one of the GRE panelists tends to favor extreme values, the influence of his elicitations upon the overall flammable gas risk results will be moderated if other panels treat ignition probabilities, combustion completeness, waste resuspension and transport, etc. On the other hand, if the same panelist provides elicitations on all these issues, the potential for excessive influence by a single individual is increased.

Also balancing the desire to have large panels are two practical considerations. First, the aggregation process discussed in Appendix C normally results in a diminishing impact of the input from the N+1 expert as N increases. Second, no expert can possibly be truly expert in all areas of phenomenology pertinent to the elicitation structure assigned to them for something as complex as quantifying the risk from flammable gas in Hanford tanks. Inevitably they must make some judgments based on information provided by other panel members or technical specialists that have more experience with specific topics. Thus the expertise of the panelists themselves can be supplemented by that of the technical specialists making presentations to the panels. Within limits, therefore, project success may not be very sensitive to the division of the experts into panelists versus technical specialists so long as the panelists and technical specialists taken together represent the full range of experience needed to address all of the key phenomenology.

When defining the number and size of the panels, then, the project management team inevitably must consider the logistical, budgetary and schedular constraints as well as the diversity of expertise required to evaluate the technical issues. The desire is to have panel members with broad general knowledge to evaluate a wide range of phenomenology based on the information supplied by a suite of specialists. For this project to be successful, the current best estimate is that two or three panels should be defined, with 6 to 12 members per panel. The combination of two panels at the minimum size is likely ruled out by the diversity issues discussed above, while the combination of three panels with a size near the maximum is likely to be ruled out by practical considerations. When the present preliminary elicitation structure is refined in the course of Phase 2, these estimates of panel number and makeup will also be refined.

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APPENDIX E

PROTOTYPE ANALYSIS FRAMEWORK

As discussed in Section 4, "economy of analysis" is a key guiding principle for developing the analysis framework for SCOPE. The requirements that determine what quantitative information is needed, what its sources should be, and how the quantities should be combined are to be found in the range of questions that the system is intended to support, the metrics that are to be calculated, and the degree of accuracy in those metrics that the decision-maker requires. However, it is also true that the analysis of information needs may influence the setting of requirements, since it might become apparent that the funds or time required to develop the SCOPE analysis framework and analysis tool might be driven by some aspects of the requirements that are not important to the decision makers. Ultimately, the design of the SCOPE framework may therefore be iterative in nature.

To begin this iterative process, one of the activities pursued in phase 1 of the SCOPE project was to develop a preliminary overview of the information required to support decisions about safety controls for TWRS facilities. This "zero'th" order overview did not attempt to match the information needs to the spectrum of safety controls being considered, but instead sketched a broad-brush outline of the full range of controls that might be considered and the full range of phenomena that could affect assessments of the effectiveness of controls. The study was limited, however, to flammable gas issues.

E.1 Modeling and Data Needs

Waste modeling and data needs include:

- Steady-state gas generation rates
- Gas storage amounts and morphology
- GRE models considering waste layer depths and specific gravities
- Quantification of release amounts during global and local waste-disturbing operations.

Tank headspace and ex-headspace modeling and data needs include:

- Headspace mixing of released gases
- Headspace dilution with outside air
- Ex-tank GRE source, mixing and dilution model (including ventilation system regions, pits and outside of tank openings).

Equipment, spark source, and operations data needs include:

- Gas monitoring, alarm and equipment shutdown model
- Spark frequency for different circuit designs
- Mechanically induced spark frequency, including mechanical impact frequency, spark/ impact probability, location, and coincidence with GREs
- Electrostatic spark frequency, including charge/discharge potential, bonding status, material conductivity, spark discharge frequency, and location.

Natural initiator data needs include:

- Lightning frequency and lightning pathways to potentially flammable regions
- GRE likelihood and release fraction vs. seismic event magnitude
- Estimates of coincident ignition sources (e.g., banging equipment, electrical system failures) during lightning or earthquake.

Consequence calculation needs include:

- Flammability model
- Combustion completeness and headspace pressure rise model
- Release mechanism and model for in-tank sources
- Release mechanism and model for ex-tank sources
- Structural response model
- Response of ventilation systems, filters, riser covers, pit covers.

E.2 The SCOPE Scenario Evaluation Matrix

As discussed in Section 4.2, The SCOPE-AT would organize flammable gas hazards of concern at TWRS and the phenomenological steps of their manifestation in a scenario evaluation matrix (Table E-1). Four broad hazard categories are considered:

1. Gas Release Event in Tank Headspace. Gas is released in an episodic manner so that either a small headspace region may be flammable (plumelike subcase) or the whole headspace may be flammable. Several initiating events contribute to this scenario, each with its own frequency, and each with its own associated volume of gas release: (a) spontaneous rollover GRE, (b) spontaneous nonrollover GRE, (c) waste-intrusive operation, and (d) earthquake or other act of nature.

2. Gas Buildup in Equipment. Gas collects in equipment during an intrusive operation and a flammable mixture develops so that a burn within the equipment could cause ejection of waste.

3. Flammable Gas Outside Headspace. A flammable gas mixture exists in a region outside the headspace (i.e., a tank pit or ventilation duct) due to gas release in the tank.

4. Subsurface Gas Burn. Gas within the waste is ignited *in situ*.

For each hazard category, scenario steps (described in more detail in the following section) are:

1. Frequency: Frequency of the hazard or operation.

Table E-1. Scenario Evaluation Matrix

SCOPE DSS Evaluation Matrix for Flammable Gas Issue				
	Scenario			
	Headspace Burn	Burn in Equipment	Exheadspace Burn	Subsurface Burn
1. GRE Frequency P(GRE)	• Intrusive equipment • Rollover GRE • Nonrollover GRE • Earthquake	• Drill string	• Tank pit • Vent system	• N/A
2. Ignition Frequency P(burn/GRE)	• Spark frequency in headspace • Spark location	• Interior ignition frequency	• Ignition frequency per location	• Frequency of subsurface ignition
3. *Damage Frequency* P(damage/burn)	• *Burn* completeness • Pressure rise • HEPA fragility	• *Pressure rise* • Equipment Fragility	• Burn completeness • Pressure rise • Location fragility	• *Amount of gas* burned • Headspace pressure rise
4. Release Frequency P(release/damage)	• Release from tank and waste surfaces • HEPA leading	• Ejected waste	• Release from surfaces	• Ejected waste entrained extank

2. Ignition Frequency: The frequency of ignition; formally this is the conditional probability of ignition given the occurrence of the hazard.

3. Damage Frequency: The conditional probability of pertinent damage given ignition.

4. Release Frequency: The conditional probability of release given damage.

The scenario evaluation matrix merely illustrates the overall organization of SCOPE-AT risk calculations. The real key to evaluation of risk for a given control procedure or piece of equipment is the set of associated functional attributes employed in the risk calculation. Specific attributes and the evaluation of risk itself are discussed in the next section.

E.3 Walkthrough of Detailed Scenario Evaluations

For each of the sixteen elements in the scenario evaluation matrix, a calculation process is needed that combines input data in a well-defined manner to produce outputs in the form of metrics. Some metrics will actually be intermediate steps in the calculations (e.g., whether a HEPA filter failed, whether a combustion event occurred). The emphasis for the following walkthroughs, however, is the source term to the environment, since it is expected that calculations of dose (both toxicological and radiological) will be needed for comparisons with risk guidelines.

Gas Release Frequency and Magnitude

The frequency of headspace gas release events and the fraction of gas emitted in a GRE are separate data items to be evaluated for either:

Rollover GRE
Nonrollover GRE
GRE due to waste-intrusive event, or
Earthquake.

The volume of gas released is simply the estimated amount of stored gas (a tank data item) times the release fraction.

If a GRE is of sufficient volume, then flammable gas can collect in pits above a tank or in the ventilation system. The relationship between size of GRE volume and potential for causing flammable mixtures in the ex-tank regions is quantified based on the volume released to the headspace, a plume model for estimation of dilution during travel to the entry riser, and evaluation of the amount of gas that leaves the tank through its various exits. Note that a ventilation system may keep the pressure negative for small releases and no gas may then enter a pit.

For each intrusive operation whose equipment can collect significant quantities of stored gas, its frequency must be prescribed, and the actual release as a fraction of gas present in the disturbed region must be available for the calculations.

Ignition Frequency

The ignition frequency is the probability of a spark occurring during the time gas is flammable and in the same location as the gas. The spark frequency must thus be summed over all pieces of equipment in a given location. The duration of flammability depends upon the particular scenario as discussed below. In any case, the overall ignition frequency is found by considering a Poisson process for probability of a spark during the time window of flammability.

A GRE sufficient to cause the well-mixed headspace to exceed the LFL leads to a "global burn" scenario, while a GRE of smaller volume leads to a "plume burn" scenario because a spark must be collocated with the flammable gas before it becomes too dilute to burn; each scenario obviously has a different duration. The global burn GRE flammability duration is calculated using the standard well-mixed exponential dilution law given the tank ventilation rate, with a nominal release duration added to account for mixing of released gases in the headspace. The plume burn GRE flammability duration is calculated using an experimentally based plume dispersal model whose functional form resembles the exponential dilution law, and which accounts for the ventilation inlet velocity and orifice diameter.

Another plume burn issue is the size of the flammable region, and whether the spark is contained within it. A buoyant plume model is employed to evaluate the region size and it depends upon the GRE volume, duration, and area. Two different models exist, one for rollover GREs whose release area is a nontrivial fraction of the tank, and one for nonrollover GREs whose release area is assumed to be small, on the order of a square foot for example, and which lead to a well-defined plume. The physics of mixing is different in each situation, where perimeter entrainment dominates mixing for the nonrollover GRE plume case, and mixing for the rollover GRE case occurs by turbulent diffusion of lighter GRE gases mixing upward into heavier headspace gases over the entire release area. For a nonbuoyant plume, a different model yields the layer height.

For the ex-headspace burn scenario, the plume models mentioned above are employed in the first place to determine if the case is pertinent. If so, the methods described above are used to determine the duration of flammability.

For the equipment burn hazard, the frequency of a spark inside the equipment per operation is required, and the duration of a flammable mixture depends upon the released volume and purging rate. For the subsurface burn hazard, the frequency of subsurface ignition is evaluated for each intrusive operation or natural cause.

Damage Frequency

Damage states are currently defined for HEPA failure and dome failure based upon failure thresholds, i.e., fragility curves, and other required damage states are ventilation system failure and pit cover lifting for burns in those locations. A post-combustion pressure must be calculated for a burn and compared with the damage criterion in any case. Generally, not all the flammable gas will burn, so the pressure rise depends upon a model for incomplete combustion. In rare but possible cases, complete combustion can occur and the damage model criterion for this state is an equivalent hydrogen mole fraction exceeding 8% in a well-mixed region.

For headspace burns, the burn completeness must be determined based upon the volume of gas released, headspace volume (hence the gas configuration: well-mixed vs. plume), and spark location. The resulting pressure rise is calculated and compared with the HEPA fragility curve to determine the HEPA failure probability. Combustion completeness and pressure rise are determined for ex-tank locations just as for the tank headspace using appropriate concentrations and volumes, and compared to the local fragility curve.

The pressure rise inside equipment depends upon the gas concentration, and damage to the equipment depends upon the individual fragility curve. The deflagration to detonation transition (DDT) may be assessed for equipment burns.

If the frequency of subsurface burns is not sufficiently low, then the amount of gas participating in such a burn must be estimated, and its effect on headspace pressure can be calculated.

The current incomplete combustion model is valid for well-mixed cases and it contains adjustable parameters previously fitted to experimental data. The model considers gas composition, geometry, and turbulence. Stylized gas configurations would be calculated using the model.

DDT potential inside equipment is considered far greater than in a tank headspace, because the concentrations achievable in a tank headspace are normally no greater than the threshold at which DDT is remotely possible. Within equipment, high concentrations could occur, and the tubelike geometry with many obstacles and no venting transverse to the direction of a flame front are favorable to DDT.

Release Frequency

A model or relationship between postburn pressure or temperature and the amount of release may be employed to assess consequences. The model would consider entrainment of particles from the waste surface and other surfaces such as tank walls, tank ceiling, or ex-tank surfaces. Several release scenarios must be addressed. Each requires knowledge of the local waste composition and the inventory at risk for release:

> *Headspace burn.* Released mass due to chemical and physical mechanisms from exposed surfaces (walls, dome, waste).
>
> *Pit or ventilation duct burn.* Similar to the headspace burn, but different contamination surface loadings expected.
>
> *Burn underneath waste.* Release due to expulsion of waste into the headspace with mechanical formation and entrainment of aerosols.
>
> *Burn within equipment.* Ejection of material present in the equipment directly to the tank exterior is possible given equipment failure. Also, if some of the burned gas is relieved into the waste, this could cause mechanical aerosol formation and entrainment into the headspace.

Tank and Equipment Attributes

A tank-specific data file is suggested to capture the key attributes related to the tank, the stored waste, the installed ventilation system, the installed equipment and planned operations and activities. Key attributes are indicated below and relate to gas generation and retention, gas releases, spark source attributes, and response of the tank to gas releases and postulated gas burns. Key attributes related to the tank and waste include:

- Tank farm
- Tank number
- Empty tank volume (chose one of 5 types)
- Tank diameter (chose one of 2 types)
- Tank vacuum under normal operations
- Sealed pits (volume and contamination loading for each)
- Unsealed pits (volume and contamination loading for each)
- Normally open risers (number and diameter for each)
- Waste sludge volume

Waste supernatant volume
Waste supernatant specific gravity (density)
Waste rheology type (saltwell pumped or not saltwell pumped)
Waste gas production rate (or tanks specific values for key parameters in a generation rate model, such as TOC, decay hat load, and nitrate concentration, etc.)
Waste retained gas void fraction (chose one of several groups)
Waste retained gas composition (chose one of several types)
Waste surface type for entrainment calculation (dry sludge, dry saltcake, wet solids, supernatant)

Tank ventilation system and unique attributes, including:

HEPA Filters: Fragility curve, contamination loading.

Vent System: Flow rate, inlet orifice diameters and locations, failure frequency, repair time, contamination loading.

Installed Equipment - A tank-specific data file is suggested to capture the spark source attributes for the equipment installed in each tank/ventilation system. A list of installed equipment appears in Appendix B, Table B-1. Equipment attributes will include:

Electrical equipment:	Fraction of time energized Frequency for "sparks" (per hour energized) "Spark" location
Mechanical equipment:	Fraction of time in motion Material spark resistance category Impact energy potential category Impact frequency (impacts per hour) Impact spark location
Electrostatic:	Charge/discharge frequency Bonding and material conductivity category Spark location
Lightning channelling:	Target category (% of strikes to the farm that cause sparks in the tank or ex-tank locations) Locations of lightning sparks
Seismic sparks:	Probability that the equipment would cause a spark as a result of an earthquake (three values for three different size seismic events) Location of seismic spark

Operations and Activities - Operations and activities are also an important part of the flammable gas risk profile. Operations and activities are listed in Tables E-2 to E-4. In addition to the location and spark frequency attributes of the systems, operations add an attribute for a PDF of effective volume of waste disturbed by the operation. It is assumed that the release fraction is 1.0 in the disturbed waste. Where this is not appropriate, the volume of gas releases can be adjusted by adjusting the effective volume to be different from the actual volume of the waste disturbed.

Sparks can result from electrical circuits (normal operations or faults) associated with equipment used in these activities, mechanical sparks from impacts arising from moving or dropping equipment, electrostatic sparks from nonconductive or nonbonded conductive equipment. Equipment (especially tall equipment such as cranes) can present a lightning target. In addition, activity-related equipment poses a spark hazard during seismic events. A data file capturing the electrical, mechanical, electrostatic, lightning and seismic spark frequency per activity is needed. This will represent the spark frequency for each activity and provide a menu of activities that can be performed in any tank.

A key difference between permanently installed equipment and activity-related spark sources is the generally short time that activity-related equipment is present in a potentially flammable region. Therefore, the spark frequency needs to be summed over the number of expected activities and their duration for each tank to model these spark sources appropriately. Key operations and activity attributes, therefore, include:

Number of operations per year
Duration for each operation
Effective volume of waste disturbed

Electrical equipment:	Fraction of time energized Frequency for "sparks" (per hour energized) "Spark" location Correlation of spark with gas release
Mechanical equipment:	Material spark resistance category Impact energy potential category Impact frequency (impacts per operation) Impact spark location Correlation of spark with gas release
Electrostatic:	Charge/discharge frequency per operation Bonding and material conductivity category Spark location Correlation of spark with gas release

Table E-2. Representative Dome-Intrusive Operations and Activities
• Riser preps (asbestos removal) • Riser examination with high intensity lamp • Riser geometry measurements • Shield plug installation and removal • Swabbing risers for radiation readings • Flange work • Gauge plugs • Gas sampling with heated vapor probes • Standard hydrogen monitoring system/gas mass spectroscopy • Ammonia gas sampling • ENRAF/FIC/manual tape waste level measurements • Zip cord waste level measurements • ENRAF/FIC/manual tape repair, replacement, removal • DST high level detection and alarm • Use of camera, video, lights • Surface moisture monitoring system • Equipment removal (that is located in the dome space and not inserted below the waste surface) including retrieval devices and de-con • Water wands used to flush contamination from equipment in the tank dome space • Welding and grinding on the outside boundary or in a location where sparks or hot slag can enter the tank

Lightning channelling:	Target category (% of strikes to the farm that cause sparks in the tank or ex-tank) Locations of lightning sparks
Seismic sparks:	Probability that the equipment would cause a spark as a result of an earthquake (three values for three different-size seismic events) Location of seismic spark Correlation of spark with gas release

Table E-3. Representative Waste-Disturbing Operations

<u>Global Waste-Disturbing Operations</u>

- Saltwell pumping
- Submersible pump operation
- Emergency pumping of supernatant
- Mixer pump operation
- Transfer pump operation
- Air lift circulator operation
- Jet pump operation
- Chemical additions
- Large water additions
- Waste addition/removal or transfers

<u>Local Waste-Disturbing Operations</u>

- Lancing
- Hydraulic jetting (with ultrahigh pressure)
- LOW installation
- T/C tree installation
- Saltwell installation
- Multifunction instrumentation (MIT) installation
- Instrumentation Installation/Operation
  - Void meter
  - Viscometer
  - Densitometer readings
  - Sludge level (weight) measuring devices
  - Penetrometer testing
- Dip tube installation/operation/removal
- Mixer installations
- Transfer pump installation
- Equipment removal if inserted below the waste surface, including retrieval devices and de-con
  - Sludge weight removal
  - Air lance removal
  - Specific gravity probe removal
  - LOW
  - T/C tree
  - MITs
  - Pumps
- Sampling
  - Push mode core sampling
  - Auger
  - Grab
  - Rotary mode core sampling

Table E-4. Representative Ex-Tank-Intrusive Operations and Activities

- Vent and balance activities
- Exhauster (maintenance/operations)
- High-efficiency particulate air (HEPA) filter change out without primary tank isolation
- De-entrainer pad change out
- Operation of portable exhausters
- Ventilation system modifications
- Filter housing relocaiton
- Filter inlet installation
- Filter changing
- Pit cover block/cover plate removal
- Pit jumper setup and valve alignment for transfer
- Pit leak detection
- Pit activities
- Gas sampling in pits and ventilation systems
- Activities outside of open risers
- Use of greenhouse/plastic sleeving around open risers
- Drywell vans/on top of tanks, vehicle control
- Construction/tie-in activities

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APPENDIX F

PROTOTYPE SCOPE GRAPHICAL USER INTERFACE

F.1 Description

pSCOPE-AT* is a Windows application that will provide a convenient means of carrying out the SCOPE methodology. By controlling the pSCOPE-AT screens ("pointing and clicking") the user can view input data, revise input data, perform scenario calculations, and examine output metrics. The pSCOPE-AT screens are described below, along with a sample scenario calculation.

It is important to note that the phase 1 pSCOPE-AT was created to demonstrate project viability and show how the end-user would approach a specific problem. The phase 2 pSCOPE-AT would include the results of expert elicitations, more detailed scenario modeling, and a refined user interface.

Options

The Options screen, as shown in Figure F-1, controls pSCOPE-AT execution and demonstrates the SCOPE structure. "Input File" is the file containing the pSCOPE parameter database. Using the "View/Change Input" command, the user can see the attributes of a particular tank, and alter them to model the effect of possible decisions. After performing the calculations, the user looks at decision metrics to weigh the benefits (or drawbacks) of possible decisions.

Clicking the "Input File" command button creates a dialog box and allows the user to open an existing input file, as shown in Figure F-2. When the user closes the dialog box, the input file name appears on the Options screen as a reminder.

The "View/Change Input" command button allows the user to see input values and change them. This is discussed in greater detail in the description of the "DBInputFile" screen.

"Quantify Scenarios" allows the user to view intermediate values for the scenario definition and initiate the calculations.

The phase 1 "Elicitations" command button is not functional. In phase 2 editions of the SCOPE-AT, users will be able to view and revise the cumulative distribution functions or probability density functions that result from expert panel elicitations.

The "Output File" command button is not functional in phase 1, but this command button will allow the user to specify a file name where detailed scenario calculation results will be saved.

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* The term pSCOPE-AT is used to make it clear that this software is a prototype and should not be confused with versions of the SCOPE-AT that will be subject to stringent quality assurance controls and configuration management. The "p" is silent.

"View Metrics" allows the user to see the results of the scenario calculations.

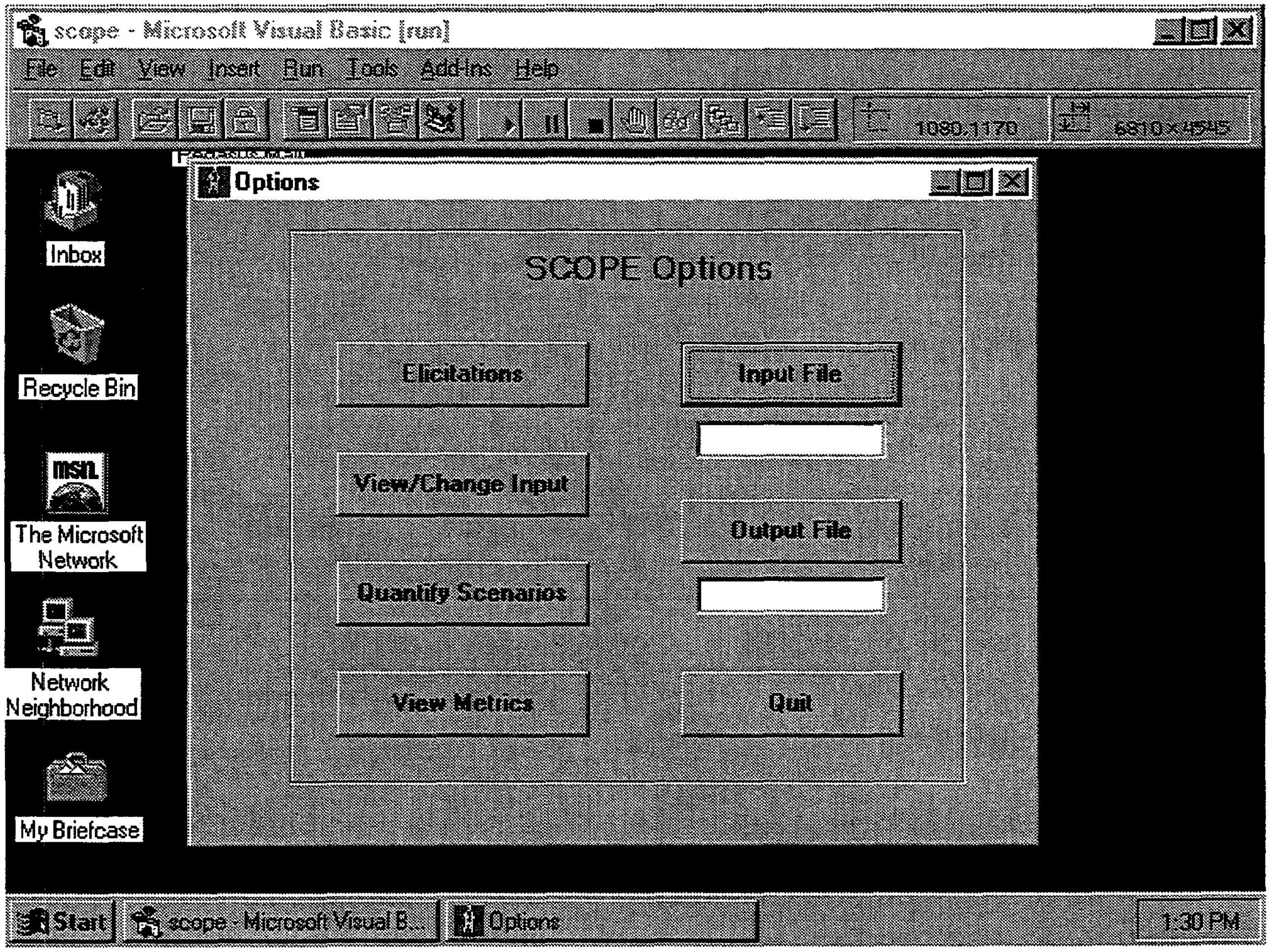

Figure F-1. pSCOPE-AT Options Screen.

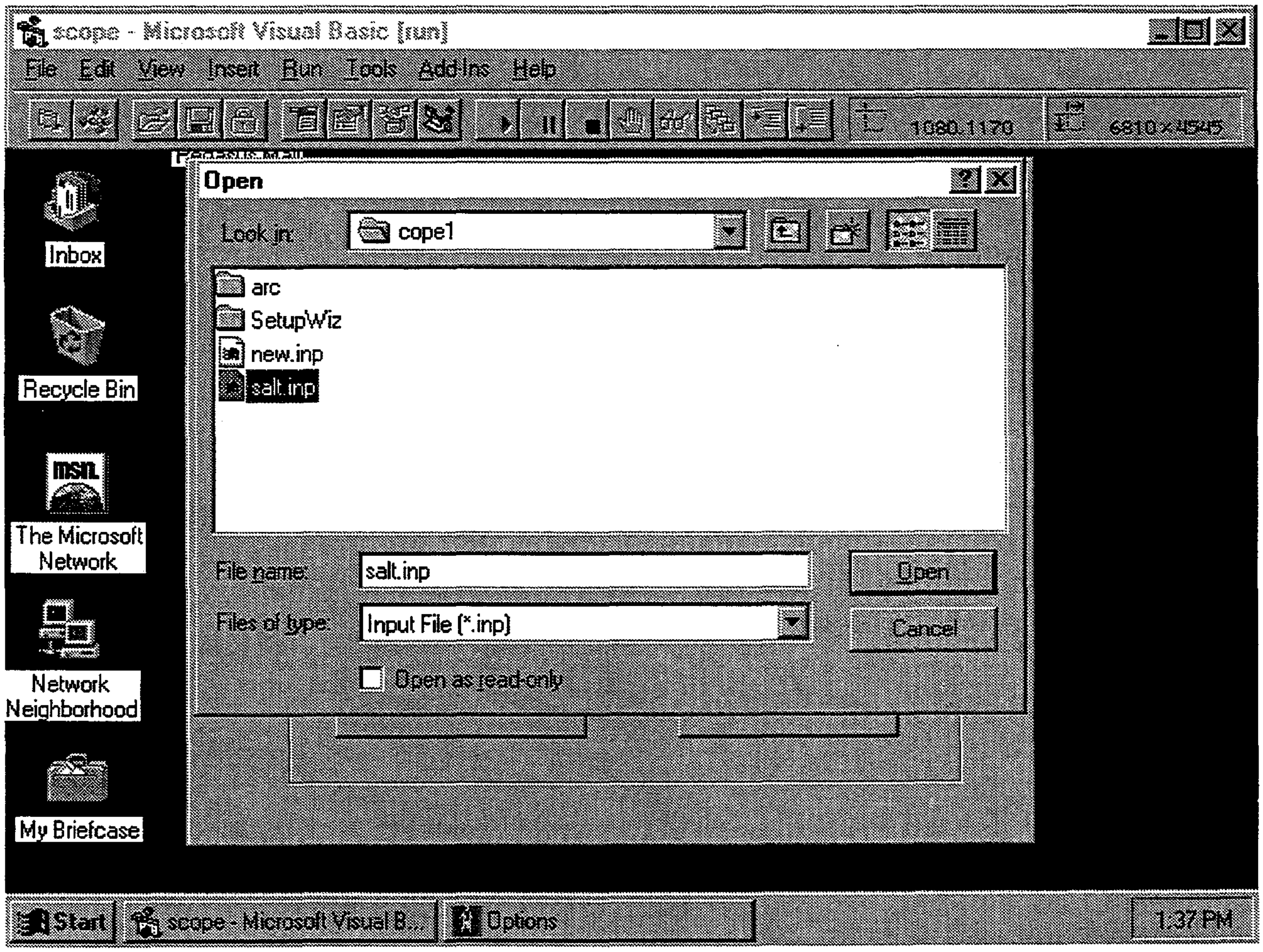

Figure F-2. Input File Dialog Box.

DBInput

The View/Change Input command allows the user to manipulate the pSCOPE parameter database. When the user clicks the View/Change Input command button on the Options screen, the Options screen disappears and the DBInputFile screen emerges, as shown in Figure F-3. At the top of the DBInputFile screen, the user can specify a title for the run, which will be saved and written to the output file. This screen allows the user to view the current values from the selected input file. If the user does not select an input file, DBInputFile uses default values.

Each value in the pSCOPE parameter database requires four descriptors: the tank, the category (equipment, waste, or operation), the function, and the attribute. As an example, the spark frequency of a motor would have the following descriptors: Tank = A101; Category = Equipment; Function = Motor; Attribute = Spark Frequency. To change the descriptor, the user clicks on the down arrow in the appropriate text box. This displays a list of choices that the user can select from by pointing the cursor. After changing a descriptor, the current value is automatically updated to reflect the new descriptor. To change the current value, the user places the cursor in the Current Value text box (by tabbing or using a mouse) and then enters the new value. The descriptors and the new value appear in the table. The user can show the changed values, or all the values. If all the values are displayed, an X in the far left-hand column indicates a changed value.

The user can save the changes, and create a new file if desired. If the user clicks the OK button rather than the Save button, the calculation will proceed with changed values, but changed values will not be saved. Clicking the OK button takes the user back to the Options screen.

Scenarios

After the user has viewed or changed the input, the next step is to click on the "Quantify Scenarios" command button to display the "Scenarios" screen, which is shown in Figure F.4. As a reminder, the input file name appears next to the screen title. This screen takes the form of four tabs, one for each pSCOPE scenario. To go from one scenario to another, the user simply clicks the desired tab.

Figure F-4 shows the Headspace Burn scenario. This screen shows intermediate values needed to quantify the scenarios. Some of these intermediate values are simply taken straight from the database, while others require some calculation. For instance, the spark frequency would be derived from the spark frequency for all the equipment and operations in the tank. Salient elicitations are also presented here. (The phase 2 edition of SCOPE should have the ability to graphically display elicitations.) These values can be changed if the user desires, but the changes cannot be saved.

The user clicks the "Quantify Scenarios" command button to proceed with the calculations, and the "Metrics" command button to display the results. A methodology and sample calculation for the Headspace Burn scenario are discussed below.

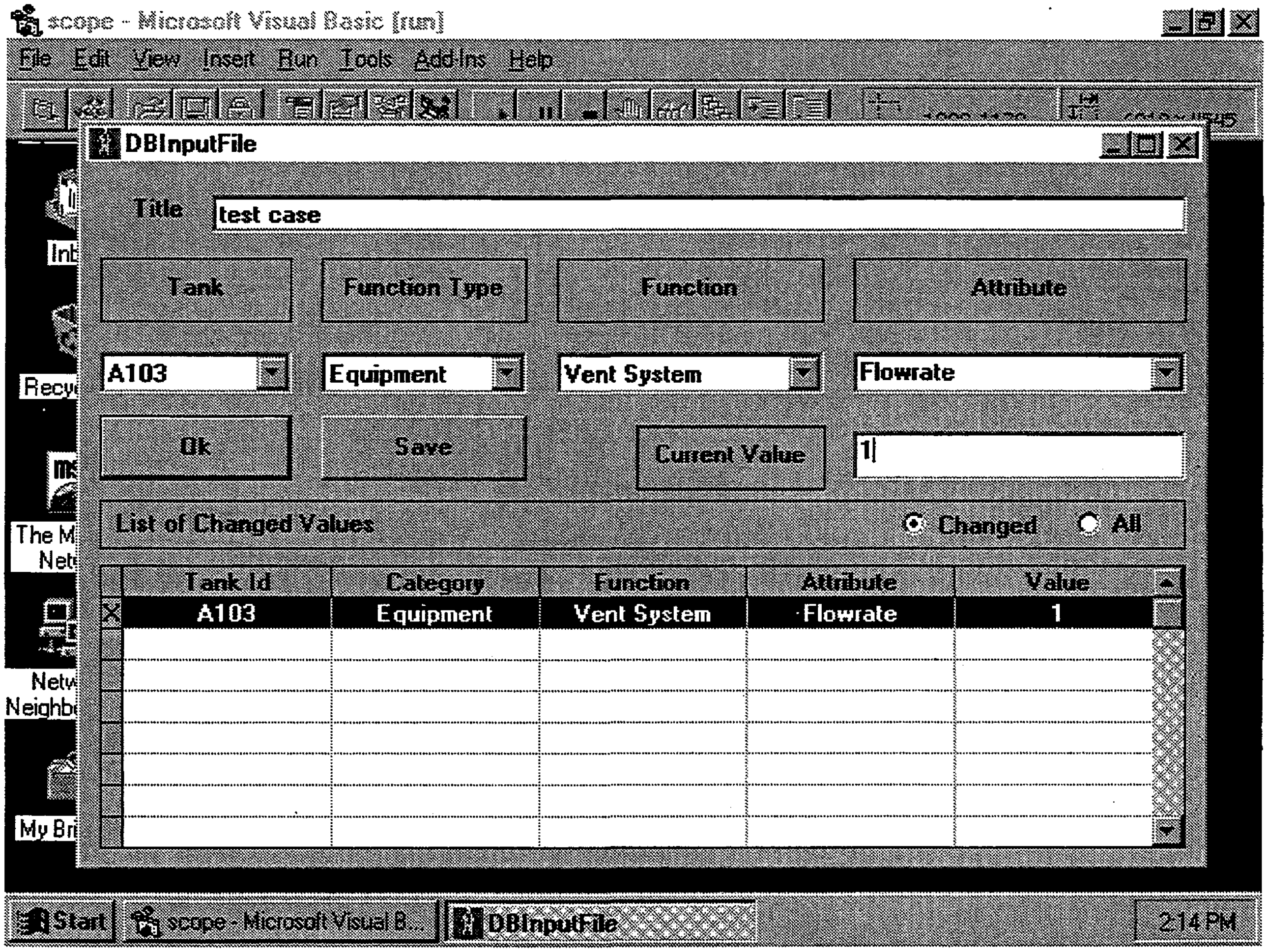

Figure F-3. pSCOPE Parameter Database Screen.

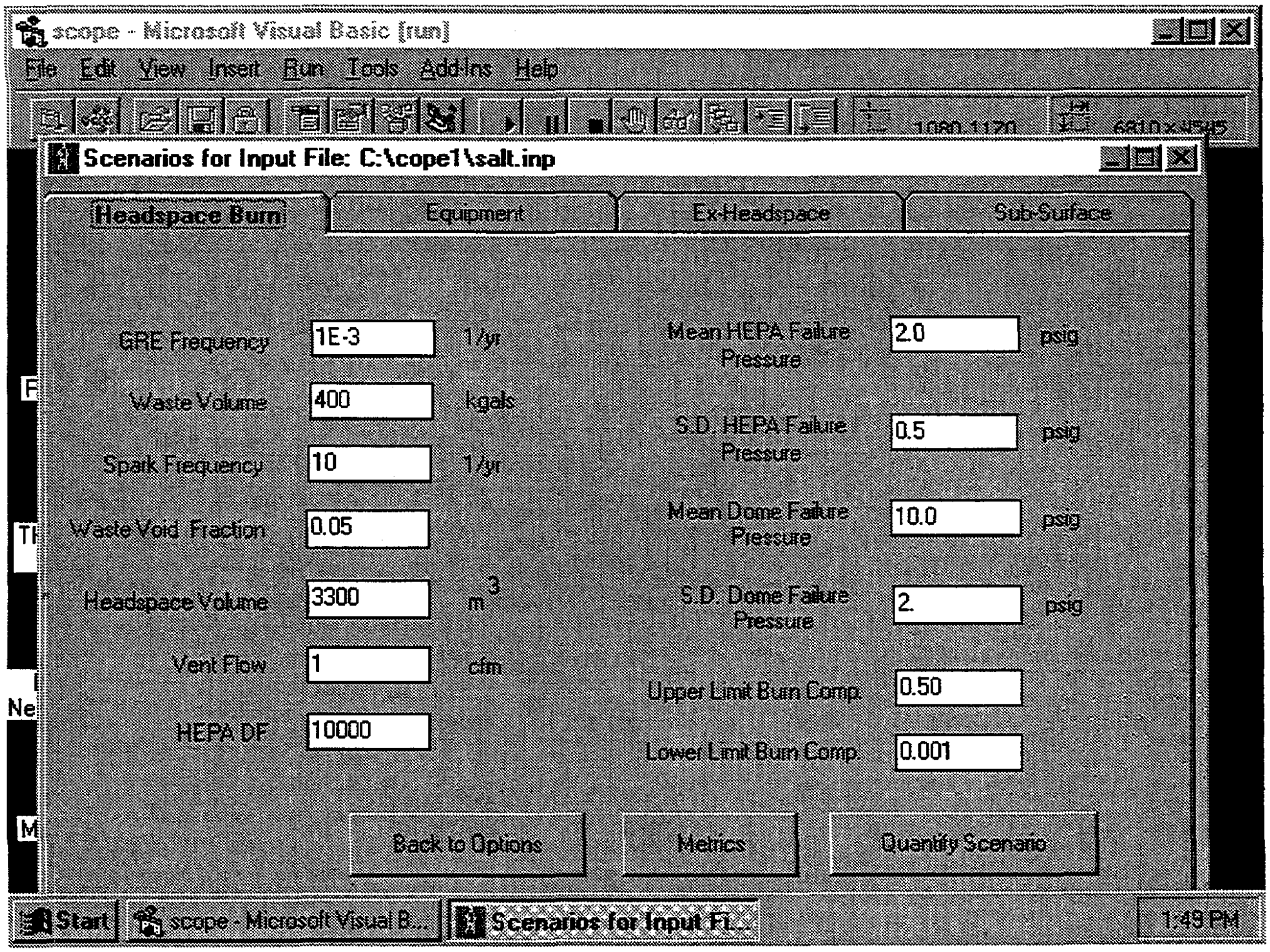

Figure F-4. Headspace Scenario Screen.

Metrics

Metrics are calculated quantities that convey the risk presented by a tank, group of tanks, or the tanks farms in general. In phase 2 of the SCOPE project, metrics will be calculated for each scenario, and aggregated to form a summary set. In keeping with the phase 1 goals, only the headspace burn is considered here. As with any risk measure, SCOPE metrics include frequencies and consequences of the damage states defined for each scenario. For each scenario, the user can display the metrics by clicking the Metrics command button on the Scenarios screen. The Metrics screen shown in Figure F-5 again uses the tab format to efficiently display the metrics for each of the four scenarios. If the user selects to view the metrics from the Headspace Burn Scenarios tab, the Headspace Burn tab is displayed by the Metrics screen. For each scenario, a Metrics tab lists the damage states, along with the following metrics:

- HEPA failure (yes or no)
- dome failure (yes or no)
- annual damage state frequency
- conditional probability that the dose exceeds the risk acceptance guideline (RAG)
- dose at 100 m (Sv)
- dose at the site boundary (Sv)
- dose to the population within a 50-mile radius (Sv)

For phase 2, the list of metrics would include measures of toxicological dose as well.

F.2 Calculation Method

Quantification of the Headspace Burn scenario is presented here to illustrate the SCOPE method. As suggested by the metrics, quantification means determining the frequency of each damage state and an associated distribution for the source term. To determine the frequency of each headspace burn scenario damage state, five questions must be answered:

- Given a gas release event, does the flammable gas release take the form of a plume or well-mixed headspace volume?
- Given a GRE, what is the probability of at least one spark occurring?
- Given a spark, what is the probability that a headspace burn occurs?
- Given a burn, does the resulting pressurization fail the HEPA filter?
- Given a burn, does the resulting pressurization fail the dome?

Six damage states are then relevant to the headspace burn:

- plume burn with no HEPA or dome failure

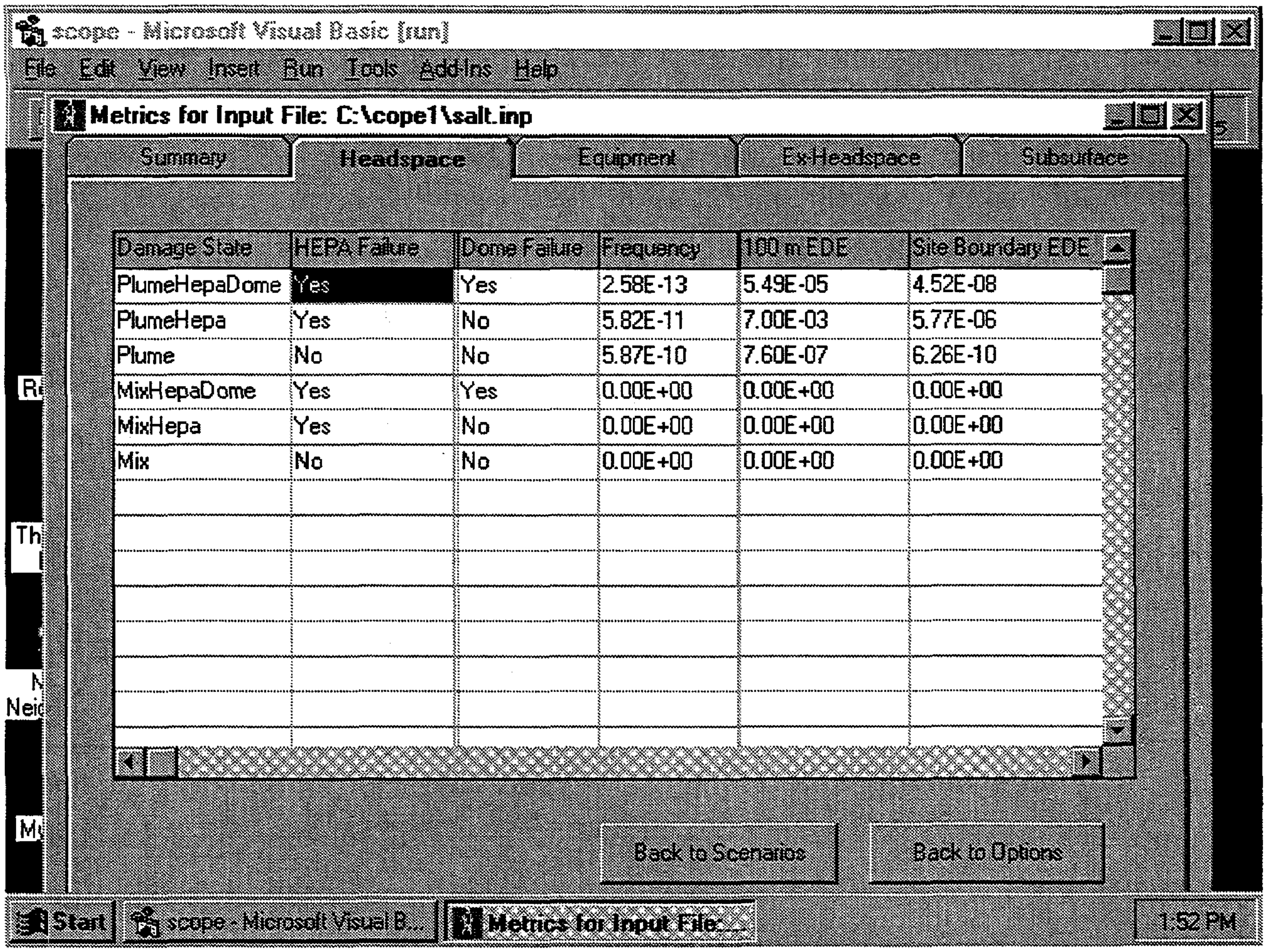

Figure F-5. Headspace Burn Metrics Screen.

- plume burn with HEPA failure, but no dome failure
- plume burn with HEPA failure and dome failure
- well-mixed burn with no HEPA or dome failure
- well-mixed burn with HEPA failure but no dome failure
- well-mixed burn with HEPA and dome failure

The scheme shown in Figure F-6 quantifies this scenario. This figure illustrates a Monte Carlo simulation where the frequency of each damage state is found by sampling random variables where necessary, repeating the calculation procedure many times, and counting how often the calculated results lead to each damage state. The simulation begins by assuming that a GRE occurs, of course. The GRE frequency is an input derived from elicitations. Other probabilities needed to quantify the frequency of each damage state are described below.

Plume or Well Mixed

For a given trial, this decision is based on the volume of the gas release. If the well-mixed flammable gas concentration does not exceed 4%, the release is a plume; otherwise the release is well mixed because the entire headspace is flammable. The flammable gas concentration is given by:

$$X = \frac{V_{gas}}{V_{gas} + V_H} \qquad \text{(F-1)}$$

where V_{gas} is the flammable gas release volume and V_H is the headspace volume. The headspace volume is deterministic, but the gas release volume is a random variable given by the following relation:

$$V_{gas} = V_w \, \alpha \, U \qquad \text{(F-2)}$$

where V_w is the waste volume, α is the void fraction of the waste, and U, which is a random number between 0 and 1, serves as an elicitation for phase 1. In phase 2, U will be replaced by an expert elicitation.

Probability of a Spark

The probability of a spark occurring while the release is flammable depends on the spark frequency and the duration of the flammable mixture. After a gas release occurs, active or passive ventilation decreases the flammable gas concentration until, at some point, the gas mixture is no longer flammable.

Consider pure hydrogen as the flammable gas and refer to the time between the release and time to fall below flammability limits as the "duration." The duration depends on the nature of the gas release (plume or well mixed) and the ventilation flow rate. If the release is a plume, the duration is assumed to be 3 minutes. If the release is well mixed, the following expression gives the duration:

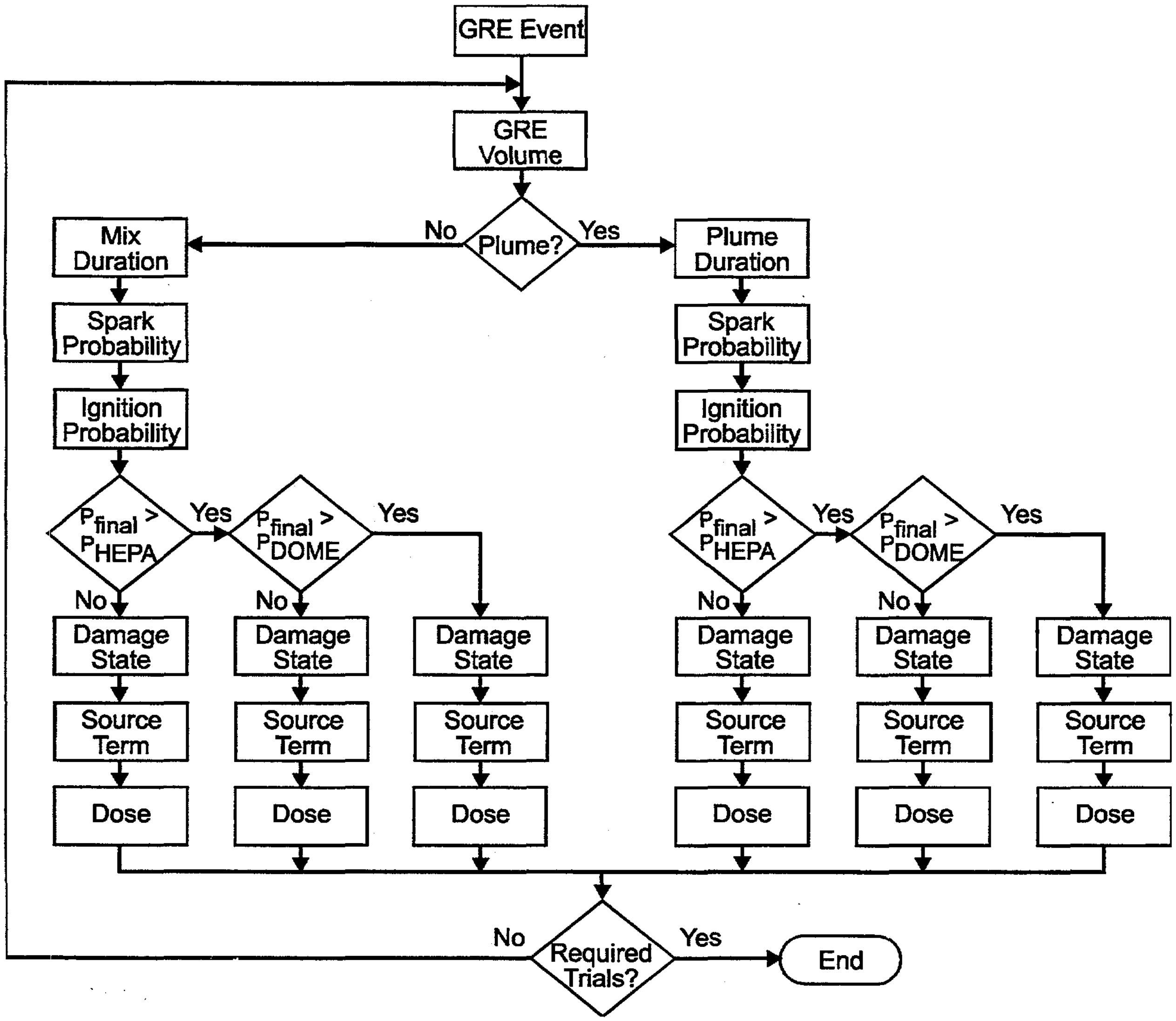

Figure F-6. Headspace Burn Scenario Calculation Flow Chart.

$$t_{mix} = \frac{V_{HS}}{W} \ln\left(\frac{X}{0.04}\right) \qquad \text{(F-3)}$$

where W is the ventilation flow rate and 4% is the lower flammability limit for pure hydrogen.

Assuming a Poisson process, the probability that at least one spark occurs while the gas release is flammable can be written as:

$$P_s = 1 - \exp\left(-t_f \bullet F_s\right) \qquad \text{(F-4)}$$

where F_s is the spark frequency and t_f is the duration. In the limit of small t_f, $P_s = t_f \bullet F_s$. The probability P_s is a random variable because for each trial, the flammable gas concentration and duration are different. For phase 1, there is no effort to determine a distribution for any random output variables. Instead, the mean is calculated based on the number of trials.

Probability of Ignition

If a spark occurs while the gas release is flammable, the probability of ignition is just the probability that the spark contacts the flammable gas. For the well-mixed scenario, the conditional probability of ignition is 1.0. For the plume scenario, the conditional probability of ignition is equal to the volume fraction given by Equation (F-1). This presumes that the spark or the plume could be located anywhere in the tank, and the probability of the spark contacting the plume just depends on how big the plume is. For the plume scenario, the conditional probability of ignition varies from trial to trial, based on the volume fraction. Again, we simply calculate the mean over all trials.

HEPA Filter Failure

HEPA filter failure depends on the final headspace pressure and the HEPA filter fragility curve. These two random variables can be quantified easily using the following assumptions: (1) the final pressure is described by adiabatic, isochoric combustion; and (2) the HEPA filter failure pressure probability density function is a normal distribution.

A simple method relates postburn pressure to the flammable gas volume burned. For the gases of interest, the preburn number of moles is nearly equal to the postburn number of moles. From an energy balance,

$$P_f = P_i \left(1 + \frac{F_v\, B\, X\, H_r}{C_v\, T_i}\right) \qquad \text{(F-5)}$$

where C_v = average heat capacity, J/kg-mole-K,
P_f = postburn pressure, Pa,
T_i = initial temperature, K,
F_v = fraction of volume occupied by flammable gas,
B = burn completeness,
X = fuel concentration in the plume,
H_r = heat of reaction, J/kg-mole, and
P_i = initial pressure, Pa.

Values for fuel concentration, F_v, and burn completeness depend on the gas release configuration (plume or well mixed). If the release is a plume,

$$F_v = X \qquad \text{(F-6)}$$

and

$$B = 10^{\left\{\log_{10}(B_{low}) + \left[\log_{10}(B_{up}) - \log_{10}(B_{low})\right] \bullet U\right\}} \quad \text{(F-7)}$$

where B_{low} and B_{up} are lower and upper limits, respectively. If the release is well mixed,

$$F_v = 1 \quad \text{(F-8)}$$

and

$$B = 0.5 + (2.0 - 0.5) \bullet U \bullet \left(\frac{X - 0.04}{0.08 - 0.04}\right) \quad \text{(F-9)}$$

with the stipulation that B cannot be less than 0.1 or greater than 1.0. Each trial for final pressure is compared to a random deviation from the HEPA fragility curve. If the final pressure is less than the random value from the HEPA fragility curve, then the trial is scored and the source term is calculated assuming the HEPA filter stays in place. If the final pressure is greater than the HEPA filter random value, then the scheme tests to see if the dome fails during this trial.

Probability of Dome Failure

As with HEPA failure, the trial for final pressure is compared to a random deviation from the dome fragility curve. Given HEPA filter failure, the scheme computes the source term in the same manner regardless of whether the dome fails. In either case, the HEPA filter is not credited. If the dome fails, however, the final pressure is capped at the dome failure pressure, i.e., the final pressure predicted by Equation (F-5) is overwritten by the random value for dome failure pressure. This reflects the assumption that the tank cannot pressurize above the dome failure pressure.

Source Term

The source term calculation determines the amount of airborne SST (or DST) material released to the Hanford environment. There is airborne material in the headspace volume prior to the event, but the deflagration itself will resuspend particulate as the flamefront passes over the waste surface. Los Alamos National Laboratory estimates that the amount of preexisting airborne material in an SST is 0.21 L (0.35 kg) [LANL, 1996]. The amount of particulate resuspended during the burn is a complicated function of burn time, flame speed, waste surface characteristics, etc. The discussion below provides a simple calculation to provide a reasonable estimate only, while still illustrating the phase 1 pSCOPE-AT.

The particulate mass resuspended during the deflagration can be expressed as:

$$M_s = \lambda \; M_T \; \Delta t + M_i \quad \text{(F-10)}$$

where λ is the resuspension rate parameter, M_t is the total mass of waste, M_i is the initial suspended mass, and Δt is the burn time. Resuspension rate parameter depends on flame speed according to the following relation:

$$\lambda = 7.39 \times 10^{-10} \; U_f^{3.08} \quad \text{(F-11)}$$

This relationship is based on the data of Reynolds and Slinn for particulate on dry gravel [Reynolds and Slinn, 1979]. Flame speed is approximated by using a laminar flame speed and then multiplying by a flame flux factor of 10 to account for turbulence. The well-known Liu et al. correlations give the laminar flame speed as a function of gas composition (hydrogen mole fraction, mainly), temperature, and pressure [Liu et al., 1981]. Each of these factors is a random variable; hence, the suspended particulate mass is a random variable, i.e., it is different for each trial.

The particulate mass expelled is given by:

$$M_e = M_s \left[1 - \left(\frac{P_i}{P_f} \right)^{\frac{1}{\gamma}} \right] \qquad \text{(F-12)}$$

Where M_e is the expelled particulate mass, M_s is the suspended particulate, and γ is the ratio of specific heats for air. Again, this is a random variable because the final pressure and resuspended mass are random variables.

Consequence Analysis

Van Keuren and Savino show a methodology for calculating inhalation dose [WHC, 1996]. For phase 1, ingestion doses are neglected relative to inhalation doses. Inhalation dose is described by:

$$EDE_I = Q \frac{\chi}{Q'} B_r \; ULD_I \qquad \text{(F-13)}$$

where Q is the volume resuspended waste, (χ / Q') is the atmospheric dispersion coefficient, B_r is the breathing rate and ULD_I is the unit liter dose due to inhalation and submersion. Values for (χ / Q'), B_r, and ULD_I are listed in Table F-1:

Atmospheric dispersion coefficients for continuous releases are used here.

Damage State Frequencies

Frequencies for each end state are computed as follows:

PlumeHepaDome

Frequency = GRE Frequency * Plume Split Fraction * Spark Prob
* Ignition Prob * Prob (HEPA Failure and Dome Failure)

PlumeHepa

Frequency = GRE Frequency * Plume Split Fraction * Spark Prob
* Ignition Prob * Prob (HEPA Failure and No Dome Failure)

Table F-1. Parameters for Dose Calculations		
X / Q′ Values		
	Continuous (s/m^3)	**Puff (1/m^3)**
On-site	3.4×10^{-2}	9.9×10^{-3}
Off-site	2.8×10^{-5}	1.1×10^{-7}
Standard Man Breathing Rate (m^3/s)		
Breathing Rate	3.3×10^{-4}	
Unit Liter Doses		
	Inhalation (Sv/L)	**Ingestion (Sv m^3) / (s L)**
SST Liquids	1.1×10^{4}	0.05
SST Solids	2.2×10^{5}	4.10
DST Liquids	6.1×10^{3}	0.07
DST Solids	5.3×10^{5}	0.48

Plume

Frequency = GRE Frequency * Plume Split Fraction * Spark Prob
* Ignition Prob * Prob (No HEPA and No Dome Failure)

MixHepaDome

Frequency = GRE Frequency * Mix Split Fraction * Spark Prob
* Ignition Prob * Prob (HEPA Failure and Dome Failure)

MixHepa

Frequency = GRE Frequency * Mix Split Fraction * Spark Prob
* Ignition Prob * Prob (HEPA Failure and No Dome Failure)

Mix

Frequency = GRE Frequency * Mix Split Fraction * Spark Prob
* Ignition Prob * Prob (No HEPA and No Dome Failure)

F.3 Sample Calculations

The method described above was executed first with the input shown in Figure F-4. These values are fictitious and do not represent any real combination of tank attributes (the "A103" designator is for illustration only). Results are shown by Figure F-5. Each of the six plant damage states is given a designator. The second and third columns state whether HEPA failure or dome failure occur. Equivalent effective dose (EDE) at 100 m is listed in the fifth column, and the site boundary EDE is listed in the last column.

The metrics in Figure F-9 indicate that there is no potential for a well-mixed headspace volume, and that all GRE take the form of plume. Plume burns are very rare, mainly due to the low GRE frequency, and short flammable gas duration associated with plumes. If a plume burn occurs, the most likely outcome is no HEPA filter failure and no dome collapse. Given a plume burn, there is only a 13% chance of HEPA failure, and very little chance (0.06%) of HEPA failure and dome collapse.

Now, consider a second example where the amount of waste is much smaller than in the first example. The headspace volume is then correspondingly larger. Suppose the salt cake volume is 950 kgal, and the headspace free volume is 1200 m^3. The user implements these changes by going back to the Options screen and revising the pSCOPE-DSS database, as shown in Figure F-7. Everything aside from waste volume and headspace volume is kept as before, and the tank designator of "A101" is merely a place keeper. To quantify the headspace burn scenario with the revised values, the user returns to the Options screen and selects the Quantify Scenarios command button, which results in Figure F-8. In this screen, the user then selects the Quantify Scenario command button. The cursor becomes an hourglass as the calculations proceed. When the cursor returns to normal, the user clicks the Metrics button to produce Figure F-9.

The results show that just about any headspace burn results in HEPA and dome failure, with only a slight chance of the dome surviving intact. The likelihood of a plume is negligible, and nearly all releases will result in a well-mixed headspace. This can be attributed to the large amount of waste and relatively small headspace volume for this fictitious tank. Doses at 100 m and the site boundary are 3090 mSv and 2.54 mSv, respectively. These can be compared to the risk guidelines for an unlikely event (1E-2 to 1E-4/yr), which are 5 mSv offsite and 50 mSv onsite. The flammable gas hazards document also calculates 6.1 mSv offsite and 7000 mSv onsite for an SST deflagration, which suggests that the demonstration method used here is reasonable [WHC, 1996].

It is important to note the first sample calculation represents the majority of the SSTs, whereas the second sample calculation probably presents a limiting combination of headspace volume and waste volume. The two examples illustrate how easy is to develop and compare risk metrics for various SSTs (or DSTs) using the pSCOPE-AT.

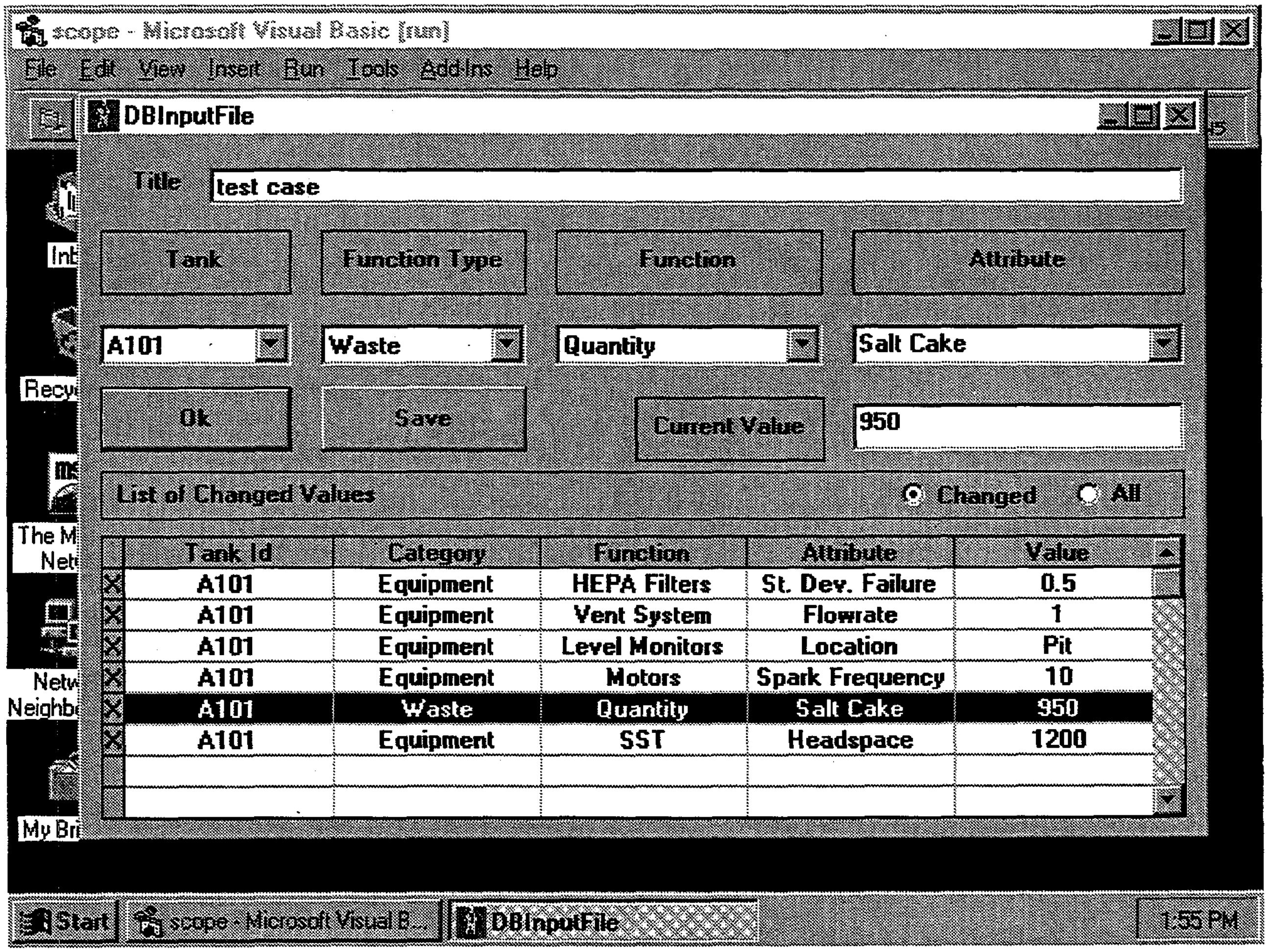

Figure F-7. Sample Calculation pSCOPE Parameter Database Screen.

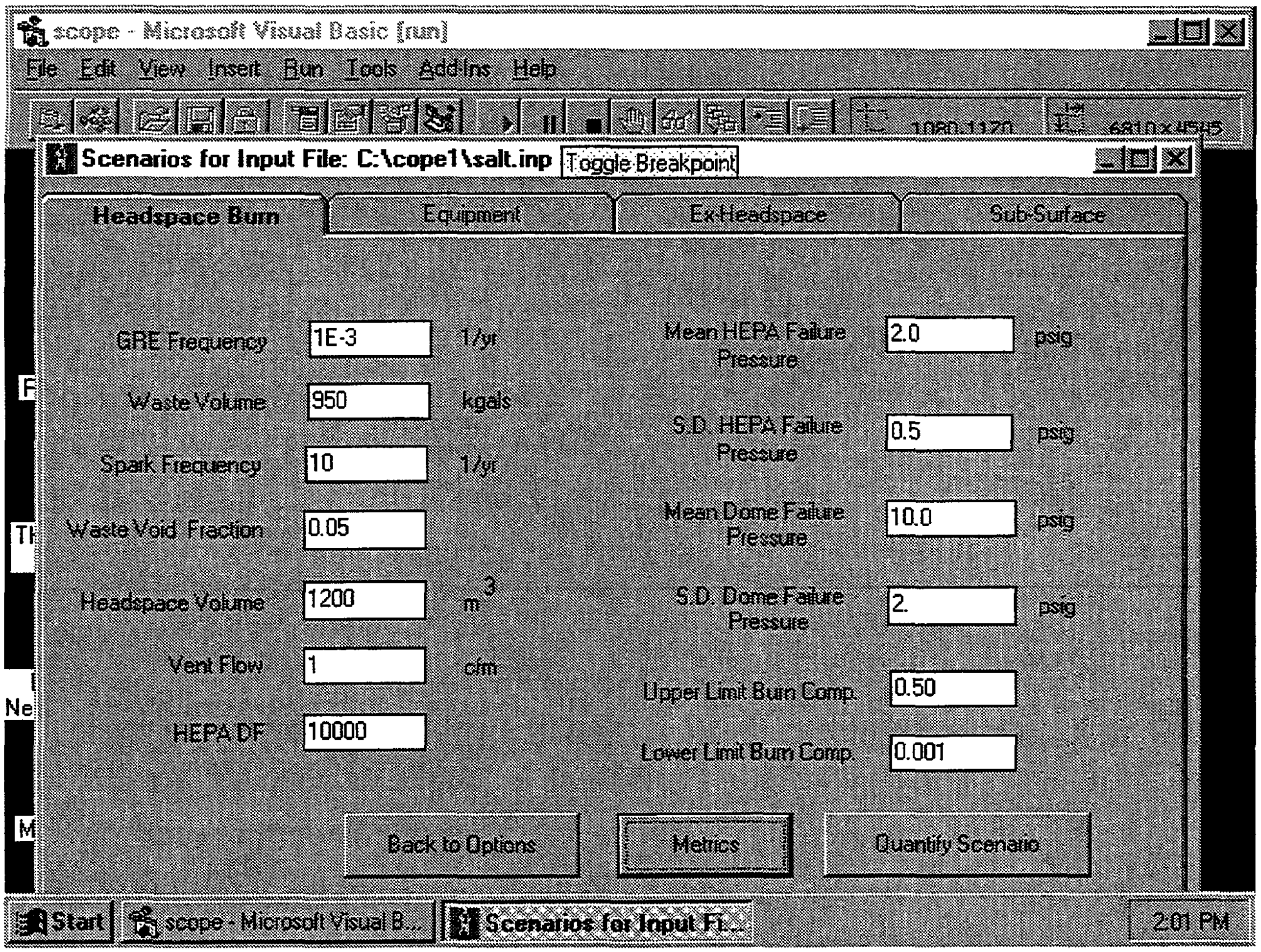

Figure F-8. Sample Calculation Headspace Burn Scenario Screen.

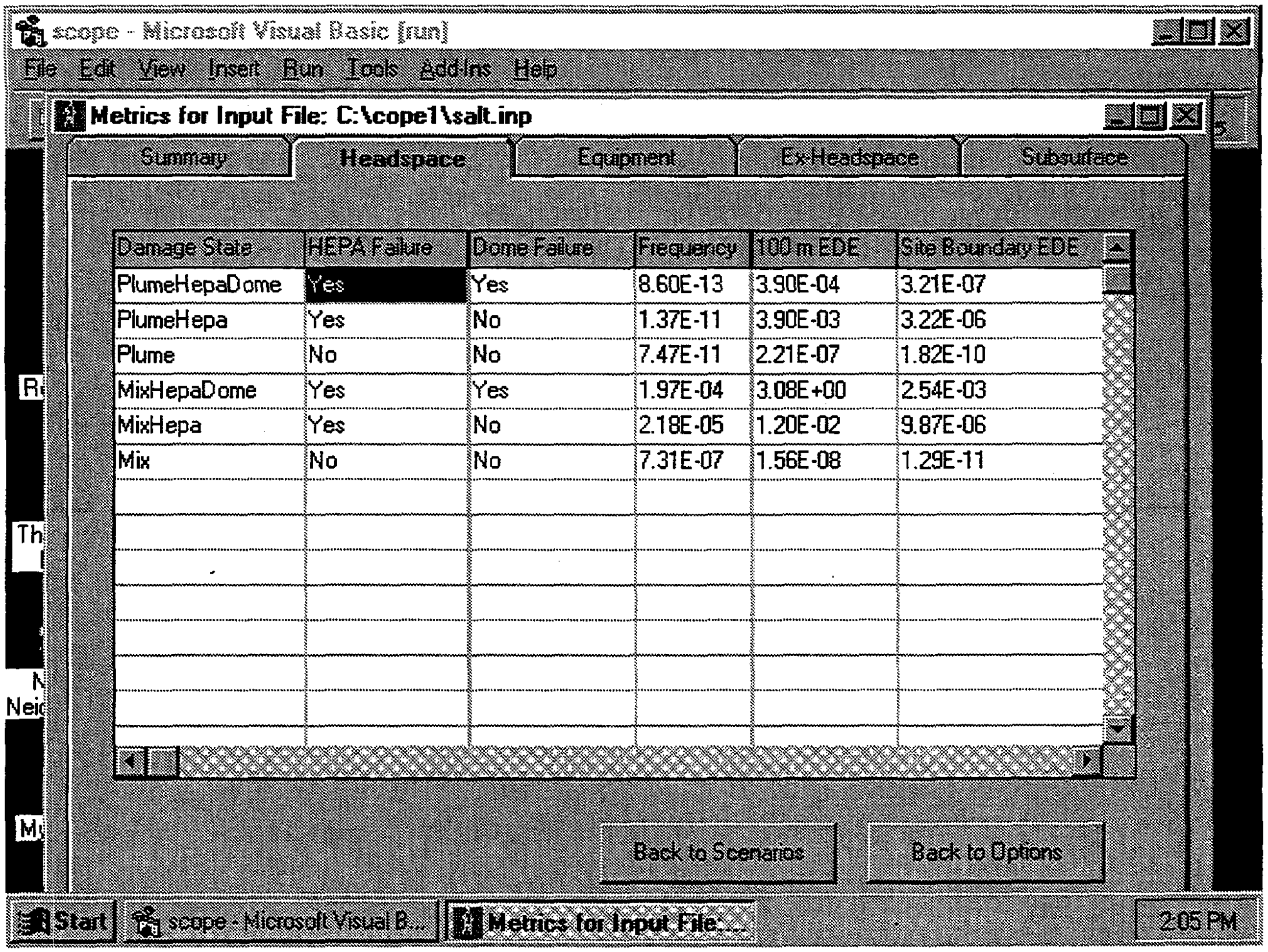

Figure F-9. Sample Calculation Metrics Screen.

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