

Exhibit 1

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**GUIDELINES ON THE SCOPE, CONTENT, AND  
USE OF COMPREHENSIVE RISK ASSESSMENT  
IN THE MANAGEMENT OF HIGH-LEVEL NUCLEAR  
WASTE TRANSPORTATION**

by

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The Nevada Agency for Nuclear Projects/Nuclear Waste Project Office (NWPO) was created by the Nevada Legislature to oversee federal high-level nuclear waste activities in the State. Since 1985, it has dealt largely with the U.S. Department of Energy's (DOE) siting of a high-level nuclear waste repository at Yucca Mountain in southern Nevada. As part of its oversight role, NWPO has contracted for studies designed to assess the socioeconomic implications of a repository.

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## INTRODUCTION

In spite of the shortcomings of probabilistic risk assessment (PRA), the Transportation Needs Assessment (Task 15.2, p. 8) recommended this as the preferred methodology to assess the risks of high level nuclear waste (HLNW) transportation. This recommendation was not without qualifications. While no new basic methodological changes are required, existing methods will need to be adapted and extended to accommodate the particular complexities and data constraints which characterize the HLNW transportation system. A PRA also will need to heed the lessons learned from the development and application of PRA elsewhere, such as in the nuclear power industry. A set of guidelines will aid this endeavor by outlining the appropriate scope, content, and use of a risk assessment which is more responsive to the uncertainties, human-technical interactions, social forces, and iterative relationship with risk management strategies, than traditional PRAs. This more expansive definition, which encompasses but is not totally reliant on rigorous data requirements and quantitative probability estimates, we term Comprehensive Risk Assessment (CRA).\*

Guidelines will be developed in three areas:

- the limitations of existing methodologies and suggested modifications;
- CRA as part of a flexible, effective, adaptive risk management system for HLNW transportation; and,
- the use of CRA in risk communication.

The guidelines concerning methodological limitations and modifications will draw on the many critiques and evaluations written to date (e.g., Freudenburg 1988; Lewis et al. 1978; NRC 1984; Gallagher et al. 1984). The guidelines concerning the use of CRA in risk management will draw primarily on the lessons learned in the development and application of PRA in the nuclear power industry. The guidelines on the use of CRA in risk communication will draw of the lessons learned from the disastrous release of the executive summary to the Reactor Safety Study (RSS), and the burgeoning literature in the field of risk communication.

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## I. METHODOLOGY OF RISK ASSESSMENT

PRA as traditionally practiced is one of the most rigorous and widely accepted methodologies for assessing risks. Since its origins in the 1970s as a method for estimating the likelihood of accidents and associated damages at nuclear plants, PRA has evolved into the cornerstone of both nuclear plant risk analysis and, more recently, of setting standards for the chemical exposure of human populations. Despite its widespread acceptance, however, PRA as a tool for assessing HLNW transport risks has numerous shortcomings. This section will highlight the major limitations of the methodology, based on several critical reviews, and suggest necessary modifications.

In 1984, the NRC conducted an appraisal of the state-of-the-art in PRA. A summary of the principal findings is presented in Table 1. Focusing on the limitations of PRA, the NRC study concluded that the data bases for low frequency events, external accident initiators, and human failure are poor and underdeveloped, and the data base for low frequency events is unlikely to improve substantially. In terms of human performance, modeling errors of misdiagnosis and potential recovery actions needs improving, and the actual behavior of affected populations during an emergency is not well understood. In addition to the findings indicated in Table 1, the study concluded that completeness is not a principal limitation in regard to the identification of dominant sequences, and uncertainty and sensitivity analyses need to be more widely used and better organized and displayed.

Also in 1984, Gallagher et al. reviewed six out of twenty completed PRAs to assess what level of effort and topic of analysis could have the highest impact in improving PRA. The study found that a moderate effort in the identification of initiating events, the assessment of human errors during normal operations, and the treatment of recovery (especially recovery of human errors) could have a major impact and lead to significant improvements in PRA. A larger effort on human errors during accidents would also yield much improved assessments. They also concluded, in contrast to the above, that the degree of completeness of a PRA does affect the substantive conclusions. Similarly, Hamilton et al. (1986, 7-6) notes that PRA "intrinsically suffers a completeness problem: it is only as good as the imagination of the analyst."

Both studies cited above refer to the use of PRA in regard to nuclear power plants. More recently, Hamilton et al. (1986) evaluated the applicability of PRA to the HLNW transportation system. This study concluded (Hamilton et al. 1986, 5-1 and 7-12) that the philosophy, approach, and organization of PRA are appropriate to HLNW disposal. No new basic methodology is needed, but existing methods may have to be adapted or extended. Additional data may be necessary, but existing methods may have to be adapted or extended. Additional data may be necessary, such as

Table 1

## STATE OF THE ART OF PROBABILISTIC RISK ASSESSMENT (PRA) OF NUCLEAR REACTORS

ASPECT OF PROBABILISTIC RISK ASSESSMENT	LEVEL OF DEVELOPMENT	RANGE OF UNCERTAINTY	IMPROVEMENT NEEDED
Qualitative systems analysis (logic modeling) <ul style="list-style-type: none"> <li>• Internal accident initiators</li> <li>• External accident initiators</li> </ul>	High confidence in qualitative insights Medium confidence in qualitative insights	$\pm$ Factor of 10 $\pm$ Factor of (10 to 30)	Modeling common cause failures. Modeling common cause failures.
Modeling human performance		$\pm$ Factor of 10	Errors of misdiagnosis. Potential recovery actions.
Data base: <ul style="list-style-type: none"> <li>• high frequency events</li> <li>• low frequency events</li> <li>• internal accident initiators</li> <li>• external accident initiators</li> <li>• equipment and human failure</li> </ul>	Fairly good Poor  Fair degree of confidence Poor degree of confidence Needs improvement		Not likely to improve substantially.
Source terms due to internal reactor phenomena	Poor confidence	Very large	Extensive research; source terms remain quite large.
Consequences, given source terms and meteorology <ul style="list-style-type: none"> <li>• mean early fatalities</li> <li>• mean population dose</li> <li>• latent cancer deaths</li> </ul>	Reasonably high confidence	$\sim 0$ to 5X $\pm$ Factor of (3 to 4) $\pm$ Factor of 10	Stochastic uncertainty.
Consequences, actual		As a function of location cannot be predicted with much precision	
Actual behavior of affected population in an emergency	Not well understood		
Difference between analysts		Factor of 3	

*Notes:*

High frequency = often observed in plant operations. Low frequency = less than once in 1,000 reactor-years. X = nominal estimate.

SOURCE: NRC (1984).

for health effects at low doses of radiation, cask integrity under accident conditions, and the influence of human factors. The authors stress that the methodology is not a constraint; in fact, it generally is more powerful than the available data. Any future risk assessment of the HLNW transportation system needs to address a wide variety of initiating events, including external events such as floods and earthquakes, and the full spectrum of consequences, with greater attention to non-radiological and economic consequences. Special emphasis must be given to the human element in causing, and recovering from, mitigating accidents. Uncertainty is an ever-present problem with all risk assessments but greater use of uncertainty and sensitivity analysis should be made to illustrate the impact of differing assumptions and variable quality of data. Finally, the authors stress the need for clarity of analysis and careful presentation of the results. The latter point stems from criticisms of the Reactor Safety Study, and is a matter of risk communication which will be addressed later in this paper.

We concur with these conclusions and generally support the recommendations. We would, however, suggest that, to improve the methodology and apply it to the case of HLNW transportation, the implications can be viewed more broadly. Given that the methodology is often more powerful than the available data, theories, and models, it is suggested that a CRA rather than a PRA is the appropriate analytical framework. PRA may be especially inappropriate regarding certain low-frequency initiating events such as sabotage and terrorism, catastrophic infrastructure failures, and natural disasters. PRA also appears inappropriate where experimental data on key issues is limited or absent, particularly regarding cask performance under severe accident conditions. A CRA calculates probabilities only where the existing data, theories and models are sufficient to support the use of rigorous quantitative methods. The use of expert judgment should be limited and clearly indicated in a CRA, and the methods of expert judgment need close attention. Judicious use of analogue arguments, e.g., experiences in transporting chemical waste for which certain data types are more abundant, also can serve to enrich the quantitative dimension of a CRA.

The conclusions that a wider variety of initiating events and consequences, including external events and human factors, needs greater attention, should be reiterated and stated more broadly. A CRA should consider the full range of initiating events and the full spectrum of consequences. Historically, PRAs have used extremely narrow definitions of risk that are inconsistent with public perceptions of an adverse consequence and a tolerable risk, and thereby direct managers to inappropriate response strategies. As a result, traditional PRAs may fail entirely to address the risk issues of greatest public concern. A **comprehensive** risk assessment needs to address the complete range of events and consequences, and be able to accommodate a broader view of risk that is more compatible with that of the public.



Freudenburg (1988) suggests that opening the process of risk assessment to input from the social sciences will encourage this kind of comprehensiveness by enlarging the definition of causes and consequences of transportation hazards. In this fashion, CRA will impart greater realism to estimates of probabilities and uncertainties, and yield results which are more coincident with public sensibilities.

We now consider various aspects for achieving this objective.

#### **A. Initiating Events**

In assessing the full range of initiating events, the social sciences have significant insights about the issues of human error and human factors, sabotage and terrorism, and organizational deficiencies that hitherto have received only limited attention by risk assessors. Social and psychological research (Fischhoff et al., 1978; Slovic et al. 1985) indicates that low probability/high consequence events are of particular concern to the public. Such events, often ruled out as "incredible" by assessors, should be incorporated in a CRA to maintain public credibility, while serving as the upper bound estimate of plausible damages. Conversely, high probability/low consequence events may be ignored because they appear to be of little significance. Given the nature of the controversy surrounding the shipment of nuclear waste, these events may serve as "signal events" with severe repercussions for the management of the system (Slovic 1987; Kasperson et al. 1988). Every minor accident, with or without radiological consequences, will, at least initially, attract significant media attention and indicate to the public the inherent risks of transporting nuclear waste and the flaws in the risk management system. It is likely that the cumulative and synergistic effects of multiple small events, especially when radioactive materials are involved, will tend to undermine public confidence in risk managers. The CRA, therefore, should consider such events carefully in the hope of identifying vulnerabilities and preventive measures.

##### **1. Human Error**

Quality control failures and human errors have been a continuing major problem throughout the nuclear power industry and in hazardous materials transportation. The OTA (1986) estimates that more than 60 percent of hazardous material accidents are the result of human errors. Human error has also been identified as a major contributor to nuclear accidents, such as at Three Mile Island in 1979 and Chernobyl in 1986, and in non-nuclear accidents, such as at Bhopal. Similarly actuarial data indicate that 80 to 90 percent of accidents in the chemical industry and 60 to 80 percent of the accidents in the airline industry involve human error (Joksimovich 1984). In a similar vein, Audin, in a review of human error potential in the transport of spent fuel, stresses the failure of the environmental assessments to properly account for

human error (Audin 1987). The result is a systematic under estimation of risks. It is essential that any CRA not repeat such shortcomings but pay close attention to human errors which might compromise engineered integrity and safety systems.

Following a review of over 20 PRAs, Joksimovich (1984, 264) recommends that "the analysis of human interactions with plant equipment should at least receive the same degree of attention as analysis of systems hardware." Previous PRAs have highlighted the importance of human factors. However, they have also illustrated that large uncertainties in the quantitative estimates of risk result from "the lack of a large data base on human behavior and because evaluation techniques in this area are still in an early stage of development" (Levine and Rasmussen 1984, 253). There have been major improvements over the last 15 years in the way PRAs handle human factors, especially through modeling human errors based on the misperception of plant conditions (Garrrick 1984, 276). Unfortunately, many improvements have yet to be made, and the poor data base will continue to be a substantial problem. Consequently, Gallagher et al. (1984, 83-84) concluded that a moderate research effort on human errors during normal operations could significantly improve PRAs, and additional improvements could be accomplished with a more extensive effort on human errors during accidents. This appears to be one area where HLNW transport may benefit from experience with chemical (including chemical waste) transport, for which data bases have been much improved as a result of the 1986 Superfund Amendments. A CRA should incorporate the role of human factors in the transportation of HLNW under both normal and accident conditions.

Human error and poor quality control may be either enabling or initiating factors in a sequence of events leading to hazardous outcomes. They may occur at any stage of the transportation system. This includes design, fabrication, testing, inspection, maintenance, quality control, operation, emergency response, or even in the risk assessment. Many kinds of human error have the same underlying causal mechanisms, consequently, they are treated here as generic factors of concern for both normal and accident conditions.

Some key issues to consider in an evaluation of human error are:

- task, physiological, and cognitive requirements;
- performance shaping factors (e.g., work environment, stress factors, fatigue);
- data availability;
- enabling vs. initiating errors;

- equipment design and operating requirements;
- observation and reversibility of errors;
- organizational structure; and,
- social environment (internal and external to the transport system).

Human errors may cause adverse impacts only if they are not corrected in time. Thus, their effects are dependent to large degree on their observability and reversibility (Levine and Rasmussen 1984). To assess the observability of errors and identify correction methods, the characteristics of the total human/task or human/machine system should be evaluated. The primary interactions are between task requirements (e.g., procedures), equipment and operating characteristics, and human physiological and cognitive capabilities.

In addition, persistent situational features should be evaluated. These include noise and illumination levels, worker fatigue and emotional stress, time pressures, and the organization of the work place. Persistent situational features, often referred to as performance shaping factors, may greatly increase the likelihood and consequences of errors. Emotional stress and time stress are performance shaping factors which have been shown to greatly affect decision behavior.

A complete evaluation of human error in the waste transportation system requires the evaluation of all levels of the socio-technical system. The organization of the workplace, including management-employee interactions, can have a significant effect on performance. Manager personalities, organizational culture, and the regulatory environment can constrain the types of risk management programs that will be acceptable and effective. Such concerns have recently been identified regarding the operation of nuclear power plants and many similar issues appear in the transportation system for nuclear waste (National Research Council 1988).

The types of errors and the rates of human errors are a function of the situation. Therefore, to evaluate fully and effectively the possible sources and impacts of human error, a comprehensive human factors analysis should be completed for the proposed HLNW transportation system. Such analyses should be performed for both transport activities (e.g., driving a truck) and cask handling activities (e.g., loading, packaging). The objective of the analysis is an overall understanding of the work environment, including goals and functions, performance shaping factors, and worker, task, and job requirements. After these issues are evaluated, the sensitivity of the system to human error can be assessed by identifying error types, their probability of

occurrence, potential for recovery, and consequences. Steps in a human/machine systems analysis include:

- describe system goals and functions;
- describe situational and performance shaping factors;
- describe personnel characteristics (including social issues);
- describe task and job requirements (including organizational issues);
- determine situations in which human errors may occur;
- estimate the probability of error occurrence for each identified error;
- estimate the probability that each error will not be corrected;
- develop changes in tasks, equipment, or systems to increase the overall system reliability; and,
- reiterate to evaluate modifications in system.

Whereas the transport of nuclear waste may appear to the lay person as less vulnerable than nuclear plant operations to human errors, such a conclusion is based more on the severity of outcome than the probability of misjudgments. In fact, the ability to standardize effectively and to enforce operating procedures in HLNW transport is confounded by the multiplicity of actors -- supervisors, loader/unloaders, drivers, inspectors -- whose decisions will affect the risk of waste movements from dozens of origins across the nation. In comparison with the insular nature of nuclear power plant operations, such individuals perform in relatively uncontrolled, vulnerable environments subject to the exogenous forces of weather, other roadway users, local highway conditions and a host of other variables beyond their control. Thus, over the course of HLNW preparation, loading, transport, and unloading, the opportunities abound for misjudgments which directly affect ultimate risk levels.

## 2. Sabotage and Terrorism

Sabotage refers to the deliberate disruption of waste shipments with the intent to steal nuclear materials or to cause harm by the release of such materials. Many of the same reasons that make the transport system vulnerable to human error also make sabotage or terrorism non-trivial hazard initiators. The experience with aircraft hijacking attests to the difficulty of protecting "moving" targets under multiple jurisdictions and

agencies over long distances. By analogy, the pattern of such events -- their timing, spacing, location -- may inform the analysis of hazard initiation in HLNW transportation.

Although it is impossible to quantify the probability of sabotage, the potential consequences can be systemically evaluated. DOE has undertaken such an evaluation by testing radioactive releases caused by sabotaging waste shipments with explosive devices, though such experiments have been questioned on the basis of alleged faulty procedures, documentation and peer review (Audin 1989).

One method of evaluation is vulnerability analysis. The list of parameters to be addressed in such an assessment is almost identical with the list for accidents (see below) since both lead to the potential release of radioactive and toxic materials. In addition, two other parameters are of concern: (1) the probability of sabotage, and (2) its severity. Past experience is too limited to allow reliable estimates of probability. Consequently, either expert judgment must be used, or acts of sabotage may be modeled without reference to probabilities, focusing only on response mechanisms to acts of sabotage and terrorism.

The severity of sabotage attacks runs the entire spectrum. Many acts of sabotage, such as deliberate tampering with vehicles or bridge destruction, result in sequences of events similar to other accidents and may be modeled in the same way. Other acts of sabotage may be deliberately directed towards exacerbating the consequences. Examples are driving damaged casks into urban areas or dumping them into a reservoir system. In the absence of probabilities, modeling these scenarios becomes a worst-case analysis.

## **B. Consequences**

Social science input in a CRA can help to broaden the definition of consequences to bring it more into line with public perceptions. As pointed out previously, the CRA goes beyond PRA by identifying signal events that may have little immediate or obvious consequences in the near term, but severe repercussions later on if they serve to cast doubts and undermine public confidence in the risk management institutions, or if they interact with high levels of public concern, when they create "signals." It is not expected that a CRA should assess these ultimate consequences in the traditional quantitative sense. Rather a CRA serves to evaluate the significance of these events and to estimate their number and probability, so that the risk management system will be better equipped to respond. A simple but major advantage of such an analysis will be to show risk managers that these events will occur relatively frequently and will not necessarily be amenable to "technical fixes."

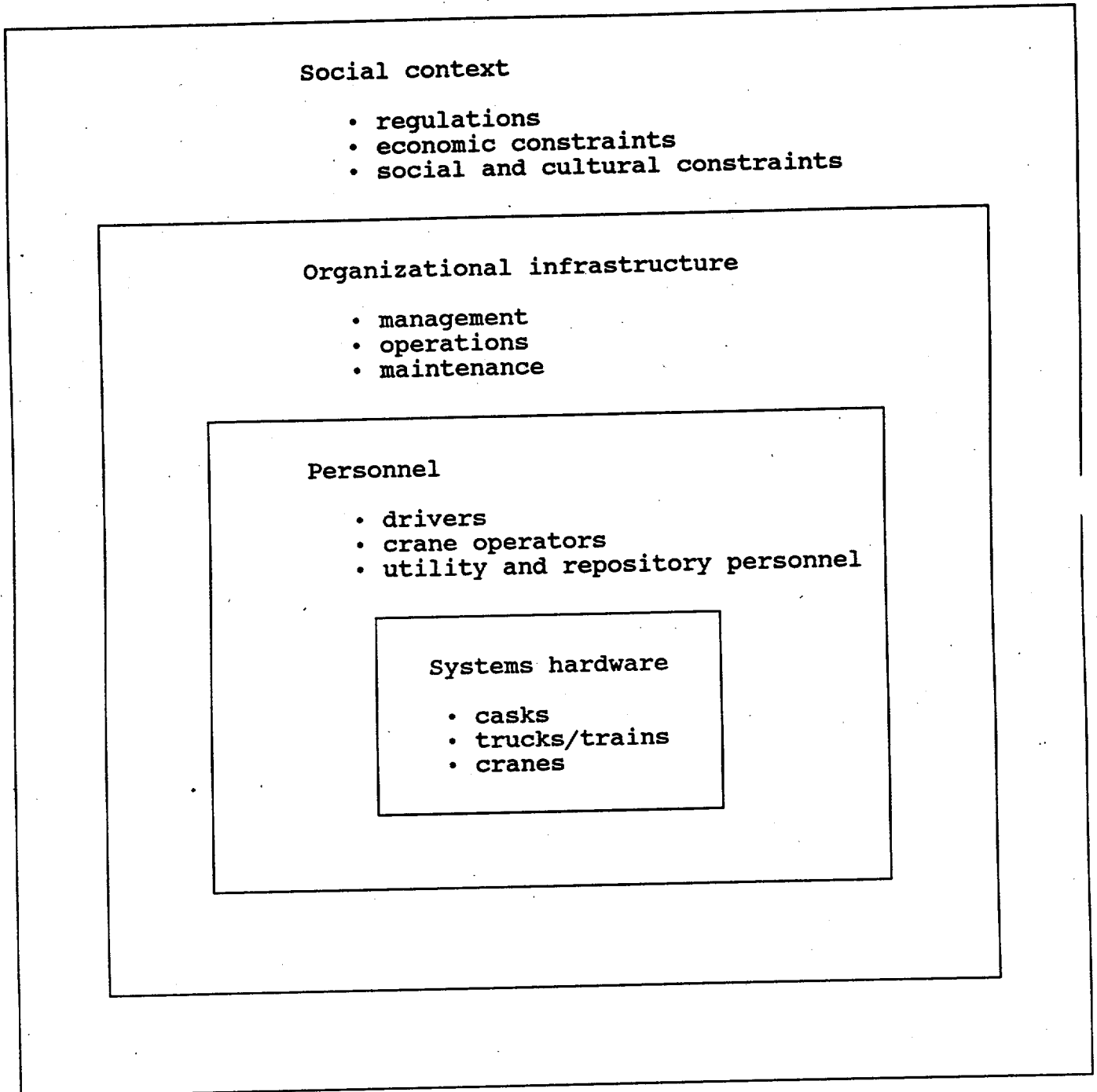
Many such consequences resulting from accidents are not ordinarily incorporated into risk assessments. These include: economic losses; the costs of emergency planning and preparedness; the behavior of public officials and households under emergency conditions; declining property values; psychological stress; and so forth. Some of these broader social and economic consequences might usefully be incorporated in a CRA, but the methodology should not be stretched beyond its limits. Rather, the results of risk assessments need to be integrated with additional socioeconomic and sociopolitical assessments in order to identify additional issues of public concern and how they might be mitigated. Concerns such as economic impacts and questions of institutional capability may have a significant impact on the ability to safely, reliably, and efficiently develop and maintain a transportation system for nuclear waste (NAS 1984). An especially important aspect of such studies is the evaluation of issues related to the social amplification of risk (Kasperson et al. 1988), or those attributes of risk events which tend to trigger adverse public reaction disproportionate to traditional measures of damages.

The need to identify and respond to all types of social concerns argues for a sociotechnical perspective for the risk management of the transportation system. A sociotechnical system refers to interacting components such as: system hardware (e.g., spent fuel casks, trucks, trains, cranes), personnel activities (e.g., drivers, crane operators), organizational infrastructure (e.g., operations, maintenance, management), and social factors (regulations, economics, culture). These are illustrated in Figure 1. If types and degree of interactions of different system components and levels are not taken into account in risk management activities, the result may well be the failure to implement effectively many of the suggested measures (National Research Council 1988).

The preferred approach should make clear that risk estimates are based on specific design and operating criteria, and that these estimates can only approach their true values if the transportation system is operated in accordance with the models and assumptions of the risk assessment. Any modifications to the system components (e.g., operations, maintenance, training) should be fed back into the risk assessment process, thereby creating a dynamic process capable of incorporating hardware and management changes into revised risk estimates. This again supports the need for a comprehensive systems approach to evaluating the transportation system. Concomitantly, new results from a risk assessment then need to be fed forward into developing new control strategies. This approach is particularly important in the transportation system because the technologies, regulatory environment, and institutional structures undergo frequent and often major changes.

**Figure 1**

**A SOCIAL-TECHNICAL VIEW OF THE HIGH LEVEL  
RADIOACTIVE WASTE TRANSPORTATION SYSTEM**



SOURCE: Adapted from National Research Council (1988)

### C. Uncertainty

Uncertainty in risk assessments may arise from several sources, including:

- poor or inadequate data;
- the choice of models and assumptions;
- the use of expert judgment as a substitute for poor or missing data;
- the assumptions about human factors, and human and organizational errors; and,
- human error in estimation techniques.

Uncertainty is inherent in any risk assessment. This is especially so in the case of the HLNW transportation system since the final choices on system design have yet to be made, and there is minimal experience with, and inadequate data on, a number of system elements.

Much of the detail concerning uncertainty will be dealt with in a companion paper by Freudenburg. We need to recognize, however, that the same features that motivate our recommendation to recast the PRA into the broader CRA concept at the same time introduce uncertainties into the results. There is little doubt that incorporation of human error and institutional conditions elevate analytical uncertainties because such variables depend heavily on qualitative information and expert judgements. Suffice it to say that recognizing these uncertainties is a partial solution, and a CRA should clearly indicate the models and assumptions used, and the likely range of uncertainty involved. Such clear indications may help to avoid misleading the public into thinking their probability and consequence estimates are etched in stone. Sensitivity analysis should be used to indicate how sensitive the findings are to the assumptions, models, and data used. The results of such sensitivity analysis should be clearly displayed in the reports and executive summary. Continuous, rigorous, independent review of the CRA will aid in the identification of erroneous assumptions, faulty expert judgment, errors of omission and commission, and other unrecognized areas of uncertainty.

### D. Some Parameters for Consideration

The CRA should consider the full spectrum of events and consequences under both normal and accident conditions. We, therefore, conclude this section on methodology by suggesting some of the parameters that need to be considered.



## 1. Normal Conditions

Both radiological and non-radiological risks occur in the normal or incident-free transportation of nuclear wastes. Handlers, crew members, and the public are exposed to the small amounts of radioactivity that penetrate through the walls of the shipping casks and the non-radiological risks such as exhaust emissions from trucks and rail locomotives. As such, there are no identifiable initiating conditions except, of course, the decision to ship nuclear waste and the choice of cask design. Poor quality control and human errors in cask design, fabrication, loading, and handling may exacerbate these normal exposures and can, therefore be seen as enabling events. Moreover, model choices in the transport system lead to measurable changes, and tradeoffs, in routine exposures to the workers and the public (Hoskins 1989). It is possible to identify probabilities for such errors, although the current methodologies are complex, and the data bases for so doing are somewhat rudimentary.

The following illustrative list indicates some of the parameters to be considered in estimating risks under normal operating conditions:

- quality control;
- human error;
- nature of waste material (amount, form, level of radioactivity);
- cask design and fabrication;
- nature of individual transportation procedures (time of day; length, number, and duration of trips; vehicle/train speed and stop-times; shielding factors);
- shipping information (number of casks);
- population at risk (workers, public);
- transport modes (truck, rail);
- transport route (route, length, population density, bridges);
- exposure pathways (inhalation, ingestion, direct);
- dose-response relationships (modeling, extrapolation); and,
- nature of consequences (acute/chronic, morbidity, mortality).

The exposure pathways under normal conditions include direct radiation from the waste package during loading and from the cask during shipping. Given the solid waste form and absence of accidents leading to volatilization or dispersion, inhalation of radioactive gases or particulates is unlikely. The primary route of exposure for non-radiological hazards is inhalation, although skin contact with, or ingestion of, lubricants and fuels is possible for crew members and maintenance staff.

The parameters necessary to estimate doses are also indicated in the above list. To estimate exposure levels at every point in the transportation network, it is necessary to know the nature of the waste material and cask, the nature of the various tasks (e.g., packing, loading, shipping, unloading), and shielding factors. Individual worker doses can be estimated from data on exposure levels during each task, task duration, the number of packages and casks processed, and the number of workers involved.

Estimating doses received by the public requires data on exposure levels at various distances from the cask, the number of casks to be shipped, transport mode, transport route (including data on population proximity and density, and the shielding factors of buildings), and the timing of shipping (including the time of day, the number and length of stops, and the expected population exposed in each case).

Having estimated doses to the various populations at risk, several models are available to predict possible adverse outcomes, including latent cancer fatalities, and genetic effects. There is considerable disagreement and controversy over the extrapolation from known effects at high doses to effects at low doses, and the assessment should provide several alternatives models for calculating the likelihood of adverse health effects, including delayed morbidity and mortality. In this fashion, a range of outcomes may be estimated.

While total, or "bottom line," risk estimates are typically the focus of public debate and policy-making, it is the individual components of risk under normal operating conditions that provide the most useful information for formulating risk reduction strategies. This point cannot be overstated. As HLNW moves through the packaging, loading, shipping, unloading, and emplacement process, each step presents a different set of exposure possibilities for humans and the environment. Furthermore, each step clearly affects all that follow, (e.g., sloppy loading increases shipping risks). Nevertheless, the tendency to look only at final risk figure obscures the relative weight of each step and may lead to suboptimal modal, routing, or other operational decisions. It may be the case, for example, that a transport system estimated to present higher aggregate risks is characterized by (a) less uncertainty, and (b) greater risk reduction opportunities for discrete components. In this instance, a

decision in favor of a lower aggregate risk transport system may be the wrong one. The estimated risk and surrounding uncertainties for each component of the transportation system should, therefore, be presented in addition to the estimated aggregate risk. This concept is equally applicable to accident conditions, the subject of the following section.

## 2. Accident Conditions

Assessing the probabilities and consequences of accidents is more complicated than assessing the risks of normal conditions, although many of the necessary parameters are the same. Some additional parameters needed are indicated below. Again, this list is intended only to be illustrative:

- frequency of accidents;
- external events (e.g., severe weather, earthquakes);
- common cause and common mode failures;
- nature of accidents (frequency, severity, location);
- release fractions;
- dispersion modeling;
- post accident behavior of officials, emergency workers, and the public; and,
- emergency response.

Human error and quality control take on added significance in accident analysis since they may act as initiating or enabling events in an accident sequence, or they may exacerbate or mitigate the final consequences. Accident frequency, both general transportation accidents and those involving hazardous materials, is an important input for this type of analysis.

Although these data are generally available for both truck and rail transport modes, their accuracy, precision, completeness, and applicability need to be evaluated with respect to CRAs for a transportation system. Special emphasis should be given to external events like plane crashes, bridge failures, earthquakes, floods, as well as combinations of events such as joint impacts of petroleum and pipeline fires with casks released during roadway accidents. Events such as earthquakes and floods may act to both initiate and exacerbate accident conditions, and impede mitigation efforts. An earthquake may initiate an accident by causing a truck to crash and burn, and thus result in a breach of the cask integrity. The earthquake may also exacerbate accident

consequences by causing infrastructural collapse that will hamper emergency response efforts.

The nature of the cask is also particularly important in accident analysis. The design and fabrication of the cask must allow it to withstand a variety of accident conditions. As yet data on cask behavior are limited to a handful of experimental crash and fire tests at the national laboratories (Hamilton et al. 1986, 10-225 to 10-28). However, these data are inadequate for a CRA, and their validity is in question (Resnikoff 1983; Audin 1989).

Intimately related to cask design and integrity is the severity of postulated accidents. This highlights a generic problem in risk assessment: what accidents are considered to be incredible and therefore beyond consideration? It is possible to identify a sequence of events leading to a massive release of radiation and a significant number of adverse effects, but is it reasonable to consider accidents with such low probabilities? These are questions that will have to be addressed at the beginning of the analysis. It is recommended that a broad spectrum of accidents be assessed, including the worst case. To omit such scenarios is to invite skepticism from critics who, in all likelihood, will eventually pose such worst case conditions.

For each accident scenario postulated, the risk assessment must calculate the release fraction or source term (i.e., the amount and type of different radionuclides released into the environment). This release may be in the form of a plume of radioactive particles and gases which will be distributed through the atmosphere and contaminate soil, water, buildings, and equipment in the area. The proximate population may be exposed by direct radiation from the plume (cloudshine) or from contaminated surfaces (groundshine), by inhalation of radioactive gases and particulates, and by ingestion of contaminated food and water. A risk assessment estimates the likely distribution of such materials and subsequent population exposures, using standardized dispersal, exposure, and dose-response models.

Most risk assessments ignore post-accident behavior. A CRA, however, must assess the impacts of the range of public behavior and emergency response activities that follow accidents. These activities may exacerbate or mitigate adverse effects and will vary according to political jurisdiction, population distribution, and other locational factors. Survey research exploring both hypothetical events ("what would you do if ...?") and actual occurrences (e.g., TMI, and acute chemical accidents) reveal a high degree of uncertainty and variation in how affected populations actually behave under different conditions. We do not have reliable predictions of how many households will respond to calls for evacuation, what distance they will travel, and, how long they will remain away. Such behavior directly affects exposure and

ultimately health impacts. A CRA must account for deviations between ideal and actual human behavior during emergency conditions. Because of the paucity of data with which to make such judgements, we believe additional survey research focused specifically on the HLNW transport issue is a necessary ingredient for a future CRA.

## II. RISK MANAGEMENT

Risk management involves the identification, estimation, and evaluation of risks, and the selection and implementation of alternative measures to prevent, control, or mitigate adverse consequences. Risk assessment, which we considered in the previous section, generally is considered the initial phase in risk management. As we have discussed, its goal is to identify hazards, estimate the probabilities (where possible) of their occurrence, and forecast the nature and magnitude of their consequences. Risk assessment is, therefore, integral to devising effective risk management. Most of the studies of transportation risks conducted to date are risk assessments, and do not attempt to address the broader issues of risk management. In practice, they should interact iteratively, moving risk management in the direction of risk minimization within the context of meeting necessary social objectives, i.e., the disposal of HLNW.

### A. Goals and Objectives

Any risk management system must have clearly articulated, achievable goals. In the present context, its primary goal is to minimize the risks resulting from the transportation of HLNW. A CRA, as we discussed earlier, helps to achieve this by revealing those system components that are most risk prone, thereby directing managers to certain design and operational modifications. These, in turn, allow for a revised CRA. This back and forth process is the essence of effective risk management. Optimally, the assessment-management interplay is a dynamic process that uncovers vulnerable points in the transport system; provides a constant flow of feedback data; and calls attention to previously ignored events and processes that may result in significant risks.

It is not the purpose of a CRA to convince the public that the risks are so small that the public should accept them. Previous attempts to use risk assessments in this fashion, such as the Reactor Safety Study (WASH 1400), have demonstrated this fallacy. Instead of focusing on the inordinately low probability estimates, public critics focused on the horrendous consequence of a major accident, and the litany of potential events leading to such an accident. Similarly, risk assessments should not be used as an excuse to conduct somewhat sensationalist "crash tests," such as some of those conducted in Britain by the Central Electricity Generating Board (Snedeker 1989), which are little more than public relations exercises. The British demonstration test "Operation Smash Hit" in which a cask is hit by a speeding locomotive actually subjected the cask to significantly less impact force than the regulatory drop test. Further, there is no empirical evidence that such demonstration testing is effective in changing public attitudes. This proviso, of course, does not preclude appropriate "real world" testing which may provide valuable data for improved risk assessments. Such tests must accurately represent maximum

credible severe accident conditions, and must be conducted under carefully controlled conditions, fully documented, and rigorously peer reviewed. Indeed, destructive testing of casks to determine failure thresholds should be an essential part of a risk assessment program.

## **B. System Design**

Since 1975 when the Reactor Safety Study (WASH 1400) first applied the technique of probabilistic risk assessment to nuclear power plants, over 20 PRAs have been completed, under the sponsorship of the NRC and individual utilities (Joksimovich 1984, Daniels and Canody 1984). PRAs have not been used in developing the basic design of nuclear power plants, however, because the methodology developed after most of the designs were in place and many plants were already constructed, or under construction. PRAs have been most useful, however, in suggesting modifications to existing designs, and operational changes to enhance safety, and indeed performance. (Some of these modifications are discussed in the following section.) Furthermore, the growing realization of endemic problems with existing designs, as uncovered with the use of PRA techniques, has stimulated a reassessment of existing designs and encouraged the notion of developing inherently safe reactors.

In contrast, those developing the nuclear waste transportation system are in a unique position to be able to use a CRA as an aid in designing the optimal system to minimize risk. Conducting such an assessment prior to the construction of the system will encourage appropriate design choices, and may help to avoid the costly post-design changes that have plagued the nuclear power utilities.

The major advantage in conducting a CRA is that it forces a rigorous analysis of the complete system in an integrated fashion. Reviews of previously conducted PRAs conclude that conceptual insights about designs are the most important benefits (Levine and Rasmussen 1984; Joksimovich 1984). They have encouraged an "entirely new way of thinking about reactor safety in a logic structure that transcends normal design practices and regulatory processes" (Joksimovich 1984, 265). PRAs have been particularly important in suggesting corrective changes in equipment, maintenance practices, operational procedures, and operator training (Daniels and Canody 1984, 285), as discussed in the following section. At a more general level, PRAs have identified dominant sequences that might otherwise have been given less attention; previously unrecognized accident sequences and unexpected events and consequences; and high probability events that can easily be avoided. PRAs have also underlined the importance of human factors and external events, such as floods, earthquakes, and hurricanes (NRC 1984). A CRA that highlights

these issues prior to construction would be a valuable tool in the design of the transportation system.

Another lesson learned from previous PRAs is that they are extremely plant specific (Garrick 1984, 277), so the findings vary quite significantly from one site to another and among plants of similar but slightly differing designs. This has implications for the design of radioactive waste transportation system. While such a system is more "open" and less complicated than nuclear power plants, it will involve widely varying conditions of climate, terrain, population density. There is, therefore, a diverse array of potentially affected environments (Hamilton et al. 1986, 8-1) and a large number of different system designs. A comprehensive risk assessment will need to accommodate this diversity, and it is likely that the findings will vary significantly among different designs. Indeed assessing the differences between alternative designs will be a major function of the CRA.

Perhaps the overriding problem with PRAs is the calculation of probabilities and degrees of uncertainty. The NRC review of PRAs (Murphy 1984) concluded that: there is still considerable doubt about the statistical techniques of PRA, especially where data are limited; estimates of extremely low probabilities cannot be validated because data for low-frequency events, by their nature, do not exist; and, more work on uncertainties is necessary. In the absence of good data, expert judgment may be used but this is fraught with problems (Freudenburg 1988).

A final problem with attempts to define probabilities is the tendency toward reification of a single number. This is a big problem, and such numbers should not be used as measures of regulatory compliance. This undue attention to specific numbers was a problem in the executive summary of the Reactor Safety Study, where such attention focused on the one in a million estimate of core melt probability to the exclusion of all the qualifying details. Consequently, in response to the Risk Assessment Review Group Report (Lewis et al. 1979) criticizing the Reactor Safety Study, the NRC issued a policy statement to NRC staff. The memorandum advised that "the overall risk assessment results of the RSS . . . shall not be used without an indication of the wide range of uncertainty associate with those estimates," and that quantitative risk assessment techniques "should not be used to estimate absolute values of probabilities of failure of subsystems unless an adequate data base exists" (NRC 1979). Avoiding the presumption that probabilities can and should be estimated for all events and consequences is essential. Rather probabilities should be calculated only where there are sufficient data to replace expert judgment and avoid leaps of faith.

While the calculation of probabilities is problematic, it is also advantageous in that it forces the collection of enormous amounts of data in a relatively rigorous and comprehensive fashion.



This aids in the identification of dominant sequences and hitherto unrecognized events, and is particularly important for its qualitative insights. The NRC review (Murphy 1984, 6) therefore concludes that PRAs are useful provided "more weight is given to the qualitative and relative insights regarding design and operations, rather than the precise absolute magnitude of the numbers generated." A comprehensive transportation risk assessment must internalize these lessons. Particular attention should be paid to the qualitative aspects of system design, with the goal of risk minimization in mind.

While PRAs clearly have a role in evaluating the desirability of alternative HLNW transportation configurations, it is no substitute for a truly comprehensive risk assessment. A CRA should consider the entire sequence of transportation of both defense and commercial nuclear wastes, from initial packaging and loading to unloading of the repository. Moreover, it should extend beyond the borders of the state of Nevada. "Upstream" activities, such as packaging and loading, and generic issues of cask design, human error, and quality control, can have significant impacts "downstream" in Nevada, such as the potential for accidental releases and the exposure of workers unloading casks at the repository. To be truly comprehensive, the risk assessment should also identify the hazard events and consequences arising in the transportation of retrieved waste, since the repository is to be designed with such an eventuality in mind. While transportation to the repository is already controversial, it is likely that the transportation of retrieved waste will be even more controversial, since retrieval would only be necessary because of technological failure.

Because a transportation CRA by definition deals with hazardous materials which originate in and move across multiple political jurisdictions, questions of equity inevitable arise in considerations of system design. It is entirely plausible, for example, that aggregate (i.e., national) risk may be minimized by routing choices which work to the disadvantage of Nevada. By shifting waste shipments of alternative routes, risks to Nevada's population may be reduced but aggregate risks to other populations may be increased. It is entirely appropriate for the risk manager to recognize explicitly these trade-offs and to seek consensus on what reasonable solutions might be developed which balance risk minimization and equity concerns. Ignoring such trade-offs may imperil the entire design process, opening the door to criticism that fairness is being sacrificed to the national interest without due consideration for the host state.

### C. System Operation

A CRA is not a static one-time analysis that results in a single document. It should be an ongoing dynamic analysis, integrated with a functioning risk management system, beyond the

design phase and throughout the operation of the HLNW transportation system. It should be continuously updated through a process of review, reevaluation, and data collection. The CRA should be adaptable and adapted to the changing conditions and needs of risk management. Thus, it should become a "living document" and a regular source of reference for those operating the system, so that appropriate engineering and operational changes can be made to ensure the system continues to meet its goal of risk minimization.

Previous PRAs have taught us a great deal about the operation of nuclear power plants. "Virtually every PRA study performed has resulted in changes in procedures and/or hardware which have reduced core damage frequency. This is not surprising, since identifying and implementing such changes is a key benefit of performing as PRA" (MHB 1989, 3-8). It is particularly important to note that many of these changes depend on qualitative rather than quantitative insights. In a recent book-length review of PRA techniques, Fullwood and Hall (1988, 294) concluded that "qualitative knowledge can be used to improve the operation of the facility without a high degree of reliance on the numerical estimates of probability and consequence." This finding further strengthens the emphasis on conducting a comprehensive rather than probabilistic risk assessment.

A transportation CRA can be expected to yield major insights in five generic areas that may enhance systems operation. These insights may come during the design phase and affect future operations, or they may arise from ongoing risk assessment during operation of the system. These five areas include:

- improvements in hardware;
- the identification of external events leading to accidents;
- human factors analysis;
- system management problems and solutions; and,
- the identification of "signal events."

Table 2 gives several examples of the plant modifications that have been indicated as necessary as the basis of PRAs conducted on nuclear power plants. Many of these include modifications to hardware as well as changes in maintenance and operational procedures.

In order to identify such necessary modifications, a CRA will need to consider the complete range of initiating events and likely consequences at each stage in the transportation sequence under both "normal" and "accident" conditions.

Table 2

**EXAMPLES OF PLANT MODIFICATIONS  
MADE OR COMMITTED TO  
ON THE BASIS OF PRA INSIGHTS**

PLANT	PLANT MODIFICATION	PRA	LEVEL
Arkansas Nuclear One	Station battery test scheduling changed to reduce probability of common-mode failures	IREP <sup>a</sup>	1
Arkansas Nuclear One	Ac and dc switchgear room cooler actuation circuitry test procedure established	IREP	1
Millstone	Logic changes made to emergency ac power load sequencer to eliminate single failure	IREP	1
Sequoyah	Procedures changed to ensure that upper compartment drain plugs are removed after refueling	RSSMAP <sup>b</sup>	2
Oconee	Procedure and hardware changes made to reduce the frequency of interfacing system LOCA	RSSMAP	2
Indian Point	Upgrading of charging-pump alternative shutdown power supply to reduce the probability of RCP seal failure	IPPSS <sup>c</sup>	3
Indian Point	Replacement of manual valves with motor-operated valves in fan-cooler service-water lines	IPPSS	3
Big Rock Point	Hardware modification to restrict flow in reject line between condenser hotwell and condensate storage tank	BRP <sup>d</sup>	3

<sup>a</sup> Interim Reliability Evaluation Program.

<sup>b</sup> Reactor Safety Study Methodology Applications Program.

<sup>c</sup> Indian Point Probabilistic Safety Study.

<sup>d</sup> Big Rock Probabilistic Risk Assessment.

SOURCE: Fullwood and Hall 1989

Workers and members of the public will be exposed to risks from the operation of the nuclear waste transportation system even under "normal" or accident-free conditions, in the absence of accidents, inadequate quality control, human error, and sabotage. Under normal operating conditions non-radiological risks include exposure to vehicular emissions, exposure to toxic substances, such as solvents, oils, and petroleum products used in the operation and maintenance of vehicles, and ergonomic and psychological stress. Radiological risks include public exposure to low level radiation during shipment, and worker exposure during packaging, loading, transporting, and unloading waste materials. Current regulations allow low levels of radiation to be emitted from even the best designed casks under the most stringent quality control programs, and in the absence of accidents. A CRA will need to assess the entire range of risks under "normal" operating conditions in order to identify appropriate modifications in hardware, operations, and maintenance.

Accidents include "internal" events or system failure, such as vehicular and loading accidents, or sabotage, external events that originate outside the waste transportation system. Both radiological and non-radiological consequences may be associated with accidents. External events include intentional (e.g., terrorism) and unintentional (e.g., airplane crashes) man-made events, and natural events, such as earthquakes and floods. Again, a CRA will need to assess the entire range of risks under accident conditions in order to identify appropriate system modifications. Power plant PRAs have been particularly useful in identifying significant external events that were previously ignored (Murphy 1984, 6). A transportation CRA should, therefore, pay close attention to external initiating events, especially since the transportation network will cover a wide range of diverse environments.

Unfortunately, many external initiating events occur with such low frequencies that quantification is difficult, and it is unlikely that the data base will improve appreciably in the future (Murphy 1984, 2). So any insights gained will come from qualitative rather than quantitative analysis. Sabotage (internal man-made event) and terrorism (external man-made event) fall into this category of low frequency events. Neither have been adequately treated in previous PRAs, but a CRA will need to pay particular attention to these if only in qualitative terms. The consequences are potentially severe and the transport system is, by nature, particularly vulnerable in comparison with nuclear power plants.

Previous PRAs of nuclear power plants have indicated the significance of operational procedures, maintenance practices, and operator training. As such, they serve to indicate where changes in plant management can improve safety. Similar benefits can be expected from a transportation CRA.

As indicated previously a comprehensive transportation risk assessment should be adapted and adaptable to the overall risk management system, and should be a continually updated source of reference. A similar recommendation was put forward by Garrick (1984, 278) several years ago: "The future of risk management lies in the computerization of the plant specific PRA . . . This concept would truly make risk management a reality and would turn a PRA into a useful living document of the nuclear age." A computerized CRA would amass data on normal and accident conditions throughout the entire transport system. Monitoring, tracking, and record-keeping of activities and events within the waste transportation system would be relatively straightforward given the relatively few shipments, sources, routes, and destinations compared with, for example, the much more complex system of transporting non-nuclear hazardous waste. Such a computerized system would allow the timely collection of a comprehensive data base which could be fed back into the CRA. In this fashion, it could be used interactively to assess the desirability of a wide range of operational adjustments.

In terms of management, a major advantage of a CRA is not so much the outcome as the process. Utilities conducting PRAs found that the process was an invaluable opportunity for in-house engineers and other personnel to become intimately familiar with the plant operations and procedures (Daniels and Canody 1984, 285). Not only does the involvement of in-house personnel improve the quality of the PRA and identify system vulnerabilities, but it also sensitizes in-house personnel to the notion of the limits to technology and that indeed things can go wrong. This is particularly important in an industry that is plagued by feelings of overconfidence and a mindset that, indeed, things can't go wrong. It may also contribute to dispelling the myth that there is always a "tech-fix." It is partly in recognition of these advantages that the NRC now requires all nuclear power plants to perform Independent Plant Examinations (IPEs) to identify plant specific vulnerabilities, and recommends that these limited visions of PRAs be conducted by in-house personnel. Obviously, a CRA would offer similar advantages in the management of the HLNW transportation system.

Finally, in terms of system operation it is important to note that a CRA will identify a large number of high probability/low consequence events. The future designers and operators of the transportation system must recognize that many of these seemingly insignificant events will have major "signal value" to the general public through social amplification and subsequent ripple effects (Kasperson et al. 1988). Many such events cannot be eliminated by design changes or technical fixes. Instead, particular attention will need to be given to operational considerations such as driver training, routing choices to avoid populated areas, emergency planning and response measures. In large part, the magnitude of the consequences of these signal events will be related to their

coverage in the media and the public perceptions of, and trust in, the risk managers' abilities to handle unusual occurrences.

### III. RISK COMMUNICATION

A great deal has been written about risk communication in recent years and several excellent guides for risk communicators are available (e.g., Hance et al. 1988; Covello et al. 1988). Nonetheless, there are no guaranteed strategies and looking for them will be a disappointing task. Risk communication about nuclear issues, including the transportation of nuclear waste, will be particularly difficult given the controversial nature of nuclear issues and the long history of public distrust (Hohenemser et al. 1977; Mitchell 1988). Effective risk communication about high level nuclear waste transportation will require the development of a credible process that encourages public dialogue and trust. Particular attention must be paid to the process as well as the content of risk communications. This section will begin by outlining some general considerations, move on to consider some of the lessons from the release of the executive summary of the Reactor Safety Study, and finish with some more specific pointers about the scope, content, and design of risk communication materials.

#### A. Goals

A CRA is not intended as a risk communication vehicle *per se*, but it will become such by default. This needs to be borne in mind in both the process and product of the assessment.

It is not the goal of a CRA to convince the public that the transport of high level nuclear waste is "safe." As noted earlier, previous attempts to use risk assessments in this way have backfired. The public tends to ignore the estimates of low probability (perhaps rightly, given the considerable uncertainty involved), and focuses instead on the bewildering diversity of initiating events and the potentially dire consequences.

In terms of risk communication, the CRA has two goals. First, by involving designers and operators of the system, the CRA can serve to dispel the myth of invulnerability and the assumption that technical fixes can effectively reduce serious risks to zero. By infusing human behavior into the analysis on both the risk initiation and control side, designers and operators will be sensitized to the role of human error and response in optimizing the transport system.

The second goal is to involve the public in a dialogue about the risks to ensure the comprehensiveness, completeness, and integrity of the assessment and the management system, to demonstrate that no one is trying to mislead the public, and to enhance the credibility of and public trust in the risk management system.

## **B. Process of Risk Communication**

The comprehensive risk assessment is but one part of the risk management system. To be credible and trusted, the risk management system as a whole must be open to public comment and criticism throughout the affected states. Moreover the public should be intimately involved in the establishment and operation of the system through public hearings and committees, such as the local emergency planning committees established under SARA Title III. Similarly, the CRA should be conducted in an open atmosphere with initiatives to secure peer and public review. Unlike the Reactor Safety Study, the CRA must confront comments and criticisms fairly and appropriately. The executive summary in particular, should be widely disseminated for public comment in the affected states.

Risk communication with the operators and designers of the transport system will be achieved in large part through their involvement in the conduct of the risk assessment itself. Other technical experts will refer to the main text. An executive summary will be produced initially during the design phase of the system, and this will need to be revised periodically as new data are gathered and incorporated during the operational phase. The executive summary will serve as the primary vehicle for risk communication with the public directly, and through the media. The summary will therefore need to pay close attention to the lessons learned from the release of the executive summary of the RSS, and the pointers outlined below.

Given the public distrust of the DOE and NRC, any risk assessment conducted by these agencies would have little credibility and would likely be a poor vehicle for risk communication. A credible risk assessment would have to be conducted by an independent body, such as a consortium of the affected states. This body might be given the resources to hire a team of experts to protect the interests of these states. As a conflict avoidance strategy, this team might pursue a joint fact-finding and methodology development mission along with DOE experts, but reserve the right to dissent if it feels appropriate to do so. Since it is intended that the risk assessment become a "living document" with continual updating and application, it would be advantageous to have continued public involvement in oversight and implementation of the analysis.

Drawing from the experience of radioactive waste and hazardous waste facility siting in recent years, a number of options are available to ensure such involvement:

- the creation of a permanent HLNW Transport Oversight Committee, comprising representatives of the populations of the various states encompassed by the transport system, to monitor performance of the system and advise



system operators of public concerns (the Oak Ridge MRS Task Force is illustrative);

- regular publication in the local media and a facility newsletter describing the systems operations, e.g., volume in transit, origin points, volume received at the repository, as well as other operational and performance information;
- regular publication through the same channels of information pertaining to actions taken by management to modify the transport system in response to areas identified for upgrade or improvement;
- the establishment of a system of warnings and penalties wherein certain events, depending upon their severity and frequency of occurrence, a financial penalty, temporary suspension, or longer term stoppage of waste transport.

These are all illustrative of the kind of mechanisms designed to enhance public involvement in ways consistent with the emerging consensus in the hazards management field -- that information access, monitoring and control -- rather than financial benefits -- are the most effective devices to build and sustain public acceptance. There are many others contained in statutes, regulations and negotiated agreements for chemical and low level radioactive waste facilities which can further inform public involvement initiatives in the HLNW transport area (White et al. 1988).

### C. Lessons from RSS

The executive summary of the Reactor Safety Study was released in October 1975 along with the main report. The summary was severely criticized for a number of reasons:

- it described only the early health effects arising from nuclear accidents and not the much larger number of delayed effects assessed in the main report;
- it gave no indication of the large uncertainties associated with probability estimates; and,
- it ignored potentially significant initiating events such as sabotage and terrorism.

Consequently, the NRC commissioned the Review Group, chaired by Harold Lewis, to review the report and recommend how risk assessments should be used in the regulatory process. The Lewis Report, as the findings of the Review Group came to be known, found failings in three areas: the executive summary; the peer review; and, the calculation and presentation of probability estimates.

The findings in each of these three areas offer important lessons for the conduct of any future risk assessment for high level nuclear waste transportation.

In regard to the executive summary the Review Group found it "is a poor description of the contents of the report, should not be portrayed as such, and has lent itself to issue in the discussion of reactor risks" (Lewis 1978, viii). Because the summary failed to indicate the full extent of the consequences in the event of accidents, and because it failed to emphasize sufficiently the uncertainties in the calculations of probabilities, "the reader may be left with a misplaced confidence in the validity of the risk estimates and a more favorable impression of reactor risks in comparison with other risks than warranted by the study" (NRC policy statement 1/18/79 p. 2). Lewis et al. (1978) concluded that the summary was not actually a summary of the report but rather a public relations exercise intended to convince the public that reactors were safe compared with the other risks to which the public is exposed (NRC policy statement 1/18/79, note #5). In light of these findings and other criticisms, the NRC withdrew its endorsement of the executive summary in January 1979. The NRC also issued a memorandum to its staff outlining the uses and limitations of risk assessment in general and the RSS in particular.

The Lewis Report also found that in the peer review process, the RSS ignored or evaded cogent criticisms, and where it did respond the response was weaker than it should have been. In terms of accident probabilities, the Lewis Report found that the error bands in the RSS were greatly understated because of: inadequate data; an inability to quantify common cause failures; and questionable methodological and statistical procedure. Hence, the emphasis now put on conceptual and qualitative insights from PRAs rather than an inordinate focus on quantitative findings.

From the NRCs experience with the RSS, any comprehensive transportation risk assessment should:

- estimate the probabilities only where the data are adequate;
- clearly indicate the use of expert judgment, where data are lacking or inadequate, and the range of uncertainty, and the process and experts used
- address the full range of events (including sabotage and terrorism) and consequences (including immediate and delayed effects);
- fully and candidly address all criticisms; and,
- include as an integral part an executive summary which, like the report itself, is subjected to peer review.

The executive summary, furthermore, should:

- not be used as a public relations exercise in an attempt to convince the public of the safety of the system;
- accurately portray the contents of the main report, including the major criticisms; and,
- emphasize the limitations of risk assessment and in particular the problems with poor data, expert judgment, and scientific uncertainty.

#### D. Some Pointers

In addition to the larger issues of the goals and process of risk communication and the lessons to be learned from the RSS, there are some more specific points to be considered concerning scope, content, and design of risk communication materials. These pointers apply mostly to the executive summary, since this will be the principal vehicle for communicating with the public. Many, however, also apply to the main CRA report, and the process of risk communication in general. While this paper considers the role of a CRA in risk communication, it should be remembered that risk communication is much broader than simply conducting a risk assessment and disseminating the findings. All manner of activities during the design and operation of the transportation system will be scrutinized by the media and the public and will serve as channels and opportunities for risk communication. A CRA is, therefore, only a small part of the wide spectrum of risk communication activities.

The executive summary should be written clearly and concisely in plain English, using lay terms that are easily understandable to the public. The goals and objective of the risk management system in general and the CRA in particular should be clearly outlined in regard to both the design and operation of the HLNW transport system. The major limitations and assumptions of the CRA should be clearly and fully stated. The goal of the executive summary should be: to enlighten not confuse; to clarify not conceal risk information; and to aid not impede valid inferences about the nature and magnitude of the risks. In short, risk communicators must recognize that while members of the public cannot know all the details, they are quite capable of prudently evaluating conflicting evidence (Freudenburg 1988), playing a role analogous to a Board of Directors who rightfully lean to conservative positions when uncertainties and potentially major harmful consequences may result from misjudgments or leniency.

In terms of scope and content, the executive summary must consider the full range of events from the most common to the most rare, and from the well known to the least understood. This comprehensive coverage is necessary to demonstrate the thoroughness

of the CRA and the risk management system. Particular attention must be paid to sabotage and terrorism even though the data may be slim, because regardless of probabilities the system is perceived to be vulnerable to these events. This, as pointed out earlier, is especially true for a transport system comprising thousands of miles of routes and millions of ton/miles of activity. Similarly, risk communicators must pay particular attention to "signal events" whose immediate consequences may not appear to be large.

The risk communicators must recognize that there are going to be large numbers of these events and that they will cause significant media attention and public concern. Such signal events should not be ignored or trivialized, they should be put in context with other activities of a similar nature. Risk managers must clearly demonstrate how the system is prepared to handle such events, for example, through a comprehensive tracking system and emergency response capability. Constant vigilance and a degree of over-preparedness may be the necessary price for public confidence.

The preference for a CRA rather than a PRA should be explained, noting that for some events and consequences the data are inadequate to calculate probabilities with reasonable certainty. The summary, and the main report, should clearly indicate the assumptions, where data are poor or lacking, and the degree of uncertainty associated with any numerical estimates of probabilities, consequences, and so forth.

The presentation of quantitative risk information is particularly problematic in any risk communication effort. The way in which such information is presented can greatly influence the interpretation by the public, and, therefore, needs particularly careful consideration. The choice of risk measures (such as the number of injuries, fatalities, and accidents) can greatly influence how the information is perceived. For example, saying that there may be as many as 1,000 fatalities over the life of the repository (10,000 years) may elicit a quite different public response than saying there may be only 1 fatality every 10 years. In general, absolute numbers tend to provoke greater concern than do ratios, and the choice of numerator (e.g., injuries, fatalities, accidents) and denominator (e.g., number of shipments, population exposed, miles travelled, years of operation) will frame the information quite differently. Risk communication materials should, therefore, use several measures, some of which may be better understood by different individuals, and which in their totality may give a more rounded perspective as the significance of the risk.

The CRA will include probability estimates where the data are adequate, but these will need careful explanation since most people do not intuitively understand these numbers. This is especially so when the probabilities are extremely small. Graphical presentations including the probabilities of comparable risks can

help (see, for example, Figures 2 and 3 taken from the EPA Citizen's Guide to Radon). The graphical presentations in the RSS have been criticized (Hohenemser et al. 1977) because they included only prompt fatalities and failed to indicate the degree of uncertainty. Comparing risks in this fashion is a useful approach but the comparison risks should be carefully chosen. Both immediate and delayed effects should be considered, and the degree of uncertainty around the estimates should be clearly indicated. Like probability uncertainty will need to be carefully explained since it too is not intuitively obvious. In drawing on other risks for comparison, careful consideration should be given to qualitative aspects, such as voluntariness, newness, reversibility, and so on (Figure 4).

Figure 2

**RADON RISK EVALUATION CHART**

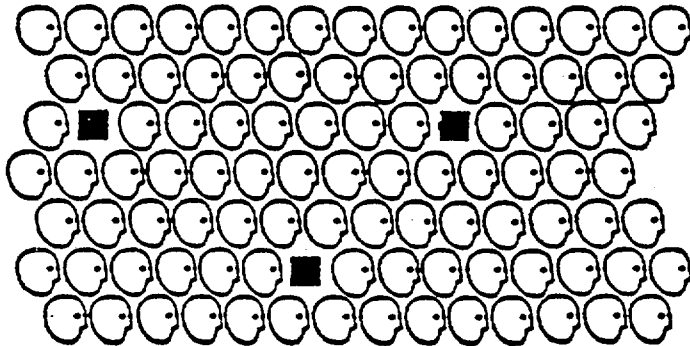
pCi/l	WL	Estimated number of lung cancer deaths due to radon exposure (out of 1000)	Comparable exposure levels		Comparable risk
200	1	440—770	1000 times average outdoor level	▶	More than 60 times non-smoker risk
100	0.5	270—630	100 times average indoor level	▶	4 pack-a-day smoker
40	0.2	120—380		▶	20,000 chest x-rays per year
20	0.1	60—210	100 times average outdoor level	▶	2 pack-a-day smoker
10	0.05	30—120	10 times average indoor level	▶	1 pack-a-day smoker
4	0.02	13—50		▶	5 times non-smoker risk
2	0.01	7—30	10 times average outdoor level	▶	200 chest x-rays per year
1	0.005	3—13	Average indoor level	▶	Non-smoker risk of dying from lung cancer
0.2	0.001	1—3	Average outdoor level	▶	20 chest x-rays per year

SOURCE: EPA (n.d.)

Figure 3

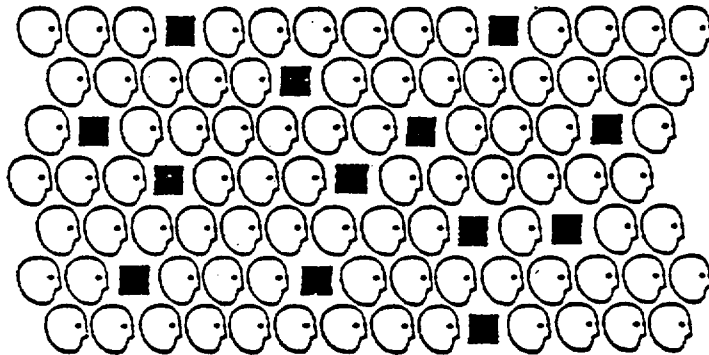
LUNG CANCER DEATHS ASSOCIATED WITH EXPOSURE TO VARIOUS LEVELS OF RADON OVER 70 YEARS

WL = 0.02  
pCi/l = 4



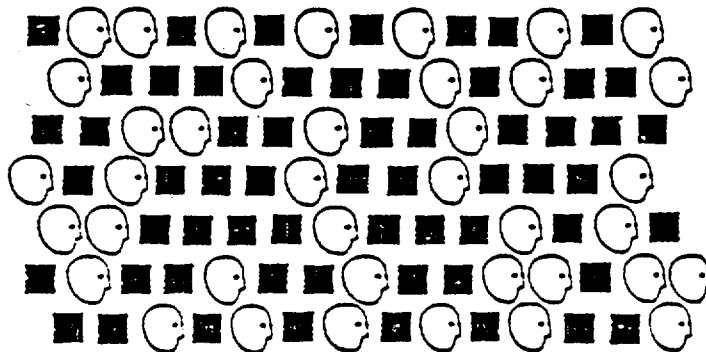
Between 1 and 5 out of 100

WL = 0.1  
pCi/l = 20



Between 6 and 21 out of 100

WL = 1.0  
pCi/l = 200



Between 44 and 77 out of 100

SOURCE: EPA (n.d.)

Figure 4

AN ARRAY OF CONSIDERATIONS INFLUENCING SAFETY JUDGEMENTS

Risk assumed voluntarily	_____	Risk borne involuntarily
Effect immediate	_____	Effect delayed
No alternatives available	_____	Many alternatives available
Risk known with certainty	_____	Risk not known
Exposure is an essential	_____	Exposure is a luxury
Encountered occupationally	_____	Encountered non-occupationally
Common hazard	_____	"Dread" hazard
Affects average people	_____	Affects especially sensitive people
Will be used as intended	_____	Likely to be misused
Consequences reversible	_____	Consequences irreversible

SOURCE: Lowrance (1976, 87)



#### IV. SUMMARY AND CONCLUSIONS

A CRA is the preferred methodology to assess the risks of HLNW transportation, and would serve as an invaluable tool in the design and operation of the transportation system. By way of concluding the discussion above, we would like to summarize the proposed three sets of guidelines intended to aid this endeavor.

##### A. Methodological Guidelines

Many methodological improvements in risk assessment techniques have been suggested, and many lessons have been learned in the conduct of previous assessments. In particular, we emphasize that:

- A CRA is preferred to a PRA.
- A CRA should calculate probabilities only where existing data, theories, and models are sufficient to support the use of rigorous quantitative methods.
- The use and limitations of expert judgement should be clearly indicated, and such judgment should be used only where more adequately derived estimates are impossible.
- Sensitivity analysis should be used to illustrate the impact of differing assumptions and variations in the quality of data.
- A CRA should cover all the sequences and phases of the transportation system for both defense and commercial nuclear wastes, and consider the full range of plausible technological configurations, such as new cask designs, model mix, and routing choices.
- A CRA should consider the likely risks involved in waste retrieval.
- The full range of initiating events should be evaluated, with particular attention to human and organizational factors, external initiating events, and sabotage and terrorism.
- The full spectrum of consequences should be carefully evaluated, with particular attention to "signal" events and social amplification.

##### B. Risk Management Guidelines

The goal of risk management is to minimize risk by selecting and implementing appropriate measure to prevent, control, or mitigate adverse consequences. Risk assessments is an inseparable part of risk management, and an invaluable aid. The guidelines

below will help to ensure that CRA promotes rather than hinders the achievement of these goals and objectives.

- A CRA should not be used to attempt to convince the public that the transportation HLNW is "safe."
- A CRA should be used as a risk management tool to achieve risk minimization by indicating optimal design and operational choices.
- A CRA should be developed prior to construction of the HLNW transportation system to encourage appropriate design choices and avoid potentially costly post-design changes.
- A CRA should be used interactively throughout the operational phase of the system, to ensure timely operational and engineering modifications and the maintenance of minimum risk levels.
- A computerized monitoring and data collection system should be developed to encourage the interactive use of the CRA during the operational phase.
- A CRA should be fully integrated with the overall risk management system.
- A CRA should be continuously updated through an interactive process of review and evaluation. A CRA should, therefore, become a "living document," and should not be a static one time analysis.

### C. Risk Communication Guidelines

A CRA is not intended to be a risk communication vehicle *per se*, but it will become one by default. In light of this, and to encourage credibility the CRA should:

- be conducted by an independent body, acceptable to all stakeholders, particularly the affected states and Indian tribes;
- be conducted in an open atmosphere with considerable room for peer and public review; and,
- include an executive summary as an integral part.

The executive summary of the CRA should be widely distributed, and careful attention should be paid to the scope, content, and design of such a document. The executive summary should:

- not be used as a public relations exercise to convince the public of the safety of the system;
- be written clearly and concisely in plain English for a lay audience;
- clearly outline the major goals, limitations, and assumptions of the CRA;
- address the full range of events and spectrum of consequences; and,
- accurately portray the findings and peer review criticisms of the main report.

Risk communication is complicated and will involve a multitude of activities aside from the distribution of an executive summary. Particular attention should be paid to the process of risk communication and public oversight. A credible process to encourage public involvement should include:

- the creation of a permanent HLNW Transport Oversight Committee, comprising representatives of the populations of the various states and Indian tribes encompassed by the transport system, to monitor performance of the system and advise system operators of public concerns;
- regular publication in the local media and a facility newsletter of data describing the systems operations, e.g., volume in transit, origin points, volume received at the repository, as well as other operational and performance information;
- regular publication through the same channels of information pertaining to actions taken by management to modify the transport system in response to areas identified for upgrade or improvement; and,
- the establishment of a system of warnings and penalties wherein certain events, depending upon their severity and frequency of occurrence, a financial penalty, temporary suspension, or longer term stoppage of waste transport.

## REFERENCES

- Audin, L. 1989. *A Critique of Analyses of Cask Sabotage Involving Portable Explosives*. UNLV/TRC. Draft.
- Audin, L. 1987. *A Review of the Effects of Human Error on the Risks Involved in Spent Fuel Transportation*. Prepared for the Nebraska Energy Office.
- Covello, V.T., P. Sandman, and P. Slovic. 1988. *Risk Communication, Risk Statistics, and Risk Comparisons: A Manual for Plant Managers*. Washington, D.C.: Chemical Manufacturers Association.
- Daniels, T.A., and K.S. Canody. 1984. "A Nuclear Utility's Views on the Use of Probabilistic Risk Assessment." *Risk Analysis* 4(4):281-286.
- EPA. n.d. *Citizen's Guide to Radon*. Washington, D.C.: EPA.
- Fischhoff, B., P. Slovic, S. Lichtenstein, S. Read, B. Combs. 1978. "How Safe is Safe Enough? A Psychometric Study of Attitudes Towards Technological Risks and Benefits." *Policy Sciences* 8:127-152.
- Freudenburg. W.R. 1988. "Perceived Risk, Real Risk: Social Sciences and the Art of Probabilistic Risk Assessment." *Science* 242(7 October):44-49.
- Fullwood, R.R., and R.E. Hall. 1988. *Probabilistic Risk Assessment in the Nuclear Power Industry: Fundamentals and Applications*. Oxford: Pergamon Press.
- Gallagher, D. et al. 1984. *Insights into PRA Methodologies*. NUREG/CR-3852. Washington, D.C.: Nuclear Regulatory Commission.
- Garrick, J.B. 1984. "Recent Case Studies and Advancements in Probabilistic Risk Assessment." *Risk Analysis* 4(4):267-279.
- Hamilton, L., D. Hill, M. Rowe, and E. Stern. 1986. *Toward a Risk Assessment of the Spent Fuel and High-Level Nuclear Waste Disposal System*. BNL-51972, Upton, New York: Brookhaven National Laboratory.
- Hence, B.J., C. Chess, and P. Sandman. 1988. *Improving Dialogue with Communities*. Trenton, NJ: New Jersey Department of Environmental Protection.
- Hohenemser, C., R.E. Kasperson, and R. Kates. 1977. "The Distrust of Nuclear Power." *Science* 196(April):25-34.

- Hoskins. 1989. *Background Report on Nuclear Waste Transportation Issues Related to the Reactor Spent Fuel Storage and Transportation Model with Regard to Transportation Cask Design.* UNLV/TRC. Draft.
- Joksimovich, V. 1984. "A Review of Plant Specific PRAs" *Risk Analysis* 4(4):255-266.
- Kasperson, R.E., et al. 1988. "The Social Amplification of Risk: A Conceptual Framework." *Risk Analysis* 8(2):177-187.
- Levine, S., and N.C. Rasmussen. 1984. "Nuclear Plant PRA: How Far Has It Come?" *Risk Analysis* 4(4):247-254.
- Lewis, H.W., et al. 1978. *Risk Assessment Review Group Report to the U.S. Nuclear Regulatory Commission.* NUREG/CR-0400. Washington, D.C.: NRC.
- MHT. 1989. *Severe Accidents at Three Mile Island Unit 1.* Unpublished.
- Mitchell, R.C. 1988. "Nuclear and Other Energy Sources." In J. Clarence Davies, V.T. Covello, and F.W. Allen, eds., *Risk Communication*, pp. 77-81. Washington, D.C.: The Conservation Foundation.
- NRC (Nuclear Regulatory Commission). 1984. *Probabilistic Risk Assessment (PRA) Reference Document.* NUREG-1050. Washington, D.C.: NRC.
- NRC. 1979a. *NRC Statement on Risk Assessment and the Reactor Safety Study Report (WASH-1400) in Light of the Risk Assessment Review Group Report.* January 18. Washington, D.C.: NRC.
- NRC. 1979b. *Staff Actions Regarding Risk Assessment Review Group Report.* Memorandum to NRC Staff, January 18. Washington, D.C.: NRC.
- NRC. 1975. *Reactor Safety Study: An Assessment of Accident Risks in Commercial Nuclear Power Plants.* WASH-1400. Washington, D.C.: NRC.
- National Research Council. 1984. *Social and Economic Issues in Radioactive Waste Disposal: Considerations for Public Policy.* Washington, D.C.: National Academy Press.
- National Research Council. 1988. *Human Factors Research and Nuclear Safety.* Washington, D.C.: National Academy Press.

- OTA (Office of Technology Assessment) 1986. *Transportation of Hazardous Materials*. OTA-SET-304. Washington, D.C.: Government Printing Office.
- Resnikoff, M. 1983. *The Next Nuclear Gamble*. New York, NY: Council on Economic Priorities.
- Slovic, P. 1987. "Perception of Risk." *Science* 236(17 April):280-285.
- Slovic, P. 1985. "Characterizing Perceived Risk." In R.W. Kates, C. Hohenemser, and R.E. Kasperson, eds., *Perilous Progress: Managing the Hazards of Technology*, pp. 91-125. Boulder, CO: Westview.
- Snedeker, D. 1989. *Transportation Package Testing: A Review of Several Programs in the U.S. and Abroad*. UNLV/TRC.
- White, A. et al. "Reconciling Statewide Needs and Local Impacts." New York State's Recommended Offsets Package for Communities Hosting LLRW Management Facility," *Waste Management '88: Proceedings of the Symposium on Waste Management*, Tucson, Arizona, Feb. 28-March 3, 1988.