COMPREHENSIVE WM/ER/D&D/LTS RISK MODEL FOR THE INEEL

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ABSTRACT

The Idaho National Engineering and Environmental Laboratory (INEEL) is investigating the development of a comprehensive and quantitative risk model framework for environmental management activities at the site. Included are waste management programs (high-level waste, transuranic waste, low-level waste, mixed low-level waste, spent nuclear fuel, and special nuclear materials), major environmental restoration efforts, major decontamination and decommissioning projects, and planned long-term stewardship activities. Also, program risks cover all activities up through final disposition, including storage, handling, treatment, transportation, and disposal. Types of risks addressed include environmental cleanup costs (from accidental releases of radionuclides or chemicals), fatalities from radiological or chemical exposures, and fatalities from standard industrial accidents. Risks are estimated for workers, other site personnel, and the public. Unlike environmental impact statements, safety analysis reports, and performance assessment risk evaluations, the risk model framework being investigated is planned to result in best estimates for environment, safety, and health risks.

Two basic types of risk estimates are included: risks from environmental management activities, and long-term legacy (no action) risks from wastes/materials. Both types of risks are estimated using the Environment, Safety, and Health Risk Assessment Program (ESHRAP) developed at the INEEL. Given these two types of risk calculations, the following evaluations can be performed:

- Risk evaluation of an entire program (covering waste/material as it now exists through disposal or other end states)
- Risk comparisons of alternative programs or activities
- Comparisons of risk benefit versus risk cost for activities or entire programs
- Ranking of programs or activities by risk
- Ranking of wastes/materials by risk
- Evaluation of site risk changes with time as activities progress
- Integrated performance measurement using indicators such as injury/death and exposure rates.

Final development of the ESHRAP code and the INEEL risk model is expected to be complete in 2002.

INTRODUCTION

Over the past six years the Idaho National Engineering and Environmental Laboratory (INEEL) has been investigating the development of a comprehensive and quantitative risk model for environmental management (EM) activities at the site. Previous work was reported at the Waste Management 1998 and 2000 Conferences. (1,2) Those applications were performed with the first and second generations of risk models and software (3) and focused on radiological and standard industrial risks from waste management (WM) operations. The risk model framework described in this paper involves a more comprehensive approach, including not only WM operations, but also environmental restoration (ER), decontamination and decommissioning (D&D), and long-term stewardship (LTS) activities. Also, a third generation of risk models and software is being developed to support this work. Finally, the types of analyses to be performed have been expanded to include integrated performance indicators, end state analysis, and others.

COMPREHENSIVE RISK MODEL FRAMEWORK

The INEEL comprehensive risk model framework consists of two basic types of quantitative risk analyses: risks from performing environmental management activities, and risks from wastes/materials evaluated for various forms and environmental settings (legacy or no action risk). Given these two types of risk evaluation capabilities, the following applications can be performed:

- Risk evaluation of an entire program (covering waste/material as it now exists through disposal or other end states)
- Risk comparisons of alternative programs or activities
- Comparisons of risk benefit versus risk cost for activities or entire programs
- Ranking of programs or activities by risk
- Ranking of wastes/materials by risk
- Evaluation of site risk changes with time as activities progress
- Integrated performance measurement using indicators such as injury/death and exposure rates.

Risks include environment, safety and health (ES&H) risks associated with activities. Activities considered include storage, retrieval, characterization, packaging, various treatment processes (both in-situ and ex-situ), loading/unloading, transportation (onsite and offsite), disposal, D&D, and LTS activities. The legacy risk measure includes long-term risks from groundwater contamination, atmospheric dispersion, and various types of intrusion scenarios. Additional details on the risk model framework are provided in the following sections.

The risk model framework is believed to be unique in the following areas: comprehensive and consistent treatment of best estimate program risk from present state through final disposal, coverage of ES&H best estimate risk, comprehensive consideration of long-term scenarios contributing to legacy risk, risk benefit versus risk cost comparison, evaluation of site risk changes with time, and integrated performance measurement. However, a comprehensive literature search has not yet been performed to support these beliefs.

ES&H RISK

A goal of the risk model framework is to cover environmental risks as well as human safety and health risks from environmental management activities. Human safety risks include accidents involving exposures to radionuclides and/or hazardous chemicals and injuries or deaths from standard industrial accidents. Included in the standard industrial accidents are transportation accidents in which the crew and/or public are injured or killed by the accident and not because of exposures to radionuclides or hazardous chemicals. Human health risks include exposures to radionuclides (or direct radiation) or hazardous chemicals during incident-free operation. Finally, environmental risk as presently modeled includes the cost of cleanup resulting from accidental releases of radionuclides or hazardous chemicals during environmental activities and the cost of lost land use. Other environmental and ecological impacts are not currently addressed, but will be added in the future.

Risks are evaluated for workers performing the environmental management activities, other site personnel, and the public surrounding the site. Three risk measures are calculated: person-rem (total exposure to workers, site personnel, and the public), fatalities (resulting from radiological or chemical exposures and from standard industrial accidents), and dollars (incorporating radiological, chemical, standard industrial, and environmental impacts). All risk estimates are intended to be best estimate. It should be noted that the risk evaluations do not address whether regulatory limits (concentrations at a given location) are met.

ACTIVITY RISK

The Environment, Safety, and Health Risk Assessment Program (ESHRAP) represents the third generation models and software for evaluating environmental management activity risk. ESHRAP analyses provide the information to determine program risks (summation of individual activity risks) and to rank activities with respect to risk. ESHRAP analyses also provide the risk cost (risk from environmental management activities) in the risk benefit versus risk cost comparisons. Finally, ESHRAP models of environmental management programs at a site have the potential to be used as an integrated indicator of operation performance data such as yearly injury rates, lost work days, personnel exposure, etc.

Components of the ESHRAP code model accidents dispersing radionuclides and/or chemicals into the atmosphere, worker direct radiation exposure during activities, long-term transport of radionuclides and/or chemicals through the vadose zone to groundwater and subsequent dispersal and exposure, standard industrial risks (worker injuries and deaths not related to the radioactive or hazardous chemical waste), and environmental cleanup costs resulting from accidental releases. Types of activities modeled include storage (above or below ground with various types of buildings or containments), retrieval and handling, characterization, repackaging, various treatment types (in-situ and ex-situ), transportation (onsite and offsite), and disposal. D&D and long-term stewardship activities are not modeled at present but will be added.

ESHRAP risk predictions are meant to be best estimate. Air dispersion calculations are no longer based on 95% or 99% atmospheric conditions at a site, but represent more of a 50% atmospheric characterization. (This area is still being investigated.) Also, personnel exposure estimates are not upper bounds, but are based on mean values from historical data for the Department of Energy. Standard industrial accident data were analyzed to obtain mean injury and death rates. Finally, much of the conservatism built into transportation risk estimates in the middle 1990s (4) has been removed by the use of more realistic input parameters (5) and more recent transportation accident rates and deaths per accident (6).

LEGACY RISK

The legacy risk measure concept is used to estimate the long-term risk of a waste or material in any form and environmental setting. Although many different types of legacy risk estimates can be postulated, the type most applicable to the risk model framework requirements is termed a minimal action risk measure. For a given waste/material form and environmental setting, it is assumed that a fence is placed around the waste/material, but no other action such as periodic inspection of waste containers or building maintenance is assumed. After 100 years, institutional control is assumed to be lost. The building (if one exists) and waste/material form degrade with time. Risks are evaluated for the public surrounding the site. A time period of 10,000 years is typically covered, although for some types of wastes/materials the time period beyond 10,000 years may be investigated. Risks result from releases to the atmosphere (for above-ground conditions), releases to the groundwater, and exposures from various types of intrusion events (scavenging, drilling, and residential).

Legacy risk measures provide information to determine the risk benefit from activities or programs. (The legacy risk before an action or program minus the legacy risk following the action or program is the risk benefit.) This risk measure also allows for the ranking of wastes/materials by risk. Finally, the legacy risk measure allows for the determination of site risk changes as programs progress.

CONVERSION TO COMMON RISK METRIC

ESHRAP risk predictions include the following types of risk: person-rem, latent cancer incidences and deaths from radiological and chemical exposure, injuries and deaths from standard industrial accidents, and costs to clean up radiological or chemical releases to the environment. The conversion from person-rem to latent cancer fatalities uses the standard 5E-4 latent cancer fatality per person-rem for the public and 4E-4 for workers. Latent cancer incidences resulting from chemical exposure are converted to latent cancer fatalities by using the same relationship observed for radiological exposure: one latent cancer fatality per 3.5 latent cancer incidences. (This relationship needs to be investigated further.) Finally, radiological and chemical exposure induced fatalities are given values of $4E+6 per fatality, while standard industrial injuries and fatalities are given dollar values used by the Department of Energy to calculate its cost index (e.g., $1E+6 per fatality). (The inconsistency in dollars per fatality between radiological and chemical fatalities and standard industrial fatalities needs to be investigated further.) The user can change all of these risk conversion factors.

SAMPLE APPLICATIONS

The risk model framework outlined in this paper is being applied to environmental management programs at the INEEL. This work is not yet complete and additional changes are being made to both the ESHRAP code and the modeling of legacy risk. However, preliminary applications have been performed and a sample of results is presented in this section. Seven examples are presented, each illustrating one of the types of applications listed at the beginning of the paper.

Fig. 1 illustrates a preliminary use of the ESHRAP code to estimate activity risks for an entire program. The program addresses aboveground, contact-handled transuranic waste (CH-TRUW) at the INEEL. This waste is presently stored in buildings and berms. All of this waste will be retrieved, characterized, processed (as needed), and shipped to the Waste Isolation Pilot Plant (WIPP) for final disposal. Shown in Fig. 1 are initial efforts to ship 3100 cubic meters of waste to WIPP followed by the retrieval of the remaining CH-TRUW. Activities modeled include initial storage (buildings and berms), retrieval, characterization, sorting, compaction, treatment, transportation, loading and unloading, and disposal. The risk measure in Fig. 1 is dollars, combining environmental impacts (costs to clean up radiological and chemical releases caused by accidents during the program activities), standard industrial injuries/deaths, and radiological and chemical latent cancer incidences and fatalities. As indicated in Fig. 1, risks are dominated by the transport of the CH-TRUW from the INEEL to WIPP. Also, most of this transportation risk is the result of injuries and deaths from truck accidents not involving releases of radionuclides.

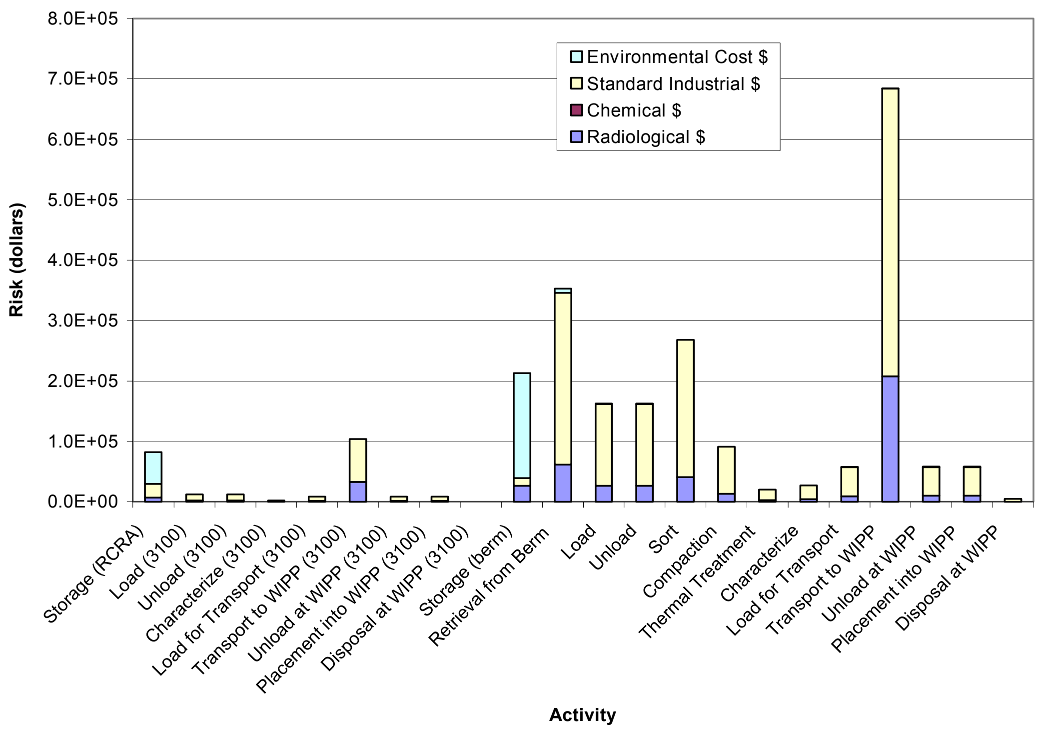

Fig. 1. CH-TRUW (Aboveground) Activity ES&H Risks.

A second preliminary application is presented in Fig. 2. Shown in the figure are the total activity safety and health (S&H) risks (risk costs) for three alternative programs for buried TRUW at the INEEL. The three programs are the following:

- Retrieval, treatment, and shipment to WIPP (baseline)
- In-situ grouting and capping
- Capping only.

The most risk is incurred by retrieving the waste, treating, and shipping to WIPP for disposal.

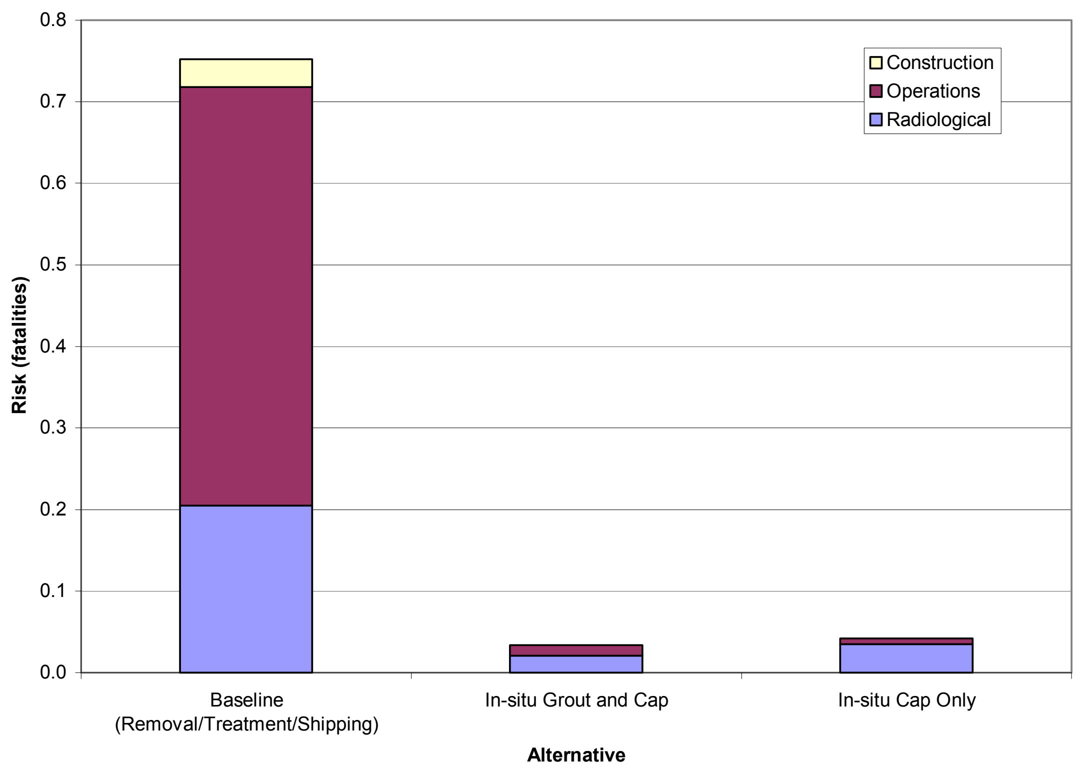

Fig. 2. Buried TRUW Program Alternative S&H Risks.

Shown in Fig. 3 are the S&H risk benefits versus risk costs from each of the three program alternatives for buried TRUW. The risk benefit is defined as the legacy risk measure of the waste before the program occurs minus the legacy risk measure of the waste after the program occurs. In the case of retrieval, treatment, and shipping to WIPP, the waste ends up in disposal at WIPP. However, for the other two programs, the waste remains buried (and capped) at the INEEL. As shown in Fig. 3, the risk benefit is greater than the risk cost for all three alternatives. However, the ratio of risk benefit to risk cost is much greater for the two alternatives that leave the waste in the ground. It should be noted that if it is assumed that the waste (buried 0.6 meter deep) is not uncovered at anytime during the 10,000-year period used to calculate the legacy risk, then the risk benefit drops dramatically. In that case, the baseline program actually has a greater risk cost than risk benefit. (This sensitivity needs to be investigated further.)

Fig. 4 presents a preliminary comparison or ranking of program S&H risks for various types of wastes and materials at the INEEL. Shown are programs for aboveground TRUW and belowground TRUW, high-level waste (HLW), spent nuclear fuel (SNF), low-level waste (LLW), mixed low-level waste (MLLW), and special nuclear materials (SNM). The program for buried TRUW was defined to include retrieval, treatment, and shipping to WIPP. As indicated in the figure, the TRUW programs have the most risk, while the MLLW and SNM programs have the least.

A preliminary risk ranking of wastes/materials at the INEEL is presented in Fig. 5. The long-term legacy risk measure is used to evaluate waste/material risks assuming minimal action is performed in the future to prevent exposures. Aboveground TRUW dominates the risk, while MLLW has the least risk.

Fig. 6 presents a preliminary INEEL site risk curve with time as environmental management programs progress. The program to ship aboveground TRUW to WIPP dominates this risk curve. As aboveground TRUW is shipped to WIPP (over the period 2000 to 2015), the site risk drops dramatically. Although not nearly as dramatic, the shipment of HLW to the Yucca Mountain repository also helps to reduce the site risk. Other program activities have significantly less impact on reducing the site risk with time and are not shown in the figure.

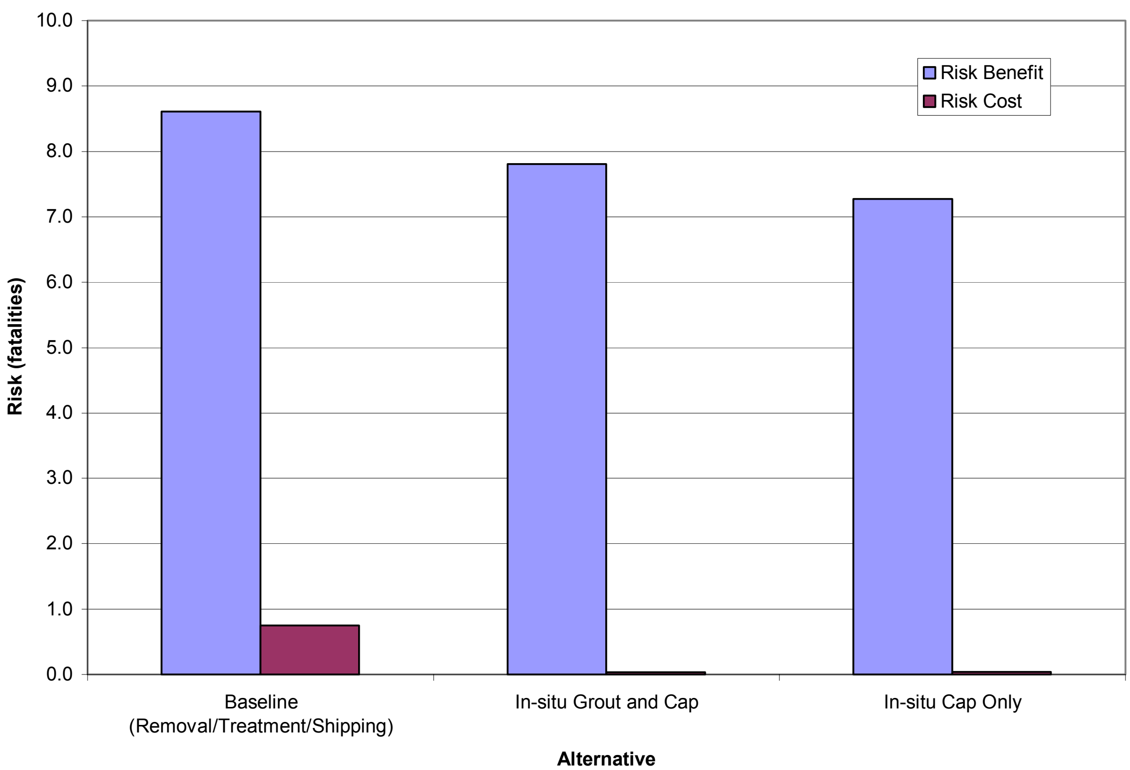

Fig. 3. Risk Benefit versus Risk Cost for Buried TRUW Program Alternatives.

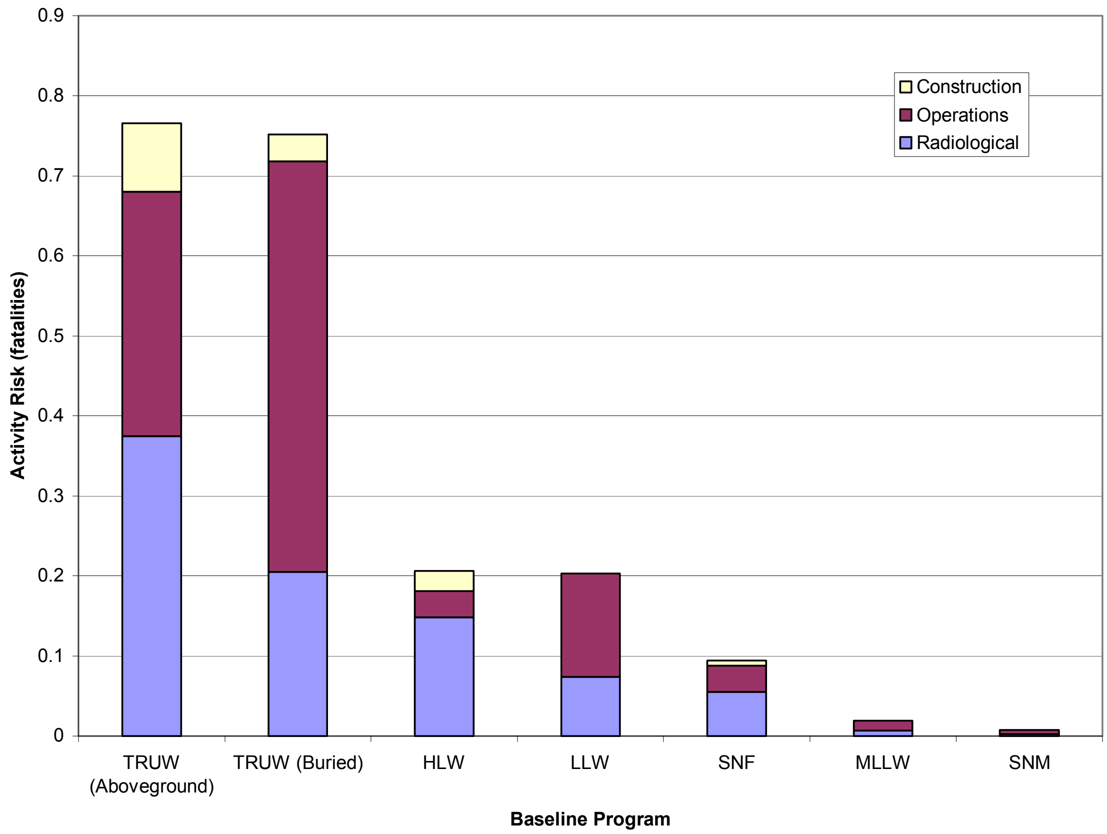

Fig. 4. INEEL Environmental Management Program S&H Risks.

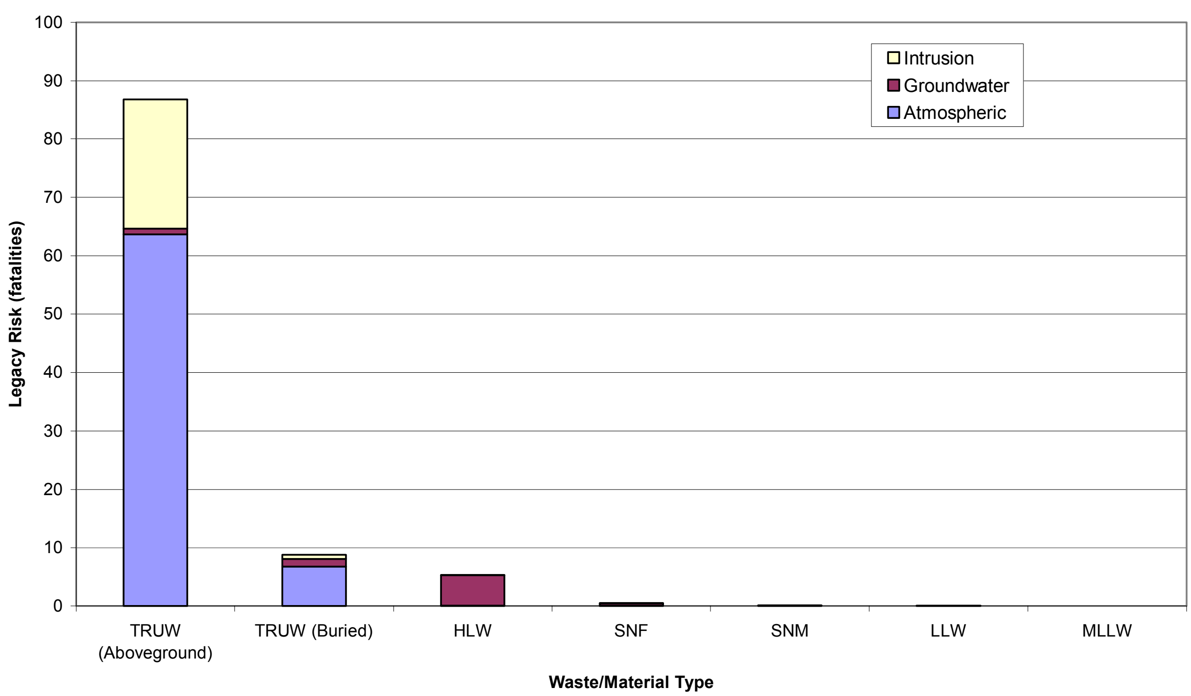

Fig. 5. INEEL Environmental Management Waste/Material Risks.

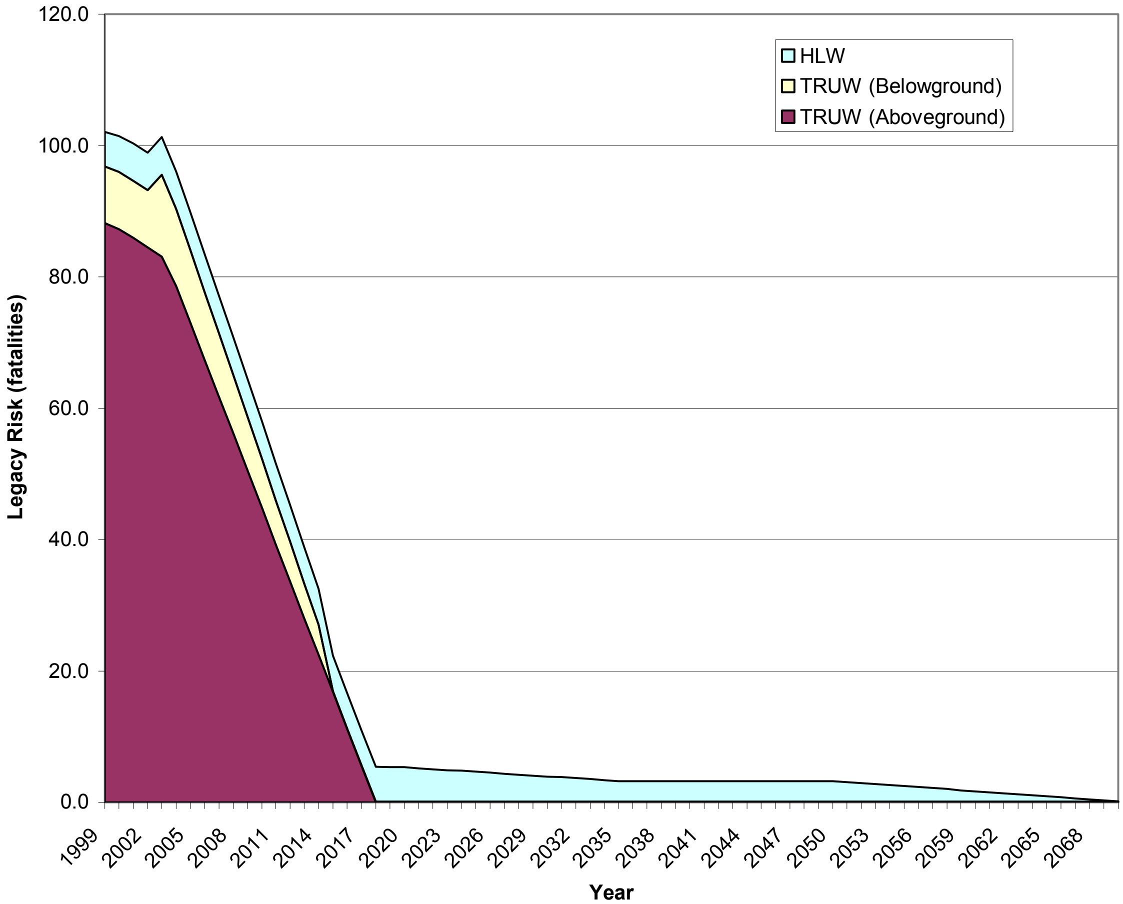

Fig. 6. INEEL Site Risk Curve.

Finally, Fig. 7 illustrates how the INEEL environmental management risk model could be used as in integrated indicator of performance. A preliminary analysis indicates that the baseline risk total for all INEEL environmental management programs (initial status through final disposition) is approximately two fatalities. As indicated in Fig. 7, this total includes contributions from the following types of events:

- Construction accidents causing injury or death (0.15 fatality)
- Standard industrial accidents causing injury or death (0.21 fatality)
- Transportation accidents causing injury or death (0.84 fatality)
- Normal radiological exposure to workers (0.38 fatality)
- Normal radiological exposure to truck crew and public from transportation (0.36 fatality)
- Radiological exposure from accidental releases of radionuclides (0.10 fatality).

This risk estimate was obtained using performance data (injury and death rates for standard industrial accidents, personnel radiological exposure, truck accident rates, etc.) representative of the entire Department of Energy complex.

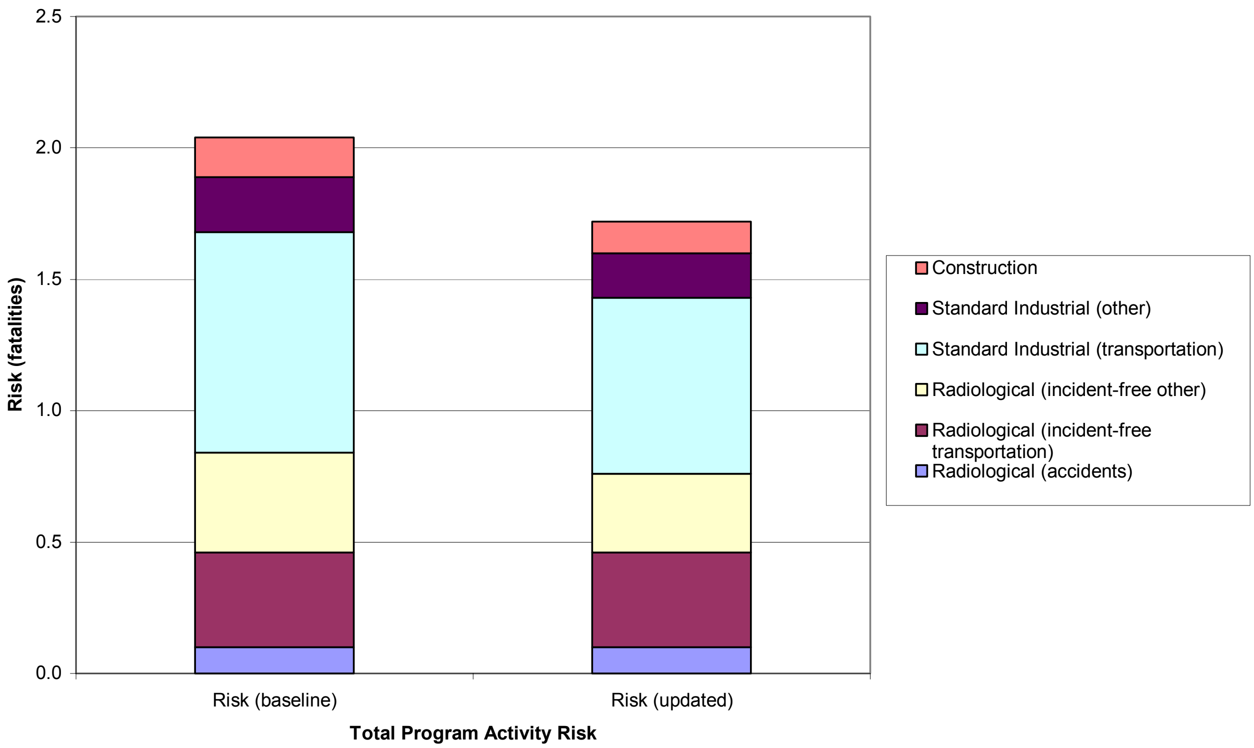

Fig. 7. INEEL Environmental Management Program Risk Integrated Indicator.

To use this total risk model as an integrated indicator of performance at the INEEL, assume that various safety programs result in a 20% reduction in construction and standard industrial accident rates at the INEEL, compared with averages for the entire complex. If this performance were maintained until environmental management programs are completed, then the construction and standard industrial accident fatalities (0.15 and 0.21, respectively) would be reduced by 20%. Also, assume that the ALARA program reduces personnel radiological exposures by 20%. This would reduce the radiological (incident free other) fatalities by 20%. Finally, assume that the offsite transportation program (not controlled by the INEEL) efforts reduce the truck accident rates by 20%. This would reduce the standard industrial (transportation) fatalities by 20%. These performance improvement assumptions are presented in Fig. 7 by the updated risk estimate. As can be seen in the figure, the total risk is reduced by approximately 0.3 fatality. Note that this model could also evaluate program or schedule changes that might result in more or less activity risk than the baseline.

All of the sample applications of the risk model framework to the INEEL are preliminary, and changes and refinements to the models could alter results presented in this paper. The purpose of these sample calculations is to indicate the types of applications possible.

FUTURE WORK

The goal for this effort is to develop the complete INEEL risk model by 2002. This will include up-to-date modeling for all of the major waste/material programs (initial status through final disposition). Also major D&D and long-term stewardship activities will be included. Also, work to refine risk modules within ESHRAP and the legacy risk measure concept will be performed throughout 2002.

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