ESTIMATION OF RISK REDUCTION RESULTING FROM WASTE MANAGEMENT OPERATIONS

S. Eide, J. Murphy, and T. Wierman
Idaho National Engineering and Environmental Laboratory
P.O. Box 1625
Idaho Falls, ID 83415-3850
(208) 526-3797, (208) 526-2930 (fax), **eidesa@inel.gov** (e-mail)

ABSTRACT

This paper summarizes preliminary efforts at the Idaho National Engineering and Environmental Laboratory (INEEL) to develop a simplified methodology for estimating risk reduction resulting from waste management operations. The method involves constructing human safety and health site risk curves resulting from waste and materials stored at the INEEL. Risk from waste management activities at the site is also analyzed. Finally, the overall results can be expressed in terms of cumulative benefit-cost risk curves, illustrating when the site risk reduction (benefit) of waste management activities outweighs the risks (costs) of such activities. The simplified risk methodology involves a five-step process, based on the concept of a "no action" risk scenario and the use of the Simplified Risk Model Version II (SRM-II). Resultant risk curves clearly illustrate the effectiveness of certain waste management activities in terms of reducing site risk. Also, the effectiveness of the overall waste management program can be evaluated, with respect to human safety and health risk. Such information may be valuable to managers in their decision-making and in presentations to stakeholders.

INTRODUCTION

Department of Energy (DOE) environmental management integration (EMI) studies characterize base case programs and potential alternatives for environmental management (EM) of DOE wastes and materials. These wastes and materials include high-level waste (HLW), transuranic waste (TRU), low-level waste (LLW), mixed low-level waste (MLLW), special nuclear material (SNM), and spent nuclear fuel (SNF). One type of input to such studies is information on risk to human safety and health. The *EM Integration Handbook* (Ref. 1), which provides general guidance for the identification and analysis of integration opportunities, indicates that there are two main risk questions to be considered:

1. How much risk reduction is achieved from the EMI activities; i.e., what is the difference in risk between the present state of the waste or material and the proposed end state? This risk reduction is referred to as the risk benefit in this paper.

2. What are the risks to the public, workers, and the environment from (during) the EMI activities? These activity risks are referred to as the risk cost.

The second risk question is typically addressed in environmental impact statements (EISs), safety analysis reports (SARs), and most other types of risk assessments. However, the first risk question is only rarely addressed in a comprehensive and quantitative manner.

The Idaho National Engineering and Environmental Laboratory (INEEL) has been investigating ways to measure the risk reduction resulting from waste management activities, or ways to address the first risk question posed above. An added stimulus for this investigation was the desire to be able to portray the risk impacts of intersite transfers of waste or materials. For example, how much is the INEEL site risk increased if waste from another DOE site is shipped to the INEEL? Or alternatively, how much is the INEEL site risk decreased if INEEL waste is shipped offsite? A promising approach being investigated involves the concept of a "no action" risk. The "no action" risk for waste stored at a DOE site can be defined as the risk to human safety and health from the waste for a 10,000-year period, similar to the assessment period for waste repositories. In this case, "no action" implies that essentially no effort is expended during the 10,000-year period to protect workers or the public from the waste as it is presently stored at a site. Using the "no action" risk concept, the first risk question listed above can be answered by evaluating the "no action" risk before and after the EMI activities are performed. For example, if HLW is being converted from a liquid form to a calcine (powder) form, the "no action" risk is evaluated for the liquid HLW as it is presently stored and for the resultant calcine HLW as it will be stored. If the "no action" risk results for the calcine HLW are lower than the results for the liquid HLW, then the calcination activity results in a reduction in site risk.

This paper discusses previous studies that have attempted to address "no action" risk, the INEEL concept of "no action" risk, trial application risk results for the INEEL, potential uses of such results, and future activities.

PREVIOUS STUDIES

DOE environmental impact statements (EISs) typically analyze what are termed "no action" alternatives. However, the definition of "no action" can vary considerably between and even within the EISs. For the Waste Management Programmatic Environmental Impact Statement (WM-PEIS) (Ref. 2), "no action" typically implied that only existing or planned facilities and operations are considered. For MLLW, the "no action" alternative was defined as storage for an indefinite period. However, only the first 20 years of such storage were analyzed. For LLW, the "no action" alternative involved treatment at existing facilities and disposal at one of six DOE disposal sites. The TRUW "no action" alternative involved an indefinite storage period (again, evaluated for only the first 20 years) at the sites that presently have TRUW. Finally, the HLW "no action" alternative in the WM-PEIS involved vitrification, canister storage, and final disposal at a repository. None of these WM-PEIS "no action" alternatives are similar to the proposed "no action" risk discussed in this paper (risk evaluation over a 10,000-year period assuming no additional waste management activities).

The Waste Isolation Pilot Plant (WIPP) Supplemental Environmental Impact Statement (SEIS) (Ref. 3) analyzed two "no action" alternatives. The first one involved treatment of TRU at each DOE site and indefinite storage at the sites (with repackaging every 20 years). The second "no action" alternative is similar to the concept discussed in this paper. The risk analysis for this "no action" alternative assumed TRUW at the seven major sites is stored as is for 100 years. After that period of institutional control, the TRUW is eventually assumed to mix with soil. Resuspension of the soil occurs, and the TRUW is then dispersed through the atmosphere. This

exposure pathway was evaluated for a 10,000-year period, using the present-day population distribution surrounding the site. The risk evaluation also addressed various intruder scenarios, but these were generally not significant contributors to risk.

Finally, the draft EIS for the proposed Yucca Mountain repository (Ref. 4) analyzed two "no action" alternatives: continued managed storage of SNF at existing sites for 10,000 years, and 100-year managed storage followed by no further action to protect the public from such material for the remaining 9,900 years. In this second alternative, following the 100-year storage period, the storage facilities and the SNF gradually deteriorate. Radionuclides eventually enter the soil and groundwater, resulting in exposure to the public and to intruders.

RISK REDUCTION METHODOLOGY

The methodology developed at the INEEL to estimate site risk reduction (and benefit-cost evaluations) from WM activities involves five steps:

1. Definition of "no action" scenario

2. Derivation of unit risk factors (URFs)

3. Development of site risk curve (changing with time)

4. Development of WM activity risk curve (changing with time)

5. Development of cumulative benefit-cost risk curve.

Each of these steps is discussed below.

For step 1, the "no action" scenario proposed is similar to that analyzed in the WIPP SEIS and the draft Yucca Mountain EIS. Risk is analyzed over a 10,000-year period, with essentially no actions taken to protect the public from radiological hazards. Specifically, the risk analysis includes the following:

- 100 years of institutional control (fencing the waste area to keep workers and intruders out, but no surveillance or maintenance of buildings or waste containers)

    Risk to site workers and the public is considered (air pathway), resulting from natural phenomena (seismic events, wind, or flood) and operational accidents (building fires and explosions, if such potential exists).

- Remaining 9,900 years following loss of institutional control

    Risk to the public is considered (air pathway and groundwater pathway), as well as risk to intruders.

For step 2, given the "no action" scenario described above, risk calculations are performed using the Simplified Risk Model Version II (SRM-II) (Ref. 5) for selected combinations of waste type, waste form, and type of storage. For example, for HLW at the INEEL, four combinations were analyzed: liquid HLW as presently stored in underground tanks, calcine HLW as presently stored in underground bins, and vitrified HLW (glass) as planned to be stored at the INEEL in the future (before shipment to a repository), and vitrified HLW as planned to be disposed of at Yucca Mountain. The 10,000-year risk results can be expressed as URFs, with the units of risk (rem or fatality) per curie of INEEL HLW. Note that these URFs are generated using a representative mix of radionuclides appropriate for the INEEL HLW. Also, radionuclide decay during the 10,000-year period is incorporated into the results.

Step 3 involves the development of the site risk curve. To generate the curve, one needs to determine the curie quantities of the various waste type/waste form/type of storage combinations at the site for each year (as WM activities progress). For example, for HLW at the INEEL, the numbers of curies of liquid HLW (in underground tanks), calcine HLW (in underground bins), vitrified HLW (in canisters), and vitrified HLW (in canisters in the repository at Yucca Mountain) need to be determined for each year. Then the INEEL site risk from HLW is simply the sum of the products of URF times curies for each HLW combination. Evaluating this HLW site risk each year (as the HLW activities progress, and liquid HLW is converted to calcine and later to glass and eventually shipped offsite) results in a site risk curve that changes with time.

Step 4 involves estimating the risks associated with the WM activities at the site. Such activities can include initial or interim storage of wastes, onsite transportation, loading and unloading, various types of treatment, shipment offsite, and disposal. Again, the SRM-II is used to estimate the risks of such activities in a comprehensive and consistent manner, which is also consistent with the "no action" risk estimates used to generate the URFs. The WM activity risk can then be presented as a risk per year, which is the format needed for step 5.

Finally, given the results of steps 3 (site risk curve with time) and step 4 (WM activity risk with time), a cumulative risk benefit-cost comparison can be constructed in step 5. The risk benefit from WM activities is defined as the reduction in site risk from the start of the year to the end of the year. The risk cost is defined as the WM activity human safety and health risk predicted for the year. Each year, this risk comparison (benefit minus cost) is calculated, and the cumulative results are plotted. When the cumulative curve rises above zero, then the human safety and health risk benefit is greater than the risk incurred.

INEEL TRIAL APPLICATION

As a trial application of the methodology outlined above, the INEEL HLW program was analyzed. Details of the INEEL HLW program, covering the activities from the present through the final shipment of HLW canisters to Yucca Mountain, were obtained from the Analysis and Visualization System (AVS) database maintained by the EMI organization at the INEEL. This database includes disposition maps for each of the waste and material types at most DOE sites. Also included is information on curie amounts, schedules for activities, waste forms, etc. At the INEEL, HLW currently exists as liquid in underground

storage tanks and calcine in underground bins. The baseline program involves conversion of the remaining liquid HLW to calcine for interim storage and vitrification of the HLW to a glass form at a later time. The vitrified HLW in canisters will be stored at the INEEL until it can be shipped to a repository such as Yucca Mountain.

URFs for the liquid, calcine, and glass HLW at the INEEL (and glass HLW at Yucca Mountain) were calculated using the SRM-II. Results are presented in Table 1. Also shown in Table 1 are URFs estimated from some other sources, for comparison purposes. As indicated in Table 1, the URF for calcine HLW is lower than that for liquid HLW. This is mainly a result of the change in waste form, with calcine being less dispersible than liquid. Also, the glass HLW has an even lower URF, again mainly because the glass waste form is less dispersible than the calcine. Finally, the URF for glass HLW in the Yucca Mountain repository is several orders of magnitude lower than those for HLW at the INEEL. This is mainly the result of the characteristics of the repository.

Given the HLW URFs for the INEEL, the site risk curve was generated using yearly information concerning the amount of curies of liquid, calcine, and glass HLW. The result is presented in Figure 1
As the remaining liquid HLW is converted to calcine and later to glass, the INEEL site risk drops. However, the most dramatic drop in site risk occurs when the HLW is shipped offsite to be disposed of at Yucca Mountain. Also shown in Figure 1 is the corresponding Yucca Mountain site risk as the INEEL HLW is placed into the repository. Note that the increase in Yucca Mountain site risk is imperceptible compared with the corresponding drop in INEEL site risk as the HLW is shipped to Yucca Mountain. (The Yucca Mountain site risk increase is not visible using the same y-axis scale as that used for the INEEL site risk curve.) This results because the Yucca Mountain repository is very effective in limiting long-term risk to the public. Figure 1 is a dramatic portrayal of the effectiveness of shipping the INEEL HLW to Yucca Mountain for disposal, in terms of reducing the INEEL site risk without significantly increasing the risk at the repository site.

Finally, in order to evaluate the risk benefit versus risk cost picture, the risks associated with the various INEEL HLW activities were estimated using the SRM-II. The results are plotted on an activity basis in Figure 2. Note that the human safety and health risk includes construction, standard industrial (during the actual waste management activity) and radiological fatalities. The results in Figure 2 have been converted to a yearly basis in Figure 3. Also shown in Figure 3 is the INEEL site risk curve from Figure 1. Using the site risk curve and yearly activity risk curves, the cumulative risk benefit-cost curve was generated and is also shown in Figure 3. As indicated in Figure 3, the cumulative risk benefit-cost curve does not rise above zero until shipping of INEEL HLW to Yucca Mountain starts around the year 2060.

Table 1. Preliminary "no action" URFs estimated using the SRM.

Material	Site	Material Form and Storage	"No Action" URF from SRM-II (fatality/Ci)	Applicable URFs from Other Sources (fatality/Ci)
HLW	INEEL	Liquid, underground tank	8.3E-8	
		Calcine, underground bin	1.2E-8	
		Glass, above-ground pad	2.0E-9	
	Yucca Mountain	Glass, deep geologic disposal	5.5E-12	2.1E-11 (Note a)
TRUW	INEEL	Loose contamination in drum, above-ground building	3.6E-5	1.4E-4 (Note b)
	WIPP	Loose contamination in drum, deep geologic disposal	1.9E-11	3.5E-11 (Note c)
LLW	INEEL	Loose contamination in drum, above-ground building	4.0E-7	
		Cement, above-ground building	4.0E-8	
		Loose contamination in drum, shallow disposal	2.4E-8	

a. The draft Yucca Mountain EIS indicates a dose of 0.1 mrem to each individual in the critical group (100-member farming community 20 km from the site) at 10,000 years. The URF was derived from this result.
b. From the WIPP SEIS for "No Action Alternative 2" for seven major TRUW sites. Using the basic inventory only.
c. From the WIPP SEIS. Inadvertent intrusion by a drilling crew results in 2E-4 fatality. Dividing by the total Ci at WIPP (when full), 5.8E+6 Ci of TRUW, the URF is 3.5E-11/Ci

This same type of risk analysis was also performed for the other five waste and material types at the INEEL: TRUW, LLW, MLLW, SNF, and SNM. Selected URFs for these other waste and material types are presented in Table 1. The overall results for the INEEL, including all six waste and material types, are presented in Figure 4. The INEEL site risk curve in Figure 4 is dominated by TRUW. So is the WM activity risk curve, until all of the TRUW is shipped offsite to the WIPP repository by approximately 2017. The cumulative risk benefit-cost curve rises above zero in 2001 and remains positive through the end of the analysis at 2080. Again, most of the risk benefit arises from the TRUW shipments offsite to WIPP.
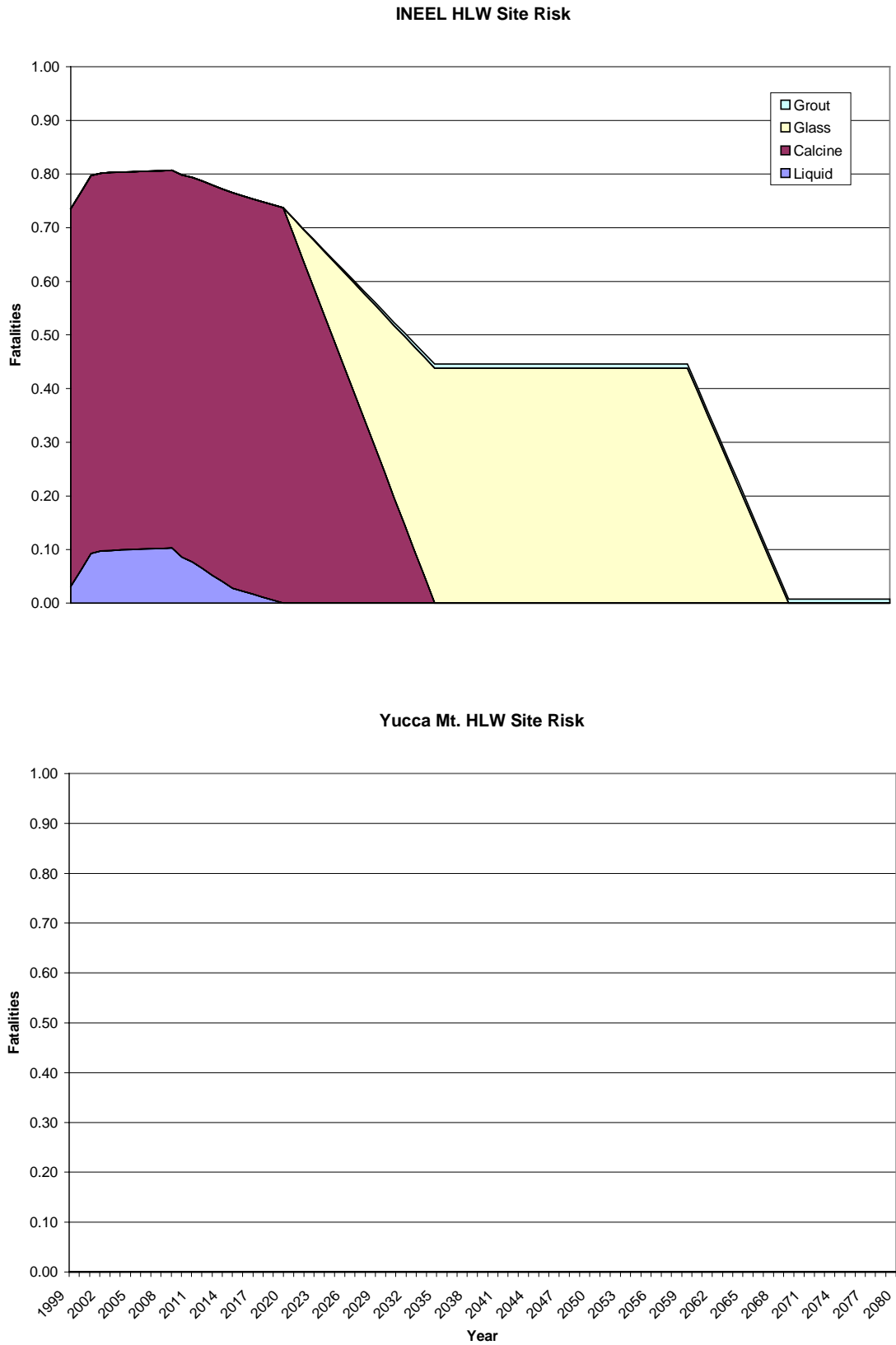
INEEL HLW Site Risk

Yucca Mt. HLW Site Risk

Figure 1. HLW site risk curves (INEEL and Yucca Mountain).

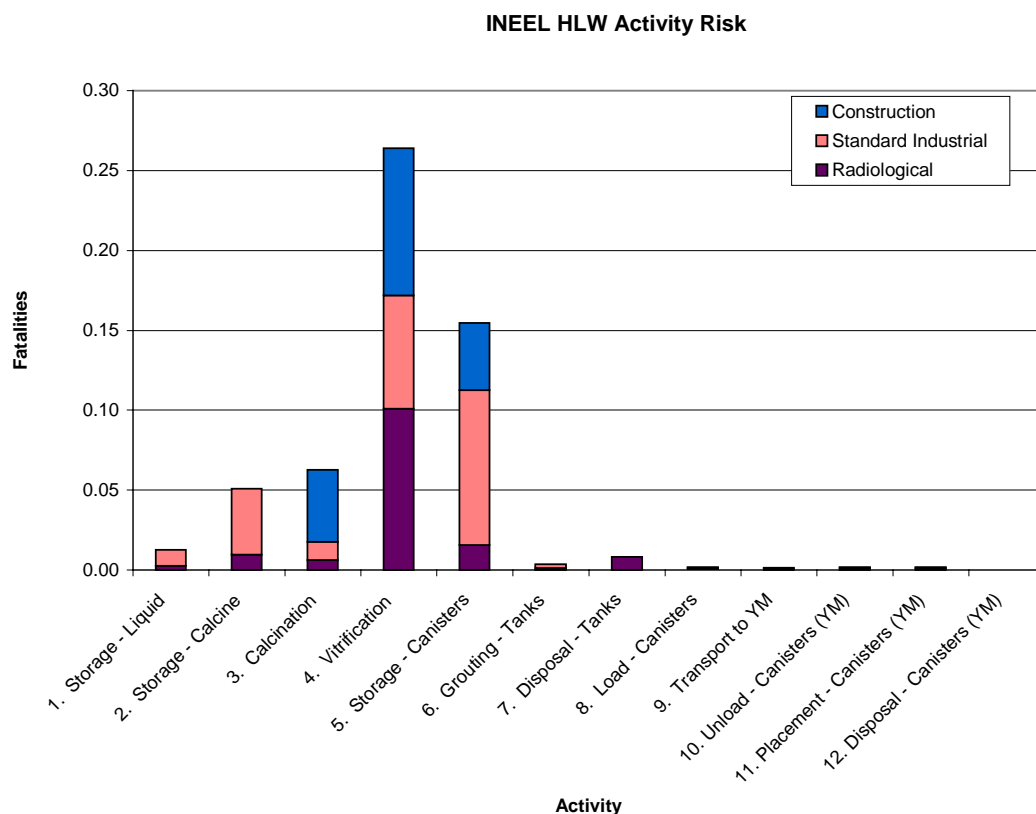**INEEL HLW Activity Risk**

Figure 2. INEEL HLW activity risk.

POTENTIAL USES

The analyses presented in this paper might prove to be useful to EM managers in their decision-making process. The analyses clearly identify the most significant activities in terms of reducing site risk. The analyses also clearly show the effectiveness of shipping HLW, SNF, and TRUW to national repositories (WIPP and Yucca Mountain). Also, these same analyses might be very useful in explaining the overall EM program to stakeholders. However, it should be made clear that the analyses only cover risk to human safety and health. Other inputs are also important to decision-making, such as environmental impacts, costs, and regulations and agreements.

FUTURE WORK

The SRM-II model, which is the fundamental tool used to generate the results presented in this paper, evaluates risk to human safety and health. Therefore, the SRM-II is an "S&H" risk model. Work is ongoing to expand the SRM-II to a full environment, safety, and health ("ES&H") risk model. Also, additional work is needed to complete the technical basis documentation, user's guide, and software application for the SRM-II.
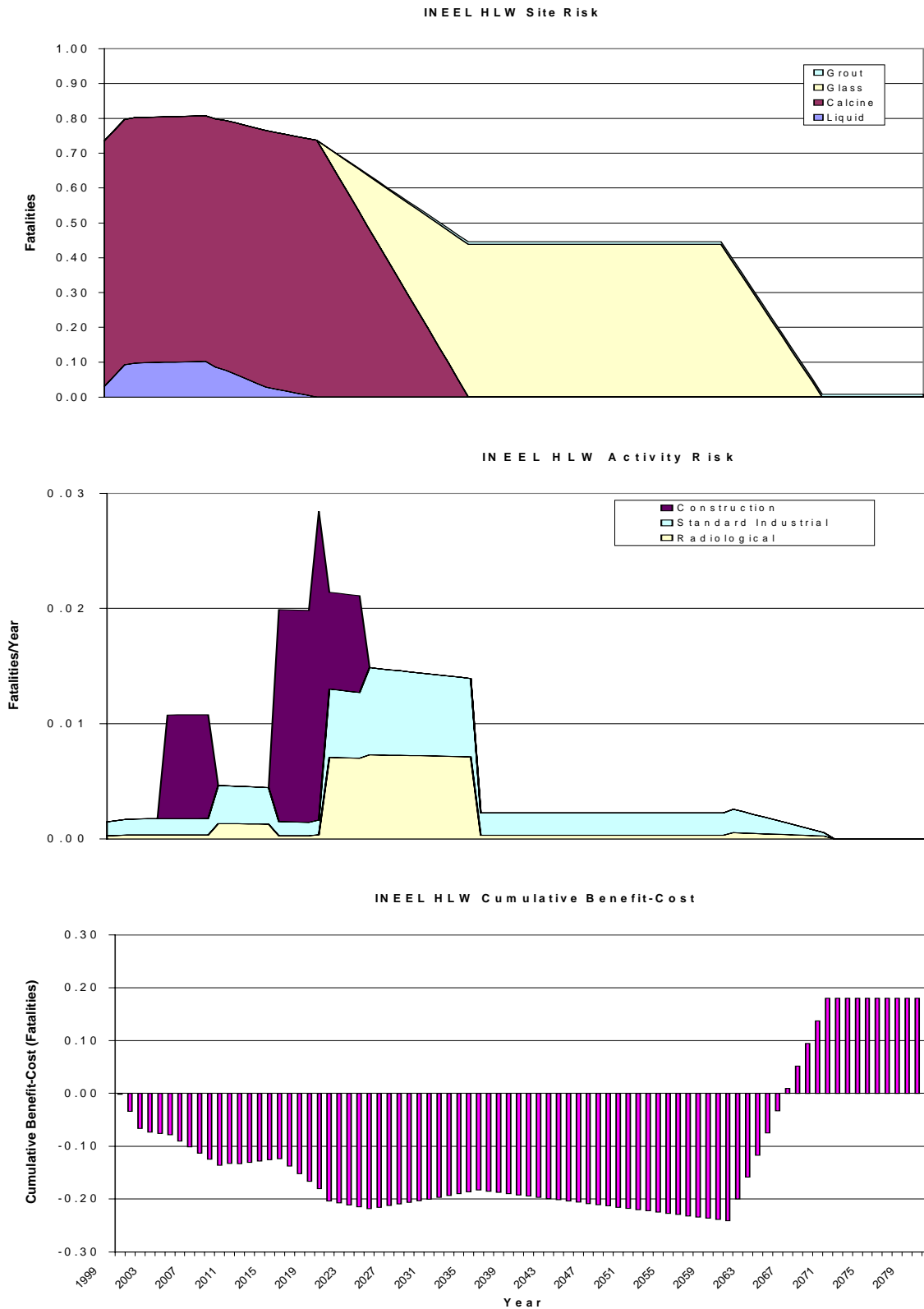
INEEL HLW Site Risk

INEEL HLW Activity Risk

INEEL HLW Cumulative Benefit-Cost

Figure 3. INEEL HLW site risk, activity risk, and cumulative risk benefit-cost curves.
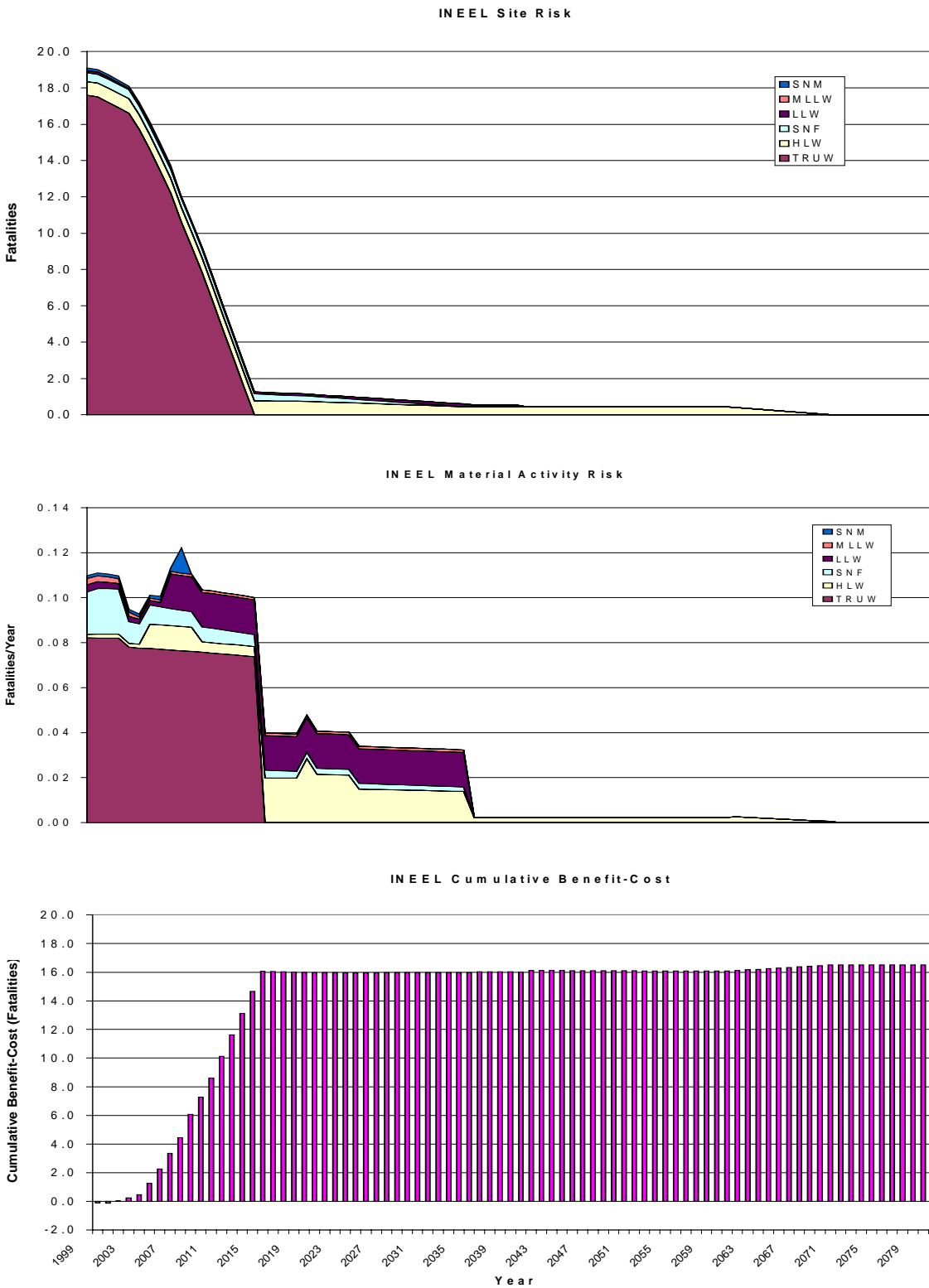
Figure 4. INEEL site risk, activity risk, and cumulative risk benefit-cost curves including all six waste and material types.

INEEL management and stakeholders need to evaluate the usefulness of the types of risk analyses and risk curves presented in this report. If such analyses are deemed to be useful, then the preliminary INEEL analyses presented in this paper will be refined based on current information on planned EM activities. Also, the environmental restoration activities (and associated waste inventories) might be added to the overall analysis to obtain a more complete picture of INEEL site risk. Finally, other INEEL activities, such as the operation of the Advanced Test Reactor, could be added to complete the INEEL risk picture.

SUMMARY

The INEEL has developed a simplified methodology to answer two important risk questions related to WM activities:

1. What is the risk reduction resulting from WM activities?

2. What is the risk from WM activities?

Most risk analyses have not attempted to address the first risk question, at least in a comprehensive and quantitative manner. The simplified methodology is based on the concept of a "no action" risk scenario that is similar to alternatives analyzed in the WIPP SEIS and the draft Yucca Mountain EIS. Using the INEEL-developed SRM-II risk software and WM activity information from the AVS database, preliminary analyses were performed for WM activities at the INEEL. The analysis results in an INEEL site risk curve (illustrating the change in site risk as WM activities progress), INEEL risk from WM activities (on an activity and yearly basis), and a cumulative risk benefit-cost curve. The yearly risk benefit is defined as the drop in site risk from the start of the year until the end of the year. The risk cost is the yearly activity risk associated with the WM activities. Results are presented in Figure 4 of this paper. The risk curves presented in Figure 4 may be beneficial to INEEL managers in their decision-making process. The curves clearly indicate the dominant activities in terms of risk and in terms of their effectiveness in reducing site risk. The same information may also be helpful to stakeholders.

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