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Legacy Risk Measure For Environmental Waste

S. A. Eide
R. L. Nitschke

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S.A. Eide and R.L. Nitschke
Idaho National Engineering and Environmental Laboratory
P.O. Box 1625, Idaho Falls, ID 83415-3850

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. Two basic types of risk estimates are included: risks from environmental management activities, and long-term legacy 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.

This paper discusses the definition and calculation of legacy risk measures and associated issues. The legacy risk measure is needed to support three of the seven types of evaluations listed above: comparisons of risk benefit versus risk cost, ranking of wastes/materials by risk, and evaluation of site risk changes with time.

INTRODUCTION

Risk-informed decision-making in the areas of hazardous waste management (including spent nuclear fuel from reactors) is enhanced if the legacy risk from materials is known. Legacy risk is defined as a long-term (10,000 years or longer) risk measure associated with hazardous materials in any form and environmental setting. As defined, the legacy risk measure is a generalization of performance assessment (PA) risk, which is typically evaluated for 1,000 or 10,000 years following closure at disposal facilities, to cover the risk of a waste material at any point during its life cycle. The legacy risk measure can be used to support three types of risk evaluations:

- Ranking of wastes/materials by risk
- Evaluation of site risk changes with time as activities progress
- Comparisons of risk benefit versus risk cost for activities or entire programs.

The third type of evaluation also requires the analysis of risks from activities or programs, which is not addressed in this paper. (That topic is addressed in another paper, "Comprehensive WM/ER/D&D/LTS Risk Model for the INEEL.") Examples where information on legacy risk measures could assist in risk-informed decision making include the following waste/material programs: high-level waste (HLW), low-level waste (LLW), mixed low-level waste (MLLW), transuranic waste (TRUW), spent nuclear fuel (SNF), and special nuclear material (SNM).

Preliminary work related to the legacy risk measure was summarized in the Waste Management 2000 paper "Estimation of Risk Reduction Resulting from Waste Management Operations." (1) The preliminary legacy risk measures generated for that paper included only a limited set of normal and disruptive scenarios over a period of 10,000 years. Work since then has identified more scenarios and phenomena that need to be considered. Also, for some types of waste the period beyond 10,000 years may need to be explored when generating legacy risk measures. This paper summarizes recent work on refining the legacy risk concept to more effectively support a comprehensive risk model framework and decision-making and on identifying and evaluating risks from future exposure scenarios.

BACKGROUND

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 considered. Risks result from releases to the atmosphere (for aboveground conditions), releases to the groundwater, and exposures from various types of intrusion events (scavenging, drilling, and residential).

Department of Energy (DOE) environmental impact statements (EISs) typically analyze what are termed "no action" alternatives, which might imply an analysis similar to the minimal action legacy risk measure described above. 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), "no action" typically implied that only existing or planned facilities and operations are considered. (2) For mixed low-level waste, the "no action" alternative was defined as storage for an indefinite period. However, only the first 20 years of such storage were analyzed. For low-level waste, the "no action" alternative involved treatment at existing facilities and disposal at one of six DOE disposal sites. The transuranic waste "no action" alternative involved an indefinite storage period (again, evaluated for only the first 20 years) at the sites that presently have such wastes. Finally, the high-level waste "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 minimal action risk measure 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) analyzed two "no action" alternatives. (3) The first one involved treatment of transuranic waste 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 transuranic waste at the seven major sites is stored as is for 100 years. After that period of institutional control, the waste is eventually assumed to degrade and mix with soil. Resuspension of the soil occurs, and the waste 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. Total latent cancer fatalities resulting from this pathway are presented in that report for seven DOE sites. The risk evaluation also addressed various intruder and residential scenarios, but these were not assigned frequencies and were not included in the totals. At least one of the residential scenarios (farm family for surface waste) could significantly increase the totals presented, depending upon the site and the frequency assumed for such an event over the 10,000-year period.

The draft EIS for the proposed Yucca Mountain repository analyzed two "no action" alternatives: continued managed storage of spent nuclear fuel 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. (4) In this second alternative, following the 100-year storage period, the storage facilities and the spent nuclear fuel gradually deteriorate. Radionuclides eventually enter surface-water runoff and contaminate sources of drinking water. This pathway dominates the total latent cancer fatality results presented. However, the residential gardener scenario could dominate this result, depending upon the site and the frequency assumed.

Finally, the recent report *Relative Hazard and Risk Measure Calculation Methodology* outlines an approach for producing "…graphic illustrations showing the relative hazard and risk reductions that occur as a result of a site's projected risk management actions." (5) This method covers five exposure scenarios: chronic airborne, chronic surface water, chronic groundwater to surface water, fire/explosion accidents, and direct contact (worker or scavenger). Hazard is estimated as a product of several terms, and term values are suggested for various radionuclides and chemicals. These terms represent the waste quantity, releasable fraction, inherent toxicity and pathway transport potential, and controls in place. The focus is on the hazard to a maximally exposed individual from a given waste/material, and not to the overall public. Finally, the method is designed to provide relative comparisons of hazard or risk reduction, and does not provide absolute values for hazard or risk, such as person-rem or latent cancer fatalities.

TECHNICAL APPROACH

To support the comprehensive risk framework discussed previously, the legacy risk measure should have the following characteristics:

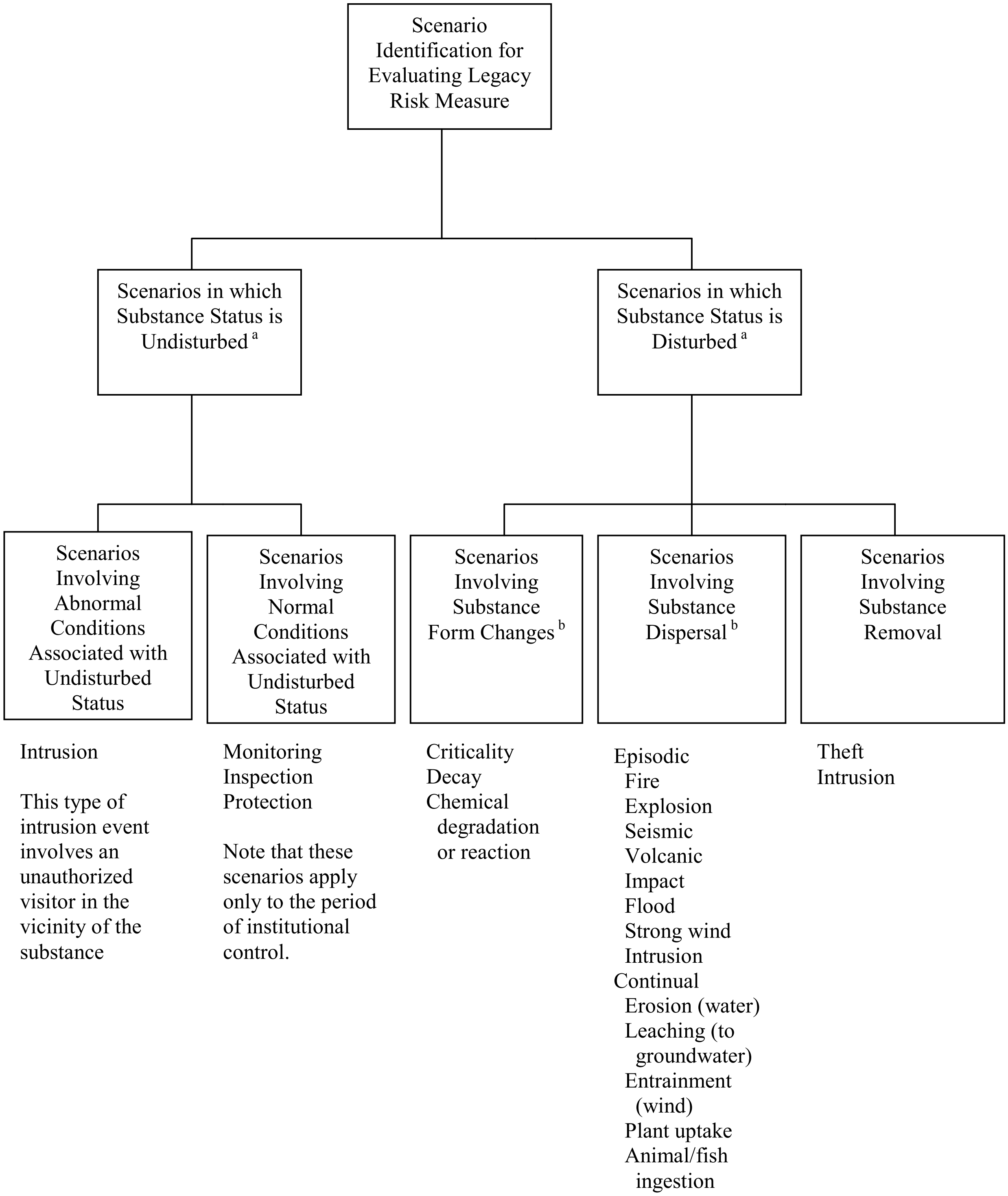
- Coverage of short-term and long-term risk
- Quantitative evaluation of absolute risk (person-rem, latent cancer fatality, or other measures)
- Best estimate risk evaluation rather than conservatively high risk evaluation
- Quantitative evaluation of risk versus time
- Consideration of risk to workers and the public
- Consideration of failure of active and passive controls (timing and probability)
- Intergenerational equity
- Transparency and simplicity
- Broad based and systematic in identification of exposure scenarios
- Consideration of uncertainty and sensitivity.

Several potential legacy risk measures might possess most or all of these characteristics, ranging from one extreme – a no action philosophy – to the other extreme – continued managed storage (status quo). The latter approach would include periodic repackaging of waste and rebuilding of storage facilities (to maintain the status quo) until the waste is no longer hazardous. This paper focuses on the no action or minimal action legacy risk measure, which focuses more on the inherent hazards associated with a waste/material and associated environmental setting than does the continued managed storage risk measure. Also, the continued managed storage option can be analyzed as a program alternative rather than using it as the baseline legacy risk measure.

To ensure a comprehensive coverage of both short- and long-term exposure scenarios, a master logic diagram (MLD) approach to scenario identification is proposed. The MLD approach has been used in risk assessments for nuclear power plants and is discussed in the report *PRA Procedures Guide*. (6) The MLD is used to help focus the search for accident scenarios while ensuring completeness. A preliminary version of an MLD for identifying exposure scenarios associated with the minimal action legacy risk measure is presented in Fig. 1. The top event in the MLD is "Scenario Identification for Evaluating Legacy Risk Measure." This event is decomposed into two lower level events that preserve the completeness of the top event: "Scenarios in which Substance Status is Undisturbed" and Scenarios in which Substance Status is Disturbed." Each of these events is further decomposed as shown in Fig. 1. At the lowest level of the MLD logic, other types of scenario identification techniques (brainstorming, review of previous studies, etc.) are needed to complete the scenario identification lists. Note that this MLD is still under development. However, as indicated in Fig. 1, the MLD structure ensures completeness down to the level at which brainstorming or other techniques are used. Also, the MLD structure focuses each of these search efforts.

To evaluate the legacy risk measure, the following steps are performed:

1. Identify the waste/material and associated environmental setting
2. Select the legacy risk measure to be used (in this case, a minimal action legacy risk measure)
3. Decide on the scope of the risk measure (human health and safety, environmental impacts, other)
4. Divide the legacy risk evaluation period (10,000 years as an example) into discrete time periods
5. Use the MLD in Fig. 1 to help identify significant exposure scenarios for each time period
6. Quantify the exposure scenario risks (frequency and consequence) for each time period
7. Sum the risks from each time period to obtain the overall legacy risk measure.



a. Substance status includes both the waste/material form and the environmental setting.
b. If very long time (>10,000 years) periods are being considered, then long-term phenomena such as climatic changes may need to be addressed.

Fig. 1. MLD for Risk Scenario Identification.

SAMPLE APPLICATIONS

As an initial application of the minimal action legacy risk measure, the contact-handled transuranic waste (CH-TRUW) stored at the INEEL aboveground in metal buildings was analyzed. The CH-TRUW is stored in drums within metal buildings, and both the drums and buildings have a design life of approximately 50 years. The CH-TRUW volume is approximately 13000 m^3 and contains approximately 6.6E+4 curies (Ci). The fraction of actinides is approximately 0.99. Two alternative legacy risk analyses were performed: one with the drums aboveground in the metal buildings (the actual case), and the other with the drums buried under two meters of soil. The legacy risk measure was calculated by analyzing risks during each of the following time periods: 0 to 100 years (with site institutional control and the drums and metal building in good shape for the first 50 years), 100 to 1,000 years (drums and building totally degraded, and waste assumed to lie on surface), and 1,000 to 10,000 years. For each time period, risk to the public was estimated by accounting for various types of intrusion scenarios (with varying frequencies depending upon the time period), normal wind entrainment of soil and waste (if located at the surface), various types of accidents (such as earthquakes, strong winds, and range fires), and long-term groundwater contamination. The present population distribution was assumed to exist throughout the 10,000-year period. (This assumption was also used in Reference 5. However, this assumption will be researched further.) Also, the worker risk during the period of institutional control (0 to 100 years) was estimated. These exposure scenarios were identified with the help of the MLD presented in Fig. 1. Preliminary legacy risk measure results are presented in Tables I and II for CH-TRUW located in drums in an aboveground metal building (the actual situation) and for drums located belowground. These risk results were generated using a modified version of the Environment, Safety and Health Risk Assessment Program (ESHRAP) software developed at the INEEL. (7) Built into this code are various frequency options for the different types of intrusion scenarios modeled (scavenger, residential, and drilling). The "moderate" frequency option was chosen for each of these intrusion scenarios.

Table I. Legacy Risk Measure Contributions for CH-TRUW in Drums in Metal Building Aboveground

Exposure Category	Risk (Fatalities)			
	0 to 100y	100 to 1000y	1000 to 10000y	Total
Air dispersion	0.042	1.3	7.3	8.6
Groundwater	0.0	4.4E-7	0.13	0.13
Intrusion	0.0	0.12	2.9	3.0
Standard industrial	2.6E-4	0.0	0.0	2.6E-4
Total	0.042	1.4	10.3	11.7

Table II. Legacy Risk Measure Contributions for CH-TRUW in Drums Located Belowground

Exposure Category	Risk (Fatalities)			
	0 to 100y	100 to 1000y	1E+3 to 1E+4y	Total
Air dispersion	0.0	0.0	0.0	0.0
Groundwater	0.0	4.4E-7	0.13	0.13
Intrusion	0.0	1.2E-4	6.7E-4	7.9E-4
Standard industrial	2.6E-4	0.0	0.0	2.6E-4
Total	2.6E-4	1.2E-4	0.13	0.13

For the CH-TRUW drums in a metal building aboveground, the total risk is 11.7 fatalities over a 10,000-year period. As expected, there is minimal risk during the period of institutional control (1 to 100 years). Most of the risk is incurred beyond 1000 years. Air dispersion from accidents (mainly range fires) and intrusion dominate this risk. The legacy risk measure can be expressed on a per curie basis (using the initial Ci total) as (11.7 fatalities)/(6.6E+4 Ci) = 1.8E-4 fatality/Ci. For CH-TRUW drums located belowground (two meters of soil cover), the total risk is 0.13 fatalities. On a per curie basis, the legacy risk measure is 2.0E-6 fatality/Ci. (Note that the belowground analysis assumed that the waste would remain covered by two meters of soil during the entire time period covered. If erosion or some other mechanism uncovered this waste, then the aboveground risk results would apply from that time on.) These analyses clearly indicate that the waste located aboveground has much more risk potential than the waste located belowground. It should be noted that this CH-TRUW is being shipped to WIPP for final disposal.

The legacy risk measure for CH-TRUW disposed of in WIPP is less than 1.0E-8 fatality/Ci, which is an indication of the effectiveness of disposal at WIPP.

Fig. 2 illustrates the use of the legacy risk measure to rank waste/material. Shown in the figure are preliminary results for various types of waste/material at the INEEL. The aboveground TRUW dominates the risk.

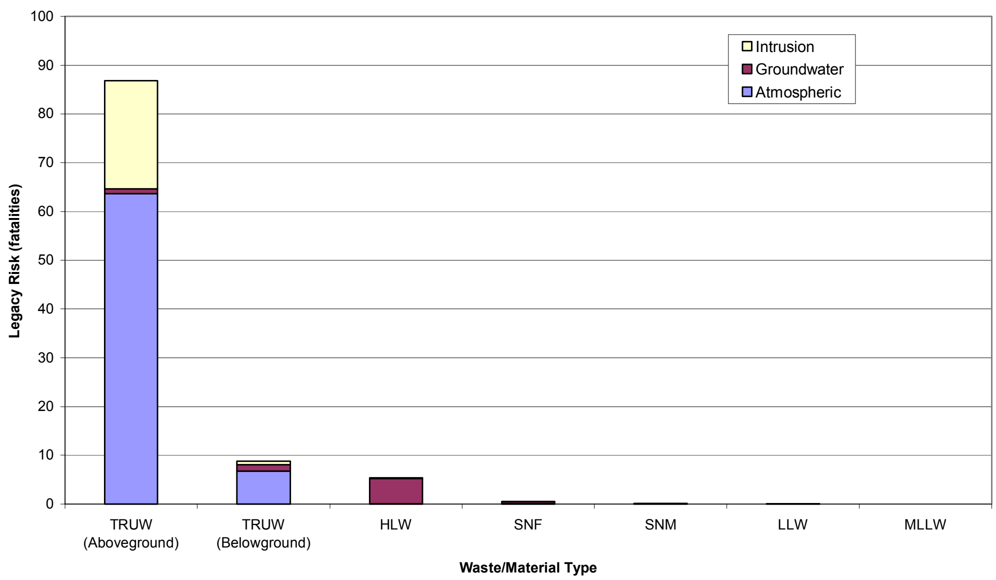


Fig. 2. INEEL Waste/Material Ranked by Legacy Risk Measure.

Shown in Fig. 3 is a preliminary INEEL site risk curve, indicating how the site risk changes with time as environmental management programs progress. Because the aboveground TRUW dominates the site risk, the program to ship this waste to WIPP is the most important program in terms of reducing the INEEL site risk.

FUTURE WORK

Future work in the area of legacy risk measures will refine the modeling of various scenarios, address the many issues associated with trying to predict risk far into the future (time period to cover, future populations and land use, intergenerational equity, discounting of future risks, frequencies of intrusion events, etc.). Also other possible types of legacy risk measures will be identified and studied.

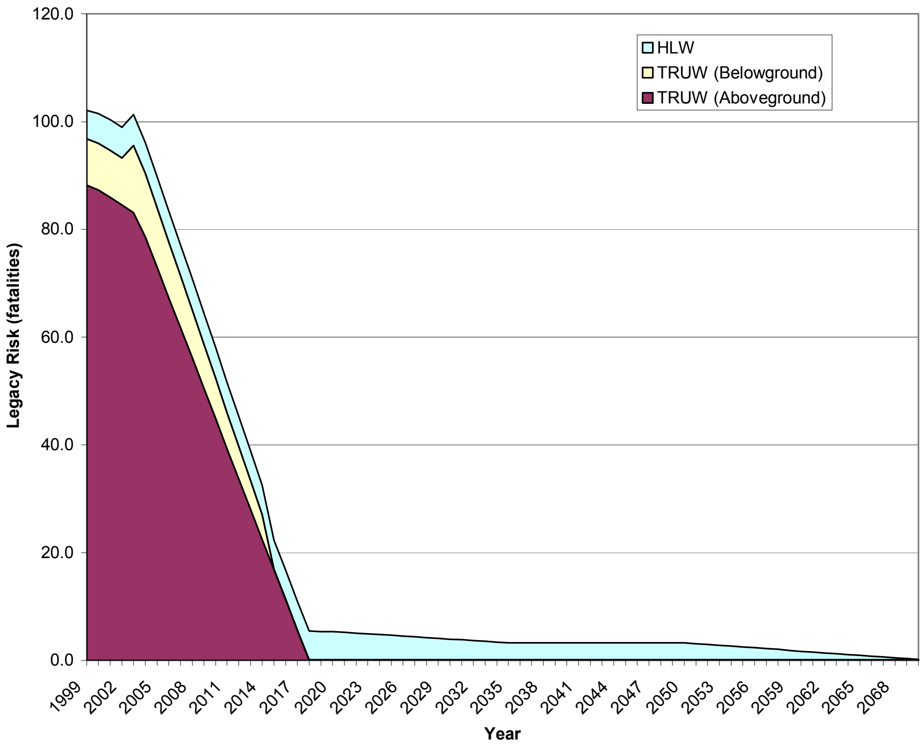


Fig. 3. INEEL Site Risk Curve Change with Time.

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