CHEMICAL AND RADIOLOGICAL RISK ASSESSMENT TECHNIQUES

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ABSTRACT

This paper presents the techniques for conducting an exposure assessment at a superfund site. The exposure assessment is the potentially most controversial aspect of risk assessment. It requires decision-making based on subjective assumptions therefore inviting closer scrutiny from regulators. The exposure assessment is subject to this scrutiny because it is used to identify exposure pathways and to estimate contaminant concentrations to which potential receptors may be exposed. The exposure assessment is divided into three parts: characterizing the exposure setting, identifying exposure pathways, and quantifying the exposure. The first component of the assessment includes analyses of contaminant and receptor characteristics which are used to identify potential exposure pathways for three periods of institutional control. Exposure concentrations are determined from a combination of characterization data, disposal inventory data, and environmental fate and transport modeling data. Specific intake values are then calculated for each of the identified pathways using the exposure concentrations and other pathway-specific intake variables.

INTRODUCTION

A baseline risk assessment is conducted for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites during the remedial investigation (RI) and feasibility study (FS) phases to evaluate alternative remedial actions (or no action). This paper will specifically address the exposure assessment, the most controversial component of the baseline risk assessment, as it applies to an existing superfund site, referred to as Site A.

The exposure assessment typically involves not only objective but also more subjective analyses than the other human health risk assessment components. Because of the subjectivity, the exposure assessment is often the portion of the risk assessment that is under greatest scrutiny from regulators. Rigorous scrutiny is necessary to ascertain that all significant pathways and receptors are addressed. The three other components to the baseline risk assessment process are data collection and evaluation, toxicity assessment, and risk characterization. These components and their relationships to the exposure assessment are illustrated in Fig. 1.

Data collection and evaluation involves gathering and analyzing site data and identifying the contaminants present that are a potential threat to human health. In exposure assessment, potential exposure pathways are identified and the individual contaminant intakes are estimated. The toxicity assessment evaluates contaminant effects and determines the appropriate toxicity values. The exposure and toxicity assessments are performed concurrently. The last component, risk characterization, summarizes and combines the exposure and toxicity assessment data to quantitatively and qualitatively express the baseline risk associated with various remedial action scenarios.

The exposure assessment component of the risk assessment is relatively simple if the nature and extent of contamination at a site is well understood. Frequently, only a few pathways (e.g., less than five) are considered significant enough to warrant a detailed analysis of receptor intakes. For Site A, however, the exposure assessment is highly complex, involving 26 pathways, 4 receptor types, and 3 different time frames over which intakes must be estimated. Where Site A information is lacking, many assumptions were made for the exposure assessment to estimate the potential current and future reasonable maximum exposure intakes. These assumptions are critical to the reliability of the assessment, and, because they are subjective, the decisions regarding their use must be based on established techniques. A discussion of some of these techniques is presented in the following sections.

EXPOSURE ASSESSMENT

The objective of the exposure assessment for Site A is to estimate the type and magnitude of exposures to receptors from identified contaminants. This is accomplished using available site-specific information along with characterization and modeling data to quantify intakes to receptors from affected environmental media. The general procedure for conducting the exposure assessment includes: (1) characterizing the exposure setting, (2) identifying exposure pathways, and (3) quantifying the exposure. Each of these steps is discussed below.

Characterizing the Exposure Setting

The exposure setting depends on site characteristics, institutional control factors, and identification of receptors. Site A characteristics include an understanding of waste disposal activities and the resulting nature and extent of contamination. Site A is bordered on the south by Creek A, which drains into River A, and on the west by Highway A. The topography consists of gently to moderately sloping land, which drains to Creek A as illustrated in Fig. 2. Site A

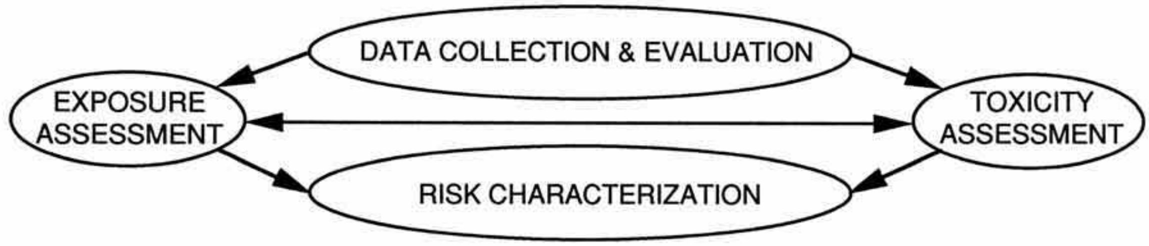

Fig. 1. Exposure assessment components.

comprises 75 acres, with approximately 15 acres used for chemical and radioactive waste disposal.

Two different methods of radiological and chemical waste disposal methods have been employed at Site A for the last 20 years. For the first 15 years, the principal method was burial in unlined trenches. Over 500 trenches (each is approximately 50 feet long by 10 feet wide by 15 feet deep) were used for the disposal of radioactive and chemical wastes mixed with soil. The approximate spacing between the trenches is 5 feet. When the waste level reached approximately 3 feet below the top, the trench was backfilled with clean soil. Because the wastes were not placed in containers, a significant portion of the contaminants may have migrated from their original disposal areas. For the last 5 years, a second method has also been used. This is the use of engineered intrusion barriers, i.e., concrete encapsulation of radioactively contaminated wastes in trenches. Barrier integrity presents a controversial component of the decision-making process because it introduces the use of subjective analysis. It is assumed that these intrusion barriers prevent direct intrusion into the wastes (i.e., penetration of the concrete barrier by a receptor and subsequent exposure to the wastes) until 300 years after disposal ceases. It is further

Fig. 2. Site A.

assumed that radiological disposal operations are ongoing and are forecasted to continue for the next 10 years. During the last 5 years there was no disposal of chemical wastes at Site A and no chemical wastes are anticipated to be disposed in the future.

To characterize the site, extensive sampling of environmental media (including groundwater, soil, surface water, and sediment) was conducted around known disposal areas. Direct sampling of contaminated disposal areas was not permitted because of the adverse radioactive exposure potential. However, waste disposal inventory data for the radioactive contaminants are available from site records. No inventory data are available for chemical contaminants.

At radioactively contaminated sites, such as Site A, the characterization of the exposure setting is based not only on the nature and extent of contamination at the site, but also on restrictions imposed by institutional controls. Institutional controls are regulatory requirements which restrict access to a site over specified time periods. For Site A, this includes an assumed operational life of 10 more years and a post-operational period of 100 years (110 years total) when use of the site will be restricted. After 110 years, it is assumed that institutional restrictions will cease and the site will be available for any use, including residential development.

Currently, there are no known public receptors being exposed to contaminants specifically from Site A. However, reasonable maximum exposures from contaminants at the site will be evaluated for several hypothetical receptors. Professional judgment combined with site-specific information is used to identify these receptors. Current hypothetical off-site receptors include a homesteader, a hunter, and a fencepost receptor. Assumptions concerning these receptors are described below.

The off-site homesteader is evaluated along River A where influence to surface water downgradient from the site is assumed to be maximum. Surface water is the only off-site environmental medium potentially affected by Site A contaminants. The homesteader uses contaminated river water as a drinking water source. This homesteader irrigates his vegetable/fruit garden and waters his cattle with contaminated River A water. A hunter is exposed to Site A wastes from contaminated deer meat. The deer ingests contaminated vegetation exclusively from Site A. The fencepost receptor represents an off-site member of the public located at a point downgradient from disposal areas along the Site A boundary and is present 24 hours per day, 365 days per year.

To account for wastes encapsulated in concrete, future exposures are assessed for a hypothetical homesteader on Site A at 110 years and 310 years. As discussed previously, the engineered barriers are designed to preclude intrusion into the wastes until 310 years after disposal. The homesteader is assumed to build a home directly on a waste disposal area in 110 years for trenches without engineered barriers and at 310 years for trenches with and without engineered barriers. Wastes, assumed to be indistinguishable from native soil, are exhumed during construction of a house and mixed with soil in the homesteader's vegetable/fruit garden. The homesteader ingests milk and meat from cattle which eats fodder grown in contaminated soil and drinks water from a contaminated source. The homesteader uses contaminated groundwater from a well immediately downgradient of the waste disposal area. A surface water body exists on-site which is used for swimming.

Identifying Exposure Pathways

An exposure pathway describes the course of a contaminant from it's source to the receptor and consists of four elements: (1) a source and mechanism of contaminant release, (2) a retention or transport medium, (3) a point of potential human contact with the contaminated medium (i.e., exposure point), and (4) an exposure route at the contact point.

The contaminant sources at Site A consist of those areas where wastes were disposed of in trenches. Many of the trenches have no engineered subsurface barriers to prevent migration to the surrounding soil, groundwater, and subsequent discharge to surface water and sediment. Therefore, the environmental media immediately surrounding the identified disposal units are also assumed to contribute directly to receptor exposures by serving as retention and transport media for the wastes.

Exposure points and exposure routes are highly dependent upon specific receptor characteristics. Therefore, exposure points and routes of exposure were determined using hypothetical reasonable maximum exposure scenarios. These include current off-site exposures to a deer hunter, a fencepost receptor, and a homesteader located on River A downstream from Site A. In addition, a homesteader in the future located directly on Site A will be exposed from many exposure points and routes. These pathways and receptors are summarized in Table I for current and future institutional control time periods.

Quantifying the Exposure

The final step in the exposure assessment process at Site A involves the quantification, frequency, and duration of the exposure. This procedure is conducted in the following two stages: estimation of media and biota tissue exposure concentrations and subsequent quantification of pathway-specific intakes.

Media exposure concentrations are required for groundwater, soil, surface water, sediment, and air. Additionally tissue exposure concentrations are estimated by using these environmental media concentrations in conjunction with transfer factors for fruit, vegetables, milk, beef, fish, and deer.

The chemical and radiological media exposure concentrations at Site A are estimated by using a combination of characterization data, disposal inventory data, and environmental fate and transport modeling data. Since no chemical disposal inventory data are assumed to be available, both current and future chemical media exposure concentrations are estimated using characterization data alone. Although characterization data do not accurately represent chemical source concentrations, these are the only chemical data assumed to be available. To be conservative in future projections of chemical concentrations, it is assumed that steady-state conditions exist with regard to future chemical exposures and that chemical concentrations in the environment do not change over the 310-year period of analysis.

Characterization data, disposal inventory data, and modeling data are available for estimating current and future radioactive media exposure concentrations. Disposal inventory data are used to estimate current soil concentrations at the disposal areas and modeling is used to estimate future soil, groundwater, surface water, and sediment concentrations at the site. Radiological characterization data are used to estimate current soil, groundwater, surface water, and sediment concentrations. Exposure concentrations in air are calculated based on current and future concentrations of radionuclides in soil and surface water. Current radiological surface water concentrations to the off-site homesteader are estimated by using environmental fate and transport modeling data.

For chemicals and radionuclides, biota tissue exposure concentrations are calculated by multiplying the media exposure concentrations by transfer coefficients. When transfer coefficients are not available for chemicals, regression equations are used to calculate a transfer coefficient. The regression equations are based on the octanol/water partition coefficient (Kow)(1,2).

TABLE I

Significant Site A Receptor Scenarios.

Potential Receptors	Period Of Institutional Control	
	Controlled (Current)	Uncontrolled (Future: 110 YR & 310 YR)
Hunter Receptor (Off-site) (1)	• Ingestion-Fauna (R,C)	
Fencepost Receptor (Off-site) (1)	• Inhalation-Air (R,C) • Direct Radiation-Soil (R)	
Site A Homesteader (On-site)		• Direct Radiation- Soil (R) • Inhalation-Air, GW (R,C) • Ingestion-GW,Biota (R,C) • Incidental Ingestion-Soil, SW,Sediment (R,C)
River A Homesteader (Off-site) (2)	• Direct Radiation- Soil (R) • Inhalation-Air (R,C) • Ingestion-SW,Biota (R,C) • Incidental Ingestion-Soil R,C)	

Key: GW = Groundwater
SW = Surface water
R = Assessed for radionuclide components
C = Assessed for chemical components
1 = The boundary receptors (deer hunter and fencepost receptor) are present only in areas that are accessible to the public.
2 = Off-site receptor located downstream from Site A next to River A. Includes contamination to specific media through irrigation using contaminated River A surface water.

5.12 3480.2

The tissue exposure concentrations for food include fish, plants, and terrestrial animals. To obtain the tissue exposure concentration in fish for chemicals and radionuclides, the transfer coefficient is multiplied by the surface water exposure concentration. For plants there are three contributors to the tissue exposure concentration. These include direct deposition onto plant surfaces, soil uptake, and air-to-leaf uptake (3,4,5,6) for chemicals. For radionuclides, only direct deposition onto plant surfaces and soil uptake contribute to exposure. To quantify these contributions from chemicals and radionuclides, the appropriate transfer coefficient is multiplied by either soil, water, or air exposure concentrations (3,4,7). Chemical and radiological exposure concentrations in terrestrial animal tissues are quantified by multiplying transfer coefficients by the total mass ingested by an animal per day (7,8).

Estimations of exposure concentrations use the 95 percent upper confidence limit on the arithmetic average concentration that is contacted over the exposure period. This concentration does not reflect the maximum concentration that could be contacted at any one time. However, it is regarded as a reasonable maximum estimate of the concentration likely to be contacted over time (2).

Once exposure concentrations are estimated for all media and biota, reasonable maximum intake values are calculated for chemical and radiological compounds within identified pathways. Chemical intake is defined as the amount of contaminant at the exchange boundaries of an organism that is available for absorption. A generic equation for calculating chemical intake is presented below (2,7):

$$I = (C \times CR \times EF \times ED)/(BW \times AT)$$

where:

I = Intake (mg chemical/kg body weight-day)

C = Average media exposure concentration or tissue exposure concentration (e.g., mg/liter, mg/Kg)

CR = Contact rate (e.g., liter/day, kg/day)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

BW = Average body weight off exposed individual (kg)

AT = Averaging time, period over which the exposure is averaged (days)

Radionuclide intake/exposure is determined by an environmental transport factor (ETF). This consists of pathway factors that affect migration of a radionuclide or transmission of ionizing radiation along a pathway from the source to the point of human exposure (7). A generic equation for calculating radiological ETF is presented below (9):

$$ETF = I \times C \times O \times \exp(-D \times T)$$

where:

ETF = Environmental transport factor (e.g., pCi, $(pCi/m^3) \times hr$)

I = Annual intake of contaminated environmental medium (e.g., m^3, hr)

C = Average media exposure concentration or tissue exposure concentration (pCi/m^3)

O = Other pathway specific factors (e.g., occupancy factors, depth factors, etc.)

D = Radiological decay constant for contaminant

T = Time for decay

Chemical and radiological intakes are calculated on-site for a hypothetical homesteader receptor and off-site for a homesteader on River A, a hunter and a fencepost receptor. The receptors are exposed to the site contaminants via a combination of exposure routes (i.e., inhalation, incidental ingestion, ingestion, and direct radiation) and media. Table II presents a matrix between receptors and their potential exposure pathways.

For the exposure assessment at Site A, the on-site homesteader is simultaneously exposed to contaminants from 13 different intake pathways. The off-site homesteader is exposed to contaminants from nine intake pathways, the fencepost receptor from three pathways, and the hunter from one pathway.

SUMMARY

This paper discussed the techniques used to conduct an exposure assessment at a complex site contaminated with chemical and radioactive wastes. Since the nature and extent of contamination is not well understood at this site, professional judgment and site-specific information are both required to successfully conduct the exposure assessment. This exposure assessment presents techniques used to estimate the magnitude of potential exposures and the pathways by which receptors are potentially exposed. The results of the assessment will be quantification of current and future pathway-specific intakes to receptors from individual chemicals and radionuclides. Conducting this exposure assessment illustrates the use of both objective and subjective analyses.

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TABLE II

Receptor and Exposure Pathways Matrix

PATHWAYS	RECEPTORS			
	On-Site Homesteader	Off-Site Homesteader	Off-Site Hunter Receptor	Off-Site Fencepost Receptor
INHALATION				
Air				
Vapor	X			X
Particle	X	X		X
Showering	X			
INCIDENTAL INGESTION				
Surface water	X			
Soil	X	X		
Sediment	X			
INGESTION				
Groundwater	X			
Surface water		X		
Fruit	X	X		
Vegetables	X	X		
Milk	X	X		
Beef	X	X		
Fish	X	X		
Deer			X	
DIRECT RADIATION				
Soil	X	X		X

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