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Human Health Risk Assessments for Superfund

*James T. Hamilton**
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ED. NOTE: The raw data that form the basis of this article were collected under a cooperative agreement between Duke University and the Environmental Protection Agency and were not provided to the *Ecology Law Quarterly*. Appendix A contains a complete list of the sites used in this study, and some backup data are on file at the *Ecology Law Quarterly*.

INTRODUCTION

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)[1] is scheduled for reauthorization in the spring of 1995,[2] and Congress must decide either to continue the Superfund program in its current form or to modify it in some manner.[3] Congress cannot sensibly decide how to reauthorize CERCLA without understanding the program's progress toward one of its fundamental missions: the reduction of risks to human health and the environment from uncontrolled hazardous waste sites.[4] While the Superfund program has generated voluminous site-specific data on human health risks, until recently there has been no comprehensive analysis of this data to facilitate programmatic evaluation.[5] This article sets forth the first analysis of our systematic collection of risk assessment data from the ten U.S. Environmental Protection Agency (EPA) regional offices throughout the United States.[6] Comprehensive health risk data review is essential to a rational reassessment of the existing Superfund program.[7]

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1. Pub. L. No. 96-510, 94 Stat. 2767 (1980) (codified as amended at 42 U.S.C. §§ 9601-9675 (1988 & Supp. IV 1992)) (commonly known as Superfund).

2. Although Congress failed to reauthorize Superfund in 1994, the Clinton Administration plans to reintroduce Superfund reform in the 104th Congress. *See Superfund: Time Restraints, Wrangling Kill Reform Bill; New Effort To Change CERCLA Promised Next Year*, 25 Env't Rep. (BNA) No. 23, at 1172 (Oct. 14, 1994).

3. As early as 1992, the House Subcommittee on Energy and Commerce began considering the effectiveness of the existing Superfund program with respect to both cleanup expenses and efficiency. *See Outlook 1992: Superfund*, 22 Env't Rep. (BNA) No. 39, at 2197 (Jan. 24, 1992).

4. *See* United States v. Akzo Coatings of Am., Inc., 949 F.2d 1409, 1416-17 (6th Cir. 1991) (citing S. Rep. No. 848, 96th Cong., 2d Sess., at 98 (1980), *reprinted in* 1 Cong. Res. Service, 97th Cong., 2d Sess., A Legislative History of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Superfund), at 405 (1980)). *See generally* 42 U.S.C. § 9604(a). Section 104(a) of CERCLA authorizes government action "[w]henever (A) any hazardous substance is released . . . or (B) there is a release . . . of any pollutant or contaminant which may present an imminent and substantial danger to the public health or welfare . . . to protect the public health or welfare or the environment."

5. In part, a comprehensive analysis had not been done because of the significant costs associated with collecting this information from EPA regional offices. Collecting the necessary documents from regional offices and entering the data for our study has been a process that has involved seven full-time staff members since May 1993.

6. For a description of data collection procedures used in this research, see discussion *infra* part II.

7. Studies of data produced at Superfund sites have generated related debates over the progress and stringency of cleanups, and the driving forces behind the process. *See, e.g.*, Carolyn B. Doty & Curtis C. Travis, *The Superfund Remedial Action Decision Process: A Review of Fifty Records of Decision*, 39 JAPCA J. 1535, 1542-43 (1989) (suggesting that contamination, and not actual public health risk *per se*, was the basis for remedy selection); John A. Hird, *Superfund Expenditures and Cleanup Priorities: Distributive Politics or the Public Interest?*, 9 J. Pol'y Analysis & Mgmt. 455, 478-79 (1990) (suggesting that the cleanup process is based on the level of hazards posed by a site); *cf.* U.S. Envtl. Protection Agency, Unfinished Business: A Comparative Assessment of Environmen-

An exhaustive data review also provides a better foundation for policy formulation. A substantial amount of quantitative information exists in the administrative record for each Superfund site on the cancer and noncancer risks for different populations potentially affected by chemical releases.[8] Advocates of divergent policy positions have extracted anecdotal evidence from this data to support widely inconsistent portrayals of risk at Superfund sites.[9] Some advocates extract case studies that highlight the salience of hazardous wastes and the great risk they pose to affected populations,[10] while others use site data to trivialize risk by showing that the sites are only dangerous to children who eat large quantities of contaminated dirt.[11] Our analysis is drawn from a comprehensive Superfund data set; thus, our results

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TAL PROBLEMS xix (1987) [hereinafter UNFINISHED BUSINESS] (concluding that generally EPA resources are not allocated to what experts perceive as the most significant public health risks, but are aligned more closely with the public's perception of risk).

Commentators have questioned the assumptions employed in assessing risks. *See, e.g.*, David E. Burmaster & Robert H. Harris, *The Magnitude of Compounding Conservatisms in Superfund Risk Assessments*, 13 RISK ANALYSIS 131, 131-32 (1993); ENVIRON, A COMPARISON OF MONTE-CARLO SIMULATION-BASED EXPOSURE ESTIMATES WITH ESTIMATES CALCULATED USING EPA AND SUGGESTED MICHIGAN MANUFACTURER'S ASSOCIATION EXPOSURE FACTORS 1-3 (1993); HAZARDOUS WASTE CLEANUP PROJECT, EXAGGERATING RISK: HOW EPA'S RISK ASSESSMENTS DISTORT THE FACTS AT SUPERFUND SITES THROUGHOUT THE UNITED STATES 5 (1993).

Data analysis also has generated debates about the costs and relative benefits of reducing risks. *See, e.g.*, JAN PAUL ACTON & LLOYD S. DIXON, RAND CORP., SUPERFUND AND TRANSACTION COSTS: THE EXPERIENCES OF INSURERS AND VERY LARGE INDUSTRIAL FIRMS x-xv (1992) (discussing the effects on insurers and potentially liable parties); Shreekant Gupta et al., *Cleanup Decisions Under Superfund: Do Benefits and Costs Matter?*, 13 RESOURCES 13, 17 (1993) (examining the degree to which EPA considers costs and benefits in selecting remedies at Superfund sites).

8. An administrative record must be established for all sites undergoing CERCLA remediation. 42 U.S.C. § 9613(k)(1). The record contains all documents that serve as the basis for remedy selection, and typically will include risk assessments, sampling data, and the Remedial Investigation/Feasibility Study (RI/FS), as well as the site Record of Decision (ROD). *See* OFFICE OF SOLID WASTE AND EMERGENCY RESPONSE, U.S. ENVTL. PROTECTION AGENCY, OSWER DIRECTIVE NO. 9833.3A-1, FINAL GUIDANCE ON ADMINISTRATIVE RECORDS FOR SELECTING CERCLA RESPONSE ACTIONS 1, 23 (1990) [hereinafter ADMINISTRATIVE RECORDS].

9. For example, there is a notable gap between "expert" and public perception of risk. *See, e.g.*, STEPHEN BREYER, BREAKING THE VICIOUS CIRCLE: TOWARD EFFECTIVE RISK REGULATION 20-21 (1993) (stating that EPA experts rank health risks from hazardous waste sites between "medium" and "the most important," while public perception ranks hazardous waste sites as the number one health risk); SCIENCE ADVISORY BD., U.S. ENVTL. PROTECTION AGENCY, SAB-EC-90-021, REDUCING RISK 12-14 (1990) (stating that public opinion differs from actual risk levels).

10. *See, e.g.*, Phil Brown, *Popular Epidemiology Challenges the System*, ENVIRONMENT, Oct. 1993, at 16; Michael Weisskopf, *Superfund Toxic-Waste Cleanups: Is the EPA Cutting Corners?*, WASH. POST, Nov. 25, 1987, at A17.

11. For example, one commentator has questioned EPA's $9.3 million expenditure to clean a swamp site so that it is not only safe for children to eat dirt for 70 days per year, but for 260 days per year. Richard L. Stroup, *Newly Vulnerable to Superfund's Claws*, WALL ST. J., Jan. 4, 1994, at A10; *see also* BREYER, *supra* note 9, at 12; Keith Schneider, *New View Calls Environmental Policy Misguided*, N.Y. TIMES, Mar. 21, 1993, at D3.

provide decisionmakers with a better foundation for weighing policy options.

A number of underexplored questions have framed our analysis. Who are the people most affected by Superfund site health risks? How do these risks arise? What are the magnitudes of these risks? Are they in fact trivial, or do they pose serious threats to public health? Most important from a policy standpoint, what are the implications for policy options that currently favor the more "permanent" options of hazard treatment and removal[12] versus onsite containment and land use restrictions?[13]

To address these issues, we analyze the exposure pathways considered in the human health risk assessments conducted at seventy-eight Superfund sites with Records of Decision (RODs)[14] signed in 1991 or 1992. Each exposure pathway is a unique mechanism by

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12. EPA recognizes the risk associated with excavation and removal but, consistent with the 1986 Superfund Amendment and Reauthorization Act (SARA), generally expresses preference for more permanent options over potentially less effective or enforceable options, such as institutional controls. *See* 42 U.S.C. § 9621(b), (d). *See generally* 40 C.F.R. § 300.430(a)(1)(iii)(D) (1993) (discussing limited availability of institutional controls).

The public can be more skeptical. In a conflict over EPA's selected remedy for the Smuggler Mountain mine site in Colorado, local citizens maintained that EPA had required treatment far in excess of existing risks. They argued that the Agency had failed to consider that its chosen remedy would exacerbate health risks around the site by stirring up lead dust during excavation and raising the probability of accidents during transport of the waste. *See Risk Assessment: Officials Involved in Superfund Clean-Ups Blast EPA for Not Using Actual Exposure Data*, 16 Chem. Reg. Rep. (BNA) No. 11, at 587 (June 12, 1992).

13. The General Accounting Office's (GAO's) 1992 study of Records of Decision (RODs) generated from 1987 to 1990 indicated that EPA selected *treatment* as the sole remedy in 50% of the cases, while private parties did so at only 36% of the sites. RESOURCES, COMMUNITY, AND ECONOMIC DEVELOPMENT DIVISION, GENERAL ACCOUNTING OFFICE, GAO/RCED-92-138, SUPERFUND: PROBLEMS WITH THE COMPLETENESS AND CONSISTENCY OF SITE CLEANUP PLANS 23 (1992), *reprinted in Administration of the Federal Superfund Program, 1992: Hearings Before the Subcomm. on Investigations and Oversight of the House Comm. on Public Works and Transportation*, 102d Cong., 2d Sess. 541 (1992) [hereinafter GAO]. By comparison, EPA utilized *containment* as the sole remedy at 25% of the sites, compared with 43% for cleanups led by private parties. *Id.* The remaining sites received a combination of treatment and containment. *Id.* While EPA clearly prefers treatment over containment, the opposite appears to be true for private parties.

14. EPA generates a ROD for all sites on the National Priorities List (NPL). These top priority release sites are targeted for long-term remediation and response, and only these sites may receive Superfund-financed remediation. *See* 42 U.S.C. § 9605(a)(8)(B); 40 C.F.R. § 300.425(a)-(b) (1993). After a remedial action is selected for a site, a ROD is drafted to detail facts, analyses of facts, and site-specific policy determinations that were considered during the remedy selection process. *See* 40 C.F.R. § 300.430(f)(5) (1993).

RODs are available on hardcopy, *infra* note 42, and online (excluding tables), *see generally* OFFICE OF EMERGENCY AND REMEDIAL RESPONSE, U.S. ENVTL. PROTECTION AGENCY, EPA/540/G-89/005, SUPERFUND AUTOMATED RECORDS OF DECISION SYSTEM (RODS) USER MANUAL (1988) (providing details on access and usage of online system). There is no central repository for Remedial Investigation/Feasibility Studies (RI/FSs), *infra* note 97, which provide much of the supporting documentation needed for our analysis. *See* which a population may be exposed to chemicals at, or originating from, the site.[15] Exposure pathways take into consideration the "sources, releases, types, and locations" of site contaminants; the likely fate of these chemicals in the environment, including persistence, transport, and transfer through differing media; and the means by which potentially exposed populations might come into contact with contaminated media.[16] Pathways are often defined specifically for receptors in different areas, age groups, and time frames of exposure.[17]

We focus on the distribution of these exposure pathways across different categories of analysis used in risk assessments. These categories include: (1) the timeframe of the exposure scenario (i.e., current use or potential future uses); (2) the location of the exposure (i.e., onsite or offsite); (3) the exposed population (i.e., resident, worker, recreational user, or trespasser); (4) the age of the exposed population (i.e., child or adult); (5) the exposure medium (i.e., soil, air, or groundwater); and (6) the exposure route (i.e., dermal contact, inhalation, or ingestion).[18] By quantifying and categorizing exposure pathway data collected from EPA regional offices, our study determines which exposure pathway categories are most widely considered in EPA's remedy selection process at Superfund sites.[19]

After looking at the number of risk pathways associated with each category, we then add to the analysis the cancer and noncancer risks associated with each pathway to determine which pathway categories pose the greatest risk to human health. Through this process we gain insight into the type and magnitude of the risks that the Superfund program is remediating. We then use this pathway-specific risk data to explore the effectiveness of policies that seek to reduce risk by eliminating pathways (i.e., restricting land use options).

This article is structured in six sections. Section I provides background on how risk assessment data are used at Superfund sites. Sec-

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discussion *supra* note 8. For a discussion of the RI/FS, see *infra* notes 39-54 and accompanying text.

15. *See* Office of Emergency and Remedial Response, U.S. Envtl. Protection Agency, OSWER Directive No. 9285.701A, EPA/540/1-89/002, Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual Part A (Interim Final) 6-4 (1989) [hereinafter HHEM]; *see also* discussion *infra* parts I.C, III.

16. HHEM, *supra* note 15, at 6-4, 6-8.

17. *Id.*

18. *See infra* part III.

19. This article does not link these risk assessments to population data to derive estimates of potential deaths or diseases, nor does it conduct sensitivity analyses of risk assessment assumptions or calculate estimates of the relative cost of risk reductions. We will explore these questions in future research with an expanded version of this data set. Many factors apart from health risk assessment data contribute to EPA remedy selection. For a full discussion, see generally Linly Ferris & David Rees, Comment, *CERCLA Remedy Selection: Abandoning the Quick Fix Mentality*, 21 Ecology L.Q. 785 (1994).

tion II details the construction and organization of our data base. Section III reports the results of our analysis regarding the distribution of cancer and noncancer exposure pathways from seventy-eight Superfund sites. Section IV explores the magnitude of the risks associated with different pathways, and section V breaks down the risks attributable to each of the chemicals most commonly found in our site analysis. We conclude with the implications for managing risk that these results provide and how they may contribute to the CERCLA reauthorization process.

I
RISK ASSESSMENTS AT SUPERFUND SITES

A. Legislative and Regulatory Context

A primary impetus for the Superfund program was a concern with the impact of hazardous waste on human health.[20] The risks posed by exposure to contaminants from abandoned hazardous waste sites like Love Canal generated tremendous public outcry,[21] stimulating Congress to pass CERCLA in 1980.[22] Section 104(a) of CERCLA permits response to hazardous waste sites whenever a "hazardous substance is released or there is a substantial threat of such a release into the environment," or whenever a release or threat of release poses "an imminent and substantial danger to the public health or welfare. . . ."[23] The Act defines this "response" authority broadly to include, *inter alia*, "such actions as may be necessary to monitor, assess, and evaluate the release" and "such other actions as may be necessary to prevent, minimize, or mitigate damage to the public health or welfare or to the environment."[24] Pursuant to CERCLA, EPA has re-

20. *See supra* note 4.

21. Love Canal was an abandoned channel that Hooker Chemical Company filled with toxic waste and capped with earth or clay. *See* ADELINE G. LEVINE, LOVE CANAL: SCIENCE, POLITICS AND PEOPLE 10-11 (1982). The Niagara Falls Board of Education purchased the site in 1953 and built a school and playground on the site. *Id.* at 11-12. Toxic sludge eventually seeped onto the surface and into residential basements, prompting New York's Health Commissioner to declare a public health emergency. *Id.* at 7-11.

22. 42 U.S.C. §§ 9601-9657 (1988). The highly publicized chemical waste dump at Love Canal often is cited as the impetus for Superfund. *See, e.g.*, Hird, *supra* note 7, at 455; JAN PAUL ACTON, RAND CORP., UNDERSTANDING SUPERFUND: A PROGRESS REPORT 4-5 (1989).

23. 42 U.S.C. § 9604(a)(1).

24. *Id.* § 9601(23), (25) (defining "respond" and "remove"). CERCLA specifically authorizes the President to take response and removal actions, but that power largely has been delegated to agencies such as EPA. Exec. Order No. 12,580, 52 Fed. Reg. 2923 (1987).

sponsibility for assessing the human health impacts of a hazardous release,[25] and planning remedial actions to minimize those impacts.[26]

Congress gave EPA broad discretion along with this sizable responsibility, imposing only the most general policy constraints on EPA's discretion to choose remedial actions for Superfund sites. In the 1986 Superfund Amendments and Reauthorization Act (SARA),[27] Congress stated that remedial actions are preferable if they employ treatment methods that "permanently and significantly reduc[e] the volume, toxicity, or mobility of hazardous substances" at sites.[28] SARA also requires that Superfund remedial actions comply with any federal standard considered to be an "applicable or relevant and appropriate . . . requirement" (ARAR).[29] Furthermore, state ARARs must be met at Superfund sites if they are stricter than federal ones.[30] Thus, EPA must meet established standards where applicable or appropriate, but it has wide discretion over the remedies used to achieve these standards.

Risk assessments are a tool used by EPA to guide officials in exercising EPA's discretion by helping officials decide when and how to act. For example, EPA regulations implementing Superfund[31] require that a site-specific baseline risk assessment be conducted to "characterize the current and potential threats to human health and the environment that may be posed by contaminants migrating to ground water or surface water, releasing to air, leaching through soil, remaining in the soil, and bioaccumulating in the food chain."[32] In addition, in a directive published in April 1991 on the role of the baseline risk assessment in Superfund remedy selection, the Office of Solid Waste and Emergency Response states: "Where the cumulative carcinogenic site risk to an individual based on reasonable maximum exposure for both current and future land use is less than 10^{-4}[33] and the noncarcin-

25. The National Contingency Plan explicitly directs the lead agency—often EPA—to conduct a site-specific baseline risk assessment to characterize potential threats to human health and the environment. *See* 40 C.F.R. § 300.430(d)(4) (1993).

26. 42 U.S.C. § 9604(a)(1).

27. Pub. L. No. 99-499, 100 Stat. 1613 (1986) (amending 42 U.S.C. §§ 9601-9675 (1988 & Supp. IV 1992)).

28. *Id.* § 9621(b)(1).

29. *Id.* § 9621(d)(2)(A)(ii).

30. *Id.* § 9621(d)(2)(A) (1988 & Supp. IV 1992). For a more complete discussion of ARARs, see *infra* notes 43-54 and accompanying text.

31. The National Contingency Plan is codified at 40 C.F.R. § 300.1-.1105 (1993).

32. *Id.* § 300.430(d)(4).

33. Carcinogenic risk is commonly expressed as the "probability of an individual developing cancer over a lifetime," usually averaged over 70 years. *See* HHEM, *supra* note 15, at 8-6. Therefore, a risk level expressed as "10^{-6}" would predict one additional cancer case per 1,000,000 exposed individuals; "10^{-5}" would predict one additional cancer case per 100,000 exposed individuals; and "10^{-4}" would predict one additional cancer case per 10,000 exposed individuals.

ogenic hazard quotient is less than one,[34] action generally is not warranted unless there are adverse environmental impacts. [footnotes added]"[35] Regional EPA decisionmakers may choose to take action at sites with cancer risks smaller than 10^{-4}, but RODs recommending remedial action at sites with risks "within the 10^{-4} and 10^{-6} range must explain why remedial action is warranted."[36] The directive also declares that "EPA uses the general 10^{-4} to 10^{-6} risk range as a 'target range' within which the Agency strives to manage risks as part of a Superfund cleanup."[37] Thus, baseline risk assessments guide EPA in establishing both whether action should be taken at a site and the degree of remediation required.

The baseline risk assessment conducted at each site has four objectives: (1) to analyze the risks that might exist if no remedial actions or institutional controls were adopted at a site ("baseline risks") and help determine if actions are required at the site; (2) to provide information to help determine what maximum levels of chemicals may remain onsite without sacrificing the public health; (3) to compare the potential health impacts of remedial actions; and (4) to evaluate and document the public health threats posed by the site.[38]

The baseline risk assessment is only the first step of the site characterization process in the remedial investigation and feasibility study (RI/FS). An RI/FS also provides regional EPA decisionmakers with a quantitative assessment of human health risks at a site,[39] a description of remedial action objectives,[40] and an analysis of the alternatives proposed to reach these objectives.[41] After evaluating an RI/FS, EPA selects a remedial action, and then documents the reasons for its selection in the ROD for each site.[42]

34. For a discussion of how hazard quotients are calculated and evaluated, see *infra* notes 68-71 and accompanying text.

35. OFFICE OF SOLID WASTE AND EMERGENCY RESPONSE, U.S. ENVTL. PROTECTION AGENCY, OSWER DIRECTIVE NO. 9355.0-30, ROLE OF THE BASELINE RISK ASSESSMENT IN SUPERFUND REMEDY SELECTION DECISIONS 1 (1991) [hereinafter ROLE OF RISK ASSESSMENT].

36. *Id.* EPA suggests that carcinogen concentrations that represent an excess upperbound individual lifetime cancer risk of between 10^{-4} and 10^{-6} are acceptable. 40 C.F.R. § 300.430(e)(2)(i)(A)(2).

37. ROLE OF RISK ASSESSMENT, *supra* note 35, at 4.

38. HHEM, *supra* note 15, at 1-1.

39. *Id.* at 1-3; *see also* 40 C.F.R. § 300.430(d)(1)-(2).

40. HHEM, *supra* note 15, at 1-3; *see also* 40 C.F.R. § 300.430(e)(i).

41. HHEM, *supra* note 15, at 1-3 to 1-4; *see also* 40 C.F.R. § 300.430(e)(9).

42. For a more complete discussion of the remedy selection process, see generally Ferris & Rees, *supra* note 19.

RODs (including tables) are physically available to the public in three locations: (a) the Superfund docket in Washington, D.C., *see* Richard E. Schwartz & Robert C. Davis Jr., *Navigating EPA's Informational Sea*, NAT. RESOURCES & ENV'T, Winter 1990, at 54; (b) the site information repository, containing the administrative record for the action (the location of which is published in local newspapers), *see* 42 U.S.C. § 9613(k)(1); 40 C.F.R.

An RI/FS evaluates each proposed remedial alternative at a site according to nine criteria, including whether each alternative: (1) protects human health and the environment, and (2) complies with ARARs.[43] A remedy must pass these two criteria thresholds before EPA may select it. Remedial actions must meet ARARs of the Resource Conservation and Recovery Act (RCRA),[44] Clean Water Act (CWA),[45] Safe Drinking Water Act (SDWA),[46] Clean Air Act (CAA),[47] other federal statutes,[48] and state environmental and facility-siting laws.[49] ARARs generally fall into three categories: (1) ambient or chemical-specific requirements limiting the amount or concentration of a chemical that may remain onsite;[50] (2) performance or design requirements limiting the technologies or actions involving hazardous wastes at a site;[51] and (3) location-specific requirements restricting the concentration of hazardous substances at a site because of its location.[52] The remedial objectives in an RI/FS are usually set in terms of particular chemical concentrations that may remain after the remedial action is complete.[53] Where ARARs are not available or are not protective of human health and the environment, remedial standards may be set by reference to risk assessment data.[54]

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§ 300.430(c)(2)(iii); ADMINISTRATIVE RECORDS, *supra* note 8, at 8, 12, 26; and (c) the regional administrative records center, typically located at EPA regional headquarters, *see* ADMINISTRATIVE RECORDS, *supra* note 8, at 9, 26.

43. The nine criteria for evaluating remedial actions are: (1) overall protection of human health and the environment; (2) compliance with applicable or relevant and appropriate requirements (ARARs); (3) long-term effectiveness and permanence; (4) reduction of toxicity, mobility, or volume; (5) short-term effectiveness; (6) implementability; (7) cost; (8) state acceptance; and (9) community acceptance. 40 C.F.R. § 300.430(e)(9)(iii). Overall, the depth of EPA's analysis is limited by its stated goal of completing the RI/FS in 18 months at a cost of $750,000 per operable unit and $1.1 million per site. *See* HHEM, *supra* note 15, at 3-1.

44. *See* OFFICE OF EMERGENCY AND REMEDIAL RESPONSE, U.S. ENVTL. PROTECTION AGENCY, OSWER DIRECTIVE NO. 9234.1-01, EPA/540/G-89/006, CERCLA COMPLIANCE WITH OTHER LAWS MANUAL PART I: INTERIM FINAL ch. 2 (1988).

45. *See id.* at ch. 3.

46. *See id.* at ch. 4.

47. OFFICE OF EMERGENCY AND REMEDIAL RESPONSE, U.S. ENVTL. PROTECTION AGENCY, OSWER DIRECTIVE NO. 9234.1-02, EPA/540/G-89/009, CERCLA COMPLIANCE WITH OTHER LAWS MANUAL: PART II (CLEAN AIR ACT AND OTHER ENVIRONMENTAL STATUTES AND STATE REQUIREMENTS) ch. 2 (1989).

48. *See generally id.* at chs. 3-6.

49. *See id.* at ch. 7.

50. OFFICE OF EMERGENCY AND REMEDIAL RESPONSE, U.S. ENVTL. PROTECTION AGENCY, OSWER DIRECTIVE NO. 9355.3-01, EPA/540/G-89/004, GUIDANCE FOR CONDUCTING REMEDIAL INVESTIGATIONS AND FEASIBILITY STUDIES UNDER CERCLA (INTERIM FINAL) 6-7 (1988) [hereinafter GUIDE].

51. *Id.* at 6-8.

52. *Id.* at 6-7 to 6-8.

53. For example, the preliminary remediation goals often are based on chemical-specific ARARs. *See, e.g.*, 40 C.F.R. § 300.430(e)(2)(i); *see also* GUIDE, *supra* note 50, at 4-3.

54. *See* 40 C.F.R. § 300.430(e)(2)(i)(A)(2).

B. *Evaluation of Risks to Human Health*

The assessment of risk at Superfund sites across the country is a decentralized process. Contractors typically perform the risk assessment at each site, and regional EPA personnel review the assessment.[55] Since recent risk assessments generally have been conducted according to methodologies outlined in EPA's 1989 *Risk Assessment Guidance For Superfund: Human Health Evaluation Manual* (HHEM), the risk assessments are sufficiently similar across sites to permit successful integration for analysis.[56]

The baseline risk assessment begins with the collection of site data, including samples taken to determine the concentration of chemicals of concern.[57] In the next phase, exposure assessment, the risk assessor analyzes the site contaminant data, identifies exposed populations, determines potential exposure pathways, and estimates exposure concentrations and intakes by pathway.[58] The risk assessor then conducts a toxicity assessment, in which the assessor collects information on the toxicity of the chemicals at the site, often using information from EPA's Integrated Risk Information System (IRIS).[59] Finally, the risk assessor combines data from both the exposure and toxicity assessments in risk characterization models to estimate cancer risks and noncancer hazard quotients for the chemicals and exposure pathways at the site.[60]

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55. *See* HHEM, *supra* note 15, at 1-2.

56. In fact, EPA drafted the HHEM to create some degree of nationwide consistency in risk assessment procedures. *See* PATRICIA A. CIRONE & CAROL RUSHIN, U.S. ENVTL. PROTECTION AGENCY, SUPPLEMENTAL GUIDANCE FOR SUPERFUND RISK ASSESSMENTS IN REGION X 20 (rev. ed. 1992).

57. HHEM, *supra* note 15, at 4-2 to 4-3.

58. *See generally id.* at chs. 5-6.

The general equation for calculating chemical intake is:

$$CDI = \frac{CR \times IR \times ED \times EF}{BW \times AT}$$

where:

CDI = chronic daily intake [mg/kg-day]
CR = chemical concentration [e.g., mg/L in water]
IR = ingestion rate [volume/day]
ED = duration of exposure [years]
EF = exposure frequency [days/year]
BW = body weight [kg]
AT = averaging time [days]

Id. at 6-21. To determine an adult's lifetime exposure levels to carcinogens, it is frequently appropriate to calculate intake separately for both the "child" portion of life and the "adult" portion. The resulting values may be summed to yield an overall intake.

59. *Id.* at 7-13 to 7-14. IRIS values are available online; IRIS User Support may be reached at (513) 569-7254. Notice, Availability of IRIS System, 53 Fed. Reg. 20,162 (1988).

60. HHEM, *supra* note 15, at 8-1.

The analysis in this article takes these risk assessments at face value and does not explore alternative risk assessment assumptions. For a critique of EPA's use of conservative risk assessment assumptions, see Burmaster & Harris, *supra* note 7; Albert L. Nichols

The cancer risk from a chemical is expressed as the incremental individual lifetime cancer risk from exposure to the substance from the site.[61] Chronic daily intake is calculated for a particular chemical and pathway, and then is multiplied by the chemical's slope factor,[62] located in EPA's IRIS data base.[63] The slope factor is a plausible upperbound estimate of the probability of a response (in this case, the development of cancer) per unit intake of the chemical over a lifetime.[64] EPA uses a "nonthreshold" model of carcinogenesis, which assumes that no dose of a cancer-causing chemical is risk free.[65] The guidance in the HHEM directs risk assessors to adopt conservative values for parameters in modeling the exposure.[66] Chemical cancer risks within a particular exposure pathway are aggregated to yield a pathway cancer risk, which represents an individual's incremental lifetime cancer risk for exposure to a set of chemicals via that exposure pathway.[67]

The noncancer risk from a chemical is conveyed by the noncancer hazard quotient, which equals the calculated exposure intake of the chemical, divided by its reference dose.[68] The reference dose is an estimate of what the human exposure level is likely to be without appreciable risks of harmful noncarcinogenic effects over the expected period of exposure;[69] it is based on studies identifying the highest no-observed-adverse-effect-level (NOAEL).[70] Within a specific exposure

& Richard J. Zeckhauser, *The Perils of Prudence: How Conservative Risk Assessments Distort Regulation,* REGULATION, Nov./Dec. 1986, at 13. For sources generally defending the need for a cautious approach, see Robert J. Scheuplein, *Uncertainty and the "Flavors" of Risk,* EPA J., Jan./Feb./Mar. 1993, at 16; Adam M. Finkel, *Is Risk Assessment Really Too Conservative?: Revising the Revisionists,* 14 COLUM. J. ENVTL. L. 427 (1989).

61. HHEM, *supra* note 15, at 8-6.

62. *Id.*

63. *See id.* at 7-13.

64. *See id.* at 7-11.

65. *See id.* at 7-10.

66. *See id.* at 6-19 to 6-23. The HHEM directs risk assessors to use a combination of intake variables such that the combination results in an estimate of the reasonable maximum exposure (RME) for the pathway. For the contact rate, the HHEM recommends use of the 95th or 90th percentile value whenever statistical data are available, or an approximate upperbound estimate when they are not. The exposure concentration is generally the 95th percentile upper confidence limit on the arithmetic average for the exposure concentrations. *Id.* For carcinogens, assessors generally assume that individuals remain in the same area, subject to the same exposures, for 30 years (which is the national upperbound estimate of the number of years individuals spend at one residence), although in some cases assessors may feel it is appropriate to use longer or shorter durations. *See id.* at 6-22.

67. *Id.* at 8-16. EPA guidance assumes simple additivity, low intake levels of carcinogens, and independence of action of chemical risks within a pathway. *See id.* at 8-12.

68. *Id.* at 8-11. Noncancer effects could include skin irritation, neurological poisoning, or developmental effects. *Id.* at 6-23.

69. *Id.* at 7-2.

70. *Id.* at 7-7. When a NOAEL is not available, the lowest-observed-adverse-effect-level (LOAEL) may be used. *Id.* at 7-7 to 7-8.

pathway, the noncancer hazard quotients for multiple chemicals are then summed to yield an overall pathway hazard index that measures noncancer risks associated with that pathway.[71]

To explain the generation of risk numbers for cancer and noncancer risks presented in a baseline risk assessment conducted under the HHEM, we use one of our sample Superfund sites as an example: the Peerless Plating site in Muskegon, Michigan. Future cancer risks to residents living onsite were estimated for the ingestion of water contaminated with benzene.[72] First, samples were taken at the site to determine the concentration of benzene in the groundwater. The concentration generally used to calculate daily intake is the reasonable maximum exposure (RME) value, defined as the lower of the 95% upper confidence limit of the arithmetic average concentration or the highest concentration detected;[73] in this case, the RME was equal to 0.005 mg/L.[74] Next, residents' lifetime average daily intake of benzene from groundwater was calculated to yield a value of 7.5×10^{-5} mg/kg-day.[75]

The lifetime average intake for benzene at the Peerless site (7.5×10^{-5} mg/kg-day) was then multiplied by the slope factor for benzene contained in EPA's IRIS data base (2.9×10^{-2} (mg/kg-day)$^{-1}$)[76] to yield a cancer risk of 2×10^{-6}.[77] This unitless number represents the incremental lifetime cancer risk for residents associated with ingestion of groundwater contaminated with benzene. When the cancer risks for all of the other chemicals in the groundwater ingestion pathway

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71. Separate reference doses (RfDs) are determined for effects due to chronic, subchronic, and shorter-term exposures; therefore, different hazard indices are also calculated. *Id.* at 8-14.

The hazard index approach assumes that effects increase linearly with dose, that RfDs for different chemicals are based on equivalent toxicological significance, and that different compounds act through the same mechanism or with similar toxic effects. However, these assumptions may lead to overestimation of the potential for toxic effects. In cases where the hazard index exceeds unity, it is appropriate to have a toxicologist segregate compounds by toxic effect. *Id.* at 8-13 to 8-15.

72. LIFE SYSTEMS, INC., VOLUME 2 FINAL REMEDIAL INVESTIGATION REPORT, APPENDIX D, BASELINE RISK ASSESSMENT, PEERLESS PLATING REMEDIAL INVESTIGATION/FEASIBILITY STUDY, EPA CONTRACT NO. 68-W8-0093, 5-1, 7-3 (1991) [hereinafter LIFE SYSTEMS].

73. HHEM, *supra* note 15, at 6-19 to 6-22. For the Peerless Plating site RI/FS, risk assessors used the term "chemical concentration" instead of "RME." *See* LIFE SYSTEMS, *supra* note 72, at 3-9 to 3-10.

74. LIFE SYSTEMS, *supra* note 72, at A1-2. Here, the maximum detectable concentration was used because it was lower than the upper 95th percent confidence limit of 0.0052 mg/L. *See id.* at 3-9 to 3-10.

75. *Id.* at 3-9, A2-12. For the general equation to calculate chemical intake, see *supra* note 58.

76. LIFE SYSTEMS, *supra* note 72, at 4-6, 5-1.

77. *Id.* at 5-1, A2-12.

were added, the overall incremental cancer risk to future residents at the Peerless site from ingesting groundwater was 3.1×10^{-4}.[78]

Noncancer risks to future residents at the Peerless site were estimated in the following manner. Risk assessors first derived, by sampling groundwater at the site, RME concentrations for all hazardous chemicals with which the groundwater was suspected to be contaminated, using the methods described above for benzene. In this case, an exposure point concentration of 2.2 mg/L was estimated for cadmium, a noncarcinogen.[79] The chronic daily intake for cadmium was estimated in the same way as for benzene, except that the exposure duration was used as the averaging time, thus averaging the degree of potential health effects over the period of exposure only, rather than over an entire lifetime (yielding a CDI of .077 mg/kg-day).[80] EPA's IRIS data base lists the chronic exposure reference dose for cadmium (5.4×10^{-4} mg/kg-day) and also indicates that intakes above this dose may specifically have an adverse effect on kidneys.[81] The hazard quotient for cadmium was then obtained by dividing the chronic daily intake (in mg/kg-day) by the reference dose. This example yields a unitless hazard quotient for cadmium of greater than 150, indicating that adverse effects on kidneys are possible.

The hazard index for this pathway is obtained by summing the hazard quotients of all the other chemicals to which residents would be exposed by drinking groundwater contaminated by the release at the Peerless site. In this example, the hazard index equals 204.[82]

C. *Risk Assessment Pathways*

Conducting a baseline risk assessment requires decisions on which risk pathways to evaluate. These decisions can greatly impact the quantitative estimates of cancer and noncancer risks. Generally, the risk assessor determines which pathways should be evaluated,[83] though that decision is likely subject to the final approval of the remedial project manager at a site.[84] The selection is based on factors such

78. *Id.* at A2-12.

79. *See, e.g., id.* at A1-2.

80. For the general equation to calculate chemical intake, see *supra* note 58.

81. *See* LIFE SYSTEMS, *supra* note 72, at 4-2; *see also* OFFICE OF RESEARCH AND DEVELOPMENT & OFFICE OF EMERGENCY AND REMEDIAL RESPONSE, U.S. ENVTL. PROTECTION AGENCY, OERR PUB. NO. 9200.6-303 (91-1), HEALTH EFFECTS ASSESSMENT SUMMARY TABLES: ANNUAL FY-1991 A-14 (1990) [hereinafter HEALTH EFFECTS SUMMARY].

82. For a discussion of hazard indices and limits to the methodology, see *supra* note 71.

83. HHEM, *supra* note 15, at 6-4.

84. *See generally id.* at 1-2 (discussing the relationship between risk assessors (often contractors and private parties) and EPA risk managers, who are the primary decisionmakers at a Superfund site).

as the fate and transport of chemicals,[85] present and potential land and groundwater use in the area, and the likelihood of other human exposure scenarios.[86] Although EPA gives detailed recommendations in the HHEM concerning which pathways to include, the professional judgment of the remedial project manager ultimately determines whether a pathway is included or excluded from the risk assessment.[87] For example, the project manager might exclude pathways that she views as negligible relative to other pathways that affect a population.[88] The project manager also might exclude pathways for which data have been derived from highly uncertain models, particularly if the site would not otherwise rise to a level of concern.[89] Because risk assessment relies on professional judgment, there is inevitably some interregional variation in interpreting the HHEM guidance.[90]

Our data base groups the pathways used in risk assessments by a number of different variables: Time scenario of exposure, exposed population, age group, population location, medium location, exposure medium, and exposure route. These variables are explained below.

The time scenario variable refers generally to whether the land use envisioned in the risk assessment corresponds to the current use or is related to a projected future use. The risk assessor determines current land use by reviewing site inspection data, zoning information, census data, and aerial photographs.[91] Our designation of a pathway as a current or future scenario follows the applicable risk assessment's definition. Note that not all "current" risks are risk pathways that actually represent risks today. Some assessments are based on current potential scenarios, in which land use in an area does not change but other changes are assumed to have effects on risks. For example, a risk assessor may assume a change in the size of a contaminated groundwater plume that will pollute wells down gradient. These "cur-

85. *Id.* at 6-11.

86. *Id.* at 6-14 to 6-16, 6-18.

87. *See id.* at 6-17.

88. *Id.* Such discretion might explain the high frequency of ingestion pathways relative to other exposure scenarios.

89. The HHEM grants *narrow* discretion to exclude pathways based on the uncertainty of models. *Id.*

90. For example, Region IV guidance directs assessors to evaluate pathways involving direct dermal contact with soil and surface water. REGION IV, U.S. ENVTL. PROTECTION AGENCY, SUPPLEMENTAL REGION IV RISK ASSESSMENT GUIDANCE 2 (1991). In contrast, Region X guidance suggests assessment of dermal exposure to groundwater in addition to soil and surface water. CIRONE & RUSHIN, *supra* note 56, at 22-24.

91. HHEM, *supra* note 15, at 6-6.

rent potential" risks are defined as current risks in our analysis if the risk assessor described them as such.[92]

Future risks are generally those associated with changes in land use or activities. The HHEM guidance encourages risk assessors to consider a scenario in which land that is currently not residential is brought into residential use in the future.[93] The HHEM states:

> Because residential land use is most often associated with the greatest exposures, it is generally the most conservative choice to make when deciding what type of alternative land use may occur in the future. . . .

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92. Current potential risks are not "complete" pathways. A complete pathway must consist of three elements: (a) a source of exposure; (b) an exposure point where contact can occur; and (c) a route of exposure at the exposure point. *Id.* at 6-17. The decision whether to include a pathway that is not complete under existing conditions under the "current potential" or "future" designation might depend on a complex set of factors including: (a) the potential for contaminant migration given site hydrology or wind and soil conditions; (b) the presence of wells in the path of a migrating plume or the likelihood that wells may be installed within the plume; and (c) the availability of an alternate or municipal water supply.

As an example of how these distinctions differ between sites, consider the following three sites. At the Chem-Central site in Wyoming, MI, groundwater contamination does not currently affect any nearby residents, yet groundwater consumption was evaluated under a current potential scenario as well as a future scenario. OFFICE OF EMERGENCY AND REMEDIAL RESPONSE, U.S. ENVTL. PROTECTION AGENCY, EPA/ROD/R05-91/179, SUPERFUND RECORD OF DECISION: CHEM-CENTRAL, MI 13 (1991) [hereinafter CHEM-CENTRAL ROD]. The distinction between the two scenarios was that the current potential pathway involved no change in land use, while the future scenario assumed residential development of the site. *Id.*

At the Valley Wood Preserving site near Turlock, CA, groundwater ingestion also was evaluated under current and future scenarios; land use patterns indicated that future residential use was likely. OFFICE OF EMERGENCY AND REMEDIAL RESPONSE, U.S. ENVTL. PROTECTION AGENCY, EPA/ROD/R09-91/062, SUPERFUND RECORD OF DECISION: VALLEY WOOD PRESERVING, CA 6-1 (1991) [hereinafter VALLEY WOOD PRESERVING ROD]. However, in the surrounding area, nearly 100 domestic wells tap the contaminated aquifer for their water supply. *Id.* at 1-3. Potential pathways for contaminant migration include groundwater. *See id.* at 6-1.

At the Union Pacific site in Pocatello, ID, future risk due to groundwater ingestion was evaluated for both future industrial workers and future residents. OFFICE OF EMERGENCY AND REMEDIAL RESPONSE, U.S. ENVTL. PROTECTION AGENCY, EPA/ROD/R10-91/029, SUPERFUND RECORD OF DECISION: UNION PACIFIC RAILROAD YARD, ID 17 (1991) [hereinafter UNION PACIFIC ROD]. Land use onsite is, and has been, industrial since the turn of the century, so the industrial scenario does not represent a change in land use. *Id.* However, future residential use of the site is considered highly unlikely in the near term. *Id.* Furthermore, each scenario was evaluated for two aquifers, one of which is currently in use for drinking water, and the other of which is not currently in use and does not appear to be capable of sustaining a large demand for water. *Id.* at 14. The scenarios that fall into the future category thus range from fairly likely to highly improbable, and do not always represent a strict change in land use. These "likelihood distinctions" are not reflected in the risk numbers, although generally they are characterized in the text of site documents to aid the risk manager in interpreting the results of the risk assessment.

93. The HHEM guidance favors the assumption of future residential land use. *See* HHEM, *supra* note 15, at 6-7. Guidance from Regions IV and X also suggests that future residential land use always should be assumed, unless special conditions indicate otherwise; in such cases, Region IV requests justification for the exclusion. CIRONE & RUSHIN, *supra* note 56, at 21; REGION IV, U.S. ENVTL. PROTECTION AGENCY, *supra* note 90, at 2.

> Assume future residential land use if it seems possible based on the evaluation of the available information.[94]

Thus, future residential risks may be estimated even at sites that are currently undeveloped or industrial and that have a low probability of future residential use. In our data base of seventy-eight sites, there are thirty-five sites for which future residential pathway risks occur, despite the absence of any current residential risks that exceed the 10^{-6} carcinogenic risk threshold for remedial action.[95]

Our other variables for pathway risk assessments require less explanation. Exposed populations for which pathways are estimated include residents, workers, recreational users, and trespassers. Though risk assessments often are conducted with very specific age group designations for the particular pathway described, for our analysis we have collapsed the different age groupings into adult (ages eighteen and higher) and child (ages less than eighteen). The risk assessment category for population location refers to whether the particular population is exposed to the contaminant onsite or offsite. Exposure medium describes the medium through which the population is exposed to the contaminant (e.g., air, groundwater, soil, or biota[96]). Location of medium refers to whether the pathway's contaminant is onsite or offsite. Exposure route details how an individual comes into contact with the chemical. For example, soil contaminants may have multiple exposure route pathways because they enter the body through ingestion, dermal contact, or inhalation.

Breaking down cancer and noncancer pathways into these risk assessment categories facilitates the evaluation of health risks and remedies at Superfund sites. For instance, determining the relative magnitude of current versus future risks will enable policymakers to better evaluate the impact of future land use assumptions on estimates of the human health risk at Superfund sites. Designating whether risks involve residents, workers, recreational users, or trespassers is a necessary step in analyzing the efficacy of different policy options for reducing human health risks. Similarly, examining whether the populations exposed are onsite or offsite, and whether the contaminants

94. HHEM, *supra* note 15, at 6-7.

95. For a list of sites, see *infra* app. A ("List of Sites Analyzed"). Data regarding assumptions about land use and the number of pathways per site used in this analysis are on file with the *Ecology Law Quarterly*.

When determining remedial action levels for known or suspect carcinogens, 10^{-6} is used as a point of departure for establishing exposure levels whenever ARARs are not available, or whenever they are not sufficiently protective due to the presence of multiple contaminants. *See* 40 C.F.R. § 300.430(e)(2)(i)(A)(2) (1993).

96. Biota refers to plant or animal life in a region. WEBSTER'S NEW UNIVERSAL UNABRIDGED DICTIONARY 185 (2d ed. 1983) [hereinafter WEBSTER'S]. Plants and animals may accumulate chemicals, thus providing a route of exposure to humans who consume biota. *See* HHEM, *supra* note 15, at 4-15 to 4-16.

are onsite or offsite, is an essential part of evaluating the impact of remedies at Superfund sites.

In addition to categorizing risk assessment pathways, our study analyzes the contribution of specific chemicals to the risks posed. Because uncertainty may exist about the toxicity of particular chemicals, consideration of the relative frequency of these chemicals at sites and their estimated contribution to pathway risks may help determine where additional resources could be devoted to define the risks of these chemicals or to develop remedies to address particular types of contaminants.

II
DATA CONSTRUCTION

The data necessary for our analysis of human health risks at Superfund sites are spread across the country in the various site records maintained at the ten EPA regional offices. Though EPA has a central repository for RODs in Washington, the background documents that lead up to the ROD are only available at the regional level.[97] We sent researchers to the regional EPA offices with instructions to collect for each site in our sample the complete baseline risk assessment, extended excerpts from the RI/FS, the complete ROD, and any modifications to the ROD.

Although the RODs contain extensive details about the pathway risks estimated in the baseline risk assessment,[98] we considered it essential to go beyond the RODs to collect additional data for several reasons. First, a ROD does not include the full baseline risk assessment, which provides information on the parameter values used in the risk assessment calculations, the reasonable maximum exposure (RME) point concentrations of the particular chemicals employed to calculate pathway risks, and, in many cases, the average concentrations of these chemicals.[99] Further, some of the ROD risk summaries combine pathway-specific data to express the risks posed to a particu-

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97. For example, data from RI/FSs are not available in a central repository. *Science Adviser's Comments Sought by EPA on Assessing Potential Human Exposure at Sites*, 22 Env't Rep. (BNA) No. 50, at 2697 (Apr. 10, 1992).

98. *See, e.g.*, CHEM-CENTRAL ROD, *supra* note 92, at 12-13, table 6; UNION PACIFIC ROD, *supra* note 92, at 17-19.

99. This information will allow us to perform sensitivity analysis on the pathway risks both for cancer and noncancer risks in future studies. The details necessary to link pathway risks to particular populations in order to develop population risks at Superfund sites often are found only in the baseline risk assessment or RI/FS documents. *See* discussion *supra* note 8.

RODs for several of our 78 sites do not present quantitative risk estimates in table form, and the discussion in the text either refers back to the risk assessment or presents risk to specific populations as summed across contaminated media and/or routes of exposure. *See, e.g.*, UNION PACIFIC ROD, *supra* note 92, at 18 ("A more thorough description lar population.[100] Analysis of pathway-specific risks at these sites required revisiting the original baseline risk assessment data.

We gathered information from the EPA regional offices on all sites that had a ROD signed during 1991 or 1992. We chose risk assessments conducted during these two years because they had been performed after EPA published its 1989 HHEM guidance, and were more likely to follow consistent methodology, which would facilitate comparisons.[101] A total of 276 RODs were signed during this period at 266 different sites. We entered information on human health risks from seventy-eight sites into our data base for analysis in this article.[102] The nationwide distribution of these seventy-eight sites reflects the distribution of CERCLA sites across the country.[103]

For our study we collected information such as chemical concentrations, the risk assessment parameters used in the models to derive cancer and noncancer risks at both the chemical and pathway levels, and descriptions of the different pathways (e.g., the scenario, exposed population, and exposure medium associated with a particular pathway risk). We checked the data entered in two ways. First, we compared the data base figures against the original documents. Second, we did an independent calculation of the pathway risks, comparing the chemical concentration information and risk assessment parameters collected with the figures in the original documents.

Since the baseline risk assessment and the ROD for a single site may contain pathways associated with extremely small risks,[104] we developed the following decision rules for entering risks into the data base. The RODs served as the first source for pathway risk levels. If a ROD contained risk information on all cancer pathway risks that were at least 1×10^{-6} and noncancer pathway risks with a hazard index

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[of exposure pathways] can be found in Section 3.3 of the Human Health Risk Assessment (pp. 3-3 to 3-5).").

In addition, RODs may be slightly inconsistent in the level of detail provided. For a critique of the consistency of RODs, see GAO, *supra* note 13, at 30-43.

100. Summation of risks across pathways (risk additivity) may be appropriate when an individual or group of individuals is likely to be exposed to multiple "reasonable maximum" scenarios during the same time period. HHEM, *supra* note 15, at 8-16. For example, risk assessment for the Union Pacific site in Idaho presents groundwater risk as the sum of the pathway risks to residents and workers under both current and future scenarios. *See* UNION PACIFIC ROD, *supra* note 92, at 18, table 10.

101. *See supra* note 56 and accompanying text.

102. Future work on the population risks and cost/risk tradeoffs made at Superfund sites will focus on an expanded number of sites with RODs signed in 1991 or 1992. A list of the 78 sites is given *infra* app. A ("List of Sites Analyzed").

103. *Id.*

104. For example, under "current" land use conditions at the Valley Wood Preserving site, exposure to carcinogens did not create significant health risks (above the 1 in a million threshold for the pathway); there were, however, noncarcinogenic pathways that exceeded levels of concern. VALLEY WOOD PRESERVING ROD, *supra* note 92, at 6-2 to 6-3.

greater than or equal to one, we incorporated all the ROD risk data that met the following cutoff levels: 1×10^{-8} for cancer chemical level risks;[105] 1×10^{-7} for cancer pathway risks;[106] 0.01 for the noncancer hazard quotient;[107] and 0.1 for the sum of the hazard quotients, which is the noncancer pathway hazard index.[108] If a ROD did not present the minimum pathway risk data we required, we turned to the baseline risk assessment and entered the risk data according to the above decision rules. If the ROD risks were presented in forms other than by risk pathways (e.g., risks by chemical only), then we employed the baseline risk assessment figures. For each site, data on chemical concentrations and risk assessment parameters came from the baseline risk assessment.

We collected data on pathway risks smaller than the 1×10^{-6} figure often cited as a cutoff for EPA action,[109] because the aggregation of smaller risks may aid in the calculation of population risks when the human health assessment figures are combined with census population figures for future studies. For our initial analysis, however, we analyzed all cancer pathway risks greater than or equal to 1×10^{-6}, all noncancer pathway risks with hazard indices greater than or equal to one, and all chemicals associated with these pathways. These cutoffs eliminated one site in our sample, at which the no-action alternative was chosen because pathway risks were less than the thresholds. Thus, we analyze in the following section cancer and noncancer risk data from seventy-seven Superfund sites.

III
RISK PATHWAY MECHANISMS

Analyzing exposure pathways at Superfund sites sheds light on the manner in which risks arise, which in turn informs the debate over remedy selection. Do risks arise from groundwater contamination,

105. Cancer chemical level risk refers to the cancer risk posed by one chemical in a pathway. HHEM, *supra* note 15, at 8-6.

106. Cancer pathway risk is derived simply by summing the chemical level risks of all the contaminants within one pathway. *See id.* at 8-12. EPA guidance assumes simple additivity and independence of action of chemical risks within a pathway. *See id.* For a general discussion of the limits inherent in assuming risk additivity, see *supra* note 71.

Our cutoff limits at the chemical level are lower than the pathway level cutoffs to ensure that all potentially significant sums will be included.

107. A hazard quotient is the calculated exposure level of a chemical, divided by its reference dose. For a more detailed discussion of hazard quotients and reference doses, see *supra* notes 68-70 and accompanying text. For a discussion of the limits on the use of hazard indices and the general assumption of risk additivity, see *supra* note 71.

108. HHEM, *supra* note 15, at 8-13. As in the case of cancer risks, our cutoffs at the chemical level are lower than the pathway level cutoffs to ensure that all potentially significant sums are included.

109. *See* discussion *supra* note 95.

soil ingestion, or other mechanisms? Do current land uses at a site give rise to the risk exposure, or is some projected future land use responsible? These questions are of obvious interest in human health risk analysis since the nature of a pathway generating a risk will influence both the degree and duration of exposure. However, examination of risk pathways is also instructive for remedy selection policy. For instance, if the main risk is from groundwater contamination, EPA could consider switching households to other water supplies as an alternative to pump and treat remediation.[110] Despite a preference for more permanent treatment options, EPA has discretion to require less stringent intermediate options including land use restrictions,[111] capping and fencing a site,[112] and similar measures that may not eliminate the presence of a chemical but will eliminate the critical risk pathways.[113]

An examination of the number of times a pathway or a category of pathways has been a source of significant risk helps focus policy discussions. However, one should be cautious in proceeding from a pathway count to making inferences about the relative risks associated with different pathway groupings.[114] The risk level of a set of pathways is governed not only by the number of such pathways, but also by the degree of risk associated with them. Pathways for which there is a high probability of adverse health impact may carry more weight in the risk manager's remedy decision than those pathways with a lower probability. A refined analysis of the risk associated with path-

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110. *See* 40 C.F.R. § 300.415(9) (1993). However, this option currently is considered an interim measure, used only until a permanent remedy is completed.

111. *See* GUIDE, *supra* note 50, at 4-17. Land use restrictions include, for example, deed restrictions on installing drinking wells.

112. *See* 40 C.F.R. § 300.415(d)(1), (4) (1993).

Capping involves the use of a barrier—such as soil, clay, asphalt, or concrete—between the contaminated media and the potential receptor. GUIDE, *supra* note 50, at 4-17. Capping and fencing may be rejected in RODs as not meeting SARA's criteria for long-term effectiveness. *See, e.g.*, OFFICE OF EMERGENCY AND REMEDIAL RESPONSE, U.S. ENVTL. PROTECTION AGENCY, EPA/ROD/R09-92/082, SUPERFUND RECORD OF DECISION: HASSAYAMPA LANDFILL, AZ (1992).

113. For example, EPA could require containment of hazardous materials or use of materials to retard the spread and migration of a release. *See* 40 C.F.R. § 300.415(d)(5), (8).

114. For a given site, different risk assessors might estimate a different number of pathways according to their definition of what constitutes a unique pathway. For example, one risk assessor may divide each pathway by adult/child distinctions, *see, e.g.*, CHEM-CENTRAL ROD, *supra* note 92, at 12, while another may use multiple age groupings, OFFICE OF EMERGENCY AND REMEDIAL RESPONSE, U.S. ENVTL. PROTECTION AGENCY, EPA/ROD/R04-92/121, SUPERFUND RECORD OF DECISION: WOODBURY CHEMICAL (PRINCETON PLANT), FL 33 (1992) (calculating risks for infants, children, and adults). At some sites, unique pathways may be defined for different areas within the site, *see, e.g.*, UNION PACIFIC ROD, *supra* note 92, at table 10, while at other sites, pathways are defined for the site as a whole, *see, e.g.*, VALLEY WOOD PRESERVING ROD, *supra* note 92, at 6-1.

ways, as opposed to simply the number of pathways, appears in section IV.

A. *Distribution of Pathways by Risk Assessment Categories*

Table 1 provides a comprehensive overview of the distribution of the risk pathways by various parameters.[115] The columns of statistics in the table provide the pertinent breakdowns within the risk assessment categories for all 1430 pathways in the sample, including 1015 cancer pathways and 415 noncancer pathways.[116]

The first distinction in the table, and perhaps the most salient result of our study, pertains to the breakdown of risks arising from current land uses and risks arising from future uses. Future risks to current residents generally are captured under the "current" timeframe designation because that pathway does not depend on a change from current land use.[117] However, risks arising from the decision to build a residential area on land that is now a Superfund site would be "future" risks. The striking result of table 1 is that the great majority of the risk pathways pertain to future risk exposures rather than to risks associated with current uses. Overall, 70% of the cancer pathways, 79% of the noncancer pathways, and 72% of the total pathways pertain to future uses. Given that future pathways are, by definition, hypothetical scenarios created to assess risks that might arise, while current pathways generally evaluate existing conditions, it is not entirely surprising that future pathways are more numerous, since presumably the set of existing conditions is always smaller than the set of possibilities. Yet it would be significant from a policy standpoint if the majority of resources under Superfund were allocated to address hypothetical risks that consistently are presumed more serious than the actual risks.

For the next pathway category, exposed populations, table 1 shows that residential populations are the subject of the greatest number of risk pathways. Approximately three-fourths of all pathways pertain to residential populations, while the next most significant group is workers, to whom only 17% of the pathways apply. Recreational users, such as those who fish in streams on Superfund sites, account for a very small fraction of all the risk pathways analyzed. At least three hypotheses may account for this. First, recreational scenar-

115. All data tables are provided in appendix B of this article.

116. The number of pathways per site in our sample ranges from 1 to 91, with 19 being the average number of pathways per site. The total number of pathways evaluated quantitatively in the risk assessments is larger because those pathways that fell below our cutoff levels are not included in the total of 1430 pathways. Data regarding assumptions about the number of pathways per site used in this analysis are on file with the *Ecology Law Quarterly*.

117. *See* discussion *supra* part I.C.

ios may simply occur less frequently. Second, these scenarios might be evaluated more often than the data show, but do not appear in the analysis because the risks fall below levels of concern due to shorter-term exposures. Third, after evaluating a hypothetical residential scenario, risk assessors may not go on to assess quantitatively a hypothetical recreational scenario that likely is overshadowed by the risk associated with residential use.

For table 1's next category, age distribution, over 60% of the risk pathways affect adult populations, while just over one-third of the risk pathways pertain to children (i.e., those under eighteen years of age). Minors comprise only 26% of the U.S. population overall, although 37% of the risks are to this group.[118] Thus, the pathways affecting children occur almost 1.5 times as often as the representation of children in the population would predict. EPA may be making a special effort to identify potential routes of exposure for children because they are a sensitive subpopulation due to their greater sensitivity to chemical exposures,[119] and due to certain child behaviors, such as soil ingestion, that increase exposure.[120] The higher number of risk pathways pertaining to children may also be a function of the fact that children have a higher intake-to-body weight ratio than adults for pathways such as groundwater and soil ingestion. Other exposure parameter values being equal (such as exposure duration and frequency), this will cause child risks to exceed cutoffs more frequently than adult risks.[121]

Table 1 also shows the distribution of pathways by location, both of the exposed population and the exposure medium.[122] The location where risks arise is of substantial interest, particularly as it relates to the potential efficacy of policy options limiting future land uses at or near Superfund sites, and policies designed to reduce health threats to surrounding communities. Sixty-nine percent of the total pathways pertain to risks threatening onsite populations, and 80% of the pathways associated with contaminated media pertain to onsite risk exposures. Soil and groundwater represent the most prominent media, each accounting for over one-third of all pathways. The other relatively important exposure media are air (from soil), air (from water), and sediment, each of which accounts for 5% to 10% of all pathways.

118. U.S. CHAMBER OF COMMERCE, STATISTICAL ABSTRACT OF THE UNITED STATES 19 (1992). Statistics are for 1991.

119. HHEM, *supra* note 15, at 6-8.

120. *Id.*

121. The equation for calculating chemical intake is given *supra* note 58.

122. For this data analysis, location of medium refers to whether the soil, air, or water carrying the contaminant threatens exposure onsite or offsite. Thus, onsite groundwater contamination could be considered "onsite" for some effects, but also "offsite" if the plume migrated so that the location of the exposure is offsite.

The two air pathway mechanisms combined account for almost one-fifth of all media pathways.

The final component of table 1 lists the human exposure route. The dominant exposure route is ingestion, such as drinking contaminated groundwater or eating dirt. This category gives rise to 58% of all pathways. Dermal contact accounts for 23% of the exposure routes, and inhalation of vapor phase chemicals and dust are next in importance.

For the exposure routes, as well as for most of the other components of the table, the distribution of pathways is fairly similar for both cancer and noncancer pathways. The major distinctions are that noncancer pathways play a more prominent role in the future risk scenarios, are more likely to affect residential populations, are less likely to affect adults, are more likely to involve groundwater exposure rather than soil exposure, and are more likely to arise from ingestion rather than from dermal contact. The greater risk share experienced by children relative to adults under noncancer pathways may be explained in part by the fact that for noncarcinogenic pathways the averaging time is equal to the exposure period, and the factor driving risk is primarily the intake-to-body weight ratio, which is higher for children than adults. In contrast, carcinogenic risks are averaged over a seventy year lifetime (i.e., the intake-to-body weight ratio is adjusted by the exposure period divided by the number of days in a lifetime), where only a fraction of the potential exposure occurs during childhood.[123]

B. *Distribution of Pathways by Time Scenario, Exposed Population, and Population Location*

Table 2 analyzes the exposed population type and the location of the exposed population for each of the two land use scenarios: current use and future use. Overall, the scenario of a residential population moving onto a site in the future accounts for the majority of pathways, specifically 59%. In contrast, current risks to current residents and future populations in current residential areas represent only 14% of the pathways. The next most prevalent category, workers, also has more future pathways than current pathways, but the difference is less stark than for residential populations. One explanation for this difference is that pathways for future workers were not always evaluated because: (a) risk assessors may not have projected a change in land use where a Superfund site is an active facility, so all worker pathways

123. For methods to calculate chemical intake and the effects of averaging time, see HHEM, *supra* note 15, at 6-21 to 6-23; see also discussion *supra* part I.B.

would be current exposure pathways,[124] or (b) a hypothetical residential scenario would represent the most "risky" future scenario and thus would eliminate the need to quantitatively evaluate future worker risks.

Table 2 also indicates that the location of the population (onsite or offsite) makes a substantial difference in the number of risk pathways to which the population is exposed, particularly when considered with the timeframe scenario. Onsite risks under current scenarios account for 15% of the pathways, a proportion only slightly greater than the 11% for current offsite risks. For future scenarios, however, onsite risks represent 54% of the pathways, over four times as great a proportion as the 12% of pathways representing future offsite risks.

Table 3 presents a more refined breakdown of the categories considered in table 2. The top panel of table 3 shows risks attributable to current exposed population scenarios, while the bottom panel pertains to pathway distributions for future exposed population scenarios. In each case, the table provides two sets of statistics: the percentage of pathways for the particular timeframe and the percentage of the total number of pathways broken down by population groups. For the current exposed population, the dominant onsite risks are to residents and workers, each of which account for about one-fifth of the onsite risks and about 5% of the total pathways in the sample. Current residents also are subject to the largest number of offsite exposure pathways, accounting for 27% of the offsite pathways and 8% of the total pathways.

As shown in the bottom panel of table 3, residents are exposed to an even greater share of the future risk pathways. While 19% of the current onsite risk pathways pertain to residents, the future onsite residential share surges to 59% of the future pathways and 43% of all pathways. For future offsite risks, again residents are the most important group, accounting for 16% of the future scenario risks and 11% of all pathway risks in the sample.

By far the most important implication of table 3 is that future onsite residents dominate risk pathways in Superfund site risk assessments. The scenario driving the risk analysis is the assumption that there will be many more onsite residents than now exist.[125] Among the total pathways analyzed, future onsite residents account for eight times as many pathways as current onsite residents.

124. EPA has considered sites "active" if waste treatment, storage, or disposal activities were occurring. This includes sites with contaminated groundwater or widespread sediment contamination. *See* OFFICE OF EMERGENCY AND REMEDIAL RESPONSE, U.S. ENVTL. PROTECTION AGENCY, EPA/540/8-91/069, OERR PUB. NO. 9345.1-09-0, NATIONAL RESULTS—NPL CHARACTERIZATION PROJECT 31 (1991).

125. *See* discussion *supra* notes 93-95 and accompanying text.

Table 4 divides the risk pathways for each exposed population group by exposure medium and exposure route. The first column represents our calculation of the percentage of pathways for each exposed population, and the second column represents the percentage of total pathways for that row. The numbers within each category may not add up to 100% because the table does not include exposed population groups that account for fewer than 5% of the pathways.

For residents, the chief risks arise from ingestion of groundwater and soil. Resident ingestion of groundwater alone accounts for one-quarter of all pathways. Although Superfund anecdotes frequently highlight the importance of children who eat dirt,[126] it is noteworthy that ingestion of soil plays a much greater proportional role in the risk pathways for workers than it does for residents. Dermal contact with soil and ingestion of groundwater also account for a substantial share of the risks to workers and a significant share of the total pathways.

The risk pathways for recreational users and trespassers comprise a very small percentage of all pathways in the sample, but the distribution within these groups is nevertheless of interest. The primary risk to recreational users comes from dermal contact with soil, with soil ingestion and inhalation of vapor phase chemicals from soil being next in importance. For trespassers, the major risks are from ingestion of soil and ingestion of sediment, which together account for almost half of all risks to trespassers.

In summary, the majority of risks evaluated in EPA risk assessments for Superfund sites arise from hypothetical rather than existing scenarios, onsite exposures as opposed to offsite exposures, and residential use of contaminated sites in contrast to other uses. The most significant sources of risk are contaminated soil and groundwater, and the most common exposure route is ingestion.

IV
PATHWAY RISK LEVELS

Although examination of the distribution of pathways is instructive in assessing the mechanisms by which risks arise, the level of risks associated with a pathway is also of substantial consequence. Some pathways involve very intense exposure to very hazardous chemicals, while others involve relatively minimal exposure levels. In this section we explore different features of the risk distribution among pathways included in our sample. A useful starting point is the distribution of risk pathways by risk level, which appears in table 5.

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126. *See, e.g.*, BREYER, *supra* note 9, at 12.

A. *The Distribution of Risk Pathways by Degree of Cancer and Noncancer Risk*

The top panel of table 5 presents the distribution of cancer risk pathways for different risk ranges. Over one-half of the cancer pathways in the sample pertain to risk levels below 10^{-4}. However, it is quite striking that many of the pathways involve considerable risks, with eighteen of the pathways posing cancer risks in excess of one in ten. Health risk levels of this kind are not unprecedented. For example, cigarettes may pose a lifetime cancer risk of between one in five (20%) and one in three (33.3%).[127] Some of the pathway risks are very large in comparison with the targets of most government risk policies. The risk threshold for many federal risk policies is either 1 in 100,000[128] or 1 in 1,000,000,[129] and even job fatality risks for blue collar workers are only on the order of 1 in 10,000.[130] In contrast, many of the pathways in table 5 are associated with risks orders of magnitude greater than these targeted risk levels.

Such large risks arise in part because of particular risks associated with some extremely hazardous Superfund sites. The Westinghouse site in California is perhaps most noteworthy, because it accounts for four of the top ten cancer risk pathways in this analysis.[131] The risks at this site arise from, *inter alia*, high concentrations of polychlorinated biphenyls (PCBs).[132] Exposure scenarios were evaluated for both of the population groups that were, or could be, exposed to these risks: workers and onsite residents.[133] Consistent with table 1's analysis of the overall distribution of risk pathways, the future scenarios play a role in 75% of the exposure scenarios at the Westinghouse site.[134] The risk pathways most responsible for the high risk ranking of the Westinghouse site are those risks posed to adult and children residents from exposure to soil (dermal exposure and ingestion), surface workers[135] from exposure to soil (dermal exposure and ingestion), and children and adults exposed to groundwater from an

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127. W. Kip Viscusi, Smoking, Making the Risky Decision 70 (1992).

128. *See, e.g.*, W. Kip Viscusi, Risk By Choice 137 (1983) [hereinafter Risk] (specifically discussing risk levels that the Consumer Product Safety Commission has targeted for regulation).

129. *See* discussion *supra* note 95.

130. Risk, *supra* note 128, at 44.

131. A list of the top fourteen carcinogenic pathways is available on file with the *Ecology Law Quarterly*; Office of Emergency and Remedial Response, U.S. Envtl. Protection Agency, EPA/ROD/R09-92/079, Superfund Record of Decision: Westinghouse Electric (Sunnyvale Plant), CA table 6 (1991).

132. *Id.* at 17.

133. *Id.* at 18.

134. *Id.* at table 6.

135. The Westinghouse site ROD presented carcinogenic risks to workers exposed to both surface and subsurface soil. *Id.*

aquifer (ingestion), where all these risks pertain to future risk scenarios as opposed to current risk pathways.[136] The prominence of future risk pathways extends beyond the Westinghouse site: all of the top thirteen pathway risks are associated with future as opposed to current risk scenarios.[137]

The bottom panel of table 5 presents the distribution of the risk levels for noncancer pathways. These figures pertain to the hazard index associated with noncancer risk. Chemicals differ in the potency of their health effects; thus one should be careful in interpreting any aggregation of these statistics across chemicals.[138] For the most part, the chemical exposures are less than ten times greater than the hazard index threshold, but in some cases there are extreme chemical exposures 1000 times as great as the reference dose for a chemical. Table 5 clearly shows that the levels of risk at some Superfund sites pose a significant health hazard.

B. Pathway Cancer Risks by Risk Assessment Category

Table 6 provides a comprehensive overview of the magnitude of the cancer risks for all the principal risk assessment categories set out in table 1. While table 1 gives information on the percentage of pathways that pertain to each of the various risk assessment categories, table 6 presents information on the risk levels associated with each of these categories. The main statistics of interest in table 6 are the mean risk levels and the median risk levels.[139] Due to the influence of very high risk outliers, the mean risks are consistently larger than the median risks, but this disparity is roughly similar across risk assessment categories.

Table 6 reinforces the conclusion reached in the analysis of table 1[140] that future risk scenarios dominate Superfund site risk assessment. The risk levels per future risk pathway exceed the risk levels per current use pathway by a factor of five for the means and a factor of two for the medians. Not only are future risk pathways much more prevalent in Superfund human health risk assessments, but also when they occur in the analysis they have a much higher risk.

Table 6 also reveals that the chief risks facing exposed populations are those incurred by residential populations and workers. The

136. *See id.*

137. A list of the top fourteen carcinogenic pathways is available on file with the *Ecology Law Quarterly*.

138. *See* discussion *supra* note 71.

139. The mean risk is the arithmetic average of all the risks in a given grouping. WEBSTER'S, *supra* note 96, at 1114. The median risk is the risk level at which one-half the risks fall below and one-half fall above. *Id.* at 1117.

140. *See supra* part III.A.

trespasser risk levels are quite small. Coupling these low risk levels with the low frequency of trespasser pathways shown in table 1 suggests that selecting policy options that do not treat or remove chemicals but simply restrict the future use of a site pose little danger to trespassers. Even without fencing or other barriers, trespasser pathways rarely create a significant risk, and when they do, the severity of the risk is not nearly as great as for other populations at risk.

The next category in table 6 demonstrates that, despite enhanced public scrutiny of risks to children, children do not face a disproportionate share of the risks.[141] The mean level of risks faced by adults is greater than that faced by children, although the median risks are virtually identical. Thus, anecdotes implying that the highest risks estimated at Superfund sites derive from the hypothetical possibility of children eating large volumes of dirt are not supported by the data.

Table 6 also shows that in terms of the location of risks, onsite populations face the greatest risks and onsite media pose the greatest risks. Thus, preventing future development of a site or use of a site for other purposes would eliminate the most severe risks that affect human populations. Of course, such controls will not be as effective at addressing groundwater quality that may still pose a threat to offsite populations. Further, use restrictions do not address public concern over ecological damage from contaminants left in the environment.[142]

The next table 6 category, exposure media, indicates that the media posing the largest risks, such as mothers' milk (7×10^{-2}) and biota (2.7×10^{-2}), are associated with very few pathways. Yet the most prevalent pathways, those linked to soil and groundwater, still pose mean cancer risks on the orders of 1 in 100 and 1 in 1,000. Taken at face value (i.e., assuming these are accurately characterized risks to real people), these estimated risks are several orders of magnitude larger than those driving many other federal risk regulation efforts.[143]

C. *Distribution of Cancer Risks by Time Scenario*

Table 7 allocates the different risk levels between current and future risk scenarios, and indicates for those timeframes the mean and

141. Critics of public risk perception often point to cleanup policies that mandate remediating dirt so that children may eat it safely, or to the folly of removing captive asbestos from schools where the removal process itself enhances risk. *See, e.g.*, BREYER, *supra* note 9, at 12.

142. Barry Breen, *Citizen Suits for Natural Resource Damages: Closing a Gap in Federal Environmental Law*, 24 WAKE FOREST L. REV. 851 (1989) (proposing citizen actions to address natural resource damages).

143. For example, the annual risk addressed by regulation of unvented space heaters is estimated at 2.7 in 100,000; by alcohol and drugs, 1.8 in 1,000,000; and by passive restraints/belts, 9.1 in 100,000. W. KIP VISCUSI, FATAL TRADEOFFS: PUBLIC AND PRIVATE RESPONSIBILITIES FOR RISK 264 (1992) [hereinafter FATAL TRADEOFFS].

median risk levels for different exposed populations and different population locations. The top panel of table 7 presents information for the various exposed populations. The population group subject to the largest number of pathways is the residential population for future risk scenarios; this population group also faces the greatest risk: 1.1 additional cancer deaths per 100 individuals exposed. This risk level is several times greater than the risks facing current onsite residents. EPA's risk analysis consequently assumes not only that onsite resident pathways will be much more prevalent in the future than they are now, but also that such pathways will pose greater risks than those faced by current onsite residents. Future workers and future recreational users will also face greater risks than their current scenario counterparts. Only future trespassers will face a lower risk. Overall, trespassers face the lowest risk levels in the sample, and future trespassers are not only infrequent, but face an extremely small risk level.

When compared with the top panel, table 7's bottom panel illustrates a correlation between population locations (onsite or offsite) and the type of exposed population. Since future resident exposure pathways are usually hypothesized onsite, it is the onsite future scenario group that accounts for the largest number of pathways as well as the highest risk level. Significantly, the future offsite risks are relatively comparable to the future onsite risks. The onsite and offsite risks for current scenarios are quite close as well. Thus, the main difference is not in location but rather in timeframe; mean future onsite and offsite risks are at least four times larger than the risk levels assumed under current scenarios. As a result, the EPA analyses are predicated not only on an assumption that future scenarios involving exposed populations will be the dominant pathways, but also that these future scenarios will give rise to much larger risks than those currently faced.

Table 8 continues in a similar vein, showing the risk for each exposed population at each of the locations in both of the timeframes. As the previous discussion suggested, the dominant pathway pertains to future onsite residents. The relative risks for future scenarios, compared with present pathways, are consistently larger even by population location and by exposed population group. For example, the onsite risks to future residents are ten times greater than the onsite risks to current residents. Future residents not only account for 431 of the pathways, but also have one of the highest risk levels based on either the mean or the median risk amount. Other risk pathways that pose risk probabilities of comparable magnitude also occur in future scenarios, such as the risks to future onsite workers and future offsite residents. Consequently, simply restricting the onsite residential use of Superfund sites will not eliminate all future risk scenarios.

Table 9 extends the cancer risk breakdowns by adding exposure media and exposure routes for each of the exposed populations. The media involved are quite diverse, including air exposures arising from soil, air exposures arising from water, soil, groundwater, surface water, sediment, biota, structures, sludge, leachate, mothers' milk, and combinations of various other risks.[144] Some of the most common exposure media for residential populations are soil and groundwater ingestion, dermal soil contact, and air exposures arising from water. Workers face a similar mix of risks; the magnitude of the risks to workers compared to residents is slightly smaller for groundwater ingestion and about equal for soil. Recreational users face the largest risks from dermal soil contact, groundwater ingestion, and inhalation of dirt and vapor phase chemicals. Trespassers face fairly small risks in all categories, particularly compared to those threatening residential users. The largest trespasser risk pertains to biota (e.g., eating contaminated plants, fish, or animals).

D. *Risk-Weighted Shares of Cancer Pathway Risks*

Analysis of the frequency of risk pathways gives a sense of how often the pathways are pertinent, and consideration of the risk levels associated with each pathway indicates the magnitude of risks per pathway. The overall level of risk that a Superfund site generates will reflect the combined influence of pathway frequency and the magnitude of pathway risk. A fuller analysis, not possible here, also would examine the size of the populations exposed to the risks. The tables that follow combine pathway frequency and pathway risk for the various pathway categories.

Table 10 provides statistics on the risk-weighted shares of the different cancer risk pathways. Each of these pathways is weighted by the total risk factor estimated for that pathway, and the risk-weighted pathways then are summed for the entire sample. The figures in table 10 provide information on the percentage of the total risk-weighted pathways accounted for by each pathway type.

Thus, table 10 combines the influences of the frequency of pathway occurrence with the magnitude of risks to generate a hybrid of the two factors discussed above. For example, we found that future risk pathways were not only more prevalent than pathways based on current risk scenarios, but also that they posed a greater risk per pathway. The statistics in table 10 illustrate the compounding of these influences: 91% of the total cancer pathway risks are attributable to future risk scenarios. This emphasis on future risks is much greater

144. *See* pathway "count," *infra* app. B, table 9 ("Distribution of Cancer Pathway Risks"). The "combination" category refers to soil/sediment combined exposures.

than the unweighted share of future pathways, which table 1 lists as only 72%.

The other figures in table 10 represent total cancer pathway risks, future cancer pathway risks, and current cancer pathway risks broken down by risk assessment category. In terms of the age group distribution of risks, adults represent the largest risk share. Even though children's pathways occur proportionally more frequently (as shown in table 1), their weighted share of risk returns them to a fraction more representative of their proportion in the population as a whole.

The risk-weighted results in table 10 also show that for exposed populations, risks vary greatly by both population type and by timeframe. Residential populations, for instance, account for 66% of the current cancer pathway risks, escalating to 89% for future risk pathways. However, residential populations account for only 14% of all pathways.[145] Similarly, exposures to workers represent 28% of the current cancer pathway risks, despite the fact that they account for only 6% of total current pathways.[146] Worker pathway risks drop to only 9% for future risk-weighted cancer pathways, with an 11% share of total cancer pathway risks. The reduction in their share of future pathway risks may be a function of EPA's focus on identifying, for the purposes of the risk assessment, an alternative future land use that represents a reasonable worst case scenario (i.e., residential), even when a potentially more likely future scenario (i.e., industrial) still poses significant risks to workers.

The location of the populations most affected by the weighted risks also changes dramatically depending on the timeframe of the risk scenario. The percentage share of onsite population risks rises from 41% to 81% when one moves from current to future risk scenarios, while the role of offsite risks drops from 45% to 17%. The implications of both the exposed population and the location of population weighted risk analyses again suggest that future risk scenarios greatly emphasize risks posed to onsite residents.

For the exposure media listed in table 10, the most noteworthy pattern is that groundwater risks account for almost one-half of future cancer pathway risks, but only one-third of current cancer pathway risks. On the other hand, the role of biota drops substantially for future pathway scenarios. This may be a function of the greater uncertainty inherent in inhalation and biota models, combined with the role of professional judgment. If a risk assessor deems biota pathways unlikely under current scenarios, she may judge it unreasonable to as-

145. *See infra* app. B, table 3 ("Distribution of Pathways by Scenario, Population Location, and Exposed Population").

146. *Id.*

sume they will appear at some later point. Biota pathways generally are evaluated only for classes of chemicals that are known to bioaccumulate, and we have limited knowledge of how chemicals interact with, and are amplified or suppressed by, the environment.[147]

Finally, the risk-weighted exposure route data in table 10 show that ingestion accounts for roughly two-thirds of the total pathway cancer risk, and dermal exposures represent another one-fourth of the total risk.

Table 11 divides risk-weighted pathways into individual exposure media. Each row of the table combines a timeframe, location, age, and exposed population variable to generate a particular risk scenario, such as current onsite risks to adult workers. For each of these risk scenarios, the table provides the percentage of the risk-weighted pathways accounted for by each of the exposure media. Table 11 makes clear that Superfund risks are almost entirely attributable to groundwater contamination and soil-related risks, which combine to account for between 76% and 99% of the cancer risk in each exposure scenario. Soil-related hazards represent 58% of the risks for current onsite adult workers, 64% of the risks for future onsite adult workers, 32% of the risks for future onsite adult residents, and 56% of the risks for future onsite child residents. Future offsite adult residents are the only group for whom the groundwater risks are of overwhelming importance relative to other pathways because groundwater risks constitute virtually the entire set of exposure pathways for this group. Airborne risks from chemicals in soil also play a substantial role in some scenarios, particularly in the case of current onsite adult workers.

Table 12 examines risk-weighted pathways for each of the scenarios presented in table 11, but it considers the role of different exposure routes rather than exposure media. Ingestion is by far the most important exposure route, since it accounts for the largest fraction of the risks for almost every scenario. Future onsite adult workers are the only exception, for whom dermal contact poses a more substantial risk than ingestion. Even for future onsite adult workers, however, ingestion risks represent 44% of all risk levels. In the extreme case of future offsite resident adults, ingestion accounts for 96% of the risk.

147. For example, it is clear that dioxin bioaccumulates in fish. Judy S. LaKind & Daniel Q. Naiman, *Comparison of Predicted and Observed Dioxin Levels in Fish: Implications for Risk Assessment*, 4 RISK-ISSUES IN HEALTH & SAFETY 253, 253 (1993). LaKind and Naiman argue that EPA's model for estimating dioxin does not accurately predict contamination of fish in the wild. They argue that this is true, in part, because dioxin bioaccumulation is impacted by site-specific information such as food chain structure, fish species, fish age, fish size, river flow, seasonal effects, and concentrations of organic matter in the effluent and receiving water. *Id.* at 260-62.

E. Maximum Site Risk Pathways

Although risk-weighted pathways provide one insightful way to analyze the range of risk levels, examining the single pathway that poses the greatest risk at each Superfund site also may be instructive. Table 13 gives a summary of the distribution of the maximum risk pathways for different sites, providing breakdowns by the same pathway categories used to characterize the overall percentage distribution of pathways (table 1) and the percentage distribution of risk-weighted pathways (table 10).

In the first category, current versus future risks, the results for the maximum site pathways fall between the overall pathway distribution (table 1) and the risk-weighted pathways (table 10). Future risk pathways accounted for 72% of all pathways and 91% of all risk-weighted pathways. Not surprisingly, table 13's 79% figure for the maximum site cancer pathways in future risk scenarios lies between these two estimates, because sites associated with the maximum risk received greater weight when computing the risk-weighted pathway share.

The maximum risk pathway results in table 13 do not always parallel the distribution of cancer pathways set forth in table 1. Soil-related pathways account for 38% of the cancer pathways, and groundwater pathways account for 31% of the cancer pathways (see table 1). The risk-weighted pathway shares in table 10 are only marginally different: soil has a 33% risk-weighted share and groundwater has a 48% risk-weighted share. If, however, one examines the maximum site pathway, the role of the soil pathway drops to 20%, and the groundwater share rises to 65%, far in excess of the overall risk-weighted share of cancer risk pathways. The public debate may have placed inordinate attention on the role of groundwater hazards simply because these risks are frequently the maximum risk pathways at Superfund sites.[148] Our more comprehensive analysis, taking into account the frequency of pathways as well as their severity, implies that the risks associated with groundwater contamination are much less than would be suggested by an analysis focussed solely on maximum

148. *See* UNFINISHED BUSINESS, *supra* note 7, at 8.

The public has become increasingly aware of the hazards of groundwater contamination. Many farmers consider contamination of groundwater and surface water the most serious threat to agriculture. Larry J. Smith, *Finally Survey Statistics to Back Me Up*, LEWISTON MORNING TRIB., Mar. 22, 1993, at A11. Public concern over groundwater contamination from leaking underground storage tanks (LUSTs) has fostered a complete industry for piping and equipment designed to prevent such leaks. *See, e.g.*, Tom Sixman & Vince Saunders, *Basics of Plastic Containment Piping*, 47 PLANT ENGINEERING 76, 76 (1993).

By comparison, an EPA study ranked groundwater risks as "medium or low" in four categories of risk: cancer, noncancer, ecological, and welfare. UNFINISHED BUSINESS, *supra* note 7, at xix.

risk pathways. However, groundwater exposure pathways have the potential to affect larger populations than soil exposure pathways.

Table 14 provides a distribution of the maximum pathway cancer risks for different exposure routes in the two timeframes. The dominant cell in this table is future ingestion risks, which comprise fifty-five of the maximum risk pathways and a very large risk level of 5.3×10^{-2}. Current and future dermal exposures also pose a considerable risk, but these maximum risk pathways are much less frequent than ingestion risk pathways. Thus, dermal exposure pathways may have significant site-specific impact, but their general impact on remedy decisions across Superfund sites likely is overshadowed by other exposure route pathways.

Table 15 further subdivides the maximum pathway cancer risks by examining the risks for different population groups and population locations. The top panel, which pertains to current risk scenarios, indicates that eighteen of the maximum pathway cancer risks involve current risk pathways. Of these, thirteen pertain to onsite locations, and the mean maximum pathway cancer risks vary from 2.8×10^{-3} for offsite workers to 9.1×10^{-2} for current residents (location not indicated). By contrast, the bottom panel of table 15 shows that sixty-eight maximum risk pathways pertain to future scenarios, most frequently to onsite residents.[149] The mean risks associated with these maximum risk pathways range from 6.7×10^{-2} for future onsite residents to 9.7×10^{-3} for future onsite workers.

Tables 16 and 17 detail the maximum risk cancer pathways for current and future scenarios respectively. Panel 1 on both tables indicates how these maximum site risk pathways are distributed by exposure route, and panel 2 shows this distribution according to both population location and the type of exposed population. For both current and future maximum risks, ingestion is the dominant pathway. Table 16, panel 2 indicates that current maximum risks occur most frequently for offsite residents and onsite workers. Table 17, panel 2 reveals that onsite residents face the maximum future risks since their pathways account for forty-eight of the eighty-two maximum future risk pathways as well as the largest magnitude of risk, 5.9×10^{-2}.

V
CHEMICALS ASSOCIATED WITH RISK PATHWAYS

The final part of our analysis considers the overall risk levels and distribution of risk pathways by chemical. This may be particularly

149. The count of 85 pathways does not equal the number of sites for two reasons: (a) not all sites have a unique maximum risk, in which case all maximum risks of the same value were included; and (b) some sites lack carcinogenic or noncarcinogenic pathways.

useful because government agencies frequently target specific chemicals for special policy emphasis.[150] This section assesses which chemicals are most prominent in the analysis of Superfund cancer and noncancer risks.

Table 18 summarizes the distribution of cancer-causing chemicals based on the frequency with which they are mentioned in the pathway risk assessments, and table 19 provides comparable statistics for the noncarcinogens. Each list is restricted to the top twenty-five chemicals. For the carcinogens in table 18, the most prominent chemical is arsenic. Chemicals such as beryllium, trichloroethylene, and benzene are next in importance, and highly regulated chemicals such as vinyl chloride and PCBs also make the list. For the noncarcinogens in table 19, arsenic again plays a leading role, since some risk assessors treated it as a noncarcinogen, and heavy metals are among the most prominent other chemicals on the list.

Table 20 weights the chemical-specific cancer risks to account for the number of times the risks occur and the magnitude of the risks associated with an exposure pathway when they do occur. The statistics in the first column give the percentage share of the total cancer risk attributable to that particular chemical, and the second column of data provides the average cancer risk posed by each of the chemical-specific pathways. The leading entry in each of these columns is Aroclor 1260,[151] which accounts for 31% of the total cancer risk in our data base, with an average risk per Aroclor 1260 pathway of 1.8×10^{-2}.

Perhaps more than the simple list of carcinogens by frequency in table 18, the risk-weighted carcinogen listing in table 20 strikes a resounding chord. Chemicals such as arsenic,[152] dioxin,[153] vinyl chloride,[154] and PCBs,[155] which are all well-known targets of government

150. *See* FATAL TRADEOFFS, *supra* note 143, at 264 (listing estimates of cost-per-life-saved values for various chemical-specific regulatory efforts, such as the 1989 EPA regulation of asbestos and the 1987 OSHA regulation of benzene).

151. Aroclor 1260, a PCB, is classified as a Group B "probable human carcinogen" based on animal studies with sufficient evidence of carcinogenicity in animals. HEALTH EFFECTS SUMMARY, *supra* note 81, at 15, B-17. In laboratory tests, Aroclor 1260 caused liver tumors in rats. *See id.* at B-17.

152. For example, arsenic is an enumerated "hazardous substance" under CERCLA. 42 U.S.C. § 6902 (1988); 40 C.F.R. § 302.4 ("List of Hazardous Substances and Reportable Quantities") (1993).

153. Dioxin is specifically regulated under the Resource Conservation and Recovery Act at 42 U.S.C. § 6924(e) (1988), and also under the Toxic Substances Control Act at 40 C.F.R. § 766.1-.38 (1993) (regulating dibenzo-para dioxins and dibenzofurans).

154. Vinyl chlorides are subject to regulation under CERCLA, 40 C.F.R. § 302.4 ("List of Hazardous Substances and Reportable Quantities"), the Clean Air Act, 42 U.S.C. § 7412(b)(1) (1988 & Supp. IV 1992), and the Clean Water Act, 33 U.S.C. § 1317 (1988) (toxic pollutant standards); 40 C.F.R. § 401.15 (1993) (list of toxic pollutants).

155. PCBs are "hazardous substances" under CERCLA, 40 C.F.R. § 302.4 ("List of Hazardous Substances and Reportable Quantities"), and also are regulated under the

regulation, play an extremely prominent role once the pathways are weighted according to the cancer risk levels. These chemicals combine relatively high frequency of appearance with high risks per pathway to play a substantial role in the risk assessments.

Table 21 breaks down chemicals' influence based on exposure media. For each medium, table 21 lists the most prominent chemicals, the percentage of the total exposure medium cancer risk accounted for by a chemical, and each chemical's average cancer risk within that exposure medium. Consider the two most prominent Superfund media: soil and groundwater. In the case of soil, table 21 shows that Aroclor 1260 is responsible for 91% of the cancer risk associated with that medium; for groundwater, arsenic accounts for over one-third of the cancer risk. These results are important because chemical-specific risks associated with a particular pathway can be reduced or nullified by choosing a policy option that eliminates that particular pathway. If our concern is with particular chemicals as opposed to absolute risk levels, then it is necessary to make distinctions across pathways because, as we have seen, different chemicals generate risks by different pathways. Moreover, if additional scientific evidence subsequently reveals that the risks of particular chemicals are more or less hazardous than was initially believed, then the effect will not be to alter the risk distribution uniformly, but rather to affect particular pathways in a disproportionate manner.

CONCLUSION

Superfund was created out of concern for the current risks posed by uncontrolled hazardous waste sites. Consideration of the risk assessments for Superfund sites indicates, however, that it is not the existing risks that are most salient. Instead, the dominant risks arise from future risk scenarios that involve alternative land uses. Indeed, these future risks account for over 90% of all the risk-weighted pathways for the Superfund sites in our sample. Chief among these future risks is the projection that future residents will reside on sites that are not currently residential.

If government intervention could eliminate future risks by land use restrictions and containment, many human health risks currently considered in risk assessments would be eradicated.[156] For example,

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Clean Air Act, 42 U.S.C. § 7412(b)(1), the Toxic Substances Control Act, 15 U.S.C. § 2605(e) (1988); see 40 C.F.R. § 761.1-.218 (1993) ("Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions"), and the Water Pollution Control Act, 33 U.S.C. § 1317 (toxic pollutant standards); 40 C.F.R. § 401.15 (list of toxic pollutants).

156. Future work will explore more quantitatively the degree to which risk could be reduced using such strategies.

access restrictions and/or deed restrictions on area properties, given effective enforcement, could prevent installation of drinking water wells in a contaminated groundwater plume or prevent development of the area for residential use, thus eliminating such risk pathways as onsite residential ingestion of groundwater. Many compounds degrade over time into less harmful substances through natural attenuation, and in such cases containment of the contaminated media might prevent the most severe risks from arising in the interim.[157] Our examination of risk pathways suggests that many of the risks likely to remain despite containment and land use restriction options (e.g., the threat to trespassers), are very low even without requiring fencing to reduce access to these risks. Eliminating the significant share of risk posed to future onsite residents through institutional land use controls alone might cause many more sites to fall below the levels requiring further action.[158] However, these strategies would require a change in EPA's current legislative mandate establishing a preference for long-term effectiveness and permanence in remedy selection.[159]

Moreover, before undertaking these more limited options, EPA should also explore whether factors omitted from our analysis, such as ecological risks, may warrant more extensive cleanup. Despite concluding that the great majority of Superfund risks are not to present populations, we cannot concur with many observers who have attempted to dismiss Superfund risks as trivial. On the contrary, many of the estimated hazards are quite substantial. Although the EPA risk threshold for considering a pathway risk is generally a lifetime cancer risk of 1 in 1,000,000, the mean risk level associated with pathways is typically several orders of magnitude larger than this threshold. Moreover, these mean risk levels pertain not only to a site generally, but also to a variety of different pathway mechanisms and different exposed populations at a site. Taken at face value, these risk assessments suggest that Superfund risks exceed the estimated risks for other federal cancer regulation efforts. Thus, even if one chooses to disregard some pathways as unlikely, the overall scale of risks is sufficiently large that casual dismissals of Superfund risks based on anecdotal evidence are not warranted.

157. Many compounds may be biologically transformed or degraded, or may undergo chemical degradation via processes such as photolysis, oxidation, or hydrolysis. *See, e.g.*, HHEM, *supra* note 15, at 6-11.

158. Of course, EPA still could justify remedial action based on its assessment of ecological damage or to comply with ARARs. *See supra* part I.A.

159. The Administration has stated that "[t]he concept of permanence will be replaced with long-term reliability . . . and the preference for treatment will be limited to 'hot-spots'." *Summaries of Clinton Administration Proposal for Superfund Reform*, Daily Rep. for Executives (BNA) No. 23, at M-2 (Feb. 4, 1994), *available in* LEXIS, Nexis Library, NWLTRS File, at 1.

Ultimately, to form a reliable assessment of the merits of the Superfund program and possible alternative modes of government intervention, one needs to refine the risk analysis in a variety of ways. Our study considered the frequency of different types of risk and their associated risk levels, but did not address the magnitude of the populations affected or the cost of achieving risk reductions.

The value of our study lies in its potential for streamlining the integration of risk analysis with the next step in the process, risk management, by providing risk managers and policymakers with a comprehensive understanding of the focus and the uses of risk analysis. The current focus of the Superfund program is risk-oriented, as are most governmental human health regulations. Given this emphasis, our analysis is especially instructive in illuminating a primary goal of the Superfund program: the reduction of human health risks.

APPENDIX A
List of Sites Analyzed

No.	SITE	STATE
1	29th & Mead Groundwater Contamination	Kansas
2	Alsco Anaconda	Ohio
3	AO Polymer	New Jersey
4	Asbestos Dump	New Jersey
5	Bioclinical Laboratories Inc.	New York
6	Buckeye Reclamation	Ohio
7	Butterworth #2 Landfill Site	Michigan
8	Cannelton Industries	Michigan
9	Charles Macon Lagoon & Drum Storage	North Carolina
10	Chem-Central	Michigan
11	Chem-Form Inc.	Florida
12	Chem-Solv	Delaware
13	Chemical Sales Co.	Colorado
14	City Disposal Corp. Landfill	Wisconsin
15	Commodore Semiconductor Group	Pennsylvania
16	Cosden Chemical Coatings Corporation	New Jersey
17	Dorney Road Site	Pennsylvania
18	Dover Municipal Well 4	New Jersey
19	DuPont (CO RDX23)	Iowa
20	Eastern Diversified Metals	Pennsylvania
21	Endicott Village Well Field	New York
22	Facet Enterprises	New York
23	Florida Steel Corp.	Florida

24	Folkertsma Refuse	Michigan
25	Frontera Creek	Puerto Rico
26	Geigy Chemical Corp. (Aberdeen Plant)	North Carolina
27	Genzale Plating Co.	New York
28	Gulf Coast Vacuum Services	Louisiana
29	H. Brown Co., Inc.	Michigan
30	Hagen Farm	Wisconsin
31	Hassayampa Landfill	Arizona
32	Havertown PCP Site	Pennsylvania
33	Hercules Inc. 009 Landfill	Georgia
34	Hertel Landfill	New York
35	Industrial Latex	New Jersey
36	Islip Municipal Sanitary Landfill	New York
37	Joseph Forest Products	Oregon
38	Juncos Landfill	Puerto Rico
39	Kin-Buc Landfill	New Jersey
40	Lagrande Sanitary Landfill	Minnesota
41	Lee Chemical	Missouri
42	Lehigh Portland Cement	Iowa
43	MacGillis & Gibbs Co./Bell Lumber & Pole	Minnesota
44	Main Street Well Field	Indiana
45	Mattiace Petrochemicals Company	New York
46	Michigan Disposal Service (Cork St. Landfill)	Michigan
47	Mosley Road Sanitary Landfill	Oklahoma
48	Oklahoma Refining Co.	Oklahoma
49	Pacific Coast Pipe Lines	California
50	Pasley Solvents & Chemical Inc.	New York

51	Peerless Plating Co., Inc.	Michigan
52	Peoples Natural Gas Co.	Iowa
53	Pester Refinery Co.	Kansas
54	Potter's Septic Tank Service Pits	North Carolina
55	Preferred Plating Corp.	New York
56	PSC Resources	Massachusetts
57	Ramapo Landfill	New York
58	Raymark	Pennsylvania
59	Resin Disposal Site	Pennsylvania
60	Revere Textile Prints Corp.	Connecticut
61	Rockaway Boro Wellfield	New Jersey
62	Roebling Steel Co.	New Jersey
63	Rowe Industries Groundwater Contamination	New York
64	Saunders Supply Co.	Virginia
65	South Andover Sites	Minnesota
66	Spickler Landfill	Wisconsin
67	Standard Auto Bumper	Florida
68	Sturgis Municipal Wells	Michigan
69	Sullivan's Ledge	Massachusetts
70	Swope Oil & Chemical Co.	New Jersey
71	Tonolli Corp.	Pennsylvania
72	Union Pacific Railroad Yard	Idaho
73	Valley Wood Preserving Inc.	California
74	Verona Well Field	Michigan
75	Westinghouse Electric (Sunnyvale Plant)	California
76	Witco Chemical Corp. (Oakland Plant)	New Jersey
77	Woodbury Chemical Co. (Princeton Plant)	Florida

APPENDIX B

Table 1
Distribution of Pathways by Risk Assessment Categories

Risk Assessment Category	% Total Pathways (N=1430)	% Cancer Pathways (N=1015)	% Noncancer Pathways (N= 415)
Scenario			
current	27.8	30.5	21.0
future	72.2	69.5	79.0
Exposed Population			
residential	73.2	71.2	78.1
worker	17.4	17.8	16.4
recreational	3.6	3.8	3.1
trespasser	5.8	7.2	2.4
Age Group			
adult	62.7	65.3	56.4
child	37.3	34.7	43.6
Location of Population			
onsite	69.2	70.2	66.7
offsite	23.2	23.3	22.9
not indicated	7.6	6.5	10.4
Location of Medium			
onsite	79.6	80.3	77.8
offsite	13.7	14.3	12.3
not indicated	6.7	5.4	9.9

Table 1 (continued)

Exposure Medium			
air (from soil)	9.0	9.0	8.9
air (from water)	9.0	10.4	5.3
soil	33.6	38.2	22.2
groundwater	37.2	30.8	52.8
surface water	1.0	1.1	0.7
sediment	5.2	5.7	3.9
biota	3.6	2.9	5.3
structures	0.1	0.2	—
sludge	0.8	0.9	0.5
combination	0.3	0.4	—
leachate	0.1	0.2	—
mothers' milk	0.3	0.2	0.5
Exposure Route			
ingestion	58.4	53.7	69.9
dermal contact	22.6	25.7	14.9
inhalation (vapor phase chemicals)	13.0	14.6	9.4
inhalation (dust)	5.7	5.8	5.3
inhalation/dermal	0.3	0.2	0.5

APPENDIX B
Table 2

Distribution of Pathways by Scenario and Exposed Population Percentage of Total Pathways (N=1430)

Exposed Population

Scenario	Residential	Worker	Recreational	Trespasser
current	13.85	6.43	1.96	5.52
future	59.37	10.91	1.68	0.28

Distribution of Pathways by Scenario and Population Location Percentage of Total Pathways (N=1430)

Population Location

Scenario	Onsite	Offsite	Not Indicated
current	15.38	10.91	1.47
future	53.78	12.31	6.15

APPENDIX B

Table 3

Distribution of Pathways by Scenario, Population Location, and Exposed Population

Current Exposed Population

Population Location	Exposed Population	% of Scenario Pathways	% of Total Pathways
onsite	resident	18.64	5.18
	worker	20.65	5.74
	recreational user	4.53	1.26
	trespasser	11.59	3.22
offsite	resident	27.20	7.56
	worker	2.27	0.63
	recreational user	2.52	0.70
	trespasser	7.30	2.03
not indicated	resident	4.03	1.12
	worker	0.25	0.07
	recreational user	0.00	0.00
	trespasser	1.01	0.28

Future Exposed Population

Population Location	Exposed Population	% of Scenario Pathways	% of Total Pathways
onsite	resident	59.15	42.71
	worker	12.97	9.36
	recreational user	2.13	1.54
	trespasser	0.19	0.14
offsite	resident	15.88	11.47
	worker	0.97	0.70
	recreational user	0.19	0.14
	trespasser	0.00	0.00
not indicated	resident	7.16	5.17
	worker	1.16	0.84
	recreational user	0.00	0.00
	trespasser	0.19	0.14

APPENDIX B
Table 4
Distribution of Pathways by Exposed Population, Exposure Medium, and Exposure Route*

Exposed Population (5% or higher)	Exposure Medium	Exposure Route	% of Pathways for Exposed Population	% of Total Pathways
Resident N=1047	air (from water)	inhalation (vapor phase chemical)	10.7	7.82
	soil	ingestion	18.6	13.60
	soil	dermal contact	8.8	6.43
	groundwater	ingestion	35.1	25.66
	groundwater	dermal contact	7.7	5.63
Worker N=248	air (from soil)	inhalation (vapor phase chemical)	5.2	0.91
	air (from soil)	inhalation (dust)	10.9	1.96
	soil	ingestion	28.2	4.95
	soil	dermal contact	24.2	4.25
	groundwater	ingestion	21.8	3.76
Recreational User N=52	air (from soil)	inhalation (vapor phase chemical)	15.4	0.55
	soil	ingestion	19.2	0.69
	soil	dermal contact	32.7	1.18
	groundwater	ingestion	7.7	0.28
	sediment	ingestion	7.7	0.28
	sediment	dermal contact	9.6	0.35
Trespasser N=88	soil	ingestion	25.3	1.47
	soil	dermal contact	18.1	1.05
	sediment	ingestion	21.7	1.26
	sediment	dermal contact	10.8	0.63

* Percentages are presented for pathways that accounted for 5% or more of the total number of pathways for a given exposed population.

APPENDIX B
Table 5

Number of Cancer Pathways by Risk Range

1E-6 to 1E-5	1E-5 to 1E-4	1E-4 to 1E-3	1E-3 to 1E-2	1E-2 to 1E-1	1E-1 to 1
301	348	205	103	40	18

Number of Noncancer Pathways by Hazard Index

1 to 10	10 to 100	100 to 1000	greater than 1000
254	126	22	13

APPENDIX B

Table 6
Pathway Mean and Median Cancer Risks by Risk Assessment Category

Risk Assessment Category	Mean	Standard Deviation	Median	N
Overall	7.5E-3	5.6E-2	3.1E-5	1015
Scenario				
current	2.2E-3	1.2E-2	1.9E-5	310
future	9.9E-3	6.7E-2	4.0E-5	705
Exposed Population				
residential	9.2E-3	6.5E-2	3.7E-5	723
worker	4.7E-3	2.9E-2	2.6E-5	180
recreational	2.8E-3	7.6E-3	4.0E-5	39
trespasser	2.8E-4	9.1E-4	9.0E-6	73
Age Group				
adult	8.6E-3	6.3E-2	3.1E-5	663
child	5.5E-3	4.1E-2	3.2E-5	352
Location of Population				
onsite	8.3E-3	5.9E-2	3.4E-5	712
offsite	6.4E-3	5.4E-2	3.0E-5	237
not indicated	3.1E-3	1.6E-2	2.1E-5	66
Location of Medium				
onsite	8.8E-3	6.2E-2	3.5E-5	815
offsite	2.1E-3	1.4E-2	2.0E-5	145
not indicated	3.7E-3	1.7E-2	1.9E-5	55

Table 6 (continued)

Exposure Medium				
air (from soil)	3.8E-3	1.9E-2	1.7E-5	91
air (from water)	1.5E-3	9.2E-3	2.9E-5	106
soil	6.5E-3	6.1E-2	2.1E-5	388
groundwater	1.2E-2	6.8E-2	1.6E-4	313
surface water	2.7E-4	7.6E-4	4.4E-5	11
sediment	7.1E-4	2.3E-3	1.9E-5	58
biota	2.7E-2	8.5E-2	4.4E-5	29
structures	1.0E-4	1.4E-4	1.0E-4	2
sludge	3.1E-3	8.3E-3	2.0E-4	9
combination	9.0E-6	3.0E-6	9.0E-6	4
leachate	5.0E-6	0.0	5.0E-6	2
mothers' milk	7.0E-2	9.9E-2	7.0E-2	2
Exposure Route				
ingestion	9.2E-3	5.6E-2	4.5E-5	545
dermal contact	8.2E-3	7.3E-2	2.1E-5	261
inhalation (vapor phase chemicals)	3.2E-3	1.7E-2	3.1E-5	148
inhalation (dust)	4.5E-4	1.5E-3	1.7E-5	59
inhalation/dermal	7.1E-5	3.9E-5	7.1E-5	2

APPENDIX B
Table 7
Distribution of Cancer Pathway Risks

(N=1015)

Panel A: Breakdown by Scenario and Exposed Population

Exposed Population

Scenario	**Residential** count mean median	**Worker** count mean median	**Recreation** count mean mediat	**Trespasser** count mean median
current	145 3.0E-3 1.9E-5	74 2.5E-3 2.1E-5	22 1.1E-3 3.7E-5	69 3.0E-4 1.2E-5
future	578 1.1E-2 4.3E-5	106 6.2E-3 3.0E-5	17 5.0E-3 8.8E-5	4 4.0E-6 4.0E-6

Panel B: Breakdown by Scenario and Population Location

Population Location

Scenario	**Onsite** count mean median	**Offsite** count mean median	**Not Indicated** count mean median
current	173 1.6E-3 2.2E-5	121 2.5E-3 1.7E-5	16 5.7E-3 6.7E-6
future	539 1.0E-2 3.6E-5	116 1.0E-2 5.9E-5	50 2.3E-3 6.7E-5

APPENDIX B

Table 8
Distribution of Cancer Pathway Risks by Scenario, Population Location, and Exposed Population

Exposed Population

Scenario	**Population Location**	**Resident** count mean median	**Worker** count mean median	**Recreation User** count mean median	**Trespasser** count mean median
current	onsite	52 1.1E-3 3.7E-5	66 2.8E-3 2.1E-5	13 1.8E-3 4.3E-5	42 2.9E-4 1.2E-5
	offsite	82 3.6E-3 1.7E-5	7 4.4E-4 6.0E-5	9 1.1E-4 1.4E-5	23 3.6E-4 2.6E-5
	not indicated	11 8.3E-3 7.9E-6	1 1.0E-6 1.4E-6	—	4 9.0E-6 5.6E-6
future	onsite	431 1.1E-2 4.0E-5	91 7.1E-3 2.9E-5	15 5.6E-3 8.8E-5	2 5.0E-6 4.8E-6
	offsite	106 1.1E-2 6.0E-5	8 2.2E-4 3.1E-5	2 5.5E-4 5.5E-4	—
	not indicated	41 2.5E-3 9.3E-5	7 1.4E-3 2.0E-5	—	2 3.0E-6 3.1E-6

APPENDIX B

Table 9

Distribution of Cancer Pathway Risks by Exposed Population, Exposure Medium, and Exposure Route

Exposure Medium
count
mean
median

Exposed Population	Exposure Route	air (soil)	air (water)	soil	ground-water	surface water	sediment	biota	structures	sludge	combination	leachate	mothers' milk
Residential	ingestion	—	—	160 2.2E-3 2.0E-5	193 1.7E-2 3.3E-4	3 9.0E-4 1.4E-4	11 1.0E-3 3.3E-4	28 2.7E-2 3.8E-5	—	3 9.0E-3 1.0E-3	2 1.1E-5 1.1E-5	—	2 7.0E-2 7.0E-2
	dermal	—	1 1.6E-5 1.6E-5	73 2.2E-2 5.4E-5	66 1.4E-3 8.0E-6	5 3.1E-5 4.4E-5	11 3.3E-4 4.0E-6	—	—	2 1.0E-4 1.0E-4	2 7.0E-6 7.0E-6	—	—
	inhalation (vapor phase chemical)	19 1.3E-2 3.1E-5	93 1.5E-3 3.7E-5	—	11 3.0E-4 7.0E-6	—	—	—	—	—	—	—	—
	inhalation (dust)	35 6.3E-4 1.7E-5	1 2.6E-5 2.6E-5	—	—	—	—	—	—	—	—	—	—
	inhalation/dermal	—	—	—	2 7.1E-5 7.1E-5	—	—	—	—	—	—	—	—

Table 9 (continued)

Exposed Population	Exposure Route	air (soil)	air (water)	soil	ground-water	surface water	sediment	biota	structures	sludge	combination	leachate	mothers' milk
Worker	ingestion	—	—	54 2.3E-3 1.5E-6	32 8.1E-3 1.8E-4	—	2 5.1E-3 5.1E-3	—	1 2.0E-4 2.0E-4	—	—	—	—
	dermal	—	—	48 8.3E-3 2.4E-5		5 1.0E-5 3.0E-6	—	2 5.1E-3 5.1E-3	—	—	—	—	—
	inhalation (vapor phase chemical)	9 2.3E-3 1.7E-5	8 2.5E-3 3.5E-5	—	—	—	—	—	—	—	—	—	—
	inhalation (dust)	18 1.2E-5 7.0E-6	1 1.0E-5 1.0E-5	—	—	—	—	—	—	—	—	—	—
Recreational	ingestion	—	—	8 1.6E-5 1.3E-5	2 3.0E-2 3.0E-2	—	4 5.0E-6 3.0E-6	—	—	—	—	—	—
	dermal	—	—	12 4.0E-4 2.3E-4	—	1 1.0E-6 1.0E-6	5 4.2E-5 3.4E-5	—	—	—	—	—	—
	inhalation (vapor phase chemical)	4 1.1E-2 1.1E-2	2 6.0E-6 6.0E-6	—	—	—	—	—	—	—	—	—	—
	inhalation (dust)	1 1.1E-3 1.1E-3	—	—	—	—	—	—	—	—	—	—	—

Table 9 (continued)

Exposed Population	**Exposure Route**	**air (soil)**	**air (water)**	**soil**	**ground-water**	**surface water**	**sediment**	**biota**	**structures**	**sludge**	**combination**	**leachate**	**mothers' milk**
Trespasser	ingestion	—	—	19 1.7E-4 1.2E-5	—	—	15 3.0E-4 9.0E-6	1 2.3E-3 2.3E-3	1 8.0E-6 8.0E-6	2 1.7E-4 1.7E-4	—	2 5.0E-6 5.0E-6	—
	dermal	—	—	14 5.4E-4 2.3E-5	2 3.0E-6 3.0E-6	2 5.4E-5 5.4E-5	8 1.5E-4 1.9E-5	—	—	2 1.8E-5 1.8E-5	—	—	
	inhalation (vapor phase chemical)	2 3.0E-6 3.0E-6	—	—	—	—	—	—	—	—	—	—	—
	inhalation (dust)	3 3.5E-4 7.0E-6	—	—	—	—	—	—	—	—	—	—	—

APPENDIX B
Table 10
Risk-Weighted Shares of Cancer Pathway Risks

Risk Assessment Category	% of Total Cancer Pathway Risk	% of Future Cancer Pathway Risk	% of Current Cancer Pathway Risk
Scenario			
current	8.8		100.0
future	91.2	100.0	
Age Group			
adult	74.9	74.5	78.5
child	25.1	25.5	21.5
Exposed Population			
residential	87.3	89.4	65.6
worker	11.0	9.4	27.7
recreational user	1.4	1.2	3.6
trespasser	0.2	0.0	3.1
Location of Population			
onsite	77.5	81.0	40.9
offsite	19.9	17.4	45.4
not indicated	2.7	1.6	13.7
Exposure Medium			
air (from soil)	4.5	4.2	7.3
air (from water)	2.1	2.0	3.1
soil	32.9	34.2	19.4
groundwater	47.7	49.1	32.8
surface water	0.0	0.0	0.0
sediment	0.5	0.5	1.0
biota	10.0	7.5	36.5
structures	0.0	0.0	0.0

Table 10 (continued)

sludge	0.3	0.3	0.0
combination	0.0	0.0	0.0
leachate	0.0	0.0	0.0
mothers' milk	1.8	2.0	0.0
Exposure Route			
ingestion	65.4	64.6	74.1
dermal exposure	28.0	29.2	15.6
inhalation (vapor phase)	6.2	5.9	9.4
inhalation (dust)	0.3	0.3	0.9
ingestion/dermal combination	—	—	—
inhalation/dermal combination	0.0	—	—

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Table 11
Percentage of Cancer Risks by Exposure Medium, by Risk Assessment Scenario*

Exposure Medium

Scenario	air (soil)	air (water)	soil	ground-water	surface water	sediment	biota	sludge	mothers' milk
current, onsite, adult, worker	11.3	10.7	58.1	19.8	—	—	—	—	—
future, onsite, adult, resident	3.3	3.9	32.3	44.1	0.1	0.0	15.5	0.8	—
future, onsite, adult, worker	0.3	0.0	63.8	32.7	—	3.1	—	—	—
future, onsite, child, resident	9.8	0.2	55.9	24.2	0.0	0.9	0.0	0.1	9.0
future, offsite, adult, resident	0.3	0.2	0.2	99.3	0.0	0.0	0.0	—	—

* Scenarios for pathways were defined by timeframe, population location, age group, and exposed population. Results are presented for scenarios with 50 or more observations in the data base.

APPENDIX B
Table 12
Percentage of Risks by Exposure Route, by Risk Assessment Scenario*

Exposure Route

Scenario	**Ingestion**	**Dermal**	**Inhalation (vapor phase chemical)**	**Inhalation (dust)**
current, onsite, adult, worker	52.0	25.9	21.3	0.7
future, onsite, adult, resident	64.3	28.6	6.8	0.4
future, onsite, adult, worker	44.4	55.3	0.2	0.1
future, onsite, child, resident	48.2	41.7	10.1	0.0
future, offsite, adult, resident	95.8	3.8	0.2	0.3

* Scenarios for pathways were defined by timeframe, population location, age group, and exposed population. Results are presented for scenarios with 50 or more observations in the data base.

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Table 13
Distribution of Maximum Site Pathways by Risk Assessment Categories*

Risk Assessment Category	% Cancer Pathways (N=86)	% Noncancer Pathways (N=73)
Scenario		
current	20.9	13.7
future	79.1	86.3
Exposed Population		
residential	84.9	95.9
worker	15.1	2.7
recreational	—	—
trespasser	—	1.4
Age Group		
adult	86.0	41.1
child	14.0	58.9
Location of Population		
onsite	69.8	64.4
offsite	23.3	28.8
not indicated	7.0	6.8
Location of Medium		
onsite	83.7	79.5
offsite	9.3	13.7
not indicated	7.0	6.8
Exposure Medium		
air (from soil)	3.5	6.8
air (from water)	7.0	1.4
soil	19.8	6.8
groundwater	65.1	76.7
surface water	—	1.4
sediment	2.3	1.4

Table 13 (continued)

biota	2.3	4.1
structures	—	—
sludge	—	—
combination	—	—
leachate	—	—
mothers' milk	—	1.4
Exposure Route		
ingestion	77.9	89.0
dermal contact	11.6	2.7
inhalation (vapor phase chemicals)	8.1	4.1
inhalation (dust)	2.3	4.1
ingestion/dermal	—	—
inhalation/dermal	—	—

* This count may not equal the number of sites for two reasons. First, some sites do not have a unique maximum risk. In this case all maximum risks were included. Second, some sites may lack either carcinogenic risk or noncarcinogenic risk.

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Table 14
Distribution of Maximum Pathway Cancer Risks Across Sites, by Scenario and Exposure Route

Scenario

Exposure route	**Current** # sites mean median	**Future** # sites mean median
ingestion	12 2.6E-2 4.5E-3	55 5.3E-2 2.0E-3
dermal	4 1.1E-2 7.9E-3	6 1.6E-1 1.1E-3
inhalation (vapor)	2 2.3E-4 2.3E-4	5 3.9E-4 1.1E-4
inhalation (dust)	—	2 5.0E-3 5.0E-3
ingestion/dermal	—	—
inhalation/dermal	—	—

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Table 15
Distribution of Maximum Pathway Cancer Risks Across Sites, by Scenario, Exposed Population, and Population Location

CURRENT
(N=18)
Population Location

Exposed Population	**Onsite** # sites mean risk median	**Offsite** # sites mean risk median	**Not Indicated** # sites mean risk median
resident	6 7.1E-3 1.3E-3	3 4.4E-2 1.1E-3	1 9.1E-2 9.1E-2
worker	7 1.2E-2 1.1E-2	1 2.8E-3 2.8E-3	—
recreational	—	—	—
trespasser	—	—	—

FUTURE
(N=67)
Population Location

Exposed Population	**Onsite** # sites mean risk median	**Offsite** # sites mean risk median	**Not Indicated** # sites mean risk median
resident	42 6.7E-2 2.2E-3	16 5.7E-2 1.1E-3	5 1.9E-2 1.5E-3
worker	5 9.7E-3 2.0E-3	—	—
recreational	—	—	—
trespasser	—	—	—

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Table 16
Distribution of Current Maximum Site Cancer Pathways
N=80

Panel 1: By Exposure Route

Route

Ingestion # pathways mean median	**Dermal** # pathways mean median	**Inhalation (vapor)** # pathways mean median	**Inhalation (dust)** # pathways mean median	**Ingest/ dermal** # pathways mean median	**Inhal/ dermal** # pathways mean median
45 1.1E-2 5.0E-4	19 5.4E-3 1.1E-4	9 2.2E-3 2.2E-5	7 1.6E-4 1.7E-5	—	—

Panel 2: By Exposed Population and Population Location

Exposed Population

Population Location	**Resident** # pathways mean median	**Worker** # pathways mean median	**Recreation** # pathways mean median	**Trespasser** # pathways mean median
onsite	12 4.3E-3 5.6E-4	23 1.3E-2 2.6E-4	2 7.2E-5 7.2E-5	8 4.3E-4 7.4E-5
offsite	22 8.9E-3 1.8E-4	2 1.4E-3 1.4E-3	1 5E-4 5E-4	5 1.3E-3 5.8E-5
not indicated	5 3.7E-2 3.9E-4	—	—	—

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Table 17
Distribution of Future Maximum Site Cancer Pathways
N=82

Panel 1: By Exposure Route

Route

Ingestion # pathways mean median	**Dermal** # pathways mean median	**Inhalation (vapor)** # pathways mean median	**Inhalation (dust)** # pathways mean median
65 4.7E-2 1.9E-3	7 1.4E-1 1.0E-4	7 3.6E-4 2.1E-4	3 3.9E-3 1.6E-3

Panel 2: By Exposed Population and Population Location

Exposed Population

Population Location	**Resident** # pathways mean median	**Worker** # pathways mean median	**Recreation** # pathways mean median	**Trespasser** # pathways mean median
onsite	48 5.9E-2 1.82E-3	7 1.21E-2 2.00E-3	—	—
offsite	21 4.35E-2 1.0E-3	—	—	—
not indicated	6 3.12E-2 1.77E-3	—	—	—

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Table 18
Top 25 Carcinogens

Chemical	Frequency	% of Total Chemical Cancer Pathways	Average Cancer Risk
arsenic	515	9.07	2.8E-3
beryllium	309	5.44	5.9E-5
trichloroethylene	283	4.98	3.3E-4
benzene	269	4.74	5.6E-5
tetrachloroethylene	248	4.37	7.7E-4
benzo(a)anthracene	244	4.30	5.5E-4
chrysene	242	4.26	5.6E-4
benzo(a)pyrene	215	3.79	1.0E-3
benzo(b)fluoranthene	213	3.75	5.4E-4
di(2-ethylhexyl)phthalate	205	3.61	6.4E-5
benzo(k)fluoranthene	197	3.47	1.0E-3
indeno(1,2,3-cd)pyrene	183	3.22	9.2E-5
dibenzo(a,h)anthracene	139	2.45	3.5E-5
methylene chloride	131	2.31	1.4E-3
Aroclor 1260	129	2.27	1.8E-2
aldrin	128	2.25	3.5E-5
1,1-dichloroethene	126	2.22	2.1E-3
vinyl chloride	123	2.17	4.0E-3
Aroclor 1254	117	2.06	5.1E-6
pentachlorophenol	104	1.83	1.8E-3
chloroform	90	1.59	2.0E-4
polychlorinated biphenyls	83	1.46	3.5E-3
2,6-dinitrotoluene	80	1.41	3.6E-5
1,2-dichloroethane	76	1.34	4.2E-4
hexachlorobenzene	75	1.32	6.2E-6

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Table 19
Top 25 Noncarcinogens

Chemical	Frequency	% of Total Chemical Noncancer Pathways	Average Hazard Quotient
arsenic	204	6.55	18.49
manganese	163	5.23	2.29
barium	160	5.14	0.42
nickel	118	3.79	1.41
vanadium	116	3.73	0.39
cadmium	114	3.66	2.90
zinc	108	3.47	0.29
mercury, metallic	99	3.18	0.82
chromium	98	3.15	237.30
antimony	94	3.02	3.98
di(2-ethylhexyl)phthalate	87	2.79	0.61
chromium, hexavalent	76	2.44	10.51
napthalene	74	2.38	12.95
ethyl benzene	70	2.25	5.21
tetrachloroethylene	67	2.15	7.70
toluene	65	2.09	0.91
total xylenes	60	1.93	1.85
copper	57	1.83	0.31
beryllium	53	1.70	0.04
1,1,1-trichloroethane	49	1.57	0.47
acetone	48	1.54	2.12
chromium, trivalent	47	1.51	4329.00
1,1-dichloroethene	45	1.45	1.36
methylene chloride	42	1.35	10.21
benzene	39	1.25	43.26

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Table 20
Percentage of Total Cancer Risk by Chemical

Chemical	Total Cancer Risk %	Average Cancer Risk
Aroclor 1260	31.0	1.8E-2
arsenic	17.6	2.8E-3
2,3,7,8-tetrachlorodibenzo-p-dioxin	6.5	8.7E-3
vinyl chloride	6.5	4.0E-3
carbon tetrachloride	4.6	8.0E-3
chromium	4.1	1.4E-2
polychlorinated biphenyls	3.8	3.5E-3
1,1-dichloroethene	3.4	2.1E-3
benzo(a)pyrene	2.9	1.0E-3
benzo(k)fluoranthene	2.7	1.1E-3
tetrachloroethylene	2.5	7.7E-4
pentachlorophenol	2.5	1.8E-3
methylene chloride	2.4	1.4E-3
chrysene	1.8	5.6E-4
benzo(a)anthracene	1.7	5.5E-4
benzo(b)fluoranthene	1.5	5.4E-4
trichloroethylene	1.2	3.3E-4

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Table 21
Percentage of Total Cancer Risk by Chemical and by Exposure Medium*

Medium	Chemical	% per-Medium Cancer Risk	Average per-Medium Cancer Risk
air (from soil)	chromium	90.6	1.4E-2
	asbestos	3.8	6.5E-2
	arsenic	1.7	1.3E-4
	methylene chloride	1.6	3.7E-4
	trichloroethylene	1.3	3.7E-3
air (from water)	1,1-dichloroethene	83.7	3.4E-3
	benzene	4.9	1.1E-3
	trichloroethylene	3.1	5.4E-5
	vinyl chloride	2.4	1.0E-4
	chloroform	1.8	9.9E-5
	methylene chloride	1.1	5.0E-5
soil	Aroclor 1260	91.0	2.0E-2
	polychlorinated biphenyls	1.8	1.1E-3
	arsenic	1.5	1.6E-4
	benzo(k)fluoranthene	1.3	2.4E-4
groundwater	arsenic	35.3	8.8E-3
	vinyl chloride	13.4	6.0E-3
	2,3,7,8-tetrachlor-dibenzo-p-dioxin	9.6	3.9E-2
	carbon tetrachloride	9.6	2.0E-2
	tetrachloroethylene	5.1	1.4E-3
	pentachlorophenol	5.1	1.0E-2
	methylene chloride	4.8	2.6E-3
	1,1-dichloroethene	4.3	1.8E-3
	benzo(a)pyrene	3.0	7.2E-3
	trichloroethylene	2.3	5.7E-4
	Aroclor 1260	2.1	7.5E-3

* Only chemicals contributing 1% or more of the per-medium cancer risk are included.

Table 21 (continued)

surface water	arsenic	75.3	5.4E-4
	beryllium	20.6	1.5E-4
	methylene chloride	3.7	5.4E-5
sediment	carcinogenic PAHs	95.1	2.8E-3
biota	polychlorinated biphenyls	31.4	1.2E-1
	benzo(k)fluoranthene	20.7	2.3E-2
	benzo(b)fluoranthene	13.2	7.8E-3
	benzo(a)pyrene	11.7	1.0E-2
	chrysene	11.1	5.3E-3
	benzo(a)anthracene	11.0	5.6E-3
sludge	chrysene	22.7	1.3E-3
	benzo(a)anthracene	20.4	1.1E-3
	benzo(a)pyrene	18.4	1.7E-3
	benzo(b)fluoranthene	18.4	1.7E-3
	benzo(k)fluoranthene	18.4	1.7E-3
leachate	Aroclor 1254	64.2	3.2E-6
	arsenic	35.8	1.8E-6
	benzo(k)fluoranthene	5.3	4.8E-7
	chrysene	5.3	4.8E-7
	benzo(a)pyrene	4.9	4.5E-7
	benzo(a)anthracene	4.9	4.4E-7
	indeno(1,2,3-cd)pyrene	3.9	4.7E-7