Chapter 1

Introduction and Summary

INTRODUCTION

About 100 waste sites across the United States contain serious dioxin contamination; 18 of these, in 10 States, are Superfund sites.[1] Treating dioxin contamination at these sites is both costly and difficult. Current cleanup standards require that treatment reduce dioxin residuals to very low levels.[2] The allowable level of residuals is so strict because of past studies and the Environmental Protection Agency's (EPA) assessment that dioxin poses a serious cancer hazard. Recently, EPA has decided to reevaluate dioxin's toxicity and its regulatory requirements,[3] however, currently approved cleanup projects and most of those planned must meet the current standard.

The term dioxin encompasses all aromatic organic chemicals known as dibenzo-p-dioxins. The dibenzo-p-dioxins of greatest concern to public and environmental health belong to a group of chemicals called halogenated dioxins. Because they are most common, the 75 chlorinated dioxins that contain one or more chlorine atoms in their molecular structure are the form given most attention.[4] Dioxins are extremely insoluble in water and slightly soluble in organic solvents. They have a strong affinity for absorption on organic matter and are very biologically and environmentally stable.[5] Therefore, as environmental contaminants, they persist for long periods of time.

Dioxins are undesirable byproducts formed during the manufacture of some useful chemicals such as chlorophenols, chlorobenzenes, and chlorophenoxyl pesticides. Almost all dioxin-containing products are no longer manufactured.[6] For example, Dow Chemical and Vertac ceased production of phenoxy herbicides in 1979 and 1983, respectively. However, past use has resulted in contamination of a variety of sites. Dioxin contamination is now found primarily in soil and in processing waste containers stored at inactive production sites. Of the 500,000 metric tons of dioxin-contaminated materials reported by EPA in 1986,[8] more than 98 percent consisted of dioxin-contaminated soil; most of the remaining consisted of stored, processed material.

While ***not*** a subject covered in this background paper, there also is public concern about other current sources of dioxin that may result in releases to the environment. For example, dioxin may be formed and subsequently released into the atmosphere during the incineration of trash, garbage, and discards (municipal solid waste) containing chlorinated materials.[9] Plans for studying and controlling

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[1] U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, *National Dioxin* study-Report to Congress, EPA/530/SW-87/025 (Washington, DC: August 1987), p. II-3; "Current National Priorities List" (dioxin sites only); information provided by G. Willey, U.S. EPA, Hazardous Waste Evaluation Division, Site Assessment Branch, June 17, 1991.

[2] The current action level is 1 part per billion ppb) (of 2,3,7,8-tetrachlorodibenzo-p-dixoin (TCCD) equivalents) when the site is in a residential area. When the site is in a nonresidential, nonindustrial area the action level is 20 ppb. The 1 ppb level was established as a response to a Centers for Disease Control risk assessment that established this as a "level of concern." See: R.D. Kimbrough H. Falk, P. Stehr, and G. Fries, "Health Implications of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) of Residual Soil," *J. Toxicol. Environ. Health, vol. 14, 1984,* pp. *49-93.*

[3] *EPA is currently reviewing the potnency* of dioxin. A reevaluation report Written by the Office of Research and Development With the help of outside scientists will be completed next year. See: David J. Hanson "Dioxin Toxicity: New Studies Prompt Debate, Regulatory Action," *Chemical & Engineering News,* Aug. 12, 1991, pp. 7-14.

[4] The most toxic of the chlorinated dioxins is 2,3,7,8-TCDD. In addition to 2,3,7,8 -TCDD, other products of concern include chlorinated dibenzofurans (CDFs), chlorophenols, chlorobenzenes, and chlorophenoxy compounds.

[5] U.S. Environmental Protection Agency, Hazardous Waste Engineering Research Laboratory, *Treatment Technologies for Dioxin-Containing Wastes, EPA/600/2-86/096 (Cincinnati,* OH: October 1986), pp. 1.3-1.4, 3.4-3.7; D. Oakland, "Dioxins: Sources, Combustion Theories & Effects," London Scientific Services, 54th Annual NSCA Conf. Proc., Brighton, U.K., 1987.

[6] The one exception in the United States is pentachlorophenol (PCP). EPA estimates that current PCP production at Vulcan Chemicals in Wichita, KS, may be responsible for the generation of up to 5,000 pounds of dioxins and other related chemicals annually; however, these chemicals are generally contained within the treated wood produced at the plant.

[7] 2,4,5 -trichlorophenol.

[8] U.S. Environmental Protection Agency, op. cit., footnote 5.

[9] For a complete discussion on the potential routes or pathways by which humans may be exposed to dioxin emissions from incinerators, see: G.F. Fries and D.J. Paustenbach, "Evaluation of Potential Transmission of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin-contaminated Incinerator Emission to Humans Via Foods," *J. Toxicol. Environ. Health,* vol. *29,* 1990, pp. 1-43.

dioxin emissions from municipal waste incinerators were recently published by EPA.[10] Another dioxin source is the manufacturing and chlorine bleaching of pulp and paper products. Some dioxin containing effluents are discharged from pulp and paper plants into surface waters. Dioxin contamination is also found at abandoned paper production plants and at paper waste disposal sites.[11]

In the past, a variety of incidents have led to dioxin contamination of the environment. A few examples of such incidents include: the accidental discharge of dioxin from a trichlorophenol/hexachlorophene production plant in Seveso, Italy; dioxin contamination of large quantities of soil at a Gulfport, Mississippi, Naval Ship Yard Repair Base from the leakage of stored drums of Agent Orange; and the use of dioxin-containing still-bottom waste oils[12] as a road dust suppressant in towns such as Times Beach, Missouri. Contamination of soil has also occurred in areas where dioxin-contaminated herbicides were used for vegetation control or where material from these contaminated areas was used for construction purposes.[13]

Human health effects from exposure to dioxin have been studied by scientists for about two decades. Animal studies showed dioxin to be the most potent carcinogen ever tested. However, studies of humans exposed to low doses of dioxin have not demonstrated excess cancers among these groups.[14] A recent epidemiologic study of chemical workers at 12 plants in the United States exposed to dioxin, however, does provide evidence of carcinogenic effects following chronic exposure to relatively high doses.[15] Scientists are now debating a relatively new theory about the action of dioxin on a molecular level, and some believe that the outcome of this debate could change the way EPA estimates the levels of dioxin exposure that are dangerous to human health. At present, Environmental Protection Agency standards for dioxin exposure are generally considered conservative and are much lower than those recommended by the World Health Organization and most other countries' regulatory agencies.[16] Whether or when exposure limits in the United States will change, however, is not known and has not been analyzed by OTA for the purposes of this background paper.

Nevertheless, exposure of humans to dioxin continues to be of great public concern. For many reasons, sites with dioxin-contaminated soil have been studied for a long time, but no actual cleanup work has begun. Because communities surrounding these sites have been told of the dangers of dioxin and have been convinced that something needs to be done, they have been disappointed that so few remedial actions have occurred. Further, since they have read that no technology can totally destroy dioxin or that some technologies can pose other health hazards, the public is understandably skeptical of technological solutions now being proposed.

Because of the public's concern, OTA was asked to prepare an analysis of alternative technologies for

[10] U.S. Environmental Protection Agency, Office of Research and Development Office of Environmental Engineering and Technology Demonstration, *Municipal Solid Waste Research Agenda (Washington* DC: April 1991), p. 32.

[11] For a comprehensive analysis of the environmental effect associated with the pulp and paper making industry and technologies available for reducing dioxin releases, see: Office of Technology Assessment, *Technologies for Reducing Dioxin in the Manufacture of Bleached Wood Pulp-Background Paper, OTA-BP-O-54 (Washington DC:* U.S. Government Printing Mice, May 1989).

[12] In some cases, still-bottom residues were mixed with waste oil from a variety of sources, probably largely used crankcase oil; and in at least one other case, it is suspected, undiluted still-bottoms themselves were applied directly to roads and horse arenas.

[13] M.A. Karin and P.W. Rodgers (~.), *Dioxins in the Environment* (New York, NY: Hemisphere Publishing Inc., 1985); S. Cerlesi, A. Di Domenico and S. Ratti, "2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) Persistence in the Seveso (Milan, Italy) Soil," *Ecotox. Environ. Safety,* vol. 18, 1989, pp. 149-164; A. Di Domenico, G. Viviono, and G. Zapponi, "Environmental Persistence of 2,3,7,8-TCDD at Seveso," in O. Hutzinger, RW. Frei, E. Merion, and F, Pocchiari (eds.), *Chlorinated Dioxins and Related Compounds: Impact on the Environment (New York, NY:* Pergamon Press, 1982), pp. 105-144; D.A. Oberacker, J.J. Cudahy, and M.K. Richards, "Remediation (Clean Up) of Contaminated Uncontrolled Superfund Dumpsites by Incineration and Other Popular Technologies," 1991 (paper submitted for publication).

[14] Michael Gough, "Human Health Effects: What the Data Indicate," *The Science of the Total Environment, vol.* 104, undated, pp. 129-158, 1991; G.F. Fries and D.J. Paustenbach, "Evaluation of Potential Transmission of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin-Contaminated Incinerator Emissions to Humans Via Foods," *J. Toxicol. Environ. Health,* vol. 29, 1990, pp. 1-43; D.J. Paustenbach et al., "Recent Developments on the Hazards Posed by 2,3,7,8-tetrachlorodibenzo-*p*-dioxin in Soil: Implications for Setting Risk-Based Cleaning Levels at Residential and Industrial Sites," this paper was submitted for publication to the *J. Toxicol. Environ. Health,* June 1991.

[15] M.A. Fingerhut, W.A. Haperin, D.A. Marlow, et al., "Cancer Mortality in Workers Exposed to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin,' 'New England *Journal of Medicine,* vol. 324, No. 4, Jan. 24, 1991, pp. 212-218.

[16] The World Health Organization is the coordinating agency of the United Nations responsible for international health work. Some Of the activities carried out by WHO include: providing advice and practical assistance to national governments to strengthen their national health services; providing means to control or eradicate major disease; and improving sanitation.

Table I-I—Dioxin-Contaminated Sites on the National Priorities List as of Mar. 14, 1991 (effective date of Revised Hazard Ranking System)

		Observed release		
Site name[a]	Location	Ground-water	Surface water	Air
Standard Steel & Metal Salvage Yard	Anchorage, AK	No	No	No
Arkwood, Inc.	Omaha, AR	No	No	No
Jacksonville Municipal Landfill	Jacksonville, AR	No	No	No
Rogers Road Municipal Landfill	Jaoksonville, AR	No	No	No
Vertac, inc.	Jacksonville, AR	No	Yes	Yes
Wedzeb Enterprises, inc.	Lebanon, IN	No	No	No
Parsons Chemical Works, inc.	Grand Ledge, MI	No	Yes	No
Minker/Stout/Romaine Creek	Imperial, MO	No	Yes	Yes
Shenandoah Stables	Moscow Mills, MO	No	No	Yes
Syntex Agribusiness, Inc.	Verona, MO	Yes	Yes	No
Times Beach site	Times Beach, MO	No	No	No
Brook industrial Park	Bound Brook, NJ	Yes	No	No
Diamond Aikali Co.	Newark, NJ	No	No	Yes
Hooker (Hyde Park)	Niagara Falls, NY	No	Yes	Yes
Love Canal	Niagara Falls, NY	No	Yes	No
Mallory Capacitor Co.	Waynesboro, TN	No	No	No
Saunders Supply Co..	Chuckatuck, VA	No	No	No
Centralia Municipal Landfill	Centralia, WA	No	No	No

[a]Several other Superfund sites known to contain dioxin contamination (e.g., Baird & McGuire in Holbrook, Massachusetts) were excluded because dioxin was not the only reason for their inclusion by EPA on the National Priorities List.

SOURCE: "Current National Priorities List" (dioxin sites only), and supplementary information communicated by G. Willey, U.S. Environmental Protection Agency, Hazardous Site Evaluation Division, Site Assessment Branch, June 17 and Sept. 12, 1991.

treating soil and other materials contaminated by dioxin. This analysis is thus focused on the efficacy, availability, and merits of various technologies that could be used to treat dioxin contamination. This report evaluates the various technologies that are proven and readily available to be applied as well as those still in the research stage. It compares the advantages and limitations of these technologies, and explores the factors that will determine whether they may actually be applied to a dioxin cleanup operation.

This OTA background paper, however, is not meant to represent a complete summary of all potentially applicable technologies that have been developed to date but is a review of those treatment processes with most promise to treat dioxin-contaminated soils.

Table 1-1 lists the contaminated sites known to contain dioxin that EPA has placed on the National Priorities List (NPL) for cleanup (also known as Superfund sites). These sites represent the major dioxin cleanup challenges that the technologies covered in this paper would address.

Federal Efforts To Address the Dioxin Problem

The potential hazard posed by dioxin has been addressed by Federal and State agencies in a number of ways for about 25 years. It has been identified as a toxic substance, advanced notification and treatment requirements for dioxin disposal have been written, a national dioxin strategy has been established, and incineration has been selected as the preferred technology for dioxin destruction. Table 1-2 contains a chronological description of major regulatory activities carried out in the United States since 1966 to address the dioxin problem.

In November 1983, EPA issued its national strategy to investigate, identify, and remediate

Table 1-2—Major Regulatory Initiatives To Address Dioxin

1966: U.S. Department of Agriculture (USDA) and the Food and Drug Administration (FDA) establish residue tolerance for the herbicide 2,4,5-T in food products.

1974: Centers for Disease Control (CDC) identifies dioxin as the toxic substance in Missouri waste oil.

1976: Resource Conservation and Recovery Act (RCRA), the first Federal law governing waste cleanup or proper disposal is passed.

1979: The Environmental Protection Agency (EPA) issues an emergency suspension order banning use of the phenoxy herbicide 2,4,5-T.

1980: EPA requires advanced notification of disposal of dioxin-contaminated waste. Drums of waste contaminated with dioxin are found on the Denney Farm in Missouri. The first clear evidence that the half-life of dioxin in Missouri soil was much longer than 1 year, based on the laboratory findings obtained at the University of Missouri's Environmental Trace Substances Research Center.[a]

1982: EPA discovers dioxin levels up to 1,200 parts per billion (ppb) in Times Beach, MO, and contamination in 14 other Missouri sites. Meremec River overflows in December, and officials worry about contamination spreading to other sites (it did not).

1983: EPA and Missouri Department of Natural Resources offer to buy Times Beach because of the unavailability of demonstrated treatment technologies and the uncertainty about when cleanup would be completed.

EPA issues a proposed rule allowing disposal of dioxin-contaminated waste only in approved landfills and a "national dioxin strategy" for investigating, identifying, and cleaning up sites contaminated with dioxin (99 sites across the United States were identified with potentially serious dioxin contamination).

1985: RCRA dioxin-listing rule now defines waste streams designated as acutely hazardous. Moreover, this rule replaces the regulation concerning the disposal of waste contaminated with 2,3,7,8-TCDD under the Toxic Substance Control Act (TSCA).

1986: Because dioxin wastes are banned from land disposal under the Hazardous and Solid Waste Amendments (HSWA) of 1984, EPA issues interim rule that these wastes must be treated to a detectable level of 1 ppb in the waste extract for TCDD and five other compounds.They must also be treated to a nondetectable level for 2,4,5-T and three other compounds.

EPA efforts to prevent potential dioxin exposure include regulation of dioxin-containing discharges under the Clean Water Act.

1987: The Risk Assessment Forum of the Environmental Protection Agency develops and publishes 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) Toxicity Equivalent Factors (TEFs).

1988: EPA issues its Record of Decision to employ incineration as a remedial technology at Times Beach, based on results from a research incineration project at Denney Farm, MO. EPA Dioxin Disposal Advisory Group (DDAG) recommends a general approach for the disposition of pentachlorophenol (PCP) and PCBs waste and contaminated soil. The recommended levels of this approach were 1 ppb TCDD equivalents for residential areas and 20 ppb TCDD equivalents for industrial or nonresidential sites.

1990: State of Connecticut issues dioxin ambient air quality standard of 1 picogram per cubic meter (1 picogram = one-trillionth of a gram) to protect the public from combined effects of dioxin from all media, sources, and exposure routes.

1991: EPA orders reevaluation of the risk assessment model for dioxin in light of the increasing scientific data available. This effort will focus primarily on reassessing health effects due to dioxin, gathering new laboratory data, and investigating ecological effects.

[a]Half-lives for dioxin ranging from 25 to 100 years (subsurface soils) and from 9 to 35 years (surface soils) have been suggested since then. Recent efforts to control dioxin emissions, such as Connecticut's dioxin ambient air quality standard, have assumed half-live values for dioxin of nearly 6 years (2,120 days). For more details see: Dennis J. Paustenbach, "Recent Developments on the Hazards Posed by 2,3,7,8-tetrachlorodibenzo-*p*-dioxin in Soil: Implications for Setting Risk-Based Cleanup Levels at Residential and Industrial Sites," paper submitted for publication to *J. Toxicol. & Environ. Health,* June 1991; H.V. Rao and D.R. Brown, "Connecticut's Dioxin Ambient Air Quality Standard," *Risk Analysis,* vol. 1, No. 2, 1990, pp. 597-603.

SOURCES: J.R. Long and D.J. Hanson, "Dioxin Issue Focuses on Three Major Controversies in U.S.," *Chemical & Engineering News, vol. 61,* June 6,1983, p. 25; P.E. des Rosiers, "National Dioxin Study," J.H. Exner (cd.), *Solving Hazardous Waste Problems: Learning From Dioxins, ch. 3,* pp. 34-53, ACS Symposium Series 338, Washington, DC, 1987; R.D. Kimbrough et al., "Health Implications of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) Contamination of Residential Soil, *J. Toxicol. & Environ. Health,* vol. 14, 1984, p. 47; H.V. Rao and D.R. Brown, "Connecticut's Dioxin Ambient Air Quality Standard," *Risk Analysis,* vol. 1, No. 2, 1990, pp. 597-603; U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, *National Dioxin Study-Report to Congress,* EPA/530/SW-87/025 (Washington, DC: August 1987), pp. V1-V5; J.S. Benin and D.G. Barnes, Risk Assessment Forum, "Interim Procedures for Estimating Risks Associated With Exposures to Mixtures of Chlorinated Dibenzo-*p*-dioxins and Dibenzofurans (CDDs and CDFs)," EPA/625/3-87/O12, March 1987; A.F. Yonders, C.E. Orazio, R.K. Puri, and S. Kapila, "On Translocation of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin: Time-Dependent Analysis at the Times Beach Experimental Site," *Chemosphere, vol. 19, 1989,* p. 41a.

dioxin-contaminated areas.[17] Accompanying the congressionally mandated strategy was a plan to conduct research to determine existing contamination levels and available treatment and disposal methods. Evaluation of environmental and human health risks posed by dioxin contamination of various media was also part of the study.

As part of its strategy, EPA identified suspected areas of dioxin contamination by the source of dioxins. By the end of its study, EPA had identified 99 sites across the United States with potentially serious dioxin contamination. As expected, the majority were sites where chlorinated organics had been produced or used in the formulation of pesti-

[17]U.S. Environmental Protection Agency, Office of Water and Office of Solid Waste and Emergency Response in Conjunction With Dioxin Management Task Force, *Dioxin Strategy* (Washington, DC: Nov. 28, 1983).

cides and herbicides, or disposed of on land.[18] As indicated in table 1-3, *9* of the 14 sites with the highest measured levels of dioxin contamination were located in Missouri.

In addition to its high dioxin contamination, the Denney Farm, Missouri, site attracted national attention because it was there that EPA tested and perfected the mobile rotary kiln incineration technology now recommended for dioxin cleanup. The field testing of mobile incineration at Denney Farm started in February 1986 and concluded in June 1989.[19] Since then, this system has been upgraded by commercial firms and employed with success at several small contaminated sites. So far, incineration is the only remediation technology that has been shown effective at destroying dioxin in soil.

Mobile incineration has yet to be applied at larger dioxin-contaminated sites such as those on the NPL and listed in table 1-1. At three of these Superfund sites, EPA has selected incineration as the remedial technology. These are: the Arkwood site and Vertac Chemical Corp. site in Arkansas and the Times Beach, Missouri site. At the Vertac site, current plans are to incinerate 28,500 drums containing dioxin-contaminated phenoxy herbicides from still bottoms.[20] Prior to implementing this plan, however, the contractors will have to submit adequate trial-burn data to demonstrate that mobile incineration will meet the required performance criteria and the local air pollution standards. These trials began during 1991 and are continuing. If they are successful and prove to meet the standards, operations may proceed soon after. Continuous public opposition and some recent operating equipment problems at Vertac have contributed to delays in the project.[21] Developments at the Vertac site are being monitored closely by some environmental groups, and the level of success achieved there could substantially influence public acceptability of future incineration projects.

EPA's Record of Decision of September 29,1988 for the Times Beach Superfund site calls for the incineration of more than 92,000 cubic yards of dioxin-contaminated soil. Companies with incineration technology capability are currently being invited to submit contract proposals for treating this soil. (App. A summarizes the activities proposed for remediation at Times Beach.) The plans and progress at this site are also being carefully watched by the environmental community.

How Regulations Affect Technology Development[22]

The Superfund law or CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act) requires that the application of remedial technologies at Superfund sites protect human health and the environment according to established Federal, State, and local regulations. In implementing this mandate, EPA has developed a process to identify the extent of contamination at sites considered national priorities for cleanup, to select and evaluate cleanup technologies, and to apply the appropriate remedy. During an early step in the process known as the Feasibility Study, efforts are made to develop, screen, and evaluate existing proven and alternative remedial technologies that may be applied to the site. Thus far, technology selection for dioxin sites such as Vertac and Times Beach has been based on general categories (e.g., thermal treatment) rather than on specific treatment processes (e.g., rotary kiln, circulating-bed combus-

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[18] Paul E. des Rosiers, "Evaluation of Technology for Wastes and Soils Contaminated With Dioxins, Furans, and Related Substances," *Journal of Hazardous Materials,* vol. 14, 1987, p. 120.

[19] U.S. Environmental Protection Agency, Office of Research and Development, Hazardous Waste Engineering Research Laboratory, Destruction *of Dioxin-Contaminated Soils and Liquids by Mobile Incineration,* EPA/600/S2-87/033 (Cincinnati, OH: June 1987); U.S. Environmental Protection Agency, Office of Research and Development Risk Reduction Engineering Laboratory, *EPA Mobile Incineration System Modifications, Testing and Operations, February* 1986 *to June* 1989, EPA/600/52-87/033.

[20] Actually, EPA selected incineration for the on-site cleanup under its removal authority and the State of Arkansas selected incineration for treatment of the drummed, still bottoms waste.

[21] "Snafus Plague Vertac Barrel Burn Tests," *Superfund,* July 12, 1991, p. 4.

[22] U.S. Environmental Protection Agency, Office of Research and Development, Risk Reduction Engineering Laboratory, *SITE Program Demonstration Test Soliditech, Inc., Solidification/Stabilization Process,* vol. 1, EPA/540/5-89/005a (Cincinnati, OH: February 1990); U.S. Environmental Protection Agency, Office of Research and Development Risk Reduction Engineering Laboratory, *SITE Superfund Innovative Technology Evaluation: Technology Profiles,* EPA/540/5-90/006 *(Cincinnati,* OH: November 1990); Arthur D. Little, Inc., *Evaluation of Available Cleanup Technologies for Uncontrolled Waste Sites-Final Report,* prepared for The Office of Technology Assessment, Nov. 15, 1984; U.S. Environmental Protection Agency, Office of Solid waste and Emergency Response, and Office of Radiation Programs, *Assessment of Technologies for the Remediation of Radioactively Contaminated Superfund Sites, EPA/540/2-90/001* (Washington DC: January 1990), p. 1.

Table 1-3-Sites With Highest Dioxin Contamination Levels in Soil Identified in EPA's 1987 National Dioxin Strategy

Site	Location	Concentration (ppb)
Diamond Alkali	Newark, NJ	51,000
Hooker Chemical	Niagara Falls, NY	18,600
Brady Metals	Newark, NJ	3,500
Denney Farm	Aurora, MO	2,000
Piazza Road	Rosati, MO	1,800
Shenandoah Stables	Moscow Mills,MO	1,750
Quail Run Mobile Home Park	Gray Summit, MO	1,650
Dow Chemical Co.	Midland, MI	1,500
Times Beach	Times Beach, MO	1,200
Vertac	Jacksonville, AR	1,200
Syntex Agribusiness	Verona, MO	979
Sullins Residence	Fenton, MO	820
Sontag Road	Ballwin, MO	588
Bliss Tank Property	Frontenac, MO	430

SOURCE: U.S. Environmental Protection Ageney, Office of Solid Waste and Emergency Response, *National Dioxin Study—Report to Congress*, EPA/530/SW-87/025 (Washington, DC: August 1987), pp. 11.22-11.33.

tion, infrared thermal combustion, dehalogenation, etc). A specific technology is selected after contract proposals submitted by remediation companies are evaluated and the technology is tested.

In addition to the procedures established under CERCLA for the testing and selection of technologies at Superfund sites, EPA has also established the Superfund Innovative Technology Evaluation or SITE program under its Offices of Research and Development (ORD) and Solid Waste and Emergency Response (OSWER). According to EPA, the SITE program was created to "accelerate the development, demonstration, and use of new or innovative technologies that offer permanent, long-term cleanup solutions at Superfund sites.'[23] Since its inception, the goals of the SITE program have been to facilitate and encourage the development and commercialization of alternative technologies; conduct field demonstrations of promising technologies to gather and make available data regarding their performance and application cost; and develop procedures and policies that favor the selection of alternative technologies at contaminated sites.

Several potential technologies for dioxin treatment, such as dechlorination, nondestructive treatment or stabilization, and in situ vitrification,[x] have been field-tested by EPA under the SITE program with varying degree of success. Because this opportunity, which often arises during the early stages of development, is offered only once developers may face difficulties in implementing and ensuring that their technologies are at least as effective as incineration.[25] Hence, few of these innovative technologies are likely to be applied soon to dioxin-contaminated soil.

Unlike CERCLA, which addresses abandoned waste sites, the Resource Conservation and Recovery Act (RCRA) addresses the application of treatment technologies at active hazardous waste management facilities. Under RCRA authority, EPA has established specific treatment and disposal standards for dioxin waste (see table 1-4). EPA has also used its RCRA authority to address past contamination at active facilities and to establish corrective action procedures to identify and select treatment technologies. However, unlike the Superfund law, in which identifying, evaluating, and selecting a remedial technology is scheduled to take up to 18 months, RCRA allows a maximurn of only 9 months. Even though these schedules are not necessarily met in practice, the time requirement often results in limited test and evaluation of new technologies.

To summarize, under CERCLA and RCRA, it is required that selected technologies demonstrate the ability to significantly reduce the volume, toxicity, and mobility of dioxins in a cost-effective manner. In practice, the time allowed to develop alternative technologies is limited, and the range of applications tested is narrow.

The favoring of demonstrated technologies for dioxin treatment, although protective of human

[23] U.S. Environmental protection Agency, Office of Research and Development Risk Reduction Engineering Laboratory, *SITE Program Demonstration Test Soliditech, Inc., Solidification/Stabilization Process*, vol. 1, EPA/540/5-89/005a (Cincinnati, OH: February 1990); U.S. Environmental Protection Agency, Office of Research and Development, Risk Reduction Engineering Laboratory, *SZTE Superfund Innovative Technology Evaluation: Technology Profiles, EPA/540/5-90/006* (Cincinnati, OH: November 1990).

[24] Geosafe Corp., the firm responsible for making in situ vitrification available for commercial applications,has suspended all large-scale remediation workpendinganinvestigation (and probably Systemmodifications) of a recent unexplained explosion or expulsion of the molten glass material due either to a steam pocket and/or an uncontrolled reaction from buried waste drums during a large-scale test. (Source: letter from James E. Hansen, Geosafe Corp., to Norm Neidergang, Associated Division Director, Hazardous Waste Management Division, Office of Superfund, U.S. EPA, Region V, June 21, 1991.)

[25] For more information on the technology implementation problems at the SITE program, and probable ways to solve them, see: U.S. Congress, Office of Technology Assessement, *Coming Clean: Superfund Problems Can Resolved. .* ., OTA-ITE-433 (Washington, *DC:* U.S. Government Printing Office, October 1989), pp. 50-51, 181-187.

Table 1-4-Dioxin Treatment Standard Expressed as Concentration in Waste Extract Under the Resource Conservation and Recovery Act (RCRA)

Dioxin present in waste	Concentration [a]
HxCDD-all hexaohlorodibenzo-pdioxins.......	<1 ppb
HxCDF-all hexachorodibenzofurans	<1 ppb
PeCDD-all pentachlorodibenzo-g+dioxins......	<1 ppb
PeCDF—all pentachlorodibenzofurans	<1 ppb
TCDD-all tetrachlorodibenzo-p-d ioxins	<1 ppb
TCDF-all tetrachlorodibenzofurans	<1 ppb
2,4,5-Trichlorophenol	<50 ppb
2,4,6-Trichlorophenol	<50 ppb
2,3,4,6-Tetrachlorophenol	<100 ppb
Pentachlorophenol	<10 ppb

[a]ppb= parts per billion

SOURCE: "Dioxin Treatment Standard Expressed as Concentration in Waste Extract," 40 CFR 288.41 (1989).

health and the environment as required by law, also tends to preclude serious consideration of many promising emerging technologies that need further testing. This is particularly true for dioxin treatment because most promising technologies are at an early stage of development and they lack sufficient quantitative performance data. In addition, most emerging technologies require substantial development costs. The high liability costs associated with dioxin treatment are also considered an impediment to technology development. For these reasons, and because overall innovation is difficult in any case, it is unlikely that development of new technologies for dioxin treatment can be accelerated without increases in Federal support for demonstration efforts. The uncertainty surrounding current thinking about dioxin toxicity may also slow technology development efforts because industry may wait until a decision is made to change or not to change treatment standards.

Summary of Findings

A wide range of existing and proposed hazardous waste treatment technologies that may be considered for treating dioxin in soil are analyzed in this background paper (see table 1-5). At present, incineration is the only available technology that U.S. regulatory agencies deem acceptable for treatment of dioxin-contaminated materials. Other technologies are promising, but none has been sufficiently developed or shown in tests to be adequate for routine, current cleanup work. Although it may be possible for cleanup work to be delayed at some sites until alternative technologies are proven effective or until the dioxin toxicity question is answered, it is unlikely that private industry will invest in the necessary R&D or testing to make this happen soon; on the other hand, they might if the technology has broader applications.

Dioxins present a unique problem for those seeking to develop appropriate treatment technologies because they are difficult to remove from soil for treatment, and are present in a variety of contamination settings (i.e., different types of soils and environmental conditions). To meet cleanup standards for dioxin, it is also necessary to design special treatment systems capable of removing the dioxin from its matrix. The treatment systems must also meet stringent operating requirements. Many researchers have consequently focused more attention on contaminants such as polychlorinated biphenyls (PCBs), for which the problem is somewhat simpler, the quantities of materials to be treated are much larger and more uniform, and the standards are less stringent. Moreover, when a permit under the Toxic Substances Control Act (TSCA) is obtained for PCBs, it is issued as a national permit, whereas a RCRA permit for dioxin is only site-specific—which means that anew permit must be obtained for each site.

Thermal technologies for dioxin treatment offer the most straightforward approach because, given the appropriate temperature and other conditions needed, one can be assured that the dioxins will be broken down. Thermal technologies have therefore been given the most attention, and certain incineration designs have been built, tested, and successfully applied (on a small scale) to dioxin treatment.

Effective incineration requires control and monitoring of emissions and residues. The incinerator must also handle a wide variety and large quantity of material (e.g., soil and rubble) present at most dioxin-contaminated sites. Unique site conditions combined with the current regulatory process make it necessary to qualify each proposed technology for its specific application.[26] In addition, the public is skeptical about the actual performance of incinerators operating in their communities and concerned about whether design conditions will always be maintained. Safe operating conditions appear attainable with carefully designed and applied incineration technology.

[26]This takes the form of a "test bum" for each incinerator.

Table 1-5-Development Status of Dioxin Treatment Technologies Reviewed in This Background Paper

			Status of development	
Chapter	Category	Technology	For dioxin treatment	For other waste treatment
Two	Thermal	Rotary kiln incineration	A	A
Two	Thermal	Liquid injection incineration	B[1]	A
Two	Thermal	Fluidized bed incineration	B	A
Two	Thermal	Advanced electric reactor	C	C
Two	Thermal	Infrared incineration	C[2]	C
Two	Thermal	Plasma arc pyrolysis	D	C
Two	Thermal	Supercritical water oxidation	D	C
Two	Thermal	In situ vitrification	D	C
Three	Nonthermal	Chemical dechlorination (KPEG, APEG-PLUS)	C	A
Three	Nonthermal	Base-catalyzed decomposition	D	D
Three	Nonthermal	Thermal-gas phase reduction dechlorination	E	C
Three	Nonthermal	Thermal resorption (UV destruction)	C	C
Three	Nonthermal	Bioremediation	D	C

Key to status of development
A. An operating system has been built, tested, permitted and used on a site cleanup.
B. A system has been built and tested but not permitted or used on a site cleanup.
C. A pilot plant has been built and tested with waste material.
D. Laboratory or bench-scale tests have been completed.
E. Technology is in the research or study phase.

NOTES:
[1]A sea-based system.
[2]More experience in Europe.

SOURCE: Office of Technology Assessment, 1991.

All of the above factors, as well as the low level of allowable residuals, contribute to the relatively high costs of treatment of dioxin contamination with incineration technology, and have sparked interest in alternative technologies such as chemical dechlorination and bioremediation.

Although some alternatives look promising and have been shown effective in laboratory settings (or in application to other pollutants), none have received enough development and testing to make them viable for large-scale treatment of dioxin centamination today.

Chemical dechlorination techniques (discussed in ch. 3) have certain advantages that make them good candidates for development. For example, chemical dechlorination may be used to treat dioxin-contaminated soil and sludge within enclosed reactor systems under mild temperature and pressure conditions. Such reactors could be relatively simple to build and operate with minimum production of off-gases. Chemical dechlorination techniques can also result in cost savings since reagents can be recycled. But, chemical dechlorination has not been sufficiently field tested with dioxins at this time.

Two other highly promising dechlorination technologies, now undergoing field testing, are base catalyzed decomposition and thermal gas-phase reductive dechlorination. Other technologies such as bioremediation are currently in the research stage, but if research and development proves successful, they could be useful for in situ treatment, which would eliminate many problems associated with excavating, transporting, and handling of dioxin-contaminated soil. The key factor for bioremediation technologies continues to be getting the dioxin molecules off the soil and in contact with a microorganism. Demonstration of the effectiveness of most bioremediation approaches is still some years away but laboratory tests continue to be promising.

Finally, some combinations of technologies (e.g., use of both thermal and dechlorination techniques) could also prove very effective at certain locations because the best features of each may be enhanced through careful design. Much more engineering and testing would be necessary, however, before a specific application could go forward.

Some researchers have attempted to develop innovative, in situ treatment technologies for dioxin but have encountered difficulties in measuring the extent of dioxin destruction for these processes. These researchers claim that there is limited long-term support for alternative technology research and development.

It does not appear that private industry has sufficient incentive to invest in developing alternative technologies for dioxin. Spinoffs from developments in the treatment of other contaminants (e.g., PCBs) could prove useful but, even here, investment would be required for tests with dioxins. A more aggressive government program to develop and prove alternative dioxin treatment technologies would assist in evaluating their real potential. At present, however, the development of these alternatives is moving very slowly, and any new solutions to treating dioxin contamination appear to be along way off.

Some large corporations have promoted incineration for dioxin treatment through substantial financial investments. Some other companies have designed alternative technologies that they claim could treat and destroy dioxins. In general, firms have had difficulty financing the needed development, testing, and marketing for alternative systems, as well as the legal costs and the cost of attempting to obtain an EPA operating permit. For example, even after a technology has been tested, the period required by EPA to approve a permit application often exceeds 1 year. In light of the relatively small number of contaminated sites, there appears to be little incentive for the private sector to develop new technologies for destroying dioxin in soil.

In sum, reasonably good performance data in real applications are available for thermal treatment technologies for dioxin contamination. Specific incineration technologies are commercially available that will operate effectively and safely if properly managed. Promising alternatives to incineration will require further attention and resources if we wish to determine whether they can be equally effective. If they are developed, and if specific designs can be prepared and tested and proven useful, costs and other factors could be compared. Such comparisons are not possible with currently available information.

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