Destruction of Ozone-Depleting Substances in the United States

—DRAFT—

Prepared by ICF International for

U.S. EPA's Stratospheric Protection Division

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Most information in this draft report reflects data that was available in April 2007. Questions concerning this report should be directed to:

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Acronyms

CAA	Clean Air Act
CEMS	Continuous Emission Monitoring System
CFC	Chlorofluorocarbon
CMS	Continuous Monitoring System
CPT	Comprehensive Performance Test
DE	Destruction Efficiency
DRE	Destruction and Removal Efficiency
EOL	End of Life
EPA	United States Environmental Protection Agency
HAP	Hazardous Air Pollutant
HBFC	Hydrobromofluorocarbon
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HWC	Hazardous Waste Combustor
ICFB	Internally Circulated Fluidized Bed
ICRF	Inductively Coupled Radio Frequency
MACT	Maximum Achievable Control Technology
MOP	Meeting of the Parties
NESHAP	National Emission Standards for Hazardous Air Pollutants
ODS	Ozone-Depleting Substance
PCBs	Polychlorinated Biphenyls
PCDDs	Polychlorinated Dibenzodioxins
PCDFs	Polychlorinated Dibenzofurans
PIC	Product of Incomplete Combustion
POHC	Principal Organic Hazardous Constituent
PM	Particulate Matter
RCRA	Resource Conservation and Recovery Act
SSRA	Site-Specific Risk Assessment
SVOC	Semi-Volatile Organic Compound
TEAP	Technology and Economic Assessment Panel
TFDT	Task Force on Destruction Technologies
THC	Total Hydrocarbons
UNEP	United Nations Environment Programme
VM	Vintaging Model
VOC	Volatile Organic Compound

Executive Summary

In 1988, the United States ratified the *Montreal Protocol on Substances that Deplete the Ozone Layer* (Montreal Protocol). By ratifying the Montreal Protocol and its subsequent adjustments and amendments, the United States has committed to a collaborative, international effort to regulate and phase out ozone-depleting substances (ODS), including chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons, carbon tetrachloride, methyl chloroform, methyl bromide, and hydrobromofluorocarbons (HBFCs). This international agreement led to an amendment of the U.S. Clean Air Act (CAA) in 1990 to include Title VI, Stratospheric Ozone Protection. Title VI authorizes the U.S. Environmental Protection Agency (EPA) to manage the phaseout of ODS. Among the regulations established by EPA are requirements for the safe handling of ODS and prohibitions on the known venting or release of ODS into the atmosphere. Therefore, as ODS are phased out, surplus ODS must be stored, reused (after recycling or reclamation), or destroyed.

This report examines the state of ODS destruction in the U.S., including the following topics:

- Technologies for the destruction of ODS;
- Recommendations of the Technology & Economic Assessment Panel (TEAP) of the Ozone Secretariat of the Montreal Protocol relating to the destruction of ODS;
- U.S. regulations relevant to the destruction of ODS and the amounts of ODS destroyed in the past;
- The ability of U.S. facilities to meet the TEAP recommendations for ODS destruction;
- Future amounts of ODS available for destruction and the destruction capacity of U.S. facilities; and
- The costs associated with the destruction of ODS.

The major findings of this report can be summarized as follows:

- The Task Force on Destruction Technologies (TFDT) of the TEAP has established recommendations for the destruction of ODS, hereinafter referred to as the "TEAP recommendations." Specifically, a minimum destruction and removal efficiency (DRE) is set at 99.99 percent, and maximum emissions are set for polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs)/dioxins and furans, hydrochloric acid (HCl), chlorine (Cl_2), hydrofluoric acid (HF), hydrobromic acid (HBr), bromine (Br_2), particulate matter (PM), and carbon monoxide (CO).
- In the U.S., fewer than 10 facilities employing six different technologies were identified that have commercially destroyed ODS or have received and burned ODS-containing waste-derived fuel. These facilities are permitted hazardous waste combustors (HWCs) under the Resource Conservation and Recovery Act (RCRA), and therefore, are required to meet the applicable Maximum Achievable Control Technology (MACT) standards for HWCs, including the minimum DRE of 99.99 percent for RCRA hazardous waste including ODS that are classified as hazardous waste (i.e., some CFCs, methyl chloroform, carbon tetrachloride, and methyl bromide).[1]
- The minimum DRE requirement in the MACT standards does not apply to the incineration of ODS that are *not* classified as hazardous waste (e.g., HCFCs and halons). However, it is likely that this minimum required DRE is also being met for other ODS *not* listed as hazardous wastes that are

[1] One facility is not a RCRA-permitted HWC but has reported a DRE of 99.9999 percent when destroying ODS.

destroyed by RCRA-permitted HWCs, based on their permitting requirements and actual performance data. For example, because HCFCs are easier to destroy than CFCs, the minimum DRE of 99.99 percent will be met for HCFC destruction as well (if destruction is performed by permitted HWCs) (TEAP 2002). While no information on the thermal stability of halons or trial burn data for HWCs burning halons have been identified, it is likely that minimum DREs of 99.99 percent can be achieved, given that conventional incineration technologies have in practice achieved DREs of nearly 100 times greater than 99.99 percent during trial burns of other ODS (e.g., CFC-11, CFC-113) and for other chlorinated organic compounds that have very high thermal stabilities (e.g., monochlorobenzene). Further, halon 1301 decomposes at fire temperatures above 1,562°F, and halon 1211 can decompose at fire temperatures above 900°F; these temperatures are below the combustion temperatures at which HWCs generally operate (i.e., above 1,800°F). However, care must be taken to ensure that the feed rates of halons into such units are limited to prevent the halon from affecting the stability of the combustion flame.

- Concerning emissions, most types of emissions covered by the TEAP recommendations are also regulated under the MACT standards, and most emission limits are equal to or more stringent than the TEAP recommended limits. Specifically, under the MACT standards, emissions of dioxins and furans, total chlorine (HCl and Cl_2), PM, and CO from HWCs are subject to permit limits; only those MACT standards for total chlorine emissions from lightweight aggregate kilns and for PM emissions from existing cement kilns and lightweight aggregate kilns are higher than the TEAP recommendations.[2] Although specific emission limits for HBr and HF have not been established under the MACT, the DRE, CO, and hydrocarbon emission standards have been established as surrogate controls for these substances. It is possible that for facilities combusting substantial amounts of fluorinated and/or brominated substances, emissions of HBr and HF may be subject to permit limits through site-specific RCRA permits. It is anticipated that the permitting agency may establish maximum feed rate limits for fluorine and bromine for such facilities, or the acid gas removal systems used to reduce HCl emissions would also control HBr and HF emissions.
- While several HWC facilities indicated confidence that they could meet the TEAP recommendations, they did not indicate that their technologies are currently meeting these recommendations, nor do they currently have the necessary data to document how their performance compares to the recommendations. Except for a few cases, most U.S. HWCs have not conducted performance testing using ODS, as most performance testing is done using a few representative compounds that are difficult to destroy. Conducting performance testing using ODS is possible, but would impose additional costs on facilities that would vary depending on whether the test was conducted in conjunction with an already scheduled performance test.
- The possibility remains that non-RCRA-permitted facilities could destroy those ODS not classified as hazardous waste. While it is expected that permitted HWCs would meet the DRE and emission standards if destroying non-hazardous ODS, the ability of non-permitted facilities to meet these standards would depend on whether their combustion units are operated at high enough temperatures to destroy ODS to the specified DRE, and if their air emission control systems are capable of removing the HCl, HF, and HBr that would be generated from ODS combustion.
- Overall, it should be noted that U.S.-based HWCs are highly regulated entities, subject to regulation under both the CAA and RCRA, as well as associated state statutes and regulations. Further, HWCs in the U.S. have been subjected to site-specific risk assessments (SSRAs) on a facility-specific basis to ensure that air emissions from those facilities do not pose unacceptable risks to human health and the environment, and any such risks identified are subject to and mitigated by risk-based RCRA permit limits established by the permitting agency. On the other hand, the TEAP recommendations

[2] However, HWCs may be required to conduct site-specific risk assessments (SSRAs) if there is reason to believe that operation in accordance with the MACT standards alone may not be protective of human health and the environment.

were established for facilities world-wide, many of which are not subject to any regulations and may not employ any air emissions control systems. In other words, the TEAP recommendations are designed as generic standards applicable to ODS destruction facilities, while the MACT standards for HWCs operating in the U.S. establish individualized, source category-specific emission limits and associated monitoring, reporting, and recordkeeping requirements.

Introduction

In 1988, the United States ratified the *Montreal Protocol on Substances that Deplete the Ozone Layer* (Montreal Protocol). By ratifying the Montreal Protocol and its subsequent adjustments and amendments, the United States has committed to a collaborative, international effort to regulate and phase out ozone-depleting substances (ODS), including chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons, carbon tetrachloride, methyl chloroform, methyl bromide, and hydrobromofluorocarbons (HBFCs). This international agreement led to an amendment of the U.S. Clean Air Act (CAA) in 1990 to include Title VI, Stratospheric Ozone Protection. Title VI authorizes the U.S. Environmental Protection Agency (EPA) to manage the phaseout of ODS. Among the regulations established by EPA are requirements for the safe handling of ODS and prohibitions on the known venting or release of ODS into the atmosphere. Therefore, as ODS are phased out, surplus ODS must be stored, reused (after recycling or reclamation), or destroyed.

This report explores the state of ODS destruction in the United States. The objective of this report is to investigate the following questions and related issues:

- What type and quantity of ODS are destroyed in the U.S.?
- How are ODS destroyed in the U.S.?
- What destruction criteria (e.g., regulations, standards) are employed?
- What is the future potential for destruction of ODS in the U.S.?

The report is organized as follows:

- **Section 1** describes the ODS destruction technologies approved by the Parties to the Montreal Protocol and the performance recommendations for ODS destruction
- **Section 2** presents the U.S. regulatory requirements for ODS destruction facilities
- **Section 3** discusses the specific emission limits and performance testing requirements for hazardous waste combustors that destroy ODS in the U.S.
- **Section 4** provides a list of the types of destruction technologies used to destroy ODS in the U.S., discusses the potential capacity of U.S. facilities to destroy additional ODS, and assesses whether U.S. facilities meet the TEAP emission recommendations
- **Section 5** summarizes the total quantities of ODS destroyed in the U.S. during 2003 and 2004
- **Section 6** projects the amounts of ODS that may be available for destruction in the future
- **Section 7** discusses the estimated costs associated with the destruction of ODS
- **Appendix A** presents the Montreal Protocol Code of Good Housekeeping
- **Appendix B** presents detailed descriptions of destruction technologies
- **Appendix C** presents information on the costs of performance testing

1. Montreal Protocol Approved Destruction Technologies and Performance Recommendations

According to Article 9 of the Montreal Protocol, all Parties to the Protocol are to promote the exchange of information on the best technologies for the destruction of controlled substances. In an effort to promote this information exchange, the Technology and Economic Assessment Panel (TEAP), one of the three assessment panels that reports to the Parties to the Montreal Protocol, established a Task Force on Destruction Technologies (TFDT). The Task Force released a report in 2002 that established destruction efficiency and air emissions recommendations—selected as measures of potential impacts on human health and the environment—for ODS destruction technologies and reviewed technologies already being used to destroy ODS against these criteria (TEAP 2002). At the fifteenth Meeting of the Parties (MOP), the participating Parties agreed, through Decision XV/9, to update the list of approved destruction technologies for ODS that were originally evaluated in the TEAP report. Also at this meeting, the Parties adopted a Code of Good Housekeeping for the transport, storage, and eventual destruction of ODS (UNEP 2003). The updates to the approved technologies and the Code of Good Housekeeping are presented in Annex II, Annex III, and Annex IV of the Report of the Fifteenth Meeting of the Parties to the Montreal Protocol (UNEP 2003). Annex II lists the approved technologies for destroying ODS, by ODS type, as summarized in Table 1 below. The Code of Good Housekeeping is presented in Appendix A of this report.

Table 1: Approved ODS Destruction Technologies Defined in Annex II of Decision XV/9 (15th MOP)

Technology Type	Applicability		
	Concentrated Sources[a]		Dilute Sources[b]
	CFCs and HCFCs	Halons	Foams
Destruction and Removal Efficiency (DRE) [c]	*99.99%*	*99.99%*	*95%*
Cement Kilns	Approved	*Not Approved*[d]	*Not Approved*
Liquid Injection Incineration	Approved	Approved	*Not Approved*
Gaseous/Fume Oxidation	Approved	Approved	*Not Approved*
Municipal Solid Waste Incineration	*Not Approved*	*Not Approved*	Approved
Reactor Cracking	Approved	*Not Approved*[d]	*Not Approved*
Rotary Kiln Incineration	Approved	Approved	Approved
Argon Plasma Arc	Approved	Approved	*Not Approved*
Inductively Coupled Radio Frequency Plasma	Approved	Approved	*Not Approved*
Microwave Plasma	Approved	*Not Approved*	*Not Approved*
Nitrogen Plasma Arc	Approved	*Not Approved*	*Not Approved*
Gas Phase Catalytic Dehalogenation	Approved	*Not Approved*	*Not Approved*
Superheated Steam Reactor	Approved	*Not Approved*	*Not Approved*

Source: UNEP (2003)

[a] Concentrated sources refer to virgin, recovered, and reclaimed ODS.

[b] Dilute sources refer to ODS contained in a matrix of a solid, (e.g., foam).

[c] The DRE criterion presents technology capability on which approval of the technology is based. It does not always reflect the day-to-day performance achieved, which in itself will be controlled by national minimum standards.

[d] The cement kiln and reactor cracking technologies were originally approved for the destruction of all ODS but were since limited to only CFC and HCFC destruction through Decision XV/9.

These technologies can be grouped into three broad categories: (1) incineration, (2) plasma, and (3) other non-incineration technologies. Within these three categories, 11 technologies were approved through Decision XV/9 for the destruction of concentrated sources of CFCs. Five of these technologies were approved for the destruction of concentrated sources of halons. The additional technologies were not approved for halon destruction because sufficient evidence of the use of these technologies to effectively destroy halon while meeting the designated criteria was not available. Three additional technologies not evaluated by the TFDT that have not been proven but may be suitable for ODS destruction and are known to be in use are also described in this report, including the following:

- Internally circulated fluidized bed (ICFB) incineration;
- Fixed hearth incineration; and
- Air plasma.

All of these technologies, except for gas phase catalytic dehalogenation, are known to be used for ODS destruction in the U.S. and/or abroad. Section 4 provides further discussion of known destruction technologies in the United States. All technologies are described further in Appendix B.

Although the DRE and air emission criteria used in the TEAP report to evaluate destruction technologies were not established by the Parties as required limits that must be met during ODS destruction, they can be considered as recommendations for determining whether facilities are operating with minimal impacts to human and environmental health while destroying ODS. These "TEAP recommendations" include specifications for (a) the destruction and removal efficiency (DRE); (b) emissions of polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs)/dioxins and furans, hydrochloric acid (HCl), chlorine (Cl_2), hydrofluoric acid (HF), hydrobromic acid (HBr), bromine (Br_2), particulate matter (PM), and carbon monoxide (CO); and (c) technical capability when destroying ODS on a commercial scale. Table 2 presents the DRE and emission limits recommended by the TEAP (for concentrated sources).

Other ODS Destruction Technologies

In addition to the ODS destruction technologies described in Table 1, there are other destruction and emission recapture technologies that are beyond the scope of this report. One example is methyl bromide recapture/destruction systems, which recapture methyl bromide that can then be recovered and destroyed by chemical conversion or thermally destroyed (e.g., by incineration). The September 2006 Report of the Technology and Economic Assessment Panel reviewed these systems, as described in submissions from the United States and Australia (TEAP 2006).

In the United States, an alkyl halide scrubbing system is able to chemically destroy captured methyl bromide through a proprietary scrubbing process using an aqueous reagent mix that converts methyl bromide to non-hazardous water-soluble products; this system is available for commercialization, and two commercial-scale trials have been conducted. Another system employing capture and recovery uses activated carbon to adsorb methyl bromide which is then sent for destruction. This adsorption system is in limited commercial use in the U.S. for quarantine, pre-shipment, and commodity fumigation applications at two airports in Texas and one fruit processing

Table 2: Destruction Efficiency and Air Emission Limits Recommended by TEAP for ODS Destruction

Efficiency/Emission	Limit[a]
DRE (%)	99.99[b]
PCDD/PCDFs (ng/m^3)	0.2
HCl/ Cl_2 (mg/m^3)	100
HF (mg/m^3)	5
HBr/ Br_2 (mg/m^3)	5
Particulate Matter (mg/m^3)	50
CO (mg/m^3)	100

Source: TEAP (2002)

[a] Emission limits are expressed as mass per dry cubic meter of flue gas at 0°C and 101.3 kPa corrected to 11 percent O_2.

[b] A DRE of 95 percent is required for the destruction of dilute sources of ODS (i.e., foams containing ODS).

2. U.S. Regulatory Requirements

The destruction of ODS is regulated under the authority of both the CAA and the Resource Conservation and Recovery Act (RCRA).[3] This section describes the stratospheric ozone protection regulations under the CAA, which apply to all controlled substances (i.e., ODS). Additionally, because some ODS are classified as hazardous wastes, facilities that handle these ODS are regulated under RCRA. Hazardous waste combustors (HWCs, e.g., incinerators) that destroy ODS classified as hazardous waste are also regulated by the Maximum Achievable Control Technology (MACT) standard under the CAA.

2.1 Stratospheric Ozone Protection Regulations

Under the authority of the CAA, the stratospheric ozone protection regulations (40 CFR Part 82, Subpart A) establish the following definitions relating to the destruction of controlled substances:[4]

- "*Destruction* means the expiration of a controlled substance to the destruction efficiency actually achieved, unless considered completely destroyed as defined in this section. Such destruction does not result in a commercially useful end product and uses one of the following controlled processes approved by the Parties to the Protocol:
    (1) Liquid injection incineration;
    (2) Reactor cracking;
    (3) Gaseous/fume oxidation;
    (4) Rotary kiln incineration;
    (5) Cement kiln;
    (6) Radio frequency plasma; or
    (7) Municipal waste incinerators only for the destruction of foams."
- "*Completely destroy* means to cause the expiration of a controlled substance at a destruction efficiency of 98 percent or greater using one of the destruction technologies approved by the Parties."

In other words, the stratospheric ozone protection regulations require the use of one of the technologies approved by the Parties, as listed in Section 1, when destroying a controlled substance. Additionally, if the substance is to be considered "completely destroyed" as defined in the regulations, it must be destroyed to a 98 percent destruction efficiency (DE). Unlike the TEAP recommendations, which include a DRE limit of 99.99 percent, the U.S. regulations include a DE limit of 98 percent. According to the TEAP, DE is a more comprehensive measure of destruction than DRE as it includes emissions of undestroyed chemical from all points (e.g., stack gases, fly ash, scrubber, water, bottom ash), while DRE includes emissions of undestroyed chemical from the stack gas only. However, "because of the relatively volatile nature of ODS and because, with the exception of foams, they are generally introduced as relatively clean fluids, one would not expect a very significant difference between DRE and DE" (TEAP 2002:31).

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[3] Although the destruction of ODS is not regulated under the Toxic Substances Control Act (TSCA), hazardous waste combustors that destroy PCBs must be permitted under TSCA and achieve a DRE of 99.9999 percent. These facilities could be used to destroy ODS (although if they were to destroy ODS classified as hazardous waste, they would also need to be RCRA permitted). See the text box in Section 2.3.1 for further discussion of PCB incinerators.

[4] According to 40 CFR 82.3, "the inadvertent or coincidental creation of insignificant quantities of a listed [ODS] during a chemical manufacturing process, resulting from unreacted feedstock, from the…use [of ODS] as a process agent present as a trace quantity in the chemical substance being manufactured, or as an unintended byproduct of research and development applications, is not deemed a controlled substance."

2.2 Resource Conservation and Recovery Act

In addition to the stratospheric ozone protection regulations for ODS under the CAA, several ODS that are classified as hazardous wastes are also regulated under RCRA. Therefore, the regulations that apply to facilities that handle these hazardous wastes apply to facilities in the U.S. that destroy hazardous waste ODS. Generally, RCRA requires facilities that operate hazardous waste storage tanks, manage hazardous waste containers, and operate hazardous waste treatment units to have RCRA permits, which regulate what specific hazardous waste codes the facilities are permitted to receive and store, and in what quantities. In addition, the Land Disposal Restrictions program (40 CFR Part 268) sets concentrations of hazardous constituents or methods of treatment for hazardous wastes, which must be achieved before the wastes, or waste treatment residues, are land disposed.

According to 40 CFR Part 261, Subpart D, ODS (or ODS-containing waste) may be classified as hazardous wastes if they fall under one of the following waste categories:

- Wastes from non-specific sources (Code F);
- Commercial chemical products (Code U);
- Characteristic wastes (Code D); or
- Wastes from specific sources (Code K).

However, according to 40 CFR 261.4(b)(12), refrigerants that meet the following definition are exempt from classification as hazardous wastes: "used chlorofluorocarbon refrigerants from totally enclosed heat transfer equipment, including mobile air conditioning systems, mobile refrigeration, and commercial and industrial air conditioning and refrigeration systems that use chlorofluorocarbons as the heat transfer fluid in a refrigeration cycle, provided the refrigerant is reclaimed for further use".[5] According to 56 FR 5913, this exemption includes CFC and HCFC refrigerants.

The remainder of this section discusses the circumstances in which ODS may be considered hazardous wastes under Codes F, U, D, and K.

2.2.1 Code F (Wastes from Non-Specific Sources)

ODS may be classified under hazardous waste codes F001 or F002 if they meet one of the following definitions listed under 40 CFR 261.31:[6]

- **F001**—Applies to the following spent halogenated solvents used in degreasing: tetrachloroethylene, trichloroethylene, methylene chloride, 1,1,1-trichloroethane, carbon tetrachloride, and chlorinated fluorocarbons; all spent solvent mixtures/blends used in degreasing containing, before use, a total of ten percent or more (by volume) of one or more of the above halogenated solvents or those solvents listed in F002, F004, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.
- **F002**—Applies to the following spent halogenated solvents: tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, chlorobenzene, 1,1,2-trichloro-1,2,2-trifluoroethane, ortho-dichlorobenzene, trichlorofluoromethane, and 1,1,2-trichloroethane; all spent solvent mixtures/blends containing, before use, a total of ten percent or more (by

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[5] Reclamation is defined in 40 CFR 82.152 as "to reprocess refrigerant to all of the specifications in appendix A to 40 CFR Part 82, Subpart F…that are applicable to that refrigerant and to verify that the refrigerant meets these specifications using the analytical methodology prescribed in Section 5 of Appendix A of 40 CFR Part 82, Subpart F."

[6] Waste codes F024 and F025 also apply to hazardous wastes that could contain ODS; however, these would not be considered controlled substances as they are byproducts of manufacturing processes.

volume) of one or more of the above halogenated solvents or those listed in F001, F004, or F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.

In short, carbon tetrachloride, methyl chloroform, and all CFCs and HCFCs may be classified as Code F hazardous wastes if they have been used as solvents prior to disposal. The generator of the waste is responsible for determining whether the waste is to be classified as hazardous versus non-hazardous and if hazardous, assigning as waste code. Additionally, any destruction facility receiving waste is responsible for verifying that the waste is correctly identified (EPA 2006a).

2.2.2 Code U (Commercial Chemical Products)

ODS may be classified as Code U hazardous wastes (as defined in 40 CFR 261.33) if they are commercial chemical products or manufacturing chemical intermediates that are discarded or intended to be discarded (i.e., abandoned by being disposed of; burned/incinerated; or accumulated, stored, or treated but not recycled before or in lieu of being abandoned by being disposed of, burned, or incinerated, see 40 CFR 261.2(a) and (b)). A commercial chemical product/manufacturing chemical intermediate is defined in 40 CFR 261.33(c) and (d) as:

- a chemical substance that is manufactured or formulated for commercial or manufacturing use which consists of the commercially pure grade of the chemical;
- any technical grades of the chemical that are produced or marketed;
- all formulations in which the chemical is the sole active ingredient; and
- any residue remaining in a container or in an inner liner removed from a container that has held any commercial chemical product or manufacturing chemical intermediate named in this section of the regulations.[7]

Thus, while carbon tetrachloride, methyl chloroform, methyl bromide, trichlorofluoromethane (CFC-11), and dichlorodifluoromethane (CFC-12) have designated U waste codes—U211, U226, U029, U121, and U075 respectively—this code is limited to container residues and products that were manufactured but never used. Therefore, refrigerants removed from equipment (which are not classified as hazardous wastes) and used solvents (some of which do fall under waste Code F) *would not* fall under hazardous waste Code U; a controlled substance that was manufactured and never used *would* be considered a Code U waste if it was discarded or intended to be discarded.

2.2.3 Code K (Wastes from Specific Sources)

ODS-contaminated wastes which may be generated from specific sources, such as the production of carbon tetrachloride, may be classified under several K waste codes (e.g., K016, K018, K021, K028, K029, K073, K095, K096, K131, K132, K150). However, because these waste codes apply mainly to wastes/residues from the production of various chemicals, they will not apply to controlled substances being sent for destruction.

2.2.4 Code D (Characteristic Wastes)

Code D includes wastes that exhibit any of the four characteristics—ignitability (D001), corrosivity (D002), reactivity (D003), and toxicity (D004 through D043)—as described in 40 CFR 261.21 to 261.24. The most likely characteristic to apply to ODS waste is the toxicity characteristic (TC). Carbon tetrachloride is designated under waste code D019; thus, if an extract from a representative sample of a

[7] Unless the container is empty, as defined in 40 CFR 261.7(b). According to this section, "a container that has held a hazardous waste that is a compressed gas is empty when the pressure in the container approaches atmospheric." Therefore, any heels in containers that held ODS would most likely not be considered hazardous waste.

solid waste contains a concentration of carbon tetrachloride equal to or greater than the regulatory threshold level of 0.5 mg/L, it is considered a hazardous waste.[8] Additionally, used ODS contaminated with any of the other Code D chemicals are considered hazardous wastes if an extract contains any of the contaminants listed in 40 CFR 261.24 at a concentration equal to or greater than the specified values.

2.2.5 The Mixture and Derived-From Rules

According to 40 CFR 261.3(a)(2)(iv), any combination of a listed hazardous waste with non-hazardous waste is defined as a listed hazardous waste. Even if a small amount of listed waste is mixed with a large quantity of non-hazardous waste, the resulting mixture bears the same waste code and regulatory status as the original listed component of the mixture. The mixture rule applies differently to listed and characteristic wastes. A mixture involving characteristic wastes is hazardous only if the resulting mixture itself exhibits a characteristic. Once a characteristic waste no longer exhibits one of the four regulated properties, as discussed in Section 2.2.4, it is no longer regulated as hazardous. However EPA places certain restrictions on the manner in which a waste can be treated (see the Land Disposal Restrictions regulations in 40 CFR Part 268).

Furthermore, hazardous waste treatment, storage, and disposal processes often generate waste residues (i.e., "derived-from" wastes). Residues produced from the treatment of listed hazardous wastes are generally still considered hazardous wastes under the RCRA derived-from rule (see 40 CFR 261.3(c)(2)), which states that any material derived from a listed hazardous waste is also a listed hazardous waste. For example, ash created by burning a hazardous waste is considered derived-from that hazardous waste. Thus, such ash bears the same waste code and regulatory status as the original listed waste, regardless of the ash's actual properties.

2.2.6 Summary

Table 3 summarizes the RCRA hazardous waste codes that may apply to controlled substances (i.e., not including ODS byproducts or ODS-containing wastes from chemical manufacture).

Table 3: RCRA Hazardous Waste Codes for Selected ODS

Chemical Name	Hazardous Waste Codes			
	U[a]	F	D	K
CFC-11 (Trichlorofluoromethane)	U121	F001, F002	-	-
CFC-12 (Dichlorodifluoromethane)	U075	F001	-	-
Other CFCs and HCFCs	-	F001	-	-
Carbon Tetrachloride	U211	F001	D019	-
Methyl Chloroform (1,1,1-trichloroethane)	U226	F001, F002	-	-
Methyl Bromide	U029			

[a] Code U only applies to the controlled substances listed above if they were manufactured and subsequently disposed of without ever being used.

While all known ODS destruction undertaken in the U.S. has occurred at RCRA-permitted HWCs with the exception of one facility, the possibility remains that non-hazardous waste ODS could be destroyed at non-RCRA regulated facilities, as the majority of ODS likely to be destroyed are not classified as hazardous wastes. Therefore, the regulations that apply to permitted HWCs, as discussed further below, would not apply to the destruction of non-hazardous waste ODS. See Section 4.3 for further discussion of the possibility of non-permitted facilities destroying ODS.

[8] A waste extract is obtained using a specific test method called the Toxicity Characteristic Leaching Procedure (TCLP).

2.3 Maximum Achievable Control Technology Standards

RCRA-permitted hazardous waste facilities that operate HWCs are also required by the MACT standard under the CAA to obtain a Title V Operating Permit as a hazardous air pollutant (HAP) emission source. Title V Operating Permits contain emission limits for the release of air pollutants, including HAPs, from the combustion of hazardous wastes to ensure the protection of human and environmental health. Three ODS are listed HAPs under the CAA:[9]

- Carbon tetrachloride;
- Methyl bromide; and
- Methyl chloroform.

On October 12, 2005, EPA issued a Final Rule (70 FR 59402, codified in 40 CFR Part 63, Subpart EEE) for National Emission Standards for Hazardous Air Pollutants (NESHAP) emitted by HWCs.[10] The standards were issued under Section 112(d) of the CAA as a MACT standard.[11] The Final Rule, effective December 12, 2005, applies to hazardous waste burning (a) incinerators, including rotary kilns, fluidized bed units, liquid injection units, and fixed hearth units, which are used primarily for waste destruction; and (b) boilers and industrial furnaces (BIFs), including cement kilns, lightweight aggregate kilns, industrial/commercial/institutional boilers and process heaters, and hydrochloric acid production furnaces, which are used primarily for energy and material recovery. This Final Rule, as well as the NESHAP finalized on September 30, 1999, rendered existing RCRA stack emission standards inapplicable upon demonstration of compliance with the MACT standards to avoid unnecessary duplication with the MACT standards.[12] Permits under the CAA Title V Operating Permit Program contain emission limits for HAPs and other pollutants set by these MACT standards.

Under the MACT standards, when hazardous wastes are to be destroyed by way of combustion, the combustion unit must adhere to a minimum 99.99 percent DRE and also meet the air emission limits listed in 40 CFR 63.1216 – 63.1221. The air emission limits relevant to ODS destruction include limits for dioxins and furans, PM, total chlorine (HCl and Cl_2), and CO. (See Section 4.4 for a comparison of the MACT standard limits to the TEAP recommendations.) Additional operating limitations for HWCs, including maximum hazardous waste feed rates and ranges of hazardous waste composition (e.g., maximum feed rate of chlorine to the unit), are established on a unit-specific basis by the Title V Operating Permit writers based on a review of the unit design, waste characterization data, and performance test results.

2.3.1 Comprehensive Performance Tests (CPT)

According to 40 CFR 63.1206 and 63.1207, HWCs must document compliance with emission limits (including DRE) and demonstrate performance of their continuous monitoring systems (CMS) by conducting comprehensive performance tests (CPT) every five years. During a CPT, one or two difficult-

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[9] Title V Operating Permits do not necessarily identify specific emission limits for each CAA HAP. Rather, the Title V Operating Permit may instead set a total emission limit for all CAA HAPs (e.g., 10 tons per year), so there may not be specific emission limits in the Title V Operating Permit for the three ODS that are also HAPs.

[10] The Federal Register Notice and Final Rule are available at the following EPA website: http://www.epa.gov/epaoswer/hazwaste/combust/toolkit/links.htm#hwc. Related information concerning the Final Rule is available at the following EPA website: http://www.epa.gov/epaoswer/hazwaste/combust/toolkit/index.htm.

[11] The MACT standards are industry-specific, technology-based standards designed to reduce HAP emissions.

[12] Final standards for Phase 1 sources (i.e., incinerators, cement kilns, and lightweight aggregate kilns) were originally promulgated on September 30, 1999 and established the framework for making existing RCRA stack emission standards inapplicable for the Phase 1 sources once they demonstrated compliance with the MACT standard. The October 12, 2005 final rule made the remaining RCRA stack emission standards for Phase 2 sources (i.e., boilers and HCl Production Furnaces) inapplicable upon demonstration of compliance with the MACT standard.

to-combust compounds referred to as principal organic hazardous constituents (POHCs) are fed into the unit along with wastes that have been formulated to be representative of the typical wastes fed into the system, and specific parameters are monitored (including temperature, feed rate, and air emissions).[13] Prior to conducting a CPT, a test plan must be submitted to the permitting agency for review, public comment, and approval. A test plan must contain an analysis of each feedstream to the unit (including the identification of any hazardous wastes and organic HAPs present in the feedstream) and the proposed performance test methods (including the selected POHCs). For each hazardous waste identified in the feedstream, the plan also must include (a) the ranges of the hazardous waste feed rates for each waste feed system; (b) the feed rates of other fuels and feedstocks to the unit as appropriate (e.g., for cement kilns); (c) a determination of the combustion residence time; and (d) the identification of any other relevant parameters that may affect the ability of the HWC to meet the emission standards.

Performance Testing for PCB Incinerators

Under 40 CFR Part 761, Subpart D, facilities wishing to destroy polychlorinated biphenyls (PCBs) must apply for a permit and demonstrate compliance with several combustion criteria through performance tests. Most units permitted to incinerate PCBs under 40 CFR Part 761 are also permitted to incinerate hazardous wastes under 40 CFR Part 63; however, most facilities that commercially destroy ODS are not permitted to destroy PCBs.

Performance test requirements of PCB incinerators are similar in concept to performance test requirements for HWCs. Because PCB wastes may be semivolatile organic compounds (SVOCs), solid compounds, or articles (e.g., PCB-contaminated capacitors), the POHCs chosen to test the units are SVOCs or solids. The facility operator is required to monitor operating conditions during the trial burn test, including the concentration of PCBs, CO, and oxygen in the exhaust gas and the rates and quantities of PCBs fed to the incinerator. The operator is also required to demonstrate that the temperature of the incinerator is maintained above 1,200°C for a 2-second residence time or above 1,600°C for a 1.5-second residence time, and that the DRE for the PCB compounds is 99.9999 percent or greater. (EPA 2004)

2.3.2 Principal Organic Hazardous Constituents (POHCs)

Based on the design of the combustion unit and the specific characteristics of the hazardous wastes being combusted by the unit (including their concentrations in the feedstream), POHCs that are the most difficult to combust when compared to the other wastes being destroyed by the unit are selected from the CAA list of HAPs (which include three ODS—carbon tetrachloride, methyl bromide, and methyl chloroform). POHCs may be volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), or solids, depending upon the specific characteristics of the hazardous wastes being combusted.

The difficulty-of-combustion, or "incinerability," of organic compounds are established using a quantitative thermal stability ranking system included in Appendix D of the *Guidance on Setting Permit Conditions and Reporting Trial Burn Results*, which was developed based on pilot and full scale test burn data (EPA 1989). The ranking scale ranges from 1, representing the most difficult-to-combust compound, to 320, representing the least difficult-to-combust compound.

The lowest ranked compound suitable for use in performance testing is monochlorobenzene, with a thermal stability rank of 19. (Most of the lower-ranked compounds are extremely toxic [e.g., cyanides, pyrenes] and therefore present occupational safety issues for use in performance testing.) Other difficult-to-combust compounds used as POHCs include:

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[13] A company must also submit reports if it performs modifications to the source/destruction process in a manner that could affect its ability to achieve the DRE standard. Most HWCs are also required to conduct confirmatory performance testing every 2.5 years to demonstrate compliance with the dioxin and furan emission standard.

- 1,2,4,5-tetrachlorobenzene (thermal stability rank 20);
- 1,2-dichlorobenzene (thermal stability rank 23-24);
- trichlorobenzene (thermal stability rank 26);
- tetrachloroethylene (thermal stability rank 36); and
- carbon tetrachloride (thermal stability rank 136-140).

Table 4 list the thermal stability rankings of the ODS included in the ranking scale.

Table 4: Thermal Stability Ratings of Several ODS, on a Scale of 1 to 320

ODS	Thermal Stability Rating	Difficulty to Destroy
Methyl Bromide	31-33	Most Difficult
CFC-113	85-88	↑
CFC-12	85-88	
CFC-11	89-91	
Halon 1301	116	
Halon 2402	131	
HCFC-22	133	
Carbon Tetrachloride	136-140	
Halon 1211	143	↓
HCFC-21	154-157	
Methyl Chloroform	201	Least Difficult

Source: ICF (2007)

As shown in Table 4, all ODS for which data are available are less difficult to destroy than monochlorobenzene (rank 19), a widely used POHC for testing DRE in trial burns. Although halons are not included in the ranking scale, it is expected that they would react relatively easily at the very high temperatures at which HWCs operate (see Section 4.4.4 for further information).

2.3.3 Comprehensive Performance Test Process

During the performance test, each representative POHC and the other surrogate wastes are fed into the HWC at a known and fixed feed rate, and the concentration of each POHC is monitored in the exhaust gas of the HWC.[14] The DRE is determined by the difference between the amount of the POHC fed into the HWC and the amount of the POHC emitted in the exhaust gas.[15] The operating conditions of the HWC are also monitored during the performance test, including the total hazardous waste feed rate, combustion temperature, exhaust gas oxygen and CO concentrations, and other parameters. Exhaust gas flow rate is monitored as a surrogate for the retention time of the combustion unit.

If the CPT results demonstrate that the HWC achieved the applicable DRE (e.g., 99.99 percent for hazardous wastes or 99.9999 percent for PCBs and certain chlorinated dioxin/furan-containing hazardous wastes) for the difficult-to-combust POHCs, it is then presumed that the HWC will also destroy organic compounds that are less difficult to combust to at least the same DRE, assuming that the HWC is operated within the permitted range of operating parameters under which the CPT was conducted (e.g., waste feed rate, waste composition, combustion temperature, exhaust gas flow rate). For example, several state agency permit writers indicated that monochlorobenzene, one of the most difficult compounds to combust, was specified as one of the POHCs for performance tests of HWCs under their purview (Missouri Department of Natural Resources 2005, Ohio EPA 2005). Therefore, these facilities could destroy any organic compound that is less difficult to destroy, including all ODS compounds listed as hazardous wastes.

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[14] See Section 3.3 for further information on the costs of conducting a CPT.

[15] The formula used to calculate DRE for hazardous waste incinerators, for example, is provided in 40 CFR 63.1219(c)(1).

The presumption that the performance of the unit in destroying difficult-to-combust POHCs will be representative of the performance of the unit in destroying less difficult-to-combust compounds is established as a concept in the HWC regulations (see e.g., 40 CFR 63.1220(c)(3)(ii)), explicitly stated in the performance test requirements for chlorinated dioxin and furan incineration (see e.g., 40 CFR 63.1219(c)(2)), and reflected in how permit conditions for performance testing and operation of HWCs are written in Title V Operating Permits.

2.4 Monitoring, Recordkeeping, and Reporting Requirements

Monitoring and recordkeeping/reporting requirements for HWCs are contained in 40 CFR 63.1209 and 40 CFR 63.1211, respectively. Facilities that destroy ODS must also meet the recordkeeping and reporting requirements listed in 40 CFR Part 82, Subpart A on protection of stratospheric ozone. These requirements are described in this section.

2.4.1 Hazardous Waste Combustors

Under 40 CFR 63.1209, hazardous waste combustors are required to continuously monitor (a) total hydrocarbon (THC) or CO emissions in exhaust gas using a continuous emission monitoring system (CEMS) and (b) the waste feed rate into the unit.[16] As an indicator of gas residence time, a facility operator must establish and comply with a limit on the maximum flue gas flow rate, the maximum production rate, or another parameter that is documented in the site-specific performance test plan as an appropriate surrogate for gas residence time. Facility operators are also required to measure the temperature of each combustion chamber at a location that best represents bulk gas temperature in the combustion zone and establish a minimum combustion chamber temperature for permitted operation. In the event that operating parameters fall outside of the permitted range, facility operators are required to file a report to the permitting agency.

Under 40 CFR 62.1211, facility operators are required to maintain information on site to document and maintain compliance with MACT standard Subpart EEE regulations (including data recorded by CMS) and make the operating records available for on-site inspection by the permitting agency. Facility operators are also required to develop a Documentation of Compliance that must identify the applicable emission standards under Subpart EEE and the limits on the unit operating parameters under 40 CFR 63.1209 that will ensure compliance with those emission standards.

There are no explicit regulatory requirements in Subpart EEE to monitor and record the amount of ODS being combusted in HWCs. However, RCRA-permitted facilities are required to monitor and record the types and amounts of hazardous wastes (including ODS classified as hazardous wastes) accepted in order to determine that the types and amounts of wastes accepted are in accordance with what the facility is permitted to accept under its RCRA permit. For ODS that are classified as hazardous wastes, information concerning the types and quantities accepted could be determined from the Waste Characterization Data for the facility. However, ODS that are not classified as hazardous wastes may not be identified in the RCRA permit or in the Waste Characterization Data.

2.4.2 ODS Destruction Facilities

According to the stratospheric ozone protection regulations (40 CFR Part 82, Subpart A), all facilities that destroy controlled ODS must submit to EPA a one-time report detailing the following:

- the destruction unit's destruction efficiency;

[16] Facility operators must implement a waste feed analysis plan that specifies the parameters that will be analyzed for each feed stream to ensure compliance with operating parameter limits in the regulations including applicable waste feed rate limits.

- the methods used to record the volume destroyed;
- the methods used to record destruction efficiency; and
- the names of other relevant federal or state regulations that may apply to the destruction process.

If there are changes in a facility's DE and/or methods used to record the volume destroyed or used to determine DE, the facility must submit a revised report to EPA within 60 days of the change.

Where controlled ODS were originally produced without expending allowances, ODS destruction facilities must provide a destruction verification document, which documents that the materials received will be destroyed, to the producer/importer from whom they purchased/received the ODS. This verification document must include:

- the identity and address of the person intending to destroy controlled substances;
- an indication of whether those controlled substances will be "completely destroyed" or less than completely destroyed, in which case they must provide the DE;[17]
- the period of time over which the person intends to destroy the controlled substances; and
- the signature of the verifying person.

Additionally, those facilities that destroy ODS that submitted a destruction verification to a producer and/or importer are required to report annually to EPA the names and quantities of ODS destroyed during the control period (i.e. one calendar year).

[17] "Completely destroy," as defined in 40 CFR 82.3, means "to cause the expiration of a controlled substance at a destruction efficiency of 98 percent or greater, using one of the destruction technologies approved by the Parties."

3. Destruction of ODS in Hazardous Waste Combustors

This section discusses the potential emissions resulting from the destruction of ODS, outlines the limits on air emissions from HWCs destroying ODS, discusses performance testing conducted on HWCs using ODS, and presents information from several operating permits for HWCs that are known to destroy ODS.

3.1 Emissions Associated with ODS Destruction

The incineration of CFCs and HCFCs produces air emissions including carbon dioxide, HF, HCl and Cl_2. The incineration of halons and other brominated ODS (e.g., methyl bromide) also produces HBr and Br_2. CO, hydrocarbons (HC), organic acids, and other products of incomplete combustion (PICs) and dioxins and furans are also produced from the combustion of chlorinated ODS including CFCs, HCFCs, and halons. Acid gases are generally removed using gas scrubbing systems, such as Venturi scrubbers, packed bed scrubbers, or plate scrubbers.[18] (TEAP 2002)

3.2 Limitations on ODS Emissions from Hazardous Waste Combustors

Title V Operating Permits for HWCs may or may not have explicit limits for feed rates and emissions of *individual* ODS compounds. However, the units are required to achieve, at a minimum, a 99.99 percent DRE for each RCRA hazardous waste—including all ODS that are classified as hazardous wastes—fed into the unit. The maximum feed rates and emissions of ODS from HWCs are limited by the permit limitations on unit operating conditions. For example, Title V Operating Permits typically establish maximum chlorine feed rates, which for one facility is established at 1,582 pounds per hour (EPA 2006a).

Additionally, the combustion temperature, exhaust gas flow rate, and hazardous waste feed rate are continuously monitored and recorded. Therefore, instances in which the units fall outside of the permitted range of any monitored parameter are recorded and reported. Remedial actions specified in the permit conditions and in the regulations are implemented if an excursion is detected.

ODS Products of Incomplete Combustion

In the early to mid 1990s, a substantial amount of research was conducted by EPA and academic researchers into products of incomplete combustion (PIC) formation from the combustion of ODS. One study monitored PICs, including carbon tetrachloride, methyl chloroform, and CFC-11, in the flue gas during the combustion of CFC-12 in a bench scale incinerator (EPA 1993). PIC generation rates for the ODS ranged from non-detectable to about 0.5 to 10 micrograms per gram of CFC-12 feed, equivalent to 0.001 percent of the feed. Another study measured methyl chloroform PIC emissions of 170 micrograms per cubic meter at a high CFC feed rate and did not measure any "target" PIC emissions at the low CFC feed rate (EPA 1993). A 1996 EPA study reported results from combustion of CFC-11, CFC-12, and HCFC-141b in a pilot-scale incinerator; concentrations of VOCs (volatile PICs) were reported as being "very low" in all tests conducted (EPA 1996).

The formation of PICs that are also ODS is limited by the requirements to monitor THC emissions from facilities; additionally, CPT results for HWCs include monitoring of VOC and SVOC PIC emissions, which could include ODS (e.g., carbon tetrachloride). For example, performance data that were reported for a sulfuric acid recovery unit show PIC emissions of CFC-11 of 0.0003 lb/hr when operating at a total hazardous waste feed of 4,500 lb/hr and a combustion temperature of 1800°F; and of 0.0024 lb/hr when operating at a total hazardous waste feed rate of 6,400 lb/hr and a combustion temperature of 1700°F. (EPA 2006b)

[18] The production of acid gases, especially HF, also requires specific equipment—which is not necessarily standard at incineration facilities—to prevent damage to the unit caused by corrosion. This equipment includes upgraded bag material in the bag house; HF-resistant refractory lining and binder in the combustion chambers through the quench area; and specially-lined, corrosion-resistant, fiberglass-reinforced plastic (FRP) in the scrubbing system.

Additionally, HWC operating permits typically include automatic feed cutoff limits and combustors are equipped with waste feed cutoff systems set to these limits. In the event that a monitored operating parameter (e.g., waste feed rate, combustion temperature) falls outside of the permitted range (i.e., the range within which the applicable DRE was demonstrated to be achieved during the CPT) the waste feed cutoff system activates and blocks any further waste feed to the combustor. Therefore, hazardous wastes cannot continue to be fed to the combustor if the unit is operating outside of the operating parameters that have been demonstrated to achieve the applicable DRE. (Missouri Department of Natural Resources 2005, Ohio EPA 2005)

In summary, because the DRE being achieved by an HWC generally cannot and is not required by regulation to be monitored continuously, facility operators and permitting agencies determine that the HWCs are achieving the applicable DRE by determining that the units are being operated within the permitted range of operating parameters. This permitted range of parameters is developed based on the conditions under which performance tests for the HWC were conducted*. Hazardous waste combustors that are used to destroy ODS that are classified as hazardous wastes would be required by regulation to meet the applicable DRE for those ODS, and the HWC would be determined to be achieving the applicable DRE through monitoring of the operating parameters established in the HWC operating permit.* (Missouri Department of Natural Resources 2005, Ohio EPA 2005)

3.3 Comprehensive Performance Testing Using ODS

EPA published summaries of performance test data for HWCs in support of the recently-finalized MACT standards (EPA 2006b). The summary data include pollutant-specific emissions and hazardous waste feed rates, combustion temperature, DRE, HAP emissions, chlorine feed rates, and stack gas conditions. Because most of these performance tests were conducted in the 1990s, before the new MACT standard was implemented, it is likely that facilities have since implemented stricter emissions controls in order to comply with the new standards. *Therefore, these performance test data may not reflect the current status of emissions from the facilities*.

Some of the performance tests were conducted using ODS (i.e., carbon tetrachloride, methyl chloroform, CFC-11, and CFC-113) as POHCs. There were no performance test data identified in the database for halons or other ODS that are not classified as hazardous wastes. The performance test data using ODS as POHCs are presented in Table 5 in Section 4.4. DREs greater than 99.999 percent were reported for most HWCs using carbon tetrachloride or methyl chloroform as POHCs.

3.4 Review of Selected Title V Operating Permits: Comparison of Performance and Monitoring Requirements

To understand the performance and monitoring requirements of U.S. facilities known to have destroyed ODS, selected publicly available Title V Operating Permits were reviewed for three companies operating a range of hazardous waste combustors: (1) rotary kilns, (2) cement kilns, and (3) lightweight aggregate kilns. Each of the facilities—whose company names are not disclosed—has reportedly incinerated ODS or used blended waste containing ODS as fuel. While most Title V Operating Permits cite the underlying MACT standards relevant to the facility, at times state implementation plans or other state regulations can require the establishment of source-specific HAP limits in the Title V Operating Permit.

The Title V Operating Permit for Facility A—a commercial hazardous waste treatment facility that operates two **rotary kilns**, one secondary combustion unit, and one waste-fired boiler—reflects the underlying MACT standard emission limits for incinerators as listed in 40 CFR 63.1203.[19] The permit includes a maximum waste feed rate and a limit on VOC emissions; it also requires continuous emission monitoring systems for combustion chamber temperature, exhaust gas flow rate, hazardous waste feed rate, THC, and CO to demonstrate compliance with the MACT standard. Additionally, the following emission limits for the three ODS HAPs are specified in the permit: (Arkansas DEQ 2002)

- Maximum Carbon Tetrachloride Emissions: 0.43 lbs/hr
- Maximum Methyl Bromide Emissions: 0.43 lbs/hr
- Maximum Methyl Chloroform Emissions: 0.43 lbs/hr

The Title V Operating Permit for Facility B, which operates two wet process **cement kilns,** reflects the underlying MACT standard emission limits for cement kilns as listed in 40 CFR 63.1204.[20] Performance testing is required to include continuous monitoring of kiln temperature, oxygen concentration, and kiln feed rate. The facility is also required to conduct continuous monitoring and recording of THC concentration in the exhaust gas. However, this permit does not list specific emission limits for the ODS HAPs. (Indiana DEM 2003)

The Title V Operating Permit for Facility C, which operates two **lightweight aggregate kilns**, reflects the underlying MACT standard emission limits for lightweight aggregate kilns listed in 40 CFR 63.1205 or 40 CFR 63.1221, as applicable. Monitoring conditions and performance test requirements included are similar to the monitoring and performance test requirements for Facility A's rotary kilns. As with the permit for Facility B, this permit does not list emission limits for individual ODS HAPs. (Virginia DEQ 2006)

Based on the three Title V Operating Permits described above, it is apparent that the level of detail of the permit conditions can vary. For example, the Title V Operating Permit for Facility A's rotary kilns explicitly identifies maximum emission limits, in units of pounds per hour, for the three ODS HAPs The Title V Operating Permits for the other two facilities do not contain explicit maximum emission limits for individual ODS. Overall, however, the performance testing, monitoring, and reporting requirements for the three facilities are similar.

Costs of Comprehensive Performance Testing (CPT)

The cost of conducting a CPT, which must be done every five years, can vary depending on the type and size of the facility conducting the test, the POHCs and other wastes burned during the test, and the types of sampling and analysis conducted. In general, the source of the costs can be roughly broken down as follows: 50 percent for the sampling and analytical costs, 25 percent for the purchase of any POHCs needed for the trial burns and/or additional wastes needed to obtain wastes with the correct metal content, and 25 percent for the destruction time lost during the performance of the test (Ullrich 2007). Estimates of the total costs to conduct a CPT range from $150,000 to $500,000.

However, these costs could be significantly reduced if the only desired result was to determine the DRE for a specific ODS. If an ODS was added as a POHC to an already scheduled CPT, the additional analytical costs would range from $1,000 to $3,000, plus the cost to purchase the volatile chlorinated compound needed to conduct the test. Alternatively, a separate, DRE-specific performance test would cost around $50,000 (Ullrich 2007). For additional details, see Appendix C.

4. U.S. ODS Destruction Technologies

This section describes the general process for collecting and destroying ODS, the technologies that have been used to destroy ODS in the U.S., and the

[19] Note that 40 CFR 63.1203 lists the interim standards, as full compliance with the final standards listed in 40 CFR 63.1219 is not required until October 2008.
[20] Note that 40 CFR 63.1204 lists the interim standards, as full compliance with the final standards listed in 40 CFR 63.1220 is not required until October 2008.

capacity of U.S. facilities to destroy ODS. Additionally, the MACT standards and actual DRE and emissions data from the destruction of ODS are compared to the TEAP recommendations to determine if U.S. technologies are meeting the TEAP recommendations.

4.1 Process for Collecting and Destroying ODS in the U.S.

ODS reach destruction facilities through a number of pathways. Large users may send ODS directly to a destruction facility, while smaller users may return used ODS to their distributor who in turn sends them to a destruction facility. Large users and distributors may also send used ODS to reclamation facilities, but even in such cases, some of the ODS may end up being sent for destruction. Indeed, any ODS not suitable for reclamation—either because it is too contaminated or it is not economically viable to reclaim and resell—should be destroyed. For example, one reclamation facility has indicated that when it receives ODS, which are typically either halon or a mixture of refrigerants, it conducts various tests to identify the ODS types and the level of contamination. If certain ODS that it tends to reclaim (including halons, CFC-12, and HCFC-22 with a 95 percent or higher purity level) are present and not too contaminated, it will separate them out for reclamation. The rest of the ODS are typically destroyed.

When reclamation facilities send ODS to be destroyed, they are shipped in various types of containers (e.g., steel cylinders, bulk storage tanks, ISO containers, tanker trucks, rail cars, which can range in size from 30 lbs to 200,000 lbs) to an off-site destruction facility (unless the reclamation facility has a destruction facility on-site). When ODS containers arrive at a destruction site, they are typically stored for a week to a month before the ODS are fed into the destruction unit.[21] According to information from industry representatives, the average rate at which ODS can be fed into an HWC can vary from around 500 to 2,000 pounds per hour (as compared to the maximum waste feed rate for a rotary kiln unit in Arkansas, which is 42,410 pounds per hour or a fixed hearth incinerator in Illinois, which is about 6,000 pounds per hour). For a 30,000-pound shipment of ODS, this would result in a total destruction time of 15 to 60 hours. For a plasma arc unit, the typical feed rate for ODS is around 100 pounds per hour. (Airgas 2006; Arkansas DEQ 2002; EPA 2006a; Illinois EPA 2003; RemTec 2005, 2006; Ullrich 2007)

4.2 Known Commercial ODS Destruction Technologies Used in the U.S.

Destruction facilities in the U.S. that have destroyed ODS can be categorized into three main categories:

1. those that destroy ODS-containing byproducts of chemical manufacturing, which are not considered controlled substances;[22]
2. those that burn waste for fuel and receive blended waste-derived fuel from outside sources (which may contain controlled substances, such as spent solvents, as well as substances not controlled under the CAA, such as ODS-containing byproducts from chemical manufacture); and
3. those that commercially destroy controlled substances for outside parties.

While there are a significant number of non-commercial, byproduct destruction facilities in the U.S. that have destroyed ODS-containing wastes, there are fewer than 10 known facilities that commercially destroy ODS or receive ODS-containing waste-derived fuel (hereinafter referred to collectively as "commercial facilities").

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[21] In certain cases, whole containers—not just their contents—are shredded and fed directly into the HWC.

[22] According to 40 CFR 82.3, "the inadvertent or coincidental creation of insignificant quantities of a listed [ODS] during a chemical manufacturing process, resulting from unreacted feedstock, from the…use [of ODS] as a process agent present as a trace quantity in the chemical substance being manufactured, or as an unintended byproduct of research and development applications, is not deemed a controlled substance."

These facilities can be categorized as follows:

- Incinerators
    - Rotary kilns
    - Fixed hearth units
    - Liquid injection units
- Industrial furnaces
    - Cement kilns
    - Lightweight aggregate kilns
- Plasma technologies
    - Argon plasma arc units

All of the known commercial facilities, with the exception of one, are RCRA-permitted HWCs and, therefore, must meet all regulatory requirements discussed in Section 2, including a 99.99 percent DRE.

4.3 Capacity of U.S. Destruction Facilities

RCRA-Permitted Commercial HWCs

The capacity for hazardous waste incineration at U.S. commercial HWC facilities varies greatly (e.g., 42,410 pounds per hour for a rotary kiln unit in Arkansas and 6,000 pounds per hour for a fixed hearth incinerator in Illinois) (Arkansas DEQ 2002, Illinois EPA 2003). This capacity does not necessarily translate directly into the potential capacity to destroy ODS because HWCs typically process ODS as only a small part of a much larger variety of hazardous wastes. According to information obtained from industry, the feed rate for ODS can range from approximately 500 to 2,000 pounds per hour, depending on the facility (EPA 2006a, Ullrich 2007). The ODS destruction capacity of any one facility depends on the amount of other hazardous wastes being supplied to the facility at any given time and the operating conditions of the facility (including feed rate, flame temperature, fuel composition, oxygen content).

In addition, other factors serve to limit the amount of ODS that commercial HWCs can accept for destruction. Apart from permit limits for maximum total feed rate of chlorine to the unit, discussed in Section 3.2, commercial HWCs can only combust limited amounts of fluorinated and brominated compounds, due to the corrosive nature of the acid gases (HF and HBr) that result from their incineration. The production of acid gases, especially HF, requires expensive upgrades to the HWC unit in order to prevent damage to downstream equipment caused by corrosion. This equipment includes:

- upgraded bag material in the bag house;
- HF-resistant refractory lining and binder in the combustion chambers through the quench area; and
- specially-lined, corrosion-resistant, fiberglass-reinforced plastic (FRP) in the scrubbing system.

According to one industry representative, the total capital costs to install the necessary equipment can exceed $1 million. In addition, increased operations and maintenance costs generally follow such upgrades; therefore, operators of HWCs generally perform site-specific calculations to assess the maximum feed rates of fluorinated and brominated compounds they can accept without causing corrosion concerns. Feed rates are also restricted because fluorinated and brominated compounds must be destroyed with an increased level of hydrogen to promote the formation of HF and HBr over F_2 and Br_2. During the destruction of halon, additional oxygen must also be present to prevent the halon from affecting the stability of the combustion flame, as halons are fire suppressants. All of these factors would serve to restrict the amount of ODS waste that could be feed into HWCs at any given time. (EPA 2006a)

In 2005, according to EPA's National Biennial RCRA Hazardous Waste Report, 4,332,011 metric tons of hazardous wastes were destroyed in the U.S. (EPA 2007).[23] Industry representatives present at the ODS destruction stakeholder meeting held at EPA's offices in July 2006 have suggested that commercial HWCs are currently operating at only about 70 percent of total capacity (EPA 2006a). Assuming that these units can operate continually at full capacity, it is estimated that an additional 1,856,576 metric tons of capacity can be made available for hazardous waste destruction. However, the additional 30 percent capacity may not necessarily be made wholly available to ODS, since many facilities would require equipment upgrades to be able to accept additional amounts of ODS for destruction, and future amounts of ODS for destruction may not warrant the costs to make these modifications.

Non-Commercial Facilities

Facilities that destroy ODS-containing byproducts from chemical manufacture generally do not have the capacity or infrastructure to accept ODS wastes generated offsite. Some of these facilities have indicated that they do accept offsite waste for destruction, but only wastes generated at other facilities operated by the same entity. ODS destruction units at these facilities may have additional capacity available to destroy ODS generated by other entities, but the facilities may not have adequate hazardous waste storage and handling infrastructure or the appropriate regulatory permits to do so.

Non-MACT Compliant Facilities

Non-MACT-compliant waste combustion facilities could also potentially be used to destroy ODS that are not categorized as RCRA hazardous wastes. When the CAA MACT standards for HWCs were proposed, a number of existing hazardous waste destruction facilities assessed the cost of upgrading their facilities in order to comply with the proposed MACT standards and, based on that analysis, declined to pursue operating permits under the MACT standards. These facilities are no longer regulated as HWCs and are no longer permitted to combust hazardous wastes. However, under existing regulations, such facilities could still pursue state operating permits to combust non-hazardous wastes, including ODS that are not categorized as hazardous wastes. Such facilities could also be permitted for use as fume/vapor incinerators (i.e., air emission control devices) to destroy chemical process byproducts generated on site.

Conversion of ODS into Useful Non-ODS Products

In order to explore alternatives to ODS destruction, the U.S. EPA has supported an investigation of the process of converting ODS to useful non-ODS products (e.g., conversion of halon 1211 and halon 1301 to difluoroethylene [VDF]). Research on this process has been conducted at the University of Newcastle, Australia, and other institutions. One recent study provided a design of a process for conversion of halon 1211 and halon 1301 to VDF, a non-ODS feedstock for the production of polyvinylidene fluoride, commercially known as Viton®. Research indicates that these processes could be operated commercially at a profit as an alternative to ODS destruction. (Air Force Research Laboratory 2005, Kennedy and Dlugogorski 2003)

Currently, the number of such facilities that have acquired permits to combust non-hazardous waste and their potential capacity to accept non-hazardous waste ODS for destruction is unknown. If non-MACT-compliant facilities were to destroy non-hazardous waste ODS, the following factors should be considered: (a) if they are already operating at full waste feed capacity; (b) if their combustion units are operated at high enough temperatures to destroy ODS to the specified DE;[24] and (c) if their air emission

[23] This includes hazardous wastes that were destroyed by the following management methods: incineration (H040), defined as "thermal destruction other than use as a fuel"; energy recovery (H050), defined as "used as fuel (includes on-site fuel blending before energy recovery)"; and fuel blending (H061), defined as "waste generated either onsite or received from offsite".

[24] One stakeholder indicated that non-hazardous waste incinerators are probably not operating at high enough temperatures to destroy ODS to 99.99 percent. However, others indicated that this may not be true for certain technologies, such as cement kilns or sulfuric acid furnaces. (EPA 2006a)

control systems are capable of removing the HF and HBr that would be generated from ODS combustion.

Non-Permitted Facilities

Another category of facilities that could potentially be used to destroy either hazardous or non-hazardous ODS are combustion facilities that are similar in process to facilities that are currently destroying ODS (e.g., cement kilns) but that have never obtained permits to combust hazardous wastes and have never reported destruction of ODS. Cement kilns operate at kiln temperatures in excess of 2,000°F in order to make cement clinker; cement kilns that are destroying ODS would not operate at significantly different kiln temperatures than cement kilns that are not destroying ODS, since the kiln temperature is inherent to the process of making cement clinker. Cement kilns and other combustion facilities that are similar in process to facilities that are currently destroying ODS could pursue the appropriate permits to combust hazardous waste and/or non-hazardous waste ODS, and thereby increase the ODS destruction capacity in the U.S. There are costs associated with pursuing such permits, including costs to modify the facility's operating permits and the cost to conduct performance testing. A decision by a combustion facility to pursue the appropriate permits to combust non-hazardous waste ODS would involve significantly less cost than a decision to pursue the appropriate permits to combust hazardous waste ODS. It should be noted that through Decision XV/9, the Parties to the Montreal Protocol did not approve cement kilns for halon destruction. However, the TFDT did consider cement kilns as having a high potential to meet the TEAP recommendations while destroying halons based on evidence of destruction of other halogenated substances.

4.4 Assessment of U.S. Technologies: Are They Meeting the TEAP Recommendations?

As described in Section 1, at the Fifteenth Meeting of the Parties to the Protocol, Decision XV/9 was agreed upon. This Decision updates the list of approved destruction technologies for ODS (Annex II), adopts a Code of Good Housekeeping for the transport, storage, and eventual destruction of ODS (Annex III), and reiterates the suggested substances that should be used when monitoring and declaring destruction technologies (Annex IV) (UNEP 2003). Recommended limits on the emissions of these substances were made in the TEAP report (TEAP 2002). This section assesses whether U.S. destruction facilities destroying ODS are meeting these recommended emission limits.

4.4.1 Comparison of TEAP Recommendations, MACT Standards, and Measured DREs and Emissions

Table 5 summarizes the TEAP recommendations, as well as the U.S. MACT standards for new and existing HWCs that have been used to destroy ODS commercially (i.e., incinerators, cement kilns, and lightweight aggregate kilns). Table 5 also includes actual DRE and emissions values obtained from trial burns using ODS at HWCs in the U.S., with the values that exceed the TEAP recommendations shown in bold text. Note that the trial burn data presented for each U.S. facility were collected from multiple test burns conducted over the course of several years with a number of different POHCs, including those listed in the "ODS Type" column. Not all tests measured all types of emissions or used all POHCs listed in the "ODS Type" column. Note also that the performance tests for the commercial HWCs shown in Table 5 were obtained from trial burn tests conducted in the 1990s—prior to the implementation of the current MACT standards. Some of the facilities that were tested have since implemented stricter emissions controls or other operating modifications in order to comply with the new standards (if they are still operating). Therefore, the trial burn data are not fully representative of the current operating performance of the facilities. For this reason, performance test results for these facilities that are in excess of the MACT standards are not shown in the table.

Table 5: Comparison of TEAP Recommended Emission Limits and MACT Standards for HWCs with Reported Values

Recommendation/Standard/ Combustor Type	DRE	PCDD/Fs	HCl/ Cl_2	HF	HBr/ Br_2	PM[a]	CO	ODS Type[b]
	(%)	(ng/m³)	(mg/m³)					
Recommended/Standard Limits								
TEAP Recommendations[c]								
All ODS Destruction Technologies	99.99	0.2	100	5	5	50	100	Any
HWC MACT Standard[d,e,f]								
Incinerators	99.99	0.2[g,h]	21[i]	NA	NA	30[j]	87	NA
Cement Kilns	99.99	0.2[g]	81[k]	NA	NA	**64**[l]	87	NA
Lightweight Aggregate Kilns	99.99	0.2[m]	**403**	NA	NA	**57**[n]	87	NA
Reported Values								
U.S. Hazardous Waste Combustors (Trial Burn Data)[o]								
Rotary Kiln	99.99989 99.99973 99.9997	0.007 0.01 0.006	2 2 0	NA	NA	13 16 5	9 7 3	Carbon Tetrachloride
Fluidized Bed	99.99922 99.9982 99.99928 99.99947	0.175 0.057	4 6 5 30	NA	NA	6 8 10 7	64 16 29 47	Carbon Tetrachloride Methyl Chloroform
Cement Kiln	99.99977 99.99525 99.9999 99.998 99.99943 99.9999	[o]	14 50	NA	NA	**68** **162**	[o]	Carbon Tetrachloride Methyl Chloroform CFC-113
Sulfuric Acid Recovery Unit	99.99986 99.99999 99.999997 99.99999	0.053 0.021	1 0.4 15 8	NA	NA	3 4 1 1	46 65 15	Carbon Tetrachloride Methyl Chloroform
Rotary Kiln	99.9989 99.9963 [o]	0.067 0.019	0.6 6 3 1	NA	NA	6 6 4 7	39 74 42	Carbon Tetrachloride

Source: TEAP (2002), 70 FR 59410, 70 FR 59557, EPA (2006b)
Note: All values that exceed the TEAP recommendations are shown in bold text. NA = Not Applicable.
[a] According to 71 FR 14665, the PM MACT standards for incinerators, cement kilns, and liquid-fueled boilers are currently under review by EPA and may change.
[b] The ODS type listed for the trial burn data represents the ODS POHCs used during the trial burns.
[c] Emission limits are expressed as mass per dry cubic meter of flue gas at 0°C and 101.3 kPa corrected to 11 percent oxygen.
[d] The MACT standard emission limits for total chlorine were converted from ppmv to mg/m³ using the molecular weight for HCl, as this is the most abundant constituent of total chlorine emissions.
[e] Sources may elect to comply with either the CO or an HC standard set at 10 ppmv for incinerators and cement kilns with a bypass/mid-kiln sampling system and 20 ppmv for lightweight aggregate kilns and cement kilns without a bypass.
[f] Emission limits are expressed at standard temperature and pressure, corrected to 7 percent oxygen.
[g] Or 0.40 ng/m³ and temperature control < 400°F at air pollution control device inlet.
[h] For new incinerators equipped with either a waste heat boiler or dry air pollution control system, the limit is 0.11 ng/m³.
[i] Incinerators can also meet a risk-based standard for total chlorine emissions of 77 ppmv (~52 mg/m³). New source incinerators must meet a total chlorine limit of 21 ppmv (~14 mg/m³).
[j] New source incinerators must meet a PM limit of approximately 3.4 mg/m³.
[k] Cement kilns can also meet a risk-based standard for total chlorine emissions of 130 ppmv (~87 mg/m³). New source cement kilns must meet a total chlorine limit of 86 ppmv (~58 mg/m³).
[l] New source cement kilns must meet a PM limit of approximately 5.3 mg/m³.
[m] Or rapid quench < 400°F at kiln exit.
[n] New source lightweight aggregate kilns must meet a PM limit of approximately 22 mg/m³.
[o] Because the trial burn data were taken before the updated MACT standards were implemented, the data points that are above the current allowable limits were not included as they are no longer applicable or allowable under the updated standards.

As shown in Table 5, the MACT standards for HWCs are, for the most part, equivalent to or more stringent than the TEAP recommendations. The following points should be taken into account when reviewing Table 5:

- Each Title V permitted HWC is subject to emission limits for each pollutant specified by the MACT standard. Facility-specific operating parameters—which are also contained in the Title V Operating Permit for the facility—may be based on evaluation of the types, quantities, and compositions of the hazardous wastes being destroyed and capability of the air pollution control device.
- Additional risk-based limits can be included in the facility's RCRA permit, which may be more stringent than the MACT limit, if they are demonstrated to be necessary to protect human health and the environment. The need for a site-specific risk assessment (SSRA) is evaluated by the permitting agency on a case-by-case basis in accordance with EPA SSRA policy, and may be required when there is reason to believe that operation in accordance with the MACT standards alone may not be protective of human health and the environment. For example, if an existing HWC facility wishes to accept quantities of fluorinated or brominated ODS for destruction, but the facility had not previously been evaluated or permitted with respect to combustion of such waste, then the RCRA permit for that facility could be reevaluated by the permitting agency in order to ensure that the facility would not present an increased risk to human health and the environment (i.e., that it is designed and operated to properly combust fluorinated or brominated ODS).
- HWCs generally operate well below their permitted emission levels because any excursion beyond the limits may put them out of compliance and result in a fine or other regulatory enforcement action. Also, as discussed previously, operation of the unit outside of its permit limits for monitored parameters (e.g., combustion temperature) could initiate an automatic waste feed cutoff and shutdown of the unit.
- U.S.-based HWCs are highly regulated entities, subject to regulation under both the CAA and RCRA and associated state statutes and regulations, while the TEAP recommendations were established for facilities world-wide, many of which are not subject to any regulations and may not employ any air emissions control systems. Also, HWCs in the U.S. have been subjected to SSRAs that demonstrate on a facility-specific basis that air emissions from those facilities do not pose a significant risk to human health and the environment. In other words, the TEAP recommendations are designed as generic standards applicable to ODS destruction facilities, while the CAA MACT standards and associated Title V Operating Permit limits for HWCs operating in the U.S. establish individualized, source category-specific emission limits and associated monitoring, reporting, and recordkeeping requirements.
- Even before the stricter MACT standards were implemented, which is when the trial burn data presented in Table 5 was generated, most commercial facilities for which data are available were already exceeding the minimum DRE of 99.99 percent and meeting air emission limits corresponding to the current MACT standards.

In addition to the performance test data available for U.S. HWCs, the 2002 TEAP report includes DRE and air emissions data from the destruction of ODS using various technologies. These data, which are the basis for the TEAP's technology recommendations, demonstrate the ability of several of the technologies used in the U.S. to meet the TEAP recommended limits for DRE and air emissions. While the data presented here may not be directly applicable to specific U.S. facilities, it is expected that U.S. facilities using these technology types would be able to meet the TEAP recommendations, with appropriate modifications/upgrades. Table 6 summarizes the data presented in the TEAP report for technologies that are known to have destroyed ODS in the U.S., as well as other technologies that are not known to be in use in the U.S.

Table 6: TEAP Reported DRE and Air Emissions Data for ODS Destruction Technologies

Technology Type	DRE	PCDD/Fs	HCl/Cl_2	HF	HBr/Br_2	PM	CO	ODS Type[a]
	(%)	(ng/m^3)	(mg/m^3)					
TEAP Recommendations[b]								
All ODS Destruction Technologies	99.99	0.2	100	5	5	50	100	Any
Technologies Used in the U.S. for Destroying ODS								
Rotary Kiln	>99.9999	0.03-0.15[c]	3	0.5	4	10	50	CFCs/Halons
Liquid Injection	>99.99	0.52[d]	<10	<1.0	NR	NR	<10	CFCs/Halons
Cement Kilns	>99.99	0.040	<1	0.4	NA	10	100	CFCs
Argon Plasma Arc	>99.9998	0.006	2	0.2	<4	<10	96	CFCs/Halons
Other Technologies								
Reactor Cracking	>99.999	<0.01	<100	<0.1	NA	<10	<50	CFCs
Gas/Fume	>99.999[e]	0.032	3	0.5	2	22	40	CFCs/Halons
ICRF Plasma	>99.99	0.012	5	2.4	2	5	5	CFCs/Halons
Microwave Plasma	>99.99	0.001	2	0.7	NA	11	4	CFCs
Nitrogen Plasma Arc	99.99	0.044	2	0.6	NA	9	26	CFCs
Superheated Steam Reactor	>99.99	0.041	<3	<0.8	NA	NR	<11	CFCs
Gas Phase Catalytic Dehalogenation	>99.99	<0.010	1	<0.5	NA	2	13	CFCs

Source: TEAP (2002).
Note: The data presented in the TEAP report are measured data for specific facilities located around the world.
NA = Not Applicable; NR = Not Reported.
[a] The ODS type listed represents the type of ODS shown to be destroyed by the technology.
[b] Emission limits are expressed as mass per dry cubic meter of flue gas at 0°C and 101.3 kPa corrected to 11 percent oxygen.
[c] Some rotary kilns that reported emission for the TEAP analysis indicated PCDD/F emission greater than 0.3 ng/m^3.
[d] Although the particular data provided for the TEAP report did not meet the required levels for PCDD/F emissions, it is expected that liquid injection systems could meet the required levels with the proper pollution control mechanisms.
[e] Only 99.99 percent DRE reported for halon destruction.

4.4.2 Information on ODS Destruction from EPA Stakeholder Meeting

On July 28, 2006, EPA held a stakeholder meeting to discuss the import of used ODS for destruction in the U.S., during which stakeholders provided information regarding the MACT standards and the TEAP recommendations. EPA invited interested parties to attend this open meeting. HWC companies that attended the stakeholder meeting expressed confidence that they can meet the TEAP recommendations; however, they are not currently generating all of the data that would be needed to document that they are meeting the recommendations for DRE and air emission limits of certain compounds as they are not physically measuring exhaust gas emissions of ODS and are not specifically determining the DRE for ODS during performance testing. As described in Section 2.3.1, HWCs measure the DRE for selected difficult-to-combust POHCs (e.g., monochlorobenzene) under a controlled set of operating conditions (e.g., combustion temperature, exhaust gas flow rate and temperature, hazardous waste feed rate), and then apply the measured DRE to other compounds, including ODS, that are combusted under the same set of conditions as were used in the performance testing. Except for the few tests shown in Table 5, HWCs have not conducted performance testing using ODS, and they do not measure ODS emissions directly; therefore, there is no direct documentation that the facilities are meeting the TEAP recommended 99.99 percent DRE. However, the use of POHCs in performance testing of HWCs, rather than testing a broad array of compounds, is a well-established concept within the framework of the RCRA and HWC MACT regulations.

According to the stakeholders, there are no technical limitations to physically measuring the DRE for ODS during performance testing, and such testing could be conducted during the regularly scheduled comprehensive performance testing conducted under the HWC MACT standards. The HWCs are not currently conducting testing to physically measure the DRE for ODS because there are no regulatory requirements for them to do so, and because such testing requires additional time and money. See Section 3.3 and Appendix C for a discussion of the costs associated with testing ODS.

In addition to the lack of performance measurements currently being performed by U.S. HWCs, the CAA MACT standards for HWCs do not include standards for emissions of HF, Br_2, and HBr. However, emissions of HF from ODS destruction facilities would still be regulated under the state and federal air emissions operating permits for these facilities. HF is regulated under the CAA as a HAP and is also subject to state ambient air quality standards for gaseous fluorides (total ambient air concentration expressed as HF).[25] Therefore emissions of HF from ODS destruction facilities would be limited by permit to be within these state and federal regulations. HBr and Br_2 are not regulated as HAPs under the CAA, but are subject to state regulations as toxic air pollutants. Emissions of these compounds would be limited in accordance with state regulations. Under the MACT standards, HWCs are also subject to SSRAs that would identify potential risks associated with emissions of HF, Br_2 and HBr from ODS destruction facilities regulated as HWCs.

4.4.3 Conclusions for CFC/HCFC Destruction

DRE

All known commercial ODS destruction facilities operating in the U.S. are permitted HWC facilities (with the exception of one facility that is not RCRA permitted); therefore, they are required to meet the HWC MACT standards for DRE and emissions of dioxins/furans, PM, total chlorine, and CO when destroying ODS that are also listed hazardous wastes, including some CFCs. Additionally, because HCFCs are easier to destroy than CFCs, these standards will be met for HCFC destruction as well (TEAP 2002). The incinerability of HCFC-22 and HCFC-123 were recently evaluated by Lamb and Dellinger and, because each has an Incinerability Index below Class I, they may be disposed of in incinerators with a proven DRE greater than 99.99% for at least one Class I POHC (ICF 2007).

Air Emissions

The MACT standards for HWCs are at or below the TEAP recommendations for air emissions of HCl/Cl_2, PM, CO, and dioxins and furans, with only a few exceptions; the PM MACT standards for existing cement kilns and lightweight aggregate kilns are greater than the TEAP recommended limit, as is the total chlorine MACT standard for lightweight aggregate kilns. However, the PM MACT standards for new cement kilns and lightweight aggregate kilns are significantly less than the TEAP recommended limits, and these MACT standards are currently being reevaluated by EPA. Also, while the total chlorine MACT standard for lightweight aggregate kilns is approximately four times the TEAP recommended limit, it is likely that facilities will generally operate well below this level and any emissions will be limited by permit conditions to levels below those that would present a risk to human and/or environmental health.[26]

It should be noted that the incineration of fluorinated substances would result in the production of HF, a HAP that is not addressed in the HWC MACT standards. However, if fluorinated compounds are being combusted and significant emissions of HF are expected from an HWC, it is anticipated that state permit writers may establish site-specific feed rate limits for total fluorine in the facility's RCRA permit, which may be more stringent than the MACT limit, if they are determined to be necessary to ensure protection of human health and the environment. Furthermore, site specific feed-rate limits for total fluorine may not

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[25] See e.g., Kentucky Regulation 401 KAR 53.010: Ambient Air Quality Standards (http://www.lrc.ky.gov/kar/401/053/010.htm)

[26] In general, state agencies can require a SSRA in the event that the agency concludes that emissions from a hazardous waste combustor may pose a significant risk to human health or the environment.

be necessary for combustion units designed with control equipment capable of capturing acid gasses (e.g., wet scrubbers for the control of HCl emissions).

4.4.4 Conclusions for Halon Destruction

DRE

Because halons are not listed as RCRA-hazardous wastes, permitted HWCs are not required to meet the MACT standards for their destruction, and therefore, it cannot be guaranteed with certainty that the minimum DRE is being met for halon destruction in HWCs. Indeed, the TEAP report only recommended technologies for halon destruction based on actual trials of ODS destruction units using halons—i.e., a technology deemed acceptable to destroy CFCs was not necessarily also deemed acceptable to destroy halons if that technology was not actually tested using halons. Thus, the only way to be completely certain that the DRE is being met for halon destruction in HWCs would be for U.S. facilities to conduct performance testing using halons as POHCs to directly determine the DRE achieved for each of these compounds. See Section 3.3 and Appendix C for a further discussion of costs to conduct testing of ODS.

However, based on available performance data and the chemical properties of halons, it is expected that the 99.99 percent DRE *is being met* for halons, which would suggest that testing of each non-hazardous waste ODS is not needed. In particular:

- *Findings based on existing trial burn data:* While performance data for halon destruction in U.S. HWCs could not be found, performance data for other ODS—including carbon tetrachloride, CFC-11, and CFC-113—demonstrate that conventional incineration technologies (e.g., rotary kilns) have in practice achieved DREs far greater than the 99.99 percent standard (on the order of 99.9999 percent), even when destroying chlorinated organic compounds that have very high thermal stability (e.g., monochlorobenzene). The fact that HWCs have demonstrated performance greater than the minimum DRE standard provides a substantial margin of operation with respect to the incineration of halons. Unless the thermal stability of halons is far greater than that of monochlorobenzene and other difficult-to-incinerate compounds, it would be expected that HWCs that could incinerate these other compounds to a DRE of 99.9999 percent could also incinerate halons to a DRE of at least 99.99 percent. Furthermore, similar international technologies analyzed in the TEAP report were shown to meet the minimum DRE when destroying both CFCs and halons.

- *Findings based on halon chemistry:* The incinerability of halons can be estimated based on their chemical composition, and it is expected that halons would react relatively easily at the very high temperatures at which HWCs operate (see text box for more information). The incinerability of halon 1301, halon 1211, and halon 2402 was recently evaluated by Lamb and Dellinger and, because each

> **Halon Chemistry**
>
> An inherent characteristic of halons is that they undergo chemical reaction when exposed to flame. Considering the chemistry of halons in fire extinguishing applications, it is expected that a similar chemical reaction would occur if halons were exposed to flame and a burning fuel-air mixture in an incinerator. Specifically, halon would produce HBr and Br^- and remove hydrogen and oxygen from the combustion process in the incinerator. Also, considering that the halon decomposition and the HBr/Br^- reaction occurs at relatively low flame temperatures in fire extinguishing applications, it is expected that halon would also react relatively easily at the much higher temperatures at which incinerators operate. Indeed, halon 1301 decomposes at fire temperatures above 1,562°F, and halon 1211 decomposes at fire temperatures above 900°F—well below the combustion temperatures at which HWCs generally operate (DuPont 2004, Ansul Incorporated 2006). According to the available U.S. performance test data, the lowest afterburner (secondary combustion chamber) operating temperature is 1,610°F, which is higher than the threshold temperatures needed to decompose both halon 1211 and 1301.

has an Incinerability Index below Class I, they may be disposed of in incinerators with a proven DRE greater than 99.99% for at least one Class I POHC (ICF 2007).

Air Emissions

The incineration of halons and other brominated compounds (e.g., methyl bromide) would result in the release of an additional acid gas, HBr, that is not formed during the incineration of CFCs/HCFCs and for which there is no MACT standard. Additionally, when reducing conditions are not present during the destruction of brominated compounds, Br_2 tends to form over HBr—and Br_2 is much more difficult to remove from exhaust gas than HBr.

It is anticipated that if brominated compounds are being combusted and significant emissions of total bromine are expected, permit writers may establish site-specific feed rate limits for total bromine (to control emission of HBr and Br_2) in the facility's RCRA permit, if they are determined to be necessary to ensure protection of human health and the environment. Furthermore, site specific feed-rate limits for total bromine may not be necessary for combustion units designed with control equipment capable of capturing acid gasses (e.g., wet scrubbers for the control of HCl emissions) or for units that introduce a reducing agent (e.g., a sulfur containing compound) into the combustor to minimize Br_2 emissions.

5. Amount and Type of ODS Commercially Destroyed

Table 7 presents data compiled by EPA on quantities of ODS (by type) destroyed in the U.S. for the years 2003 and 2004. This data includes both ODS destroyed commercially and ODS contained in waste used as fuel. The data presented are *not inclusive of all commercial/waste fuel ODS destruction* that occurred in the U.S. in 2003 and 2004. Whether the ODS waste destroyed was from stockpiles or serviced/retired equipment is not known.

Table 7: Reported ODS Destroyed by Type (kg) and Associated Emissions Avoided (ODP-weighted MT)

ODS Type	2003	2004
Class I (amounts reported in kg)		
CFC-11	58,846	109,884
CFC-12	23,709	62,364
CFC-113	305,254	46,782
CFC-114	464	4,044
CFC-115	4,401	6,737
Halon 1301	3	6,487
Halon 2402	41	5,400
CFC-13	153	182
CFC-112	67,252	68,327
Carbon Tetrachloride	2,523,547	1,608,251
Methyl Chloroform	1,460,762	1,234,257
Methyl Bromide	36,815	63,334
Class II (amounts reported in kg)		
HCFC-123	40,171	923
HCFC-124	1,208	391
HCFC-131	944	21
HCFC-132b	760	1,109
HCFC-133a	1,621	2,433
HCFC-141b	6,039	16,217
HCFC-142b	236,024	5,893
HCFC-21	31,929	14,341
HCFC-22	87,922	5,890
HCFC-225ca	765	951
HCFC-225cb	1,094	1,248
HCFC-233	2,609	3,959
HCFC-253fb	342	1,268
Emissions Avoided (amounts reported in ODP-weighted metric tons)		
Total	**3,366**	**2,318**

6. Projections of Future Amounts of ODS for Destruction

This section explores the total amount of ODS through 2030 that may be available for destruction in the future, including quantities that may be stockpiled in bulk. Two scenarios were developed to estimate the quantities of ODS potentially available for destruction while considering what will likely be recovered from equipment at end of life. The analysis presented is based on EPA's Vintaging Model (VM).

6.1 Bulk ODS Stockpiles

Currently, there is limited information available on current or expected future stockpiles of ODS. Research indicates that most ODS users are unlikely to keep large stockpiles for any uses that are not planned for the immediate future, due to the extra costs required to store surplus ODS and the current availability for most ODS.

However, some ODS users that are reliant on costly legacy systems and/or have special safety concerns often hold significant stockpiles of CFC-11, CFC-12, halon 1301, and/or halon 1211. These bulk stockpiles are designed to meet their immediate and future needs (for several years into the future). In addition, servicing companies in the refrigeration/air-conditioning and fire suppression sectors likely hold small stockpiles of CFCs/halons.

Large stockpiles of HCFCs are not believed to exist in the United States at this time. While the price of HCFC-22 continues to rise, it is still relatively low. The low market value of HCFC-22 has provided little incentive to collect and reclaim used HCFC-22 in anticipation of the 2010 milestone to reduce production and import. In the future, however, HCFC-22 may be stockpiled to satisfy servicing needs.

Moreover, under a business-as-usual scenario, it is unlikely that significant quantities of ODS from stockpiles will be made available for destruction, since most are intended for future use. However, excess stocks currently being held for future use could be made available for destruction if retrofitting or alternatives for legacy systems become more cost-effective.

6.2 Projected ODS Available for Destruction from Refrigeration and Air-Conditioning Equipment

The amount of ODS potentially available for destruction in any given year will be a portion of the total inventory of ODS contained in equipment and products. However, not all ODS can be easily captured and/or made available for destruction. For example, recovering ODS foam blowing agents from building and appliance foam may be difficult and expensive. Similarly, the amounts of halon that continue to be used in fire protection equipment will likely be re-used instead of destroyed to maintain existing systems until they reach the end of their useful life. Theoretically, the most accessible ODS that could be made available for destruction are those contained in refrigeration and air conditioning (AC) equipment. As such, the remainder of this section focuses on the refrigeration/AC sector, exploring various scenarios for estimating the amount of ODS refrigerant recovered during servicing events and at end of life (EOL), which could then be made available for destruction.

6.2.1 Projected ODS Recovered During Servicing Events

In order to estimate the quantity of refrigerant recovered during equipment service events that is potentially available for destruction, the following equation was used:

Annual number of units from which refrigerant is recovered during service events	x	Quantity of refrigerant recovered per unit	=	Annual quantity of refrigerant recovered during service events

To estimate the number of units involving refrigerant recovery, the following assumptions were made:

- 50 percent of industrial/commercial equipment is serviced annually.[27]
- 50 percent of equipment is serviced only when repair is needed, which is assumed to be once every five years for industrial/commercial equipment (i.e., 20 percent of units annually).
- 30 percent of all service events in the industrial/commercial sector involve refrigerant recovery (while the remaining 70 percent of service jobs do not involve the refrigeration circuit).

Therefore, 18 percent of all units are assumed to be serviced annually (i.e., 30% x [(20% x 50%) + 50%]). It is also assumed that 0.75 pounds of refrigerant are recovered from the units that are serviced, as a section of the refrigerant charge is typically isolated and recovered when performing repairs, not the entire charge.

Using the above assumptions, the Vintaging Model was used to estimate the annual quantity of refrigerant recovered during servicing events from large retail food systems, chillers, and industrial process

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[27] According to industry sources, refrigerant recovered during service events primarily originates from commercial and industrial equipment (Home Energy Center 2006, Airgas 2006).

refrigeration equipment.[28] Based on this analysis, Table 8 presents the ODP-weighted quantities of CFC and HCFC refrigerants potentially available for destruction from equipment servicing events through 2030. Years 2003 and 2004 are presented to allow for comparison with actual data on U.S. ODS destruction (presented in Section 6.3).

Table 8: Refrigerant Recovered from Servicing Events on Large Equipment (ODP-Weighted MT)

Year	CFC	HCFC
2003	3.5	15.9
2004	3.3	16.5
2005	3.1	16.8
2010	1.8	17.3
2015	0.5	17.3
2020	0.0	17.3
2025	0.0	17.9
2030	0.0	19.2

Source: *U.S. EPA Vintaging Model*. Version VM IO 5-28-08
Note: Blends have been proportioned according to the percentage of the blend that contains CFCs and/or HCFCs.

6.2.2 Projected ODS Recoverable at End of Life

The actual amount of refrigerant that is recovered at equipment EOL depends on many factors, including (a) the refrigerant charge remaining at time of disposal, (b) losses during the recovery process, and (c) residual refrigerant remaining in the system ("heel"). Because there is great uncertainty regarding the actual amount of refrigerant recoverable at EOL, this analysis considered two recovery scenarios:

- **Scenario 1**: assumes that 50 percent of the original equipment charge is recovered at EOL.
- **Scenario 2**: assumes that 10 percent of the original equipment charge is recovered at EOL.

These percentages were applied to the original charge of equipment estimated to be retired in each year to determine a range of amounts of recovered refrigerant potentially available for destruction (or reuse). In other words, potential annual supply was determined by multiplying the number of units of equipment retired in a given year by the full charge size and the respective recovery rates.

Table 9 presents the projected quantities of CFC and HCFC refrigerants potentially available for destruction from retired equipment through 2030. Years 2003 and 2004 are presented to allow for comparison with actual data on U.S. ODS destruction (in Section 6.3).

[28] Cold stores were not considered in the analysis because the Vintaging Model does not track the number of cold stores in the United States; the model tracks data for this end use on a cubic foot basis (not a per-unit basis).

Table 9: Quantity of ODS Refrigerants Potentially Available for Destruction at EOL (ODP-weighted MT)

Year	Scenario 1 (50% Recovery)		Scenario 2 (10% Recovery)	
	CFC	HCFC	CFC	HCFC
2003	6,886	655	1,377	131
2004	6,117	679	1,223	136
2005	4,215	715	843	143
2010	1,894	885	379	177
2015	1,251	1,194	250	239
2020	76	1,157	15	231
2025	0	319	0	64
2030	0	130	0	26

Source: *U.S. EPA Vintaging Model*. Version VM IO 5-28-08
Note: Blends have been proportioned according to the percentage of the blend that contains CFCs and/or HCFCs.

6.3 Comparison of Potential and Actual ODS Destruction Amounts

Table 10 presents a comparison of actual (reported) quantities of CFCs/HCFCs destroyed in 2003 and 2004 and the VM projections of ODS potentially available for destruction from servicing and EOL in those years.[29] As shown, actual quantities destroyed are much less than those estimated to be potentially available for destruction, as the large majority of recovered refrigerant is currently recycled/reclaimed and reused, not destroyed.

Table 10: Comparison of Actual ODS Destroyed vs. Potential ODS Available for Destruction in 2003 and 2004 (ODP Weighted MT)

Year	Actual (Reported) Amount of ODS Destroyed		Estimated Potential Amount of ODS Available for Destruction from Equipment Servicing and Retirement			
			Scenario 1 (50% Recovery)		Scenario 2 (10% Recovery)	
	CFC	HCFC	CFC	HCFC	CFC	HCFC
2003	397	24	6,886	655	1,377	131
2004	286	4	6,117	679	1,223	136

Source: *U.S. EPA Vintaging Model*. Version VM IO 5-28-08
Note: For the Vintaging Model estimates, quantities of CFCs or HCFCs contained in blends are included. Estimates of stockpiles are not included in this table.

7. Costs Associated with the Destruction of ODS

This section presents a discussion of reported costs to destroy and transport various types of ODS. Information was received through personal communication with destruction companies.

7.1 ODS Destruction Costs

The price of ODS destruction depends on the type of ODS, composition/purity, quantity, the type of container the ODS is stored in, and transportation needs. In general, costs are greater to destroy ODS delivered in smaller versus large containers (e.g., cylinders versus ISO tanks). Additionally, if a destruction facility has a large amount of refrigerant to destroy in a given week, prices may increase or the facility may even refuse to accept the waste (TWI 2000, RemTec 2000, Rineco 2000).

[29] The Vintaging Model estimates of ODS potentially available for destruction consider only destruction of CFC and HCFC refrigerants contained in existing equipment, while the actual destruction data could include quantities of CFCs/HCFCs destroyed from other sources (e.g., stockpiles).

7.2 Transportation and Other Associated Costs

Costs associated with transporting ODS to a destruction facility can vary greatly depending on distance and quantity, and whether the transport is within or beyond state borders. Bulk quantities in-state are the most economical to transport. According to one destruction company, a railcar carrying 190,000 pounds of waste-containing ODS costs approximately $800 for in-state shipments (about $0.42 per 100 pounds of ODS); these costs approximately double for out-of-state shipments. The same source estimates that a tank truck carrying 42,000 pounds of waste can cost as much as $700 for in-state shipments ($1.67 per 100 pounds); corresponding prices for out-of-state shipments were not provided by the source, as they are highly variable. Another destruction company reported the cost to transport waste refrigerant varies from $0.15 to $0.30 per pound, depending on the refrigerant type. Another company charges $4.00 per mile for transport in a pressurized ISO tanker, or the tanker can be leased (with a minimum 1-year lease) for $1,000 per month.

In addition, there are other costs associated with the management of used ODS. These costs are also associated with ODS being sent for destruction and should be factored into the total cost of destruction. ODS must be collected from service technicians who have removed the ODS from equipment, or from bulk customers. There also may be a need to buy-back unused refrigerant, if it has market value. Once ODS has been collected, it must be consolidated to a central location, and/or into larger containers – usually in a central storage area. Before being transported to a destruction facility, manifests must be completed and the contents of each tank identified through gas chromatography or other verifiable means

Appendix A: Code of Good Housekeeping Adopted by Decision XV/9 (Annex III)

The following "Code of Good Housekeeping" has been copied directly from Annex III of the Report of the Fifteenth Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Later (UNEP 2003):

To provide additional guidance to facility operators, in May 1992 the Technical Advisory Committee prepared a "Code of Good Housekeeping" as a brief outline of measures that should be considered to ensure that environmental releases of ozone-depleting substances (ODS) through all media are minimized. This Code, updated by the Task Force on Destruction Technologies and amended by the Parties at their Fifteenth Meeting, in 2003, is also intended to provide a framework of practices and measures that should normally be adopted at facilities undertaking the destruction of ODS.

Not all measures will be appropriate to all situations and circumstances and, as with any code, nothing specified should be regarded as a barrier to the adoption of better or more effective measures if these can be identified.

Pre-delivery

This refers to measures that may be appropriate prior to any delivery of ODS to a facility.

The facility operator should generate written guidelines on ODS packaging and containment criteria, together with labelling and transportation requirements. These guidelines should be provided to all suppliers and senders of ODS prior to agreement to accept such substances.

The facility operator should seek to visit and inspect the proposed sender's stocks and arrangements prior to movement of the first consignment. This is to ensure awareness on the part of the sender of proper practices and compliance with standards.

Arrival at the facility

This refers to measures that should be taken at the time ODS are received at the facility gate.

These include an immediate check of documentation prior to admittance to the facility site, coupled with a preliminary inspection of the general condition of the consignment.

Where necessary, special or "fast-track" processing and repackaging facilities may be needed to mitigate risk of leakage or loss of ODS. Arrangements should exist to measure the gross weight of the consignment at the time of delivery.

Unloading from delivery vehicle

This refers to measures to be taken at the facility in connection with the unloading of ODS.

It is generally assumed that ODS will normally be delivered in some form of container, drum or other vessel that is removed from the delivery vehicle in total. Such containers may be returnable.

All unloading activities should be carried out in properly designated areas, to which restricted access of personnel applies.

Areas should be free of extraneous activities likely to lead to, or increase the risk of, collision, accidental dropping, spillage, etc.

Materials should be placed in designated quarantine areas for subsequent detailed checking and evaluation.

Testing and verification

This refers to the arrangements made for detailed checking of the ODS consignments prior to destruction. Detailed checking of delivery documentation should be carried out, along with a complete inventory, to establish that delivery is as advised and appears to comply with expectations.

Detailed checks of containers should be made both in respect of accuracy of identification labels, etc, and of physical condition and integrity. Arrangements must be in place to permit repackaging or “fast-track” processing of any items identified as defective.

Sampling and analysis of representative quantities of ODS consignments should be carried out to verify material type and characteristics. All sampling and analysis should be conducted using approved procedures and techniques.

Storage and stock control

This refers to matters concerning the storage and stock control of ODS. ODS materials should be stored in specially designated areas, subject to the regulations of the relevant local authorities. Arrangements should be put in place as soon as possible to minimize, to the extent practicable, stock emissions prior to destruction.

Locations of stock items should be identified through a system of control that should also provide a continuous update of quantities and locations as stock is destroyed and new stock delivered.

In regard to storage vessels for concentrated sources of ODS, these arrangements should include a system for regular monitoring and leak detection, as well as arrangements to permit repackaging of leaking stock as soon as possible.

Measuring quantities destroyed

It is important to be aware of the quantities of ODS processed through the destruction equipment. Where possible, flow meters or continuously recording weighing equipment for individual containers should be employed. As a minimum, containers should be weighed “full” and “empty” to establish quantities by difference.

Residual quantities of ODS in containers that can be sealed and are intended to be returned for further use, may be allowed. Otherwise, containers should be purged of residues or destroyed as part of the process.

Facility design

This refers to basic features and requirements of plant, equipment and services deployed in the facility.

In general, any destruction facility should be properly designed and constructed in accordance with the best standards of engineering and technology and with particular regard to the need to minimize, if not eliminate, fugitive losses.

Particular care should be taken when designing plants to deal with dilute sources such as foams. These may be contained in refrigeration cabinets or may be part of more general demolition waste. The area in which foam is first separated from other substrates should be fully enclosed wherever possible and any significant emissions captured at that stage.

Pumps: Magnetic drive, sealers or double mechanical seal pumps should be installed to eliminate environmental releases resulting from seal leakage.

Valves: Valves with reduced leakage potential should be used. These include quarter-turn valves or valves with extended packing glands.

Tank vents (including loading vents): Filling and breathing discharges from tanks and vessels should be recovered or vented to a destruction process.

Piping joints: Screwed connections should not be used and the number of flanged joints should be kept to the minimum that is consistent with safety and the ability to dismantle for maintenance and repair.

Drainage systems: Areas of the facility where ODS are stored or handled should be provided with sloped concrete paving and a properly designed collection system. Water that is collected should, if contaminated, be treated prior to authorized discharge.

Maintenance

In general, all maintenance work should be performed according to properly planned programmes and should be executed within the framework of a permit system to ensure proper consideration of all aspects of the work.

ODS should be purged from all vessels, mechanical units and pipework prior to the opening of these items to the atmosphere. The contaminated purge should be routed to the destruction process or treated to recover the ODS.

All flanges, seals, gaskets and other sources of minor losses should be checked routinely to identify developing problems before containment is lost. Leaks should be repaired as soon as possible.

Consumable or short-life items, such as flexible hoses and couplings, must be monitored closely and replaced at a frequency that renders the risk of rupture negligible.

Quality control and quality assurance

All sampling and analytical work connected with ODS, the process and the monitoring of its overall performance should be subject to quality assessment and quality control measures in line with current recognized practices. This should include at least occasional independent verification and confirmation of data produced by the facility operators.

Consideration should also be given to the adoption of quality management systems and environment quality practices covering the entire facility.

Training

All personnel concerned with the operation of the facility (with "operation" being interpreted in its widest sense) should have training appropriate to their task.

Of particular relevance to the ODS destruction objectives is training in the consequences of unnecessary losses and in the use, handling and maintenance of all equipment in the facility.

All training should be carried out by suitably qualified and experienced personnel and the details of such training should be maintained in written records. Refresher training should be conducted at appropriate intervals.

Code of transportation

In the interest of protecting the stratospheric ozone layer, it is essential that used ODS and products containing ODS are collected and moved efficiently to facilities practising approved destruction technologies. For transportation purposes, used ODS should receive the same hazard classification as the original substances or products. In practice, this may introduce restrictions on hazardous waste shipment under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal and this should be consulted separately. In the absence of such specific restrictions, the following proposed code of transportation for ODS from customer to destruction facilities is provided as a guide to help minimize damage caused to the ozone layer as a result of ODS transfers. Additional guidance is contained in the United Nations Transport of Dangerous Goods Model Regulations.

It is important to supervise and control all shipments of used ODS and products containing ODS according to national and international requirements to protect the environment and human health. To ensure that ODS and products containing ODS do not constitute an unnecessary risk, they must be properly packaged and labelled. Instructions to be followed in the event of danger or accident must accompany each shipment to protect human beings and the environment from any danger that might arise during the operation.

Notification of the following information should be provided at any intermediate stage of the shipment from the place of dispatch until its final destination. When making notification, the notifier should supply the information requested on the consignment note, with particular regard to:

- The source and composition of the ODS and products containing ODS, including the customer's identity;
- Arrangements for routing and for insurance against damage to third parties;
- Measures to be taken to ensure safe transport and, in particular, compliance by the carrier with the conditions laid down for transport by the States concerned;
- The identity of the consignee, who should possess an authorized centre with adequate technical capacity for the destruction; and
- The existence of a contractual agreement with the consignee concerning the destruction of ODS and products containing ODS.

This code of transportation does not necessarily apply to the disposal of ODS-containing rigid insulation foams. The most appropriate way to dispose of such products may be by direct incineration in municipal waste incinerators or rotary kiln incinerators.

Monitoring

The objectives of monitoring should be to provide assurance that input materials are being destroyed with an acceptable efficiency generally consistent with the destruction and removal efficiency (DRE) recommendations listed in annex II to the present report and that the substances resulting from destruction yield environmentally acceptable emission levels consistent with, or better than, those required under national standards or other international protocols or treaties.

As there are as yet no International Organization for Standardization (ISO) standards applicable for the sampling and analysis of ODS or the majority of the other pollutants listed in annex IV to the present report, where national standards exist they should be employed. Further, where national standards exist they may be used in lieu of ISO standards provided that they have been the subject of a verification or validation process addressing their accuracy and representativeness.

As ISO develops international standards for pollutants listed in annex IV to the present report, the technical bodies charged with developing such standards should take note of the existing national standards including those identified in appendix F to the report of the Technology and Economic Assessment Panel (TEAP) of April 2002 (volume 3, report of the Task Force on Destruction Technologies) and strive to ensure consistency between any new ISO standards and the existing standard test methods, provided that there is no finding that those existing methods are inaccurate or unrepresentative.

Where national standards do not exist, the Technical Advisory Committee recommends adoption of the following guidelines for monitoring of destruction processes operating using an approved technology.

Recognizing that the Unites States of America Environmental Protection Agency (EPA) methods have been the subject of verification procedures to ensure that they are reasonably accurate and representative, that they cover all of the pollutants of interest (although not all ODS compounds have been the specific subject of verification activities), that they provide a comprehensive level of detail that should lead to replicability of the methods by trained personnel in other jurisdictions and that they are readily available for reference and downloading from the Internet without the payment of a fee, applicable EPA methods as described in appendix F to the 2002 report of TEAP may be employed.

In the interest of ensuring a common international basis of comparison for those pollutants or parameters where ISO standards exist (currently particulates, carbon monoxide, carbon dioxide and oxygen), use of those standards is encouraged and jurisdictions are encouraged to adopt them as national standards or acceptable alternatives to existing national standards.

The use of EPA or other national standards described in appendix F is also considered acceptable, however. The precedence given to the EPA methods in the present code is based on the relative comprehensiveness of the methods available (both in scope and content), and the relative ease of access to those methods.

Measurement of ODS

Operators of destruction facilities should take all necessary precautions concerning the storage and inventory control of ODS-containing material received for destruction. Prior to feeding the ODS to the approved destruction process, the following procedures are recommended:

The mass of the ODS-containing material should be determined, where practicable;

Representative samples should be taken, where appropriate, to verify that the concentration of ODS matches the description given on the delivery documentation;

Samples should be analysed by an approved method. If no approved methods are available, the adoption of United States EPA methods 5030 and 8240 is recommended;

All records from these mass and ODS-concentration measurements should be documented and kept in accordance with ISO 9000 or equivalent.

Control systems

Operators should ensure that destruction processes are operated efficiently to ensure complete destruction of ODS to the extent that it is technically feasible for the approved process. This will normally include the use of appropriate measurement devices and sampling techniques to monitor the operating parameters, burn conditions and mass concentrations of the pollutants that are generated by the process.

Gaseous emissions from the process need to be monitored and analysed using appropriate instrumentation. This should be supplemented by regular spot checks using manual stack-sampling methods. Other environmental releases, such as liquid effluents and solid residues, require laboratory analysis on a regular basis.

The continuous monitoring recommended for ongoing process control, including off-gas cleaning systems, is as follows:

- Measurement of appropriate reaction and process temperatures;
- Measurement of flue gas temperatures before and after the gas cleaning system;
- Measurement of flue gas concentrations for oxygen and carbon monoxide.

Any additional continuous monitoring requirements are subject to the national regulatory authority that has jurisdiction. The performance of online monitors and instrumentation systems must be periodically checked and validated. When measuring detection limits, error values at the 95 per cent confidence level should not exceed 20 per cent.

Approved processes must be equipped with automatic cut-off control systems on the ODS feed system, or be able to go into standby mode whenever:

The temperature in the reaction chamber falls below the minimum temperature required to achieve destruction;

Other minimum destruction conditions stated in the performance specifications cannot be maintained.

Performance measurements

The approval of technologies recommended by TEAP is based on the destruction capability of the technology in question. It is recognized that the parameters may fluctuate during day-to-day operation from this generic capability. In practice, however, it is not possible to measure against performance criteria on a daily basis. This is particularly the case for situations where ODS only represents a small fraction of the substances being destroyed, thereby requiring specialist equipment to achieve detection of the very low concentrations present in the stack gas. It is therefore not uncommon for validation processes to take place annually at a given facility.

With this in mind, TEAP is aware that the measured performance of a facility may not always meet the criteria established for the technology. Nonetheless, TEAP sees no justification for reducing the minimum recommendations for a given technology. Regulators, however, may need to take these practical variations into account when setting minimum standards.

The ODS destruction and removal efficiency[30] for a facility operating an approved technology should be validated at least once every three years. The validation process should also include an assessment of

[30] Destruction and removal efficiency has traditionally been determined by subtracting from the mass of a chemical fed into a destruction system during a specific period of time the mass of that chemical alone that is released in stack gases and expressing that difference as a percentage of the mass of that chemical fed into the system.

other relevant stack gas concentrations identified in annex II to decision XV/[…] and a comparison with maximum levels stipulated in relevant national standards or international protocols/treaties.

Determination of the ODS destruction and removal efficiency and other relevant substances identified in annex IV to the present report should also be followed when commissioning a new or rebuilt facility or when any other significant change is made to the destruction procedures in a facility to ensure that all facility characteristics are completely documented and assessed against the approved technology criteria.

Tests shall be done with known feed rates of a given ODS compound or with well-known ODS mixtures. In cases where a destruction process incinerates halogen-containing wastes together with ODS, the total halogen load should be calculated and controlled. The number and duration of test runs should be carefully selected to reflect the characteristics of the technology.

In summary, the destruction and removal efficiency recommended for concentrated sources means that less than 0.1 gram of total ODS should normally enter the environment from stack-gas emissions when 1,000 grams of ODS are fed into the process. A detailed analysis of stack test results should be made available to verify emissions of halogen acids and polychlorinated dibenzodioxin and dibenzofuran (PCDD/PCDF). In addition, a site-specific test protocol should be prepared and made available for inspection by the appropriate regulatory authorities. The sampling protocol shall report the following data from each test:

- ODS feed rate;
- Total halogen load in the waste stream;
- Residence time for ODS in the reaction zone;
- Oxygen content in flue gas;
- Gas temperature in the reaction zone;
- Flue gas and effluent flow rate;
- Carbon monoxide in flue gas;
- ODS content in flue gas;
- Effluent volumes and quantities of solid residues discharged;
- ODS concentrations in the effluent and solid residues;
- Concentration of PCDD/PCDF, particulates, HCl, HF and HBr in the flue gases;
- Concentration of PCDD/PCDF in effluent and solids.

Appendix B: Description of ODS Destruction Technologies

This section provides brief descriptions of each of the ODS destruction technologies found environmentally acceptable by the TEAP Destruction Taskforce. Three additional technologies not evaluated by the TEAP Task Force are also described, which may be suitable for ODS destruction.

Incineration Technologies

Incineration technologies utilize "a controlled flame to destroy ODS in an engineered device" (TEAP 2002: 42). There are seven different types of incinerators used for ODS destruction in the United States and abroad, as described below.

Reactor Cracking

CFCs and HCFCs (as well as HFCs) are broken down, or "cracked," into HF, H_2O, HCl, CO_2, and Cl_2 in a 2,000°C reaction chamber by the reactor cracking process. After the products are cracked, they are moved to the absorber for cooling. The entire process results in waste gases consisting mainly of CO_2, O_2, water vapor, and technical grade quality HF and HCl. The reactor cracking process results in few emissions due to the fact that hydrogen and oxygen are used as the fuel and oxidant, which results in a reduced volume of flue gas. The reactor cracking process is only designed to destroy fluorocarbons and cannot destroy foams or halons. (TEAP 2002, HUG Engineering 2004)

Gas/Fume Incineration

The gas/fume incineration process destroys CFCs, HCFCs, halons, and other wastes in a heat-resistant combustion chamber using fume steam at temperatures around 1,000°C. An external fuel such as natural gas or fuel oil is used to heat the steam (TEAP 2002). In general, most gas/fume incinerators are associated with fluorochemical production plants which do not offer destruction services to outside parties (UNEP 2006, Ineos Fluor 2005).

Rotary Kiln Incineration

Rotary kilns utilize a rotating cylinder to destroy hazardous wastes such as CFCs, halons, other ODS, and ODS-containing foams. The cylinder is set at an incline to allow the ash/molten slag to fall out. The afterburner uses temperatures around 1,000°C to ensure the breakdown of all the exhaust gases. Rotary kiln incinerators are not specifically designed to destroy ODS, so the feed must be regulated to prevent an excess of fluorine from harming the equipment. (TEAP 2002, USACE 2002)

Liquid Injection Incineration

Liquid injection incinerators inject either liquid or vapor wastes into a chamber, where they are broken down into fine droplets, converted into a gas, and then combusted (TEAP 2002, USACE 2002). These types of incinerators are most typically used to destroy wastes such as oils, solvents, and wastewater at manufacturing sites.

Cement Kilns

Cement kilns are primarily used to produce clinker from the conversion of calcium, silica, alumina, and iron to tricalcium silicates, dicalcium silicates, tricalcium aluminate, and tetracalcium aluminoferrite. Gypsum is then typically added to the clinker during the grinding process to make cement. Due to the intense heat of a cement kiln (up to 1,500°C), some cement kilns are also used to destroy organic compounds, such as ODS. However, the fluorine and chlorine content of the raw material fed into the kiln must be monitored and controlled in order not to affect the quality of the clinker. Cement kilns consist of tilted, rotating cylinders that are heated on one end. The raw material is fed into the higher, cooler end of the kiln and falls down towards the heated end. The heated gases used to convert the raw materials into clinker rise up the cylinder and are emitted out of the higher end of the kiln after passing though a pollution control device that removes the particulate matter in the gases. (TEAP 2002, Richardson 1995, CKRC 2004)

Internally Circulated Fluidized Bed (ICFB) Incineration

An ICFB incinerator consists of a vertical chamber with a bed of a heated, inert material such as sand or wood chips on the perforated bottom. Air is blown up through bottom of the chamber, creating a fluidized environment which heats up the wastes and breaks them down. When ODS are destroyed, the resultant HCl and HF are neutralized with calcium carbonate, which is added to the incinerator. (IPCC 2006, Taboas 2004)

Fixed Hearth Incinerator

Fixed hearth incinerators function similarly to rotary kiln incinerators but utilize fixed combustion chambers to destroy liquid wastes at temperatures ranging from 760-982°C. Solid wastes are placed in the primary combustion chamber where they are burned; the residue ash is removed from the primary chamber, and the by-product gases move into the secondary combustion chamber for further destruction. While fixed hearth incinerators are typically utilized to incinerate sewage sludge, medical wastes, and pathological waste, they can also be used to destroy ODS (Bungay 1994).

Plasma Technologies

Plasma technologies utilize plasma, which produces intense heat, to destroy ODS. Plasma is created when a gas interacts with an electric arc or magnetic field in an inert atmosphere (e.g., argon) at temperatures ranging from 4,726ºC to 19,727ºC and is subsequently ionized. Plasma destruction units are generally designed to be relatively small, compact, and transportable. They consume a large amount of energy in order to generate the plasma, but tend to have very high destruction efficiencies and low gas emissions (TEAP 2002). Five different types of plasma technologies are described below.

Argon Plasma Arc

Argon plasma arc technology uses the patented PLASCON™ torch to create a 10,000ºC plasma arc in the presence of argon to destroy ODS. The ODS are almost instantaneously broken down through a heat-degradation process called pyrolysis, during which the molecules are broken down into their constituent atoms and ions. This causes the ODS to be converted into an ionized gas, which is then moved into a reaction chamber or flight tube, located below the PLASCON™ torch, in order to be cooled to below 100ºC with water. The final solid and liquid by-products of the process are halide salts and water, which can be released into the municipal sewage system. The final gaseous by-products include carbon dioxide and argon, which are both released into the atmosphere. (DASCEM 2003)

In Australia, the Department of Administrative Services Centre for Environmental Management (DASCEM), which currently manages the Australian National Halon Bank, uses argon plasma arc technology to destroy both halons and CFCs. Other plasma arc facilities are located in Mexico and the U.S. (TEAP 2002, DASCEM 2006, RemTec 2006).

Nitrogen Plasma Arc

Similar to argon plasma arc technology, nitrogen plasma arc technology utilizes nitrogen plasma created by a plasma torch to break down liquefied fluorocarbon gases into CO, HF, and HCl. The CO is then combined with air to form CO_2 and HCl, and HF that are absorbed by a calcium hydroxide solution. There are five units known to be commercially destroying ODS in Japan. Because of their compact size (9 m x 4.25 m), these units can be used as mobile destruction facilities. (TEAP 2002)

Inductively Coupled Radio Frequency Plasma (ICRF)

ICRF plasma technology uses 10,000ºC plasma created using an inductively coupled radio frequency torch to destroy ODS. Gaseous ODS and steam are placed into the destruction unit through the plasma torch, heated, and then moved into a reactor chamber where the gases are broken down. The gases are then cooled and cleaned with a caustic solution to remove the acid gases. (TEAP 2002)

A consortium of stakeholders known as the Ministry of International Trade and Industry (MITI) operates an ICRF plant in Ichikawa City, Japan, which has operated commercially since 1995 (TEAP 2002). This is the only ICRF plasma destruction facility known to be in operation in the world.

Microwave Plasma

Microwave plasma technology uses 5,726ºC plus plasma, which is created using argon and microwave energy, to break down CFCs into HCl, HF, CO and CO_2. The final byproducts of the destruction process that are released into the atmosphere consist only of halide salts and CO_2, as the acid gases are removed by a scrubber and the CO is combusted with air in order to convert it to CO_2. (TEAP 2002)

Air Plasma

Air plasma technology destroys CFC and HCFCs by injecting them into a reaction chamber filled with air, LPG, and water. The air is heated to about 1,300ºC in a plasma generator, and the CFCs and HCFCs are broken down into H_2, H_2O, CO, CO_2, HCl, and HF. These resulting gases are cooled by water injection once they leave the reaction chamber and scrubbed in a spray tower. The acids are washed out of the gases as calcium chloride and fluorspar by adding calcium hydroxide to the mixture. The gas is washed a second time in a packed bed to ensure that all acids are removed. The gas is released through a stack after passing through a wet electrostatic precipitator, the fluorspar is removed as sludge in a settling tank, and the calcium chloride solution is either used for dust reduction on gravel roads or is disposed. (ScanArc Plasma Technologies 2005a)

An experimental air plasma destruction facility is in Sweden destroying CFC-11, CFC-12, and HCFC-22 at a rate of about 300 kilograms per hour (ScanArc Plasma Technologies AB 2005a,b). This is the only known air plasma facility.

Other Non-Incineration Technologies

Superheated Steam Reactor

The superheated steam reactor destroys CFC, HCFCs, and HFCs in a reactor with walls that are electrically heated to 850-1,000ºC. The fluorocarbons are first mixed with steam and air and preheated to about 500ºC before being placed in the reactor. The byproducts of the process, HF, HCl, and CO_2, are quenched with a calcium hydroxide solution to neutralize the acid gases and minimize dioxin and furan emissions. Because of their compact size, superheated steam reactors can be used as mobile destruction facilities. (TEAP 2002)

There are 11 known units in operation in Japan (TEAP 2002). It is not clear whether these units destroy ODS commercially.

Gas Phase Catalytic Dehalogenation

The gas phase catalytic dehalogenation process destroys CFCs at a lower temperature (400ºC), which requires less energy consumption. The process emits no dioxins or furans and very small amounts of other pollutants. (TEAP 2002). It is unknown whether this technology is currently in use for commercial ODS destruction.

Appendix C: Performance Testing Costs

In developing the HWC MACT standard, EPA estimated an average cost of $225,000 per unit to conduct CPT, based on tests conducted under two test conditions. However, based on a survey of all hazardous waste incinerators subject to HWC MACT standards, the average cost in 2003 for facilities to perform their HWC MACT CPTs, including planning through reporting, was between $350,000 and $400,000 (RMT 2003).[31] Costs for smaller liquid-only facilities using only a few wastes for the test would be as low as $200,000 (Ullrich 2007). According to a firm that conducts HWC MACT standard performance testing, a complete CPT for an HWC (including determination of DRE and compliance with the HWC MACT standards for stack emissions) would cost anywhere from $150,000 to $500,000, depending on the facility, HWC type and necessary test protocol (CS_2 2006). Furthermore, the costs of a CPT can be significantly reduced if wastes already held by the facility are used to conduct the test. This can also diminish the costs of lost revenue, which can occur if the facility must shut down its normal operations to conduct the test.

Scheduling a CPT that would not otherwise be conducted for the sole purpose of testing the DRE of an ODS would represent a significant cost to the HWC facility. However, a facility could conduct a separate DRE-only performance test for a single ODS, which could cost as little as $50,000 (Ullrich 2007). While the test would require planning and standard conditions, such as temperature and feed rate, it could be conducted while other wastes are being destroyed, thereby preventing a disruption in the normal operating schedule.

Additionally, because the HWC MACT standards require that HWCs conduct CPTs every five years, an ODS could be added as a POHC to an already scheduled CTP. Once a CPT is scheduled and the equipment and labor are deployed to the facility, there would be only an incremental cost to add an additional POHC to the CPT. Performance tests are generally conducted using one or two POHCs; these may include a volatile POHC (e.g., CCl_4) and a semi-volatile POHC (e.g., trichlorobenzene). Additional POHCs, including an ODS, could be specified at the time the CPT plan is being developed.

The incremental cost to add an additional POHC to the CPT would depend on the specific POHC and the specific sampling and analytical methods that would be needed to test that particular POHC. The analytical cost to add an additional volatile chlorinated POHC to the CPT would be on the order of $1,000 to $3,000, plus the cost to purchase the volatile chlorinated compound needed to conduct the test. For volatile brominated compounds (e.g., methyl bromide) a separate stack sampling train and a different analytical method would be needed than for volatile chlorinated compounds. Therefore, adding a brominated compound as a POHC would approximately double the analytical cost for the CPT; still, this cost would represent only a small incremental cost compared to the overall cost of the complete CPT.

[31] Cost estimates may include additional permitting activities, such as RCRA permit applications and/or risk assessment activities. Five respondents reported CPT costs in excess of $1 million, which includes the cost to conduct a "risk burn" for the facility to support the facility site-specific risk assessment.

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