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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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UNITED NATIONS
Office on Drugs and Crime

UNIDO

JOINT UNODC/UNIDO EXPERT MEETING ON

ENVIRONMENTALLY SAFE METHODS FOR THE DESTRUCTION/DISPOSAL OF CHEMICALS

Vienna, 6 to 8 September 2005

Organized by

Laboratory and Scientific Section
United Nations Office on Drugs and Crime

in cooperation with

Multilateral Environmental Agreements Branch
United Nations Industrial Development Organization

Report of Proceedings and Recommendations

17 October 2005

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II. Introduction to the meeting

III. Discussion and recommendations

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I. List of participants
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I. BACKGROUND and PURPOSE

1. The safe handling, storage and environmentally safe disposal / destruction[1] under economically feasible conditions of a variety of chemicals is of wide concern.

2. To respond to those concerns, the Laboratory and Scientific Section of the United Nations Office on Drugs and Crime (UNODC) and the Multilateral Environmental Agreements Branch of the United Nations Industrial Development Organization (UNIDO) are cooperating in convening an expert meeting on "Environmentally safe methods for the destruction/disposal of chemicals" in Vienna, Austria, from 6 to 8 September 2005.

3. Emerging from practical requirements, the meeting has addressed two distinct areas: (i) precursor chemicals used in the illicit manufacture of narcotic drugs and psychotropic substances, and (ii) ozone-depleting substances (ODS) controlled under the Montreal Protocol based on a discussion paper, covering both areas.

4. The primary goal of the meeting was to identify available technologies and approaches for the destruction of the precursor chemicals of interest to UNODC, and the ODS / POPS (persistent organic pollutants) of interest to UNIDO. Taking into account the needs especially of those countries without adequate chemical waste management systems, the meeting also identified alternative disposal options if a recommended approach is not available in a country, or cannot be applied because of the circumstances of the seizure (for example, if made at a remote clandestine laboratory site, e.g., jungle location), or because of a basic lack of infrastructure. Finally, based on findings, the meeting made relevant technical recommendations for future action.

5. While the meeting was a joint UNODC-UNIDO meeting for two days, the last (third) day of the meeting was devoted to the development/finalization for publication of practical guidelines for the safe handling and disposal of chemicals used in the illicit manufacture of drugs, particularly in those countries where an appropriate environmental management infrastructure is lacking.

6. The meeting was attended by 9 experts from eight countries, a representative from the Inter-American Drug Abuse Control Commission (CICAD), a technical advisor from the Precursors Control Section of the INCB Secretariat, and UNODC and UNIDO staff. The list of participants is attached as Annex I; a copy of the Agenda as Annex II.

II. INTRODUCTION TO THE MEETING

7. The meeting was opened by Ms. Sumru Noyan, Director of Operations and Deputy to the Executive Director, UNODC, and Mr. Sidi Menad Si Ahmed, Director, Multilateral Environmental Agreements Branch, UNIDO, who welcomed the participants to Vienna, and to the meeting.

8. They highlighted the joint nature of the expert meeting, which was the first of its kind in the context of the growing partnership between UNODC and UNIDO, and aimed at capitalizing on existing synergies, and maximizing cross-fertilization.

9. The official opening was followed by the presentations of the consultants, in their respective fields of expertise, on the discussion paper. Participants gave a brief overview of the methods currently used in their countries.

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[1] In this document, the term 'destruction' is used to apply to a process that results in the permanent transformation, or decomposition of all or a significant portion of the substances subjected to it. In some countries, the term 'treatment' may be used instead.

III. DISCUSSION AND RECOMMENDATIONS

10. Although clear differences between the two groups of substances were recognized, participants noted that there are key principles that are applicable to both. Subsequent discussions then centred around those common principles, which include the need for the identification of safe[2], reliable and cost-effective methods, technologies and approaches, and the desire to continuously improve them; the necessity for building partnerships with national counterparts that are in need of establishing facilities for destruction/disposal or those who may already have the required capacity; the need for appropriate training; and, ultimately, the need to develop a national environmental waste management infrastructure, and to support those infrastructures with appropriate legislative instruments.

11. All participants agreed that disposal / destruction of chemicals is a global problem, requiring the broadest possible cooperation. In that connection, they have acknowledged the joint nature of the meeting, which demonstrated the very practical ways that UNODC and UNIDO can work together.

12. After the brief general discussion, participants then split into working groups, discussing specific aspects of the two areas of concern and coming up with draft recommendations. Working Group A focused on precursor chemicals, and Working Group B on ODS controlled under the Montreal Protocol. [3]

13. Emerging from those working group discussions, participants noted the general need to promote the prevention of environmental degradation. In that context, they have noted also the need to make more use of recycling (transformation) approaches for the disposal of chemicals. Participants have noted also that, in many cases, while existing facilities and resources for disposal / destruction at the national level are often inadequate, they may be used already for the destruction (for example, the co-incineration) of the chemicals of concern.

14. More specifically, participants identified a set of common recommendations, as well as specific ones for the two areas of concern.

15. Common UNODC - UNIDO Recommendations

Participants have recommended that:

Governments should demonstrate their political willingness and commitment to develop and implement safe practices for chemical disposal / destruction by:

- Ensuring that the national waste management infrastructures take into account those situations, where seized precursor chemicals, ODS, POPs and related chemical waste are destroyed or disposed of;
- Reviewing the available facilities and resources for disposal or management of other types of wastes that may be utilized or adapted for the destruction of the chemicals of concern;
- Reviewing the adequacy of the existing legal frameworks and domestic legislation, to ensure effective control of the chemicals and their disposal / destruction;
- Introducing or strengthening as required specific plans / policies for the disposal and destruction of the chemicals of concern within the national waste management infrastructures, including specific provisions for:
  - the safe handling, and secure collection, transportation and storage of the chemicals of concern prior to their destruction;

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[2] The term 'safe' in this document refers to both environmental and occupational safety, unless otherwise indicated.

[3] Participants in individual working groups are identified in Annex I.

    - ensuring the health and safety of the individuals concerned;

  through appropriate awareness raising, training and provision of adequate equipment;
- Introducing or strengthening mechanisms for sharing information at national and international levels;
- Exploring options as to how the necessary technical and financial resources can be made available.

Governments, industry and regional and international organizations should seek at all times to improve the response to related disposal / destruction issues through the development and application of more practical, safe and cost-effective disposal / destruction technology(ies).

16. Precursor Chemicals Working Group Recommendations

Working group A reviewed the issue of the disposal of precursor chemicals. Based on the discussions, the group recommended that:

Governments should:
- always use the environmentally safest disposal approach to meet the circumstances encountered, taking into account available resources, and ensuring that any approaches used are in compliance with applicable domestic laws;
- clarify roles and responsibilities, where required, of all agencies involved in the disposal / destruction of chemicals to ensure effective coordination of activities;
- engage the services of appropriately trained personnel in all situations involving the disposal / destruction of precursor chemicals, whenever practical; and
- promote the use and development of mobile chemical treatment units for the disposal of precursor chemicals, where appropriate.

UNODC should:
- develop practical working-level guidelines on the safe handling and disposal of chemicals used in illicit drug manufacture, including model case scenarios representative of the different situations in which chemicals are to be disposed of / destroyed.

17. ODS Working Group Recommendations

Working group B reviewed the issue of the disposal of ODS. Based on the discussions, the group recommended that:

Governments should:
- Include provisions in the ODS legislation to stipulate the producer of the waste ODS responsible for its disposal.
- Encourage the training on recovery and recycling of ODS and seek to provide recycling centres with a reclamation machine to ensure a better grade of the recycled ODS thus minimizing the volume of ODS requiring destruction.
- Investigate the possibility of exporting waste ODS to other countries that have the facilities to reclaim or destroy it, provided that the laws of the importing countries allow it.
- Cooperate with customs to enforce the legal instruments in the country

Governments in cooperation with the Implementing Agencies should:
- Determine the capacity for which the establishment of a destruction facility is required.

- Select a technology in accordance with the national environmental laws and regulations, also considering the quantity of ODS to be disposed of, the cost of the technology and the cost of destruction of a kg of chemicals. Three categories of countries based on which the choice of destruction technology could be recommended have been identified:
    A. Countries having a variety of chemicals (waste ODS, hazardous chemicals and persistent organic pollutants) requiring disposal need to consider technologies that are adaptable to a wide variety of chemicals. Cement kilns, container based incineration system, gas phase catalytic reduction, liquid injection incineration, plasma technologies and rotary kiln incinerators are all *examples of technologies that may be recommended.*
    B. Countries having a small volume of waste ODS may consider acquiring a mobile/semi-mobile unit to be used at a national/regional level depending on the amount of waste ODS available. Technologies that may be mounted to mobile and semi-mobile units include container-based incineration systems, argon plasma Arc, Nitrogen Plasma Arc, gas phase chemical reduction, super heated steam reactor, vitrification and liquid phase chemical reduction.
    C. Countries having a large volume of waste ODS may consider establishing a central destruction facility to treat the waste ODS at the country level.

Countries that have agreed to a regional approach should:

- Take supplementary measures in terms of bilateral agreements between the countries to facilitate the movement of the waste ODS.

Annex I

List of participants

Mr. Héctor BERNAL CONTRERAS [*]
Tel.: (Official) +571- 3765300 ext. 1203, 1204;
300 3672447 (Mobile)
Fax: +571-3765327
E-Mail: hernanbca@hotmail.com ;
hbernal@dne.gov.co

Mr. Rainer DAHLENBURG [*]
Bundeskriminalamt (BKA), KT34
D-65173 Wiesbaden, Germany
Tel: +49- 611- 551 26 59
Fax: +49- 611- 551 38 75
E-Mail: Rainer.Dahlenburg@bka.bund.de

Ms. Mary E. GREENE [*]
Chief, Information Exchange and Partnership
Branch, Information Exchange and Services
Division, Office of Information Collection
Environmental Protection Agency (EPA)
1200 Pennsylvania Avenue, NW
Room 6416FF – EPA West (2823T)
Washington, DC 20460, USA
Tel: (+1) 202-566-1634
Fax: (+1) 202-566-1684
E-Mail: Greene.Marye@epamail.epa.gov

Mr. Martin KRYNEN [**]
General Manager, BCD Technologies
P.O. Box 116
Narangba Qld 4504, Australia
Tel.: +61-7- 3203 34 00
Fax: +61-7- 3203 34 50
E-Mail: mkrynen@bigpond.net.au

Mr. Ziggie MALYNIWSKY [*]
Chief, Supply Reduction and Control Section
Inter-American Drug Abuse Control Commission
(CICAD)
1889 "F" Street, N.W.
Washington, D.C. 20006, USA
Tel.: +1-202-458 37 42
Fax: +1-202-458 36 58
E-Mail: Zmalyniwsky@OAS.org

Ms. Rodica Ella MOROHOI [**]
Ministry of Environment and Water Management
Waste and Dangerous Chemicals Directorate
No.12, Libertatii Bv., District 5
Bucharest, Romania
Tel + Fax: +4021 317 4070 ; +4021 316 0298
E-Mail: rodica@mappm.ro

Mr. Pabalala Meshack MTHEMBI [*]
Forensic Science Laboratory, South African
Police Service
270 Pretoria Road, Silverton, South Africa
Tel: +27-12-845 5801 / 5633
Fax: +27-12-845 59 11 / 5903
E-Mail: ngokhae@saps.org.za

Mr. Teodor OGNEAN [*]
Ministry of Environment and Water Management
Bd. Libertatii 12, Sector 5
Bucharest, Romania
Tel: +4021-319-25-32
Fax:+4021-318-61 60
E-Mail: theognean@mappm.ro

Ms. Lilia S. OSORIO BRYSON [*]
Chemical Advisor, DEA Lima, Peru
Tel: +51-1-618-2156; +51-997-46585 (Mobile)
Fax: +51-1-618-2728
E-Mail: liliaob15@hotmail.com

Mr. Anil Kumar SAXENA [*]
Director & Head, Environmental Management
Group, National Productivity Council
5-6 Institutional Area, Lodi Rd.
New Delhi-110 003, India
Tel: +91-11-246 11 243; +919810218097
(mobile)
Fax: +91-11-246 98 138, 246 15 002
E-Mail: saxena_ak3@rediffmail.com ;
ak.saxena@npcindia.org

International Narcotics Control Board (INCB) Secretariat

Mr. Mark COLHOUN [*]
Technical Advisor, Precursors Control Section
INCB Secretariat
Tel: +43-1-26060-5241
Fax: +43-1-26060-5930
E-Mail: mark.colhoun@incb.org

---

[*] Participated in Working Group A on precursor chemicals.

[**] Participated in Working Group B on ODS.

CONSULTANTS

Mr. Jorge Luis ACEVEDO-GIERBOLINI *
P.O. Box 221798
El Paso, TX 79913-4978, USA
Tel: (915) 203-5345
Fax: (915) 760-6785
E-Mail: Jacevedo45@sbcglobal.net

Mr. Wayne Kenneth JEFFERY *
5121 Booth Avenue, Burnaby, British Columbia,
Canada V5G 3K1
Tel/Fax: 604 437 0816
Mobile: 604 418 4615
E-mail: wjeffery@shaw.ca

Ms. Paulína PIDANÁ **
Ekotoxikologicke Centrum Bratislava s.r.o.
Nadrazna 36
900 28 Ivanka pri Dunaji
Republic of Slovakia
Tel: +421-02-4594 3712
Fax: +421-02-4594 5223
E-Mail: ekotox@stonline.sk

UNODC

Mr. A. Howard STEAD *
Chief, Laboratory and Scientific Section (LSS)
United Nations Office on Drugs and Crime
Tel: +43-1-26060-4303 (or 4304)
Fax: +43-1-26060-5967
E-Mail: howard.stead@unodc.org

Ms. Barbara REMBERG *
Scientific Affairs Officer
Laboratory and Scientific Section (LSS)
United Nations Office on Drugs and Crime
Tel: +43-1-26060-5652
Fax: +43-1-26060-5967
E-Mail: Barbara.remberg@unodc.org

UNIDO

Ms. Rana GHONEIM **
Associate Industrial Development Officer
Multilateral Environmental Agreements Branch
UNIDO
Tel: +43-1-26026 4356
Fax: +43-1-213464356
E-Mail: R.Ghoneim@unido.org

Annex II

Annotated agenda & timetable

6 September 2005

Schedule

9:00 Registration

9:30 – 11:00 (**Room D1565**)

1. Opening of the meeting (UNODC – UNIDO)
2. Endorsement of chairman and rapporteur
3. Adoption of the provisional agenda and timetable
4. Introduction (purpose of the meeting and expected outcomes)
5. Presentation of discussion paper (by consultants)
6. Questions & Answers

11:00 Coffee break

11:15 – 13:00

7. Presentations by participants (5 minutes, each)
   - ☐ *Introduction of participants*
   - ☐ *Please give brief overview of the methods presently used in your country to deal with the handling, disposal and destruction of seized chemicals (please provide an electronic copy of your presentation for circulation and future reference)*

13:00 - 14:00 Lunch break

14:00 – 15:45

8. Working group sessions [D1565/E1571(lab)]:
   Available technologies and approaches for the environmentally safe destruction/disposal of different chemicals:
   a. Precursor chemicals (UNODC experts)
      - ☐ *Defining the problem:*
        - *Which are the circumstances/locations in your country, where precursor chemicals that need to be destroyed/disposed are encountered? What is the security situation in those locations? How close are they to major urban centres?*
        - *Which other practical, logistical, environmental aspects do you need to consider?*
      - ☐ *Methods for destruction/disposal (focus on actual methods):*
        - *Which methods are currently used in your countries? Why? What are their costs?*
        - *How do you handle and store large quantities of chemicals prior to their destruction?*
        - *How do you ensure the health and safety of the individuals involved?*
        - *What is the role of the forensic chemist in the process of destruction/disposal?*
        - *Do you have a formal training programme for individuals involved in destruction/disposal? If so, what are its key elements?*
      - ☐ *National environmental waste management infrastructure:*
        - *In connection with the chemicals under consideration, what are the key components of your country's environmental waste management infrastructure?*
        - *Who are the national counterparts/institutions, i.e., those who (i) have access to relevant technologies (e.g., for other purposes than precursor chemicals), or (ii) are in need of capacity for destruction/disposal*
      - ☐ *Legal aspects:*
        - *What is the legislative framework in your country for destruction/disposal of seized precursor chemicals? (please bring relevant legislation/regulations, etc. to the meeting)*
        - *Which legal obstacles do you face related to destruction/disposal (e.g., pre-trial disposal, ownership) and recycling? How are they overcome?*

   b. Ozone-depleting substances (UNIDO experts)
      - ☐ *Needs Assessment*

    - *What is the estimated volume of ODS (as a % of the total ODS consumption in your country) that requires disposal or destruction in your country?*
    - *Do you have accumulated stocks of ODS?*
    - *Do you face a problem of dumping second hand ODS containing equipment into your country?*
    - *Do you have large volumes of recovered un-recyclable ODSs?*
- ☐ *Recovery and recycling programme*
    - *From your experience of implementing the refrigerant management plan, what are the achievements of and impediments to implementing ODS recovery and recycling*
    - *How are you handling the recovered un-recyclable CFCs at the moment?*
    - *Do you believe that effective reclamation machines could be an alternative to refine the un-recyclable CFCs?*
    - *Would you consider exporting the un-recyclable CFCs to countries that have reclamation facilities and need CFC for servicing their installations?*
- ☐ *Practices for destruction / disposal*
    - *What is the infrastructure for ODS recovery and disposal in your country?*
    - *How are ODS actually disposed of in your country or your region?*
    - *Based on the presentations of both groups, which method do you see best suited for your country?*
- ☐ *Policy, legislative and regulatory measures*
    - *Do you have an ODS legislation in place in your country?*
    - *What is the status of the existing policies on ODS recovery and disposal in your country?*
    - *What policies regarding ODS recovery and disposal are in place in your country? Identify policy issues to be cleared at the national level.*
- ☐ *Regional approach*
    - *Would you consider a regional mechanism for ODS disposal as an option to identify an economically feasible approach?*
    - *What could be impediments to the regional approach?*
    - *What could be the issues at policy level that need to be resolved at a regional level?*

15:45 Coffee break

16:00 – 18:00

9. Working group sessions (continued)
    a. Precursor chemicals (UNODC experts)
    b. Ozone-depleting substances (UNIDO experts)

7 September 2005

Schedule

9:00 -11:00

10. Working group sessions (continued, as required)

11:00 Coffee break

11:15 – 13:00

11. Presentation of results from Working group sessions
12. Discussion
    - ☐ *What do you consider to be the common elements applicable to the destruction/disposal of both groups of chemicals?*
    - ☐ *What advice/guidance (technical recommendations) would you like to see this expert group to provide?*

13:00 - 14:00 Lunch break

14:00 – 15:45

13. Conclusions, technical recommendations and follow-up

15:45 Coffee break

16:00 – 18:00

14. Adoption of draft report
15. Closing of joint meeting

8 September 2005

Schedule

9:00-11:00

16. Introduction
17. Discussion: practical guidelines for the safe handling and environmentally safe destruction/disposal of large quantities of seized precursor chemicals (focus: countries, or regions within a country, where an appropriate environmental management infrastructure is lacking)
    - ☐ *After having reviewed the draft guidelines provided in Part A of the joint discussion paper, and taking the discussions on day 1 and 2 of the meeting into account:*
        - *Which specific methods, practical approaches, and other key information do you consider critical for inclusion in the final guidelines?*
        - *Which model scenarios ("What to do, if ...?") do you consider representative for the circumstances in which precursor chemicals are to be disposed of? Which of those should be included in the final guidelines?*

11:00 Coffee break

11:15-13:00

18. Discussion (cont'd)

13:00 - 14:00 Lunch break

14:00 – 15:45

19. Discussion (cont'd)

15:45 Coffee break

16:00 – 18:00

20. Conclusions, recommendations and follow-up
21. Closing of meeting

UNITED NATIONS
Office on Drugs and Crime

UNIDO

METHODS FOR ENVIRONMENTALLY SAFE DESTRUCTION/DISPOSAL OF CHEMICALS

DISCUSSION PAPER

PREFACE

The safe handling, storage and environmentally safe destruction/disposal under economically feasible conditions of hazardous chemicals is of wide concern.

To respond to those concerns, the Laboratory and Scientific Section of the United Nations Office on Drugs and Crime (UNODC) and the Multilateral Environmental Agreements Branch of the United Nations Industrial Development Organization (UNIDO) are cooperating in convening an expert meeting on "Environmentally safe methods for the destruction/disposal of chemicals" in Vienna, Austria, from 6 to 8 September 2005.

Emerging from practical requirements, the focus of discussions at the meeting will be in two distinct areas: (i) precursor chemicals used in the illicit manufacture of narcotic drugs and psychotropic substances, and (ii) ozone-depleting substances (ODS) substances controlled under the Montreal Protocol. Part A of this discussion paper focuses on methods for the safe handling, storage, and destruction and disposal of precursor chemicals, Part B addresses the available destruction technologies for ODS and the suitability for destruction of ODS of some of the technologies employed for the destruction of Persistent Organic Pollutants (POPs) through the Stockholm Convention on POPs.

It is clear that not only the nature of the chemicals, but also the circumstances under which they are encountered, and the requirements of the respective international frameworks will determine the methods, technologies or approaches for handling, storage and destruction/ disposal. However, despite clear differences between the two groups of substances, there are key principles that are applicable to both. These include the need for the identification of safe, reliable and cost-effective methods, technologies and approaches, and the desire to continuously improve them; the necessity for building partnerships with national counterparts that are in need of establishing such facilities for destruction/disposal or those who may already have the required capacity; and, ultimately, the need to develop a national environmental waste management infrastructure, and to support those infrastructures with appropriate legislative instruments.

The joint nature of the expert meeting is aimed at capitalizing on these synergies, and maximizing cross-fertilization.

The purpose of this paper is to stimulate discussion at the meeting on available methods, technologies and approaches for the environmentally safe destruction/disposal of different chemicals in different countries and circumstances.

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Part A

METHODS FOR SAFE HANDLING, STORAGE AND DESTRUCTION/ DISPOSAL OF LARGE QUANTITIES OF PRECURSOR CHEMICALS

INTRODUCTION

The safe handling, storage and disposal/destruction of large amounts of seized precursor and essential chemicals present unique problems to law enforcement and regulatory authorities.

Precursor chemicals used by clandestine laboratory operators in the production of illicit drugs are usually diverted from the legitimate trade and may be encountered at any stage of the chain of distribution or at the clandestine laboratory site. The location, amount and condition, will determine how seized precursor chemicals will be handled. National drug control laws and legal systems should provide for the speedy and efficient collection, processing and disposal of seized chemicals in a manner that minimizes or eliminates their long-term storage and handling. The disposal method may be destruction of the precursor chemicals on-site, transfer to a predetermined institution that has a need for them, or return to the licit trade chain of distribution.

The disposal issue, and related aspects, has been discussed at numerous meetings of the United Nations (UN) Commission of Narcotic Drugs over the past 15 years. In 1989 and 1990, a United Nations Expert Group discussed the topic of pre-trial destruction of seized narcotic drugs, psychotropic substances, precursors and essential chemicals (see Literature References 3 & 4). This background document takes into account some of the recommendations made by those Expert Group meetings, and continues from there to discuss the available methods and approaches for the environmentally safe disposal/destruction of different precursor chemicals. Aimed at providing practical guidance on the steps that should be taken when precursor chemicals are seized in large quantities, the document covers the major chemicals used in the illicit manufacture of cocaine, heroin, amphetamine, methamphetamine, MDMA/MDA and methaqualone.

The disposal of large quantities of seized drugs raises similar environmental concerns as that of precursor chemicals. In principle, therefore, the approaches to disposal/destruction described in this document are as applicable to drugs as they are to solid precursors.[1] It should be noted, however, that disposal of seized narcotic drugs and psychotropic substances by reprocessing/reuse (recycling) is regulated by the international drug conventions, to avoid offsetting the balance of legitimate demand and supply. Therefore, if reprocessing of illicit drugs is considered, it must follow the principles set out in the Conventions. Where illicit drugs are to be destroyed, guided by the need for the destruction process to be as environmentally friendly as possible, the preferred option is incineration.

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[1] The same applies also to cutting agents.

DIFFERENT TYPES OF DISPOSAL METHODS:

There is a wide range of available disposal methods, from the re-entering of chemicals into legitimate channels, for example, through recycling, to destruction on the spot. These disposal methods are described below. Methods for pre-treatment of chemicals prior to disposal, such as chemical neutralization, are also described.

Considering the different circumstances (scenarios) in which the destruction/disposal of large quantities of chemicals may have to be effected, the available methods and approaches can be classified into three groups:

1. The most desirable (i.e., most environmentally friendly) methods/approaches. They typically require availability of an environmental management infrastructure and/or closeness to urban centres. They include use of:
    a. Chemical disposal companies
    b. Recycling
    c. Incineration
    d.
2. The second scenario assumes a secure environment, but absence of an environmental management infrastructure. Methods and approaches in this group are the next best environmentally friendly option. They are typically carried out under conditions of limited resources, and require the support/guidance of a scientist to help follow the guidelines given in this document, or adequate training of law enforcement officers. They include:
    a.
    b.
3. The third scenario is a remote and/or insecure location, requiring on-site solutions. In this scenario, a balance is made between environmental concerns and the primary enforcement goal of disruption of clandestine manufacture. They include:
    a.
    b.

It is clear that the safest approaches may only be applicable in urban environments, for example, for stopped shipments at commercial ports. The least environmentally safe approach may be the only practical option in very remote mountainous or jungle environments.

1. Chemical Disposal Companies (Group 1)

Advantages
    a. Quickest
    b. Someone else does the work
    c. Safest
    d. Minimal environmental damage

Disadvantages
    a. Most expensive
    b. Not available in all areas; Usually only available in industrialized cities.

2. Recycling (Group 1)

Advantages
    a. Minimal environmental damage
    b. Minimal cost
    c. Chemical get reused

Disadvantages

a. Transportation, safety and security consideration make this method prohibitively expensive in remote locations.
b. Chemicals may be returned inadvertently to the illegal chemists.
c. Can only recycle unused/not contaminated chemicals

Note: Chemicals used in clandestine laboratories can be recycled to the following types of laboratories, sometimes at minimal or no cost. Care must be taken that the companies are legitimate.

a. University and school laboratories

b. Industrial plants:
    --oil industry
    --paint industry
    --pharmaceutical industry
    --agricultural
    --cosmetic
    --printing
    --fertilizer plants
    --perfume
    --building
    --pulp and paper
    --rubber
    --refrigeration
    --plastics
    --munitions
    --dyes
    --soap
    --pottery
    --glass

c. Chemical Laboratories:
    --Private
    --Government
    --Industrial

3. **Incineration (Group 1)**

Definition: burning by controlled flame in an enclosed area with appropriate safeguards to prevent the release of toxic chemicals into the environment.

Most organic compounds can be destroyed in properly designed and operated incinerators. Incineration is the disposal method of choice for several reasons.

Advantages

a. With proper emission controls wastes are converted to innocuous products
b. Hazardous material is not retained
c. Release of contaminants as a consequence of malfunction can be corrected relatively quickly
d. Incinerators can handle most wastes
e. The safest method of disposal
f. It promises to give the generator the best assurance of long-term safety from liability
g. It leads to a minimum amount of residue that must be disposed of in landfills

Disadvantages

a. Cost to set up and maintain

b. Emissions to the atmosphere must be controlled
c. Ash must be disposed of in a landfill site
d. Difficult to establish a commercial incinerator because of local opposition

4. **Open air burning (Group ...)**

Definition: burning by controlled or uncontrolled flames; the combustion products being released directly into the atmosphere.

Advantages
  a. Inexpensive
  b. Can be done in remote areas
Disadvantages
  a. Operator safety is important
  b. More negative environmental impact
  c. Need trained people on site to ensure the procedure is carried out correctly and safely

5. **Public Landfill (Group ...)**

Advantages
  a. Inexpensive
Disadvantages
  a. Not all chemicals can be disposed of by this method
  b. Must transport chemicals to disposal site

6. **Evaporation and dumping at sea (Group ...)**

Advantages
  a. None
Disadvantages
  a. Major negative environmental impact

7. **Explosion (Group ...)**

Advantages
  a. Quick
  b. Minimal cost
Disadvantages
  a. Environmental damage is high
  b. Hazards to the operator

8. **Disposal in the sanitary sewer (Group ...)**

Advantages
  a. Disposal of water-soluble products that do not violate local regulations
Disadvantages
  a. Environmental concerns
  b. Cannot dispose of water miscible flammable liquids

Some chemicals require pre-treatment/modification (neutralization or destruction) before they can be disposed by the disposal methods described above. Pre-treatment methods include:

1. **Biological treatment:**

   Advantages

   b. Significant cost-effectiveness for possible future considerations

   Disadvantages

   a. Not developed at this time for most chemicals

2. **Chemical Neutralization: (See methods below)**

   Advantages

   a. Cost effective because you could use seized chemicals to neutralize one another

   b. Inexpensive

   c. Can be done in the open and in remote areas

   Disadvantages

   a. Need trained people

   b. Not all chemicals can be neutralized

   c. May not have necessary chemicals at remote locations

DISPOSAL METHODS FOR CHEMICALS USED IN THE MANUFACTURE OF ILLICIT DRUGS:

This section provides Disposal Methods and Aldrich Disposal Methods for chemicals used in the clandestine manufacture of different drugs.[2] Chemicals are classified into groups/tables (acids, bases, organic solvents, metals, and other chemicals), and listed, within each group (each table), in alphabetical order. Details of the different methods (cross-referenced by number) are discussed later in this document.

Health (H), Flammability (F), Reactivity (R), and Hazard (Sax) Ratings (see Annex II for definitions of the different rating levels) for Acids, Bases, Solvents, Metals, and Other Chemicals used in the manufacture of illicit drugs are also listed in the tables below. Chemicals in Table I or II of the 1988 Convention are highlighted.

1. ACIDS

ACID	Disposal Method	Disposal Method Aldrich	H	F	R	Hazard Rating (Sax)
Acetic acid	6.2.a	B	2	2	1	3
N-Acetylanthranilic acid	12	A				
Anthranilic acid	12	A				3
Formic acid	6.2.NA2	A	3	2	0	
Gallic acid	12	A	0	1	0	3
Glacial acetic acid	6.1.a					3
Hydrobromic acid	6.2.NA2	N	3			3
Hydrochloric acid	6; 6.1.a, 6.2.NA2	N	3	0	0	3
Hydrofluoric acid	6.2.NA2		3	4	0	3
Hydroiodic acid	6.2.NA5		3			
Hypophosphorous acid	6.2.NA1					3
Nitric acid	6.2.NA4	N	2	0	1	3
Nitrobenzoic acid						
Oxalic acid	6.2.b	A	2	1	0	2
Perchloric acid	6.2.NA4		3	0	3	3
Phenylacetic acid	12	A				2
Phosphoric acid	6.2.NA1		3	0	3	3
Picric acid			2	4	4	3
Polyphosphoric acid	6.2.NA1					3
Sulfuric acid	6.1.NA1		3	0	1	3
Tartaric acid	12	A				2

NOTE: A Blank Cell in the table indicates there is no information available.

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[2] Focus is on chemicals used in the clandestine manufacture of heroin, cocaine, amphetamine, methamphetamine, ecstasy-type substances (e.g., MDMA, MDA), and methaqualone. Information on which chemicals are used for which drug can be found in Annex I.

2. BASES

BASE	Disposal Method	Disposal Method Aldrich	H	F	R	Hazard Rating (Sax)
Ammonium carbonate	5.2.NB4					3
Ammonium hydroxide	5.2.NB4	N	2	1		3
Butylamine	5.2.NB2	D	3	4	0	3
Calcium bicarbonate	5.2.NB4					2
Calcium carbonate (Lime stone)	5.2.NB4		1			2
Calcium hydroxide (Slake lime)	5.2.NB4		2			2
Calcium oxide (Quick lime)	16	O	1	0	1	3
Diethylamine	5.2.NB2; 3	D	3	3	0	3
Ethylamine	5.2.NB2; 3	D	3	4	0	3
Methylamine	5.2.NB2; 3	A	3	4	3	3
Piperidine	5.2.NB3, 3	D	2	3	3	3
Potassium bicarbonate	5.2.NB4					1
Potassium carbonate	5.2.NB4	A	3	0	0	3
Potassium hydroxide (Caustic potash)	5.2.NB4	N	3	0	0	3
Pyridine	5.2.NB2; 3	D	2	3	0	3
Sodium bicarbonate	5.2.NB4					1
Sodium carbonate (Soda ash)	5.2.NB4		2			3
Sodium hydroxide (Caustic soda)	5.2.NB4	N	3	0	1	3
Triethylamine						

NOTE: A Blank Cell in the table indicates there is no information available.

3. ORGANIC SOLVENTS

SOLVENT	Disposal Method	Disposal Method Aldrich	H	F	R	Hazard Rating (Sax)
Acetone	12	D	1	3	0	3
Acetonitrile	12	D	3	3	3	3
Acetaldehyde*	2	D	2	4	2	3
Benzene	12	D	2	3	0	3
Bromobenzene	12	C	2	2	0	
N-Butylacetate	12	D	1	3	0	3
2-Butylacetate	12	D	1	3	0	3
N-Butanol	12	D	1	3	0	3
2-Butylalcohol	12		1	3	0	3

SOLVENT	Disposal Method	Disposal Method Aldrich	H	F	R	Hazard Rating (Sax)
Carbon disulphide	4	D	2	3	0	3
Chloroform	12	B	3	1	0	3
Cyclohexanone	12	A	1	2	0	2
Diacetone alcohol	12		1	2	0	2
Dibromethane	12	A				3
Dichloromethane	12	A				
Dimethylformamide	12	B	1	2	0	3
Dimethylsulfoxide	12		1	1	0	3
Ethyl acetate	12	A	1	3	0	3
Ethyl alcohol	12	D	0	3	0	3
Ethyl ether*	10		2	4	1	3
Formamide	13	A	3	1	0	3
Hexane	12	D	1	3	0	3
N-Heptane						
Hydrogen peroxide	8, 15		2	0	3	3
Isobutyl alcohol	12		1	3	0	3
Isopropyl alcohol	12		1	3	0	3
Kerosene	12		1	2	0	3
Methyl alcohol	12	A	1	3	0	3
Methylene chloride	12		2	3	0	
Methylene dichloride (Dichloromethane)	12	B	2	1	1	
Methylethyl ketone (2-butanone)	12	D	1	3	0	3
Methyl isobutyl ketone *	12		2	3	0	
Nitroethane	12	D	2	3	1	3
Nitrotoluene						
Petroleum ether	10	D	1	4	0	3
1-Phenyl-2-propanone						
Tetrahydrofuran*	12	D	2	3	1	3
Thionyl chloride	1	N	4	0	1	3
Toluene	12	D	2	3	0	3
Xylene	12	D	2	3	0	3

* Peroxide forming (Must check for presence of peroxides before disposal by burning)

NOTE: A Blank Cell in the table indicates there is no information available.

4. METALS

METAL	Disposal Method	Disposal Method Aldrich	H	F	R	Hazard Rating (Sax)
Aluminum		H	0	1	1	3
Arsenic		P	3	2		3
Beryllium		P	4	1	1	3
Calcium	20	G	1	1	2	3
Copper						
Magnesium		P	2	4	3	3
Mercury	22	P	3			3
Potassium	20	G	3	1	2	3
Sodium	20	G	3	1	2	3

NOTE: A Blank Cell in the table indicates there is no information available.

5. OTHER CHEMICALS

CHEMICAL	Disposal Method	Disposal Method Aldrich	H	F	R	Hazard Rating (Sax)
Acetic anhydride		B	2	2	1	2
Acetyl chloride	1	B	3	3	2	3
Aluminum chloride	7,	N	3	0	2	3
Ammonium acetate	12	A				3
Ammonium chloride	12			1		2
Ammonium formate	12	N				2
Benzaldehyde	12	C	2	2	0	3
Benzyl chloride	7	B	2	2	1	3
Benzyl cyanide	9	A	3			
Boron tribromide						
Calcium hypochlorite			2	0	2	
Cuprous oxide	16					
Dimethylsulfide			4	4	0	
Ephedrine	12	A				3
Ergometrine (ergonovine)	12					
Ergotamine	12					3
Ferric chloride						
Formamide	13	A	3	1	0	3
Gamma butyrolactone	13					
Glycerine	13		1	1	0	2
Hydrogen cyanide	9		4	4	2	
Iodine	24	P	4	0	0	3
Isosafrole	12					3
Lithium aluminum hydride	11	G	3	1	2	3
Lysergic acid						
Mercuric chloride	22		3			

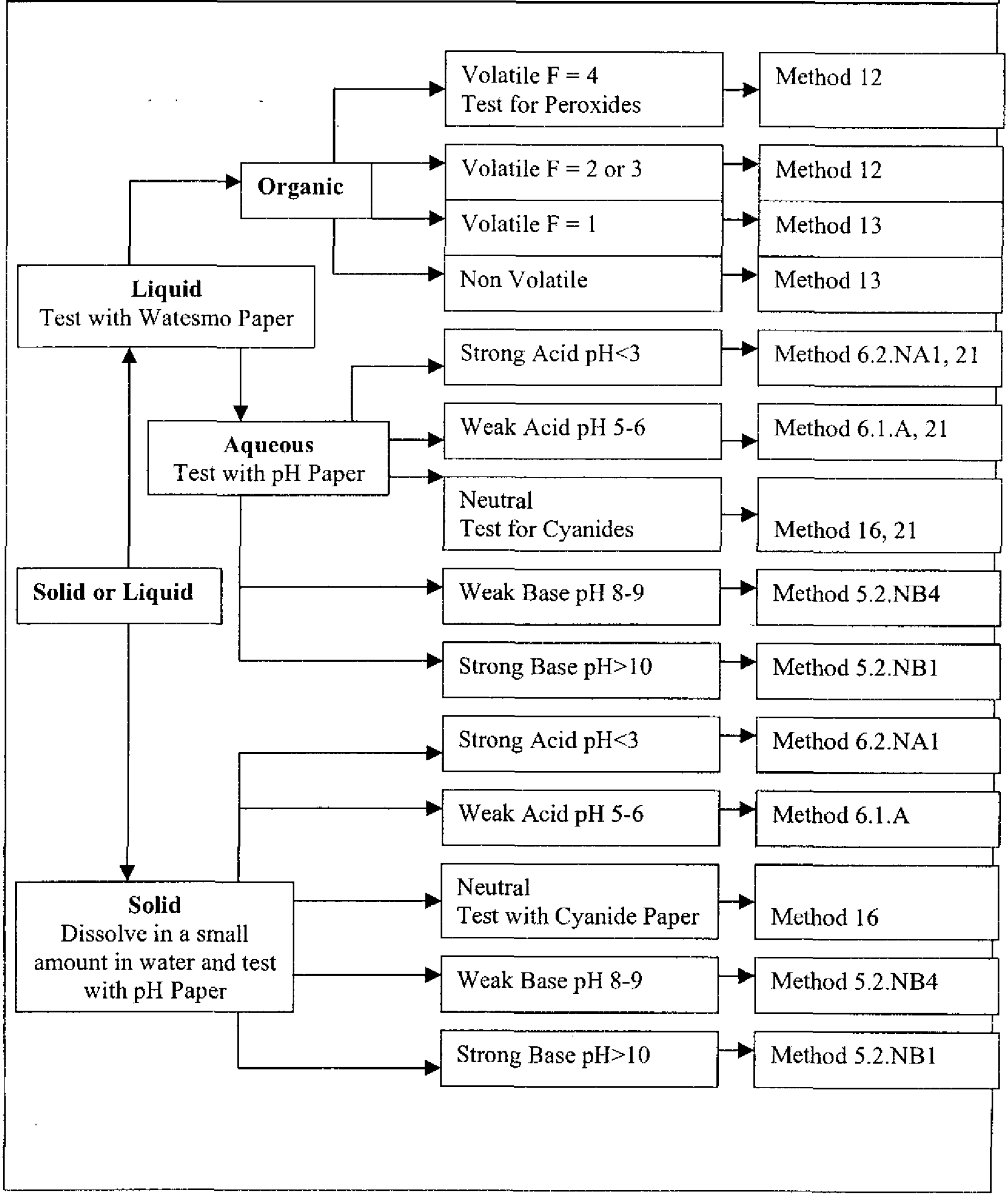
CHEMICAL	Disposal Method	Disposal Method Aldrich	H	F	R	Hazard Rating (Sax)
Mercuric bromide	22	L	3			
Mercuric nitrate	22	L				3
3,4-Methylenedioxy-phenyl-2-propanone	12					
N-Methylephedrine	12					3
N-Methylpseudoephedrine	12					
Norephedrine (phenylpropanolamine)	12					
Norpseudoephedrine	12					2
Phosphorous, red	17	K	0	1	1	3
Phosphorous, yellow	17	K	3	3	1	3
Phosphorous, white			3	3	1	3
Phosphorous oxychloride						
Phosphorous pentachloride	7,14		3	2	2	3
Phosphorous trichloride	7,14		3	2	2	3
Piperonal	12					
Palladium black						
Potassium cyanide	9	S	3	0	0	3
Potassium nitrate	7		1	0	1	3
Potassium permanganate	8, 15, 19		0	0	1	3
Propionic anhydride		C	3	1	3	2
Pseudoephedrine	12					3
Rainey Nickel		R				
Safrole						
Sodium acetate	16					
Sodium borohydride		I	2	2		3
Sodium cyanide	9	S	2	0	0	3
Sodium dichromate	23		3	0	0	3
Sodium hydride						
Sodium sulfate	16					2
Tartaric acid	12	A				2
o-Toluidine	12	A	3	2	0	3
Trichloroethylene	12	A	2			3
Urea	16	A	0			3

* Acetic anhydride converted to calcium acetate using calcium hydroxide and lime.

NOTE: A Blank Cell in the table indicates there is no information available.

SAFE DESTRUCTION OF UNKNOWN/UNLABELLED SEIZED CHEMICALS

The scheme below summarizes the approach for unknown/unlabelled chemicals. Group chemical testing is required to determine the most appropriate disposal/destruction method (for details on testing, see Annex IV).



METHODS OF CHEMICAL NEUTRALIZATION AND DESTRUCTION:

This section describes in detail the methods of destruction for individual chemicals or groups of chemicals. Methods described represent the scientifically most adequate and environmentally safest methods available. It is recognized that it may not be possible to apply those methods under all circumstances and in all locations. .

Health and safety considerations

Standard health and safety procedures should be applied when carrying out the methods described in these guidelines. It is recognized, however, that this may not always be possible, since, for example, before destruction of chemicals by neutralization is to proceed, the following precautions must be taken:

1. Ensure trained personnel are present to conduct the disposal
2. Ensure proper safety equipment is available:
   a. Rubber gloves (nitrile)
   b. Full face piece respirator
   c. Chemical resistant clothing.
   d. Required chemicals and glassware (equipment) needed for disposal are present

Planning for neutralization of acids and bases

Further details related to the planning for neutralization of acids and bases, including relevant model calculations, are included in Annex III).

Unknown chemicals

In cases where chemicals are opened, labels are missing and/or the original manufacturer's seals are damaged, chemical tests are required to identify the chemical in question and determine the most appropriate destruction/disposal method. Presumptive tests, which can be carried out at the scene (on-site), are helpful in this regard. They are outlined in Annex IV.

Methods of chemical neutralization and destruction

METHOD 1.
Organic Acid Halides: (e.g. Acetyl chloride)

a. To a large container, containing an excess of sodium bicarbonate (sodium carbonate, calcium carbonate), slowly add in the Organic Acid Halide, and mix thoroughly.
b. Dilute with water until pH 6-8 is obtained, let stand 24 hours and dispose of in a trench, or a running stream of water.

METHOD 2.
Aldehydes (e.g. Benzaldehyde)
Organic Halogen Compounds (e.g. Benzyl Chloride)

a. Dissolve in a flammable solvent (flammability rating 2 or 3) and burn in 45 gallon drums, or an open pit
b. In an open pit filled with sodium bicarbonate, slowly add the chemical and cover with scrap wood and burn

METHOD 3.
Aliphatic amines (e.g. Diethyamine)

a. In a large container containing an excess of sodium bisulfate, add the amine and dilute with a large excess of water until a pH of 6-8 is obtained.
b. Dispose of in a trench or a fast moving stream.

METHOD 4.
Carbon Disulfide

a. All equipment or contact surfaces should be grounded to avoid ignition by static charge
b. Absorb onto sand, ash, or vermiculite and cover with water
c. Ignite

METHOD 5.
Caustic Alkali and Ammonia (e.g. sodium hydroxide)

5.1. Neutralize bases (General)

Always dilute concentrated acid or base prior to neutralization. To that end, always add the acid or base to water (never the other way round).
Note that effervescence is common with older base solutions due to carbon dioxide absorption

a. Dilute concentrated alkali 1 to 10 with water (dilute alkali are less dangerous)
b. Select an acidic material. (sodium bicarbonate, potassium bicarbonate, calcium bicarbonate, limestone, strong acids (hydrochloric, sulphuric acid), must be diluted 1 pound to 10 gallons of water
c. Neutralization procedure
    1. Add dilute base to a solution of the items in "b." slowly (always check pH)
    2. Continue the process until a pH of between 6 and 8 is obtained
d. Dilute the solution further: 1 gallon with 10 gallons of water
e. Dispose of in trench
    1. If small quantities dilute 1 gallon to 100 gallons of water, *ensure pH is between 6 and 8 and discard in trench, ground, or* fast running stream

5.2. Neutralize bases (Specific)

Neutralize Base 1 (NB1)
Potassium and sodium hydroxides and alcoholic sodium or potassium hydroxide cleaning solutions

a. Add up to 2 L hydroxide solution to 10 liters water
b. Slowly add 6 N hydrochloric or other suitable acid
c. Monitor pH changes with pH paper. (**Note:** Liquid indicators can oxidize rapidly in basic solutions and give false color change)
d. When pH<9 is reached, solution can be washed down sanitary sewer with 20 parts water

Neutralize Base 2 (NB2)

Amine solutions such as ammonium hydroxide, methylamine, dimethylamine, ethylamine, and trimethylamine

a. Add up to 1.5 litres amine with 10 litres water
b. Slowly add 6 N hydrochloric or other suitable acid
c. Monitor pH changes with pH paper. (**Note:** Liquid indicators can oxidize rapidly in basic solutions and give false colour change)
d. When pH<9 is reached, solution can be washed down sanitary sewer with 20 parts water

Neutralize Base 3 (NB3)

Volatile low molecular weight amines such as allyl amine, butyl amine, diethyl amine, ethylenediamine, morpholine, pyrrolidine and tetramethylethylene-diamine

a. Add up to 1.5 litres amine with 10 litres water
b. Slowly add 6 N hydrochloric or other suitable acid
c. Monitor pH changes with pH paper. (**Note:** Liquid indicators can oxidize rapidly in basic solutions and give false colour change)
d. When pH<10 is reached, solution can be washed down sanitary sewer with 20 parts water

Neutralize Base 4 (NB4)

a. Dilute alkali with a large excess of water and neutralize with 5% HCl or 2M HCl and dilute into drain

METHOD 6.

Acids

Always dilute concentrated acid or base at a ratio of about 1:10 prior to neutralization. To that end, always add the acid or base to water (never the other way round).

6.1. Acids (Inorganic) (e.g. Hydrochloric)

a. Dilute concentrated acids: 1 to 10 with water (dilute acids are less dangerous).
b. Select a basic material (sodium bicarbonate, potassium bicarbonate, calcium bicarbonate, limestone, strong bases (sodium hydroxide and potassium hydroxide), must be diluted 1 lb to 10 gallons of water
c. Neutralization procedure
    1. Add dilute acid to a solution of the items in "b." slowly (Always check pH)
    2. Continue the process until a pH between 6 and 8 is obtained.
d. Dilute the solution further: 1 gallon with 10 gallons of water
e. Dispose of in trench
    1. If small quantities dilute 1 gallon to 100 gallons of water, ensure pH is between 6 and 8, and discard in trench, ground, or fast running stream.

6.2. Specific Acids

a. **Glacial Acetic, Acetic Acid**

Method 1:

Neutralize with 5% sodium hydroxide or sodium carbonate and pour into the drain

Method 2: (organic acids)
Mix with organic solvent and ignite (see #12)

b. **Oxalic Acid**
   Oxalic acid is decomposed to carbon dioxide, carbon monoxide, and water by heating in concentrated sulfuric acid. Wear nitrile rubber gloves, laboratory coat, and eye protection. In the fume hood (if possible) oxalic acid is added to concentrated sulfuric acid in a round-bottom flask. Using a heating mantle, the mixture is maintained at 80-100°C for 30 minutes. The sulfuric acid can be reused for the same procedure since the only nonvolatile product of the decomposition is a small quantity of water. Otherwise allow the reaction mixture to cool to room temperature, then slowly and carefully pour the sulfuric acid into a pail of cold water (or cold water and ice), neutralize with sodium carbonate, and wash into the drain.

Neutralize Acid 1 (NA1)
Non-oxidizing acids that may generate heat upon neutralization such as phosphoric and sulfuric acid

a. Dilute the acid with water (i.e., slowly add acid to water)
b. Neutralize by slowly adding 6 N sodium hydroxide solution, stirring continually
c. As heat builds up, add more water
d. Monitor pH change with a suitable indicator or check periodically with pH paper
e. When pH 5-7 is reached, the solution may be washed down the sanitary sewer with 20 parts of water

Neutralize Acid 2 (NA2)
Concentrated acids such as formic, hydrochloric, hydrobromic, and lactic acids

a. Dilute acid with water
b. Stir in 6 M sodium or potassium hydroxide solution (or other suitable base) while monitoring the pH change with Universal indicator or check periodically with pH paper
c. Once a pH of 5-7 is reached, the solution can be washed down the sanitary sewer using 20 parts water. Dilution will reduce the hazards of a strong acid, such as concentrated sulphuric acid.

Neutralize Acid 4 (NA4)
Oxidizing acids, such as nitric and perchloric acids

a. Dilute the acid with 10 parts water
b. Neutralize with a 6 M solution of potassium or sodium hydroxide. The solution may turn yellow or brown as nitric oxide forms when neutralizing nitric acid. If you use potassium hydroxide, a white precipitate of potassium perchlorate will form when neutralizing perchloric acid. This precipitate may be disposed of in the sanitary sewer with the rest of the solution.
c. Monitor pH with pH paper or other suitable indicator
d. When a pH 5-7 is reached, wash solution down the sanitary sewer using 20 parts water

Neutralize Acid 5 (NA5)
57% Hydroiodic acid

a. Dilute the dark orange/brown solution with 10 parts water
b. Rinse bottle with water and add rinsate to rest of solution to be neutralized
c. Add 6 M sodium hydroxide or other suitable base
d. Monitor pH changes with pH paper as the colour of the solution will interfere with most indicators. The solution will become nearly colourless as pH 7 is approached
e. When a pH 5-7 is reached, solution can be washed down the sanitary sewer using approximately 20 parts water

METHOD 7.
Inorganic Salts (e.g. Aluminum Chloride)

a. Add the salt to a large excess of water
b. Add excess of soda ash, sodium (calcium) carbonate and let stand 24 hours
c. Remove aqueous layer and neutralize to pH 6-8 and dispose of in a large excess of water
d. The sludge may be disposed of in land fill

METHOD 8.
Oxidizing agents (e.g. Potassium Permanganate, Hydrogen peroxide)

(see also Methods 15 & 19)

Method 1:

a. Add oxidizing agent to a large volume of a concentrated solution of sodium hypo-bisulfite (sodium metabisulfite) or a ferrous salt and acidify with 3M-H_2SO_4
b. When reduction is complete neutralize the solution with soda ash or dilute HCl
c. Dispose of with a large excess of water

Method 2:

a. Dissolve 450 grams (1 lb), in 8.0 litres of water
b. Prepare a trench at least 50 feet away from flammable trenches
c. Place green leafy material in trench
d. Do not use dry or combustible material.
e. Pour solution into trench as follows:
    1. Small amount at a time: must change color from purple to brown.
    2. Heat may be generated; adjust pouring rate so it all turns brown.
f. Observe the reaction: you may have to add more green leafy material. Watch for the disappearance of the purple color (the reaction is over).
g. Add water to trench. If purple in color add more leafy material
h. Refill the trench with dirt when finished.

Method 3:

a. See #19 below

METHOD 9.
Cyanides (e.g. Sodium Cyanide)

Method 1:

a. Place in a large container and make alkaline with a sodium hydroxide solution

b. Add an excess of ferrous sulfate solution
c. After 1-2 hrs, dispose of with an excess of water in a pit or trench

Method 2: (Conversion to thiocyanate)
a. To the cyanide add an excess of sodium hydroxide solution and calcium hypochlorite solution
b. Scoop slurry into a large container
c. Dilute with water and dispose of in a pit or trench.

Method 3:
a. Add the cyanide to an alkaline solution of calcium hypochlorite
b. Maintain an excess of sodium hydroxide and calcium hypochlorite
c. Let stand 24 hour and dispose of with a large excess of water.

Method 4:
a. Dilute with one or more volumes of ethanol followed by incineration (method 12)

METHOD 10.
Ethers:

Method 1:
a. Small amounts can be disposed of by evaporation.

Method 2:
a. Dilute 1:3 with higher alcohol and burn in a barrel or a trench.

Method 3: (Large quantities or contaminated samples)
a. Transport (safely) to an open area
b. Puncture cans at bottom with rifle fire
c. Ignite with an excelsior train or slow burn fuse

Removal of peroxides:
Add 10 ml of 5% ferrous sulfate or 6 grams of ferrous sulfate (hydrated), 6 mls of concentrate sulfuric acid in 11 mls of water or 3.5 grams of sodium iodide in 70 mls of glacial acetic acid

METHOD 11.
Hydrides (e.g. Lithium Aluminum Hydride)

Method 1:
a. Ignite in an open pit

Method 2:
a. Decompose with ethyl acetate.

Method 3:
a. In a large container, spray the hydride with dry butyl alcohol
b. Add water by spraying or fogging
c. Remove the solid into another container

d. Neutralize with HCl
e. Let settle
f. Dilute liquid with a large excess of water
g. Dispose of residue in land fill

METHOD 12.
Organic solvents (e.g. Ethanol)

Method 1: (Flammability rating 2 or 3)

a. In a safe area away from combustible material, or in 45/55-gallon drum, incinerate (use slow burning fuse to ignite)

Method 2: (Flammability rating 1 or 0)

a. Mix or dissolve in solvent with a flammability rating of 2 or 3
b. Then dispose of in same manner as Method 1

METHOD 13.
Organic amides (e.g. Formamide)

a. Dissolve or mix with a flammable solvent (2 or 3) and process as in #12

METHOD 14.
Non-Metallic Compounds (e.g. Phosphorous Trichloride)

a. To a large open area add a 50/50 mixture of dry soda ash and slake lime
b. Add non-metallic compound to 50/50 mixture
c. Spray with water (caution fire!)
d. Neutralize by dilution with a large quantity of water

METHOD 15.
Peroxides (e.g. Hydrogen Peroxide) (See also #8 & #19)

Method 1:

a. Mix or absorb the peroxide onto sand or vermiculite
b. Wet with 10% Sodium Hydroxide
c. In a 45/55-gallon drum or open pit, ignite with slow burning fuse

METHOD 16.
Dumped into Landfill (e.g. Calcium Oxide)

The following list, adapted from *Prudent Practices*, lists solid chemicals, which are not considered hazardous and are therefore suitable for disposal with regular trash (household waste).

A. **Organic Chemicals:**
Sugars and sugar alcohols
Starch
Citric acid and its Na, K, Mg, Ca, NH_4 salts
Lactic acid and its Na, K, Mg, Ca, NH_4 salts
Urea

B. **Inorganic Chemicals:**
Silica
Sulfates: Na, K, Mg, Ca, Sr, NH_4

Phosphates: Na, K, Mg, Ca, Sr, NH_4
Carbonates: Na, K, Mg, Ca, Sr, NH_4
Oxides: B, Mg, Ca, Sr, Al, Si, Ti, Mn, Fe, Co, Cu
Chlorides: Ca, Na, K, Mg, NH_4
Borates: Na, K, Mg, Ca

METHOD 17.
Phosphorous (Yellow & Red)

Yellow:

a. Cover with water and place in a 45/55-gallon drum
b. Water will evaporate
c. Yellow phosphorous will ignite and burn

Red:

a. Ignite with a slow burning fuse

METHOD 18.
Arsenic, Antimony and Bismuth Compounds

a. Use #7 above

METHOD 19.
Special Procedures for:
Calcium hydroxide, hydrogen peroxide & potassium permanganate

a. Acidify to pH 2 with sulfuric acid
b. Add 50% excess of aqueous sodium bisulfite
c. Temperature will start to increase; if not, add more sodium bisulfite
d. Adjust pH to 7; flush down drain

METHOD 20.
Alkali Metals

a. Small amounts of the metal are allowed to react with an alcohol (ethyl alcohol) in a slow controlled fashion to generate the metal alkoxide and hydrogen
b. The hydrogen gas is released into the atmosphere
c. The metal alkoxide is subsequently hydrolyzed with water to give the metal hydroxide and alcohol. *(This procedure presents a high fire risk!)*
d.

METHOD 21.
Aqueous Solutions

Aqueous solutions of water-miscible flammable organic solvents

Solutions of less than 20% acetone, ethanol, methanol and other water-soluble and miscible solvents

a. Most aqueous solutions can be disposed of in the sanitary sewer, followed by 10 volumes of water

METHOD 22.
Mercury Compounds

a. The toxicity of mercury is such that the element and its compounds should not be allowed to contaminate air or water.
b. Wear eye protection, nitrile rubber gloves, and laboratory coat.
c. Dissolve the waste mercury salts as far as possible in water.
d. Adjust the solution to pH 10 with 10% sodium hydroxide solution.

e. Add 20% sodium sulfide solution with stirring until no further precipitation occurs.
f. Withdraw a small sample of supernatant liquid and add sodium sulfide solution to check that precipitation is complete.
g. Allow the precipitate to settle, then decant or filter the supernatant liquid into the drain with at least 50 times its volume of water.
h. Package the dry mercuric sulfide for disposal in a secure landfill.

METHOD 23.

Sodium Dichromate

a. Add the solid dichromate to a container of water (about 100 mL/5 g).
b. Acidify with 3M sulfuric acid (about 40-60 ml).
c. Slowly, and with stirring, add solid sodium thiosulfate (about 15 g) until the solution becomes cloudy and blue colored.
d. Neutralize the solution with sodium carbonate. After a few minutes, a blue-gray flocculent precipitate is formed.
e. Filter immediately through Celite or let stand for a week, when much of the supernatant can be decanted. The remaining liquid is allowed to evaporate or filtered off.
f. The liquid can be washed into drain.
g. The solid residue should be washed with hot water to remove sodium sulfate, then dried, packaged, labeled, and sent to a secure landfill site.

METHOD 24.

Iodine

a. Cautiously add iodine to a solution of sodium thiosulfate (300 mL of 4%) containing sodium carbonate (0.1 g).
b. Stir until all of the iodine has dissolved (solution is colorless), then neutralize to pH 6-8 with sodium carbonate.
c. When reduction is complete, add sodium carbonate or dilute hydrochloric acid to neutralize the solution.
d. Wash into the drain.

Aldrich Chemical Disposal Methods:

A Dissolve or mix the material with a combustible solvent and burn in a chemical incinerator equipped with an afterburner and scrubber.

B The material should be ignited in the presence of sodium carbonate and slaked lime (calcium hydroxide). The substance should be mixed with vermiculite and then with the dry caustics, wrapped in paper and burned in a chemical incinerator equipped with an afterburner and scrubber.

C This combustible material may be burned in a chemical incinerator equipped with an afterburner and scrubber.

D Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting, as this material is highly flammable.

G Under an inert atmosphere, cautiously add the material to dry butanol in an appropriate solvent. The chemical reaction may be vigorous and/or exothermic. Provisions must be made for venting of large volumes of highly flammable hydrogen and/or hydrocarbon gases. Neutralize the solution with aqueous acid. Filter off any solid residues for disposal as hazardous waste. Burn the liquid portion in a chemical incinerator equipped with an afterburner and scrubber.

H Neutralize the solution and add filtering agent (10g per 100ml). Evaporate the liquid and bag the residual solid for burial in a landfill site approved for hazardous-waste disposal.

I Dissolve the solid in (or dilute the solution with) a large volume of water. Carefully add a dilute solution of acetic acid or acetone to the mixture in a well-ventilated area. Provisions should be made to vent safely the hydrogen gas given off during the decomposition. Check acidity of the solution and adjust to pH 1 if necessary. Let stand overnight. Neutralize the solution (pH 7). Evaporate the solution and bury the residue in a landfill site approved for hazardous waste disposal.

L The material should be dissolved in 1) water; 2) acid solution or 3) oxidized to a water-soluble state. Precipitate the material as the sulfide, adjusting the pH of the solution to 7 to complete precipitation. Filter the insolubles and dispose of them in a hazardous-waste site. Destroy any excess sulfide with sodium hypochlorite. Neutralize the solution before flushing down the drain.

O Bury in a landfill site approved for the disposal of chemical and hazardous waste.

P Material in the elemental state should be recovered for reuse or recycling.

R Catalysts and expensive metals should be recovered for reuse or recycling

S Treat a dilute basic solution (pH 10-11) of the material with a 50% excess of commercial laundry bleach. Control the temperature by the addition rate of bleach and adjust pH if necessary. Let stand overnight. Cautiously adjust solution to pH 7. Vigorous evolution of gas may occur. Filter any solids for burial in a chemical landfill. Precipitate any heavy metals by addition of sulfide and isolate for burial. Additional equivalents of hypochlorite may be needed if the metal can be oxidized to a higher valence state. For metal carbonyls, the reaction should be carried out under nitrogen.

SAFE HANDLING AND STORAGE OF SEIZED CHEMICALS:

If chemicals are to be stored for destruction they must be stored in a safe manner:

1. All chemicals to be stored in a cool dry place and some chemicals may require refrigeration or freezing
2. Chemicals must be separated and stored as to their chemical compatibility:
    a. Acids separate
    b. Alkali separate
    c. Oxidizers separate
    d. Volatiles separate.
    e. Water reactive chemicals separate.

Where samples need to be taken for analysis or court proceedings, enforcement officials should follow the standard protocols they use elsewhere. For example, a typical protocol may be to take samples of 50g or ml (2 ounces), or less.

A. Guidelines for Safe Chemical Storage:

1. A designated storage place for each compound. Each stock container of a chemical compound should be returned to that location after each use. Storage locations can be marked on containers
2. Do not store chemicals in alphabetical order except within "Chemical Storage Groups". Alphabetical arrangement of randomly collected chemicals often increases the likelihood of dangerous reactions by bringing incompatible materials into close proximity
3. Storage areas should not be exposed to extremes of heat or sunlight.
4. All containers must be labeled. Suspect and known carcinogens must be labeled as such and segregated within trays to contain leaks and spill.
5. This plan does not require security measures (i.e., locked cabinets) to prevent theft, but lab workers should make sure that lab doors are locked when unattended. Use of chemicals regulated by Drug Enforcement Agency may require registration and secured controlled storage.
6. Storage of liquid chemicals is more hazardous than storage of solids and is subject to numerous and varied storage requirements.
7. All containers of flammable liquids (flashpoint <140F) should be returned to the flammables cabinet or explosion-safe/proof refrigerator/freezer immediately after use. Do not store flammable liquids in cold rooms which are neither vented nor explosion proof.
8. Peroxide formers must be stored in the flammables cabinets and must be regularly inventoried to track their age. See storage and testing guidelines for peroxide formers
9. Store non-volatile liquid poisons in a refrigerator or cabinet. Amounts less than 1 liter may be stored in a cabinet if the cabinet has sliding doors not swinging. Store volatile poisons (evaporation rate above 1.0- ether=1.0) in a flammable cabinet
10. Acids and bases should be physically separated. All acids should be stored in a corrosives cabinet. Oxidizing acids (nitric, sulfuric, phosphoric, perchloric) should have secondary containment and, as a group, stored separately from other acids (organic and mineral).

B. Chemicals Stored as Groups:

Group 1	**Flammable Liquids:** alcohols, acetone, acetaldehyde, acetonitrile, benzene, cyclohexane, dioxane, ether, ethyl acetate, hexane, piperidine, propanol, pyridine, tetrahydrofuran, toluene, triethylamine, xylene
Group 2	**Poisons volatile:** carbon tetrachloride, chloroform, dimethylformamide, dimethyl sulfate, formamide, methylene chloride
Group 3	**Acids–oxidizing:** nitric, sulfuric, perchloric, phosphoric acids, and chromic acids
Group 4	**Acids–organic and mineral:** acetic, butyric, formic, glacial acetic, hydrochloric
Group 5	**Bases--liquid:** sodium hydroxide, ammonium hydroxide, calcium hydroxide
Group 6	**Oxidizers–liquid:** hydrogen peroxide (if greater than or equal to 30%)
Group 7	**Poisons non-volatile:** triethanolamine
Group 8	**Metal hydrides, pyrophorphics, and water reactives**: sodium borohydride, calcium hydride, lithium aluminum hydride. Other pyrophorics are lithium, white or yellow phosphorus, and trimethyl aluminum. Other water reactives include aluminum chloride, anhydrous, calcium carbide, acetyl chloride, sodium, potassium, phosphorous pentachloride calcium, aluminum tribromide, calcium oxide, and acid anhydrides.
Group 9	**Solids:** benzidine, cyanogen bromide, oxalic acid, potassium cyanide, and sodium cyanide

POTENTIAL NATIONAL COUNTERPARTS:

This section is intended to provide guidance on identifying available national capacity for chemical disposal. For example, if the need for an incinerator has been identified, where would one turn to in order to try and find such equipment.

Companies, industries and other national institutions that may have chemical disposal equipment (e.g., high temperature incinerators), which may be of use to police and forensic agencies that need access to chemical disposal:

a. Universities
b. Petroleum Industry
c. Pulp Industry
d. Chemical Industry
e. Waste disposal companies
f. Hospitals

To facilitate the utilization of these guidelines, a national focal point should be designated for chemical disposal.

THE ROLE OF THE FORENSIC SCIENTIST:

The role of the forensic scientist may vary depending on circumstances.

1. Clandestine laboratory
    - provide information on what drugs are being made
    - provide information on hazards in the laboratory
    - provide information on what exhibits to seize
    - provide information on what exhibits need to be analyzed

2. Chemicals seized and need to be destroyed in the field; no hazardous waste company available.
    - Separate chemicals as to compatibility/hazards
    - Decide on what methods should be used in the destruction
    - Supervise the destruction

When chemicals are to be destroyed, a trained forensic chemist (with expertise in chemical disposal) or a police officer (trained in chemical disposal) must be present at all destructions and oversee the destruction.

However, it is recognized that operational field conditions will sometimes mean that attendance of trained personnel may not be possible.

SUMMARY OF LEGAL IMPLICATIONS:

The discovery, seizure, processing and disposal of large amounts of precursor chemicals encountered in the enforcement of National Drug Control Laws present unique problems to law enforcement and regulatory entities. Among the problems encountered are:

1. The location where the chemicals are found
2. The establishment of ownership
3. The lack of legal authority to seize, dispose of, or destroy these chemicals
4. The handling of these substances in a manner that is consistent with protecting the health and safety of the personnel processing them
5. The destruction of substances in a manner that is consistent with current environmental concerns

Outlined herein are different approaches for consideration and possible incorporation into the National Drug Control Laws.

Large quantities of chemicals with multiple legitimate uses, which transit in the international and national commerce, are required for the clandestine manufacture of illicit drugs. The individuals and organizations that operate clandestine laboratories divert these chemicals from the licit trade. The recommended methods of controls to prevent and/or uncover chemical diversion are found in the United Nations Drug Conventions. This document takes those recommendations to the next logical step: What actions should be taken when Precursor Chemicals are encountered as a result of member states implementing the recommendations of the UN Drug Conventions?

Precursor chemicals used by clandestine laboratory operators in the production of illicit drugs may be encountered at any stage of the licit chain of distribution or at the clandestine laboratory site. The location, amount and condition, will determine how seized precursor chemicals will be handled. National Drug Control Laws and Legal Systems should provide for the speedy and efficient collection, processing and disposal of seized chemicals in a manner that minimizes or eliminates their long-term storage and handling. The disposal method may be destruction of the precursor chemicals in place, transfer to a predetermined entity that has a need for them, or return to the licit trade chain of distribution.

Listed below are legal factors and other circumstances that must be considered when determining how national drug laws will treat seized precursor chemicals destined for the use in clandestine drug manufacturing:

1. The national legitimate requirements for a particular chemical must be established in order to determine what type of control measures, if any, will be applied (e.g. quotas, permits, etc.).

2. The national judicial and legal requirements must be established to determine how chemicals seized at clandestine laboratory sites (and at border crossings, including stopped shipments) will be classified (e.g. contraband, hazardous material, abandoned, etc.)

3. The legal ownership, as well as the rights, if any, of the legal owners of chemicals seized at any point in the "licit" chain of distribution must be established to facilitate the processing of the seized chemicals through the judicial process.

4. The national legal process to seize and dispose of chemicals destined for use in clandestine drug manufacturing must be established in order to allow for quick disposal (e.g. return to supplier, public sale, destruction, etc.) and to eliminate the need for long-term storage.

Overcoming Legal Obstacles:

1. Classifying seized chemicals as contraband, hazardous materials, or abandoned products, depending on the circumstances surrounding the seizure, will grant authority to the legal system to finalize forfeiture and order the method of disposal.

2. Legal owners of chemicals seized while in the "licit" chain of distribution may have certain rights under national laws. It is imperative that those rights be tempered to allow the courts to facilitate the processing of seized chemicals in a timely fashion.

3. National laws must be amended to ensure that courts authorize the quick disposal or destruction of seized chemicals in order to prevent the possible disappearance of the chemicals in order to protect the public health and safety, and the environment (pre-trial destruction).

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Annex I

CHEMICALS USED IN THE MANUFACTURE OF ILLICIT DRUGS

(including all substances in the 1988 Convention and others specifically used in the clandestine manufacture of cocaine, heroin, amphetamine/methamphetamine, ecstasy-type substances, and methaqualone)

Legend
1= Cocaine
2= Heroin
3= Methamphetamine/amphetamine
4= MDMA/MDA
5= Methaqualone

1. ACIDS

ACID	Used in Manufacture of
Acetic acid	2, 3
N-Acetylanthranilic acid	5
Anthranilic acid	5
Formic acid	3, 4
Gallic acid	
Glacial acetic	
Hydrobromic acid	
Hydrochloric acid	1, 2, 3, 4, 5
Hydrofluoric acid	
Hydroiodic acid	3
Hypophosphorous acid	
Nitric acid	
Nitrobenzoic acid	5
Oxalic acid	
Perchloric acid	3
Phenylacetic acid	3
Phosphoric acid	5
Picric acid	
Polyphosphoric acid	
Sulfuric acid	1, 3, 4
Tartaric acid	2, 3

2. BASES

BASE	Used in Manufacture of
Ammonium carbonate	
Ammonium hydroxide	1, 2, 3, 4, 5
Butylamine	3
Calcium bicarbonate	2

BASE	Used in Manufacture of
Calcium carbonate (Lime Stone)	1
Calcium hydroxide (Slake lime)	1, 2, 3
Calcium oxide (Quick lime)	1, 2
Diethylamine	
Ethylamine	
Methylamine	3, 4
Piperidine	
Potassium bicarbonate	2
Potassium carbonate	1, 2
Potassium hydroxide (Caustic potash)	1, 2, 3, 4
Pyridine	2, 3, 5
Sodium bicarbonate	1, 2, 3, 4, 5
Sodium carbonate (Soda ash)	1, 2, 4, 5
Sodium hydroxide (Caustic soda)	1, 2, 3, 4
Triethylamine	5

3. ORGANIC SOLVENTS

SOLVENT	Used in Manufacture Of
Acetone	1, 2, 3, 4
Acetonitrile	3
Acetaldehyde	3
Benzene	1, 3, 4
Bromobenzene	
N-Butylacetate	1
2-Butylacetate	1
N-Butanol	1
2-Butylalcohol	
Carbon disulphide	
Chloroform	1, 2, 3, 5
Cyclohexanone	
Diacetone alcohol	1,
Dibromethane	4
Dichloromethane	4
Dimethylformamide	4
Dimethylsulfoxide	
Ethyl acetate	1, 2, 3
Ethyl alcohol	1, 2, 3, 4, 5
Ethyl ether	1, 2, 3, 4, 5
Formamide	3
Hexane	1, 3
N-Heptane	5
Hydrogen peroxide	
Isobutyl alcohol	

SOLVENT	**Used in Manufacture Of**
Isopropyl alcohol	1, 3, 4
Kerosene	1
Methyl alcohol	1, 2, 3, 4, 5
Methylene chloride	
Methylene dichloride (Dichloromethane)	1
Methylethyl ketone (2-butanone)	1, 2
Methyl isobutyl ketone	1
Nitroethane	3
Nitrotoluene	5
Petroleum Ether	1, 3
1-Phenyl-2-propanone	3
Tetrahydrofuran	3, 4
Thionyl chloride	2, 3
Toluene	1, 4, 5
Xylene	1

4. METALS

METAL	**Used in the Manufacture of**
Aluminum	
Arsenic	
Beryllium	
Calcium	
Copper	3
Magnesium	
Mercury	3
Potassium	
Sodium	3

5. OTHER CHEMICALS

CHEMICAL	**Used in Manufacture of**
Acetic anhydride	2, 3, 5
Acetyl chloride	2,
Aluminum chloride	2, 3, 4
Ammonium acetate	3, 4
Ammonium chloride	2, 3, 4
Ammonium formate	3
Benzaldehyde	3
Benzyl chloride	3
Benzyl cyanide	
Boron tribromide	2
Calcium hypochlorite	
Cuprous oxide	4
Dimethylsulfide	

CHEMICAL	Used in Manufacture of
Ephedrine	3
Ergometrine (ergonovine)	
Ergotamine	
Ferric chloride	3
Formamide	
Gamma butyrolactone	
Glycerine	
Hydrogen cyanide	
Iodine	3
Isosafrole	4
Lithium aluminum hydride	3
Lysergic acid	
Mercuric chloride	3, 4
Mercuric bromide	4
Mercuric nitrate	
3,4-Methylenedioxyphenyl-2-propanone	4
N-Methylephedrine	
N-Methylpseudoephedrine	
Norephedrine (phenylpropanolamine)	3
Norpseudoephedrine	3
Palladium black	3
Phosphorous, red	3
Phosphorous, white	
Phosphorous, yellow	
Phosphorous oxychloride	5
Phosphorous pentachloride	2, 3
Phosphorous trichloride	2, 5
Piperonal	
Potassium cyanide	
Potassium nitrate	
Potassium permanganate	1
Propionic anhydride	
Pseudoephedrine	3
Rainey Nickel	3
Safrole	4
Sodium acetate	3
Sodium borohydride	3
Sodium cyanide	
Sodium dichromate	4
Sodium hydride	5
Sodium sulfate	1, 3
Tartaric acid	2, 3
o-Toluidine	5
Trichloroethylene	
Urea	

Annex II

HEALTH, FLAMMABILITY, REACTIVITY AND HAZARD RATINGS

A Health (H) Ratings

4: A few whiffs of the gas or vapor could cause death. The gas, vapor, or liquid could be fatal on penetrating the protective clothing. Must use specific protective clothing.

3: Material extremely hazardous to health, but area may be entered with extreme care. Full protective clothing must be used. No skin surface should be exposed.

2: Material hazardous to health, but area may be entered freely with self-contained breathing apparatus (SCBA).

1: Material only slightly hazardous to health it may be desirable to wear SCBA.

0: No hazard.

B. Flammability (F) Ratings

4: Very flammable gases, very volatile flammable liquids, and materials that, in the form of dusts or mists, readily form explosive mixtures when dispersed in the air. Flash point below 73 F.

3: Liquids which can be ignited under almost all normal temperature conditions; Any material that ignites spontaneously at normal temperatures in air; Flash point below 100 F.

2: Liquids which must be heated before ignition can occur; Solids which give off flammable vapors; Flash point > 100 F but < 200 F.

1: Material, which must be preheated before ignition, can occur.
Flash point > 200 F.

0: Materials that will not burn.

** A liquid, which has a flash point of less than 60^0C (140^0 F), is considered ignitable. This category includes almost all organic solvents.

C. Reactivity (R) Ratings

4: Materials which in themselves are readily capable of detonation or of explosive decomposition or explosive reaction at normal temperature and pressures.

3: Materials which in themselves are capable of detonation or of explosive decomposition or of explosive reaction, but which require a strong initiating source. Includes materials which are sensitive to thermal or mechanical shock at elevated temperatures and pressures or which react explosively with water without requiring heat.

2: Materials, which are normally unstable and readily undergo violent chemical change but do not detonate; Includes materials, which react violently with, water or which may form potential explosive mixtures with water.

1: Materials, which are normally, stable but may become unstable at elevated temperatures and pressures; May react with water with some release of energy but not violently.

0: Materials, which are normally stable even under, fire exposed conditions and which are not reactive with water.

D. Hazard Rating (Sax)

This rating identifies the level of toxicity or hazard. Ratings are assigned on the basis of low (1), medium (2), or high (3) toxic, fire, explosive, or reactivity hazard.

3: Indicates an LD 50 below 400 mg/kg or an LC 50 below 100 ppm or the material is explosive, spontaneously flammable or highly reactive.

2: Indicates an LD 50 of 400-4000 mg/kg or an LC 50 of 100-500 ppm or the material is highly flammable or reactive.

1: Indicates an LD 50 of greater than 4000 mg/kg or an LC 50 of greater than 4000 ppm, or that the material is combustible.

Annex III

Planning For Neutralization of Acids and Bases
(University of Wisconsin Safety Manual 1993)

Safety Note:

Always add concentrated acid or base to water as recommended in the tables to dilute them prior to neutralization

1. Before starting the procedure, calculate quantities of acid or base needed for neutralization. The relative strengths of commonly used acids and bases are summarized in the adjacent tables.
2. Try a small batch first. Measure a few milliliters of waste acid into a beaker and gradually add a measured amount of base while testing its pH and observing its reaction. Assess the amount of heat and fumes generated, and the amount of base needed. Use these observations for scaling up your neutralization. Remember that, when scaling up, the lower ratio of surface area to volume may make heat dissipation a problem. Ice, going slow, and stirring, all help.
3. Add the maximum amount of concentrated acid or base solution listed in the following tables to 10 L water in a 5-gallon bucket. A rule of thumb is to dilute up to 20 moles of acid protons per 10 liters of water.

Strength of Concentrated Acids

Concentrated Acid	Amount to furnish one mole of acid proton ("Strength")	Maximum volume per neutralization in a 5-gallon bucket	Maximum volume per neutralization using 10 L of water
Acetic Acid Glacial	57.1 ml	1.5 L	1.1 L
Formic Acid 88%	43.6 ml	1.2 L	0.9 L
Hydrochloric acid	83 ml	2.2 L	1.6 L
Hydrofluoric acid 50%	34.6 ml	0.75 L	0.7 L
Hydriodic acid			
Nitric acid	67 ml	1.0 L	1.3 L
Perchloric acid	83 ml	1.0 L	1.6 L
Phosphoric acid 85%	45.6 ml	1.2 L	0.9 L
Sulfuric acid	27.7 ml	0.75 L	0.5 L
Trichloroacetic Acid, 20% Solution	817 ml	3.0 kg/L (30%)	16.3 L

Strength of Bases Used for Neutralization

Base	Amount to furnish one mole of base protons	Notes
Ammonium Hydroxide (15 M)	67 ml	
Calcium Hydroxide	37 G	Add as a powder to neutralize acid
Magnesium Hydroxide	29 G	Add as a powder to neutralize acid
Potassium Hydroxide	56 G	Dissolve 336 G KOH per litre of water to make ^N solution
Sodium Bicarbonate	84 G	Causes foaming
Sodium Carbonate	53 G	Causes foaming
Sodium Hydroxide	40 G	Dissolve 240 G NaOH per litre of water to make 6N solution

Sample Calculation
300 ml of ammonium hydroxide, 1.5 L of hydrochloric acid, 250 ml of sulfuric acid 400 ml 20% trichloroacetic acid solution

Step One: Calculate how many moles of acid protons you have.
Hydrochloric acid: 1500 ml ÷ 83.0 ml/mole = 18 moles
Sulfuric acid: 250 ml ÷ 27.2 ml/mole = 9 moles
Trichloroacetic acid: 400 ml ÷ 871 ml/mole = 0.5 moles
Total amount =28 moles acid

Step Two: Calculate how many moles of base you have:
Ammonium hydroxide: 300 ml ÷ 67 ml/mole = 5 moles base

Step Three: Subtract moles of base from moles of acid:
28 moles acid - 5 moles base = 23 moles base needed

Step Four: Calculate the grams of sodium hydroxide you would need to complete the neutralization: 23 moles base × 40 g/mole NaOH = 920 grams NaOH

Conclusion: Therefore, an additional 920 grams sodium hydroxide is needed to complete the neutralization.

Annex IV

Chemical Tests To Be Conducted On Unknown Solids/Liquids:

Typically, the identity of unknown chemicals should be confirmed by laboratory analysis. However, presumptive group tests, which can be carried out at the scene (on-site), are helpful for determining the most appropriate destruction/disposal methods. Testing is particularly important if chemicals are opened, labels are missing and/or the original manufacturer's seals are damaged. The following is an outline for field testing to determine the nature and chemical and physical properties of unknown chemicals. It is not an outline for presumptive testing of substance identity.

Available test papers:

Watesmo Paper: Determines if solvent is aqueous or organic
pH Paper: Determines strength of acid or base
Peroxide Paper: Determines amount of peroxides present
Cyanide Paper: Determines if cyanides are present

The first step of the field testing procedure is to describe the physical characteristics of the unknown chemical:

The physical description should include the state of the material (solid, liquid), the colour, and the consistency (for solids) or viscosity (for liquids). For liquid materials, describe the clarity of the solution (transparent, translucent, or opaque). If an unknown material is a bi- or tri-layered liquid, describe each layer separately, giving an approximate percentage of the total for each layer.

After taking appropriate safety precautions for handling the unknown, including the use of personal protection devices, remove a small sample for use in the following tests.

1. **Water reactivity**
   Carefully add a small quantity of the unknown to a few millilitres of water. Observe any changes, including heat evolution, gas evolution, and flame generation.

2. **Water solubility**
   Observe the solubility of the unknown in water. If it is an insoluble liquid, note whether it is less or more dense than water (i.e., does it float or sink).
   Conclusion: Most non-halogenated organic liquids are less dense than water.

3. **pH**
   Test the material with multi-range pH paper. If the sample is water-soluble, test the pH of an 10% aqueous solution. It may also be desirable or even required to carry out a neutralization titration.

4. **Ignitability (flammability)**
   Place a small sample of the material (5mL) in an aluminium test tray. Apply an ignition source, typically a propane torch, to the test sample for one-half second.
   Conclusion: If the material supports its own combustion, it is a flammable liquid with a flash point of less than 60°C. If the sample does not ignite, apply the ignition source again for one second. If the material burns, it is combustible. Combustible materials have a flash point between 60 and 93 °C.

5. Presence of peroxides

A. Commercial test papers can be purchased from:
   1) EM Scientific cat no: 100111-1
   2) Lab Safety supply cat no: 1162
   3) Aldrich Chemical cat no: Z10-,168-0
   Approximate costs:

B. Add 1 ml. of substance to be tested to a freshly prepared solution of 100 mg of sodium (potassium) iodide in 1 ml of glacial acetic acid. Yellow color equals low concentration of peroxides; Brown color equals high concentrations of peroxides.

B.2. Add 1-3 mls of the liquid to be tested to an equal volume of acetic acid, and add a few drops of 5% potassium iodide solution and shake. The appearance of a yellow to a brown color indicates the presence of peroxides.

C. Add substance to be tested to 1 ml of a freshly prepared 10% solution of potassium iodide to 10 ml of ethyl ether in a 25 ml glass-stoppered cylinder of colorless glass protected from light. A resulting yellow color indicates the presence of 0.005% peroxides.

C.2. Add 0.5 ml of the solution to be tested to a mixture of 1 ml of 10% potassium iodide solution and 0.5 ml of dilute hydrochloric acid to which has been added a few drops of starch solution just prior to the test. The appearance of a blue to blue-black colour within a minute indicates the presence of peroxides.

D. Prepare a solution of 5 ml. of 15% ferrous ammonium sulfate, 0.5 ml of 1N sulfuric acid and 0.5 ml of 0.1N ammonium thiocyanate. Shake with an equal quantity of the solution to be tested. If peroxides are present a red colour will develop.

E. Wet commercially available starch-iodide paper with 1 N hydrochloric acid, and then place a small portion of the unknown on the wetted paper. A change in colour of the paper to dark purple is a positive test for an oxidizer.

6. Presence of sulfide

The test for inorganic sulfides is carried out only when the pH of an aqueous solution of the unknown is greater than 10. Add a few drops of concentrated hydrochloric acid to a sample of the unknown while holding a piece of commercial lead acetate paper, wetted with distilled water, over the sample.

Conclusion: Development of a brown-black colour on the paper indicates generation of hydrogen sulfide. **Because of the toxicity of the hydrogen sulfide formed during this test, only a small sample should be tested, and appropriate ventilation should be used.**

7. Presence of cyanide

The test for inorganic cyanides is carried out only when the pH of an aqueous solution

of the unknown is greater than 10. Prior to testing for cyanides, the following stock solutions should be prepared: 10% aqueous sodium hydroxide (solution A), 10% aqueous ferrous sulfate (solution B), and 5% ferric chloride (solution C). Mix 2ml of the sample with 1ml of distilled water and 1ml each of solutions A, B, and C. Add enough concentrated sulfuric acid to make the solution acidic.
Conclusion: Development of a blue colour (prussian blue, from ferric ferrocyanide) indicates cyanide. **Because of the toxicity of the hydrogen cyanide formed during this test, only a small sample should be tested, and appropriate ventilation should be used.**

8. **Presence of halogen**

Heat a piece of copper wire until red in a flame. Cool the wire in distilled or de-ionized water, and then dip the wire into the unknown. Again heat the wire in the flame.
Conclusion: The presence of halogen is indicated by a green colour around the wire.

9. **Chemical test to determine the presence of specific acids**
   a. Prepare 3 separate solutions of the acid to be tested by adding 1-2 drops of the acid to 1 ml of de-ionized water
      i. SILVER NITRATE TEST:
      Add 1-2 drops of 5% silver nitrate reagent to the solution and observe the precipitate (ppt), if any. If a ppt is observed add 1-2 drops of concentrated ammonium hydroxide and observe if the ppt dissolves
      ii. BARIUM NITRATE TEST:
      Add 1-2 drops of 5% barium nitrate reagent and observe the ppt, if any
      iii. BASIC BARIUM NITRATE TEST:
      Add 1-2 drops of 50% NaOH, make sure pH is basic
      Add 1-2 drops of 5% barium nitrate reagent and observe the ppt, if any
   b. Add 1/2 ml of concentrate NH4OH to a 50 ml Beaker. Slowly add 1-2 drops of the acid to be tested to the NH4OH, ensure pH is >8. Add 40 ml of acetone to ppt the ammonium salt. Filter, collect ppt, air dry ppt, and run IR.

Acid	**Silver Nitrate**	**Silver Nitrate + NH4OH**	**Barium Nitrate**	**Basic Barium Nitrate**
HBr	Pale Yellow ppt	Dissolves	No ppt	No ppt
HI	Yellow ppt	White ppt	No ppt	No ppt
HCL	White ppt	Dissolves	No ppt	No ppt
H_2SO_4	No ppt	No ppt	White ppt	White ppt
HNO_3	No ppt	No ppt	No ppt	No ppt
H_3PO_4	No ppt	No ppt	No ppt	White ppt
H_3PO_2	Black ppt	No ppt	No ppt	No ppt

Annex V

Model scenarios

E.g.:

Seizure of	P-2-P at commercial port ?
Seizure of	acetic anhydride at remote/insecure border crossing “solvent” at jungle lab site

Part B

DESTRUCTION TECHNOLOGIES FOR OZONE DEPLETING SUBSTANCES

1. Introduction

Part B of the discussion paper presents a summary of the basic chemical characteristics of ozone depleting substances (ODS), studies the chemical reactions capable of breaking up the ODS molecules, looks into the available destruction technologies for contaminated and surplus stocks of ODS and considers the linkage with other multilateral agreements by examining suitability for the destruction of ODS of some of the destruction technologies employed through the Stockholm Convention on Persistent Organic Pollutants (POPs). A special focus is given to the mobile and the semi-mobile technologies, which could be cost-effective options of destruction. The paper therefore tries to build on and benefit from the developments in the area of destruction of POPs.

Parties to the Montreal Protocol have since the second meeting of the Parties in 1992 taken several decisions, I/12F, *II/11, III/10, IV/11, V/26, VII/35, XII/8, XIV/6 and XVI/15,* on the definition, review, evaluation and recommendation of appropriate destruction technologies thus recognizing the urgency of the problem of the increased stocks of ODSs in Article 5 Countries, lacking the technology and the infrastructure to dispose of the chemicals. Exact excerpts of the decisions are included in Annex I to this document. At this point it is however useful to refer to the definition of destruction as per Article 1, paragraph 5 of the Montreal Protocol "a destruction process is one which, when applied to controlled substances, results in the permanent transformation, or decomposition of all or a significant portion of such substances".

The cost effectiveness of the approved list of destruction technologies has always been a re-emerging question. Most Article 5 Countries do not have the financial means to adopt these technologies and resolve the problem. Therefore there is a need to adopt a comprehensive approach of waste ODS management, which is not limited to the option of destruction. Experience from Article 2 Countries shows that the introduction of legislative instruments and the involvement of the industry are essential factors.

2. Properties and Chemical Characteristics of ODS

2.1. General Characteristics of ODS

The ODS addressed in this report include Chlorofluorocarbons (CFCs or freons), Hydrochlorofluorocarbons (HCFCs), Halons, other fully halogenated CFCs, Carbon tetrachloride, Methyl chloroform, Methyl bromide and Fluoroform.

ODS share some common characteristics, which made them ideal for use in many applications as refrigerants, foam blowing agents, solvents, propellants, fumigants and fire extinguishers. These properties include stability, non-toxicity, chemical inertness and non-flammability. Despite their highly attractive commercial value, ODS were found to have the capacity of destroying the protective ozone layer by reacting with the ozone molecules. To allow different chemicals to be compared using a common unit, scientists developed a method for characterizing the relative depletion caused by different ODS. Ozone Depleting Potential (ODP) is the ratio of calculated ozone column change for each mass unit of a gas emitted into the atmosphere relative to the calculated depletion for the reference gas. Two other important indicators of ODS are the lifetime and decomposition temperature.

2.2. Categories of ODS and Chemical Structure

The chemicals under study are grouped into 5 categories based on their basic chemical characteristics and ability for chemical reactions:

a. ***Category I Fluorocarbons:*** such as Tetrafluoromethane (CF_4), 1,1,1,2,2,2-hexafluoroethane (CF_3CF_3) and 1,1,1,2,2,3,3,3-octafluoropropane ($CF_3CF_2CF_3$). Fluorocarbons are organic compounds analogous to hydrocarbons ranging from gases to volatile liquids. They are chemically very stable and therefore their chemical and biological degradation is practically impossible.

b. Category II, Chlorofluorocarbons (CFCs): CFCs are haloalkanes or halogen carbons containing a C-Cl bond in addition to the C-F bond. They also range from gases at normal temperatures to volatile liquids. Their chemical destruction is possible through C-Cl bond. CFCs can react with metals, strong bases and the like.

c. Category III, Bromofluorocarbons (Halons): Haloforms are used as narcotic substances. Their chemical destruction is possible through the reaction of C-Br bond which is more stable than C-Cl bond. They can be destructed by ways similar to the substances of Category II.

d. Category IV, Hydrochlorofluorocarbons (HCFCs): These chemical substances contain beside C-Cl and C-F bonds also a C-H bond. This factor expands destruction potentials through the C-H bond too. Here arises a possibility of easier biodegradation. CHFC bonds are fissile by chemical reaction such as reaction with concentrated bases or metals. The question of economy of these reactions still remains.

Some specific reactions can be used for disposal of relatively vaporous dihalofluorine chemical substances through the addition of carbene. A possibility of reaction of dihalofluorocarbene on polymeric unsaturated skeleton with comparatively simple technological accomplishment exists. A reaction of difluorodibromomethane with carbene way can serve as an example.

e. Category V, Other Substances: Category V includes chemical substances containing Cl or Br without F. In terms of chemical destruction, these compounds are the most reactive. They are used for chemical cleaning of textile, as solvents in chemical industry or as reagents in various reactions. Their chemical destruction is relatively simple with high specificity.

Table 1 below summarizes by category; the name, symbol, ODP, lifetime and decomposition temperature:

Common Name	Chemical Name	Chemical Formula	ODP	Lifetime	Decomposition Temperature
CFCs					
CFC-11	trichlorofluoromethane	CCl_3F	1.0[1]	50[1]	
CFC-12	Dichlorodifluoromethane	CCl_2F_2	0.82[1]	102[1]	
CFC-113	1,1,2- trichlorotrifluoroethane	CCl_2FCClF_2	0.9[1]	85[1]	
CFC-114	1,2-dichlorotetrafluoroethane	$CClF_2CClF_2$	0,85[1]	300[1]	
CFC-115	chloropentafluoroethane	$CClF_2CF_3$	0.4[1]	1,700[1]	
CFC Mixtures (Refrigerator and Cooling Mixtures)					
CFC 500	(73.8%) dichlorodifluoromethane + (26,2%) ethylidene fluoride	Cl_2F_2/CH_3CHF_2			
CFC 502	(48,8%) chlorodifluoromethane + (51,2%) chloropentafluoroethane	$CHClF_2/CClF_2CF_3$			
CFC 503	(40,1%) trifluoromethane + (59,9%) chlorodifluoromethane	$CHF_3/CClF_3$			
HCFCs					
HCFC-22	chlorodifluoromethane	$CHClF_2$	0.04[1]	13.3[1]	480 °C[5]
HCFC-123	2,2-dichloro-1,1,1-trifluoroethane	$CHCl_2CF_3$	0,014[1]	1.4[1]	
HCFC-124	2-chloro-1,1,1,2-tetrafluoroethane	$CHClFCF_3$	0.03[1]	5.9[1]	
HCFC-141b	1,1-dichloro-1-fluoroethane	CH_3CCl_2F	0.10[1]	9.4[1]	> 200 °C[5]
HCFC-142b	1-chloro-1,1-difluoroethane	CH_3CClF_2	0.05[1]	19.5[1]	204-260 °C[6]
Halons					
HALON-1211	bromochlorodifluoromethane	CF_2ClBr	5.1[1]	20[1]	500 °C[7]
HALON-1211	bromotrifluoromethane	CF_3Br	5.1[1]	20[1]	500 °C[7]
HALON-2402	1,2-dibromotetrafluoroethane	$C_2F_4Br_2$	6.0[2]	20[4]	
Other fully halogenated CFC					
CTC	Carbon tetrachloride	CCl_4	1.20[1]	42[1]	> 100 °C[9]
TCA (Methyl chloroform)	1,1,1-trichloroethane	CH_3CCl_3	0.12[1]	5.4[1]	> 54 °C[10]
Methyl bromide		CH_3Br	0.64[1]	1.3[1]	
Fluoroform			0[11]	250[13]	

2.3. Chemical Reactions

ODS exhibit a wide range of structural types, which makes it difficult to find a universal chemical method for their degradation. But various chemical methods can be applied to the groups of compounds similar in their reactivity.

CFCs, for instance, have low boiling points, are non-reactive and are not water-soluble and. It is therefore problematic to find an effective chemical process for their final degradation. Another property of CFCs, the stability, makes photolysis by the energetic ultraviolet radiation in the upper stratosphere, the best means to break the CFC molecule.

In principle, the safe destruction of CFCs and other halogenated compounds requires three steps; detaching the C-F and C-Cl bonds in the molecules; converting the constituent atoms to stable molecules, that is C to CO2, F to HF, Cl to HCl and Br to HBr; and finally neutralizing the acids.

2.3.1. Group I (CFC, HCFC, CTC and methyl bromide)

A number of methods can be applied for the destruction of CFC, HCFC, CCl_4, CH_3Br. These include

a. Direct chemical destruction – Reactions of the compounds listed above with reactive reagents, which have inorganic bonded fluorine. For example melting with NaOH.

b. Chemical destruction using organic fluorine intermediates - Reaction of the same compounds with reagents yielded to different organic fluorine compounds thus producing inactive fluorine compounds. A good example is the reaction of CF_2Br_2 with difluorocarbene on an activated double bond. Using this method, gas fluorine is transformed to solid fluorine, which can be decomposed via several reactions.

c. Chemical destruction via dehalogenation - This method is very pure one for the decomposition of these chemicals by hydrogenation using different catalysts.

d. Chemical destruction on surface – Compounds under study can be degraded through reactions on solid surface state such as reaction on zeolites.

2.3.2. Group II (CFC, HCFC, CCl_4, CH_3X)

A great deal of the work on the chemical methods for destroying these stable compounds is still in the stage of research and development.

a. Catalytic decomposition – Using this method, CFCs are decomposed as a result of the continuous circulation of CFC and steam on a solid catalyst. High performance solid catalysts include zeolite, alumina, binary oxide of TiO_2 - ZrO_2 and iron oxide supported on activated carbon.

b. Reagent decomposition – Through this way, CFCs are gradually decomposed by a sodium naphthalene reagent dissolved in an organic solvent. The solution then reacts with gaseous or liquid CFC generating NaCl and NaF through the neutralization between Na^+ ions in the reagent and Cl and F in CFC.

c. Super critical water decomposition – As both the temperature and pressure of water increase, water and steam reach the same density. A condition is achieved in which it is impossible to differentiate water from steam, which is referred to as the "critical point". If the temperature and pressure exceed this critical point, water becomes "super critical water" possessing extremely high oxidizing properties. This technique utilizes the power of super critical water for state-facilitating hydrolysis. It is reported by the Central Pollution Control Board at the Ministry of Environment in India that CFC-11 and CFC-113 are almost completely decomposed at temperature of 400 °C and atmospheric pressure of 320 atm.

d. Hydrogenation of CFCs adsorbed onto activated carbon. Halocarbons including CFCs are among the compounds that are the most highly attracted to the carbon and consequently adsorbed onto the surface of the activated carbon. Hydrogenation reduces the unsaturated bonds between the carbon atoms by reaction with a hydrogen molecule thus attaching a hydrogen atom to each carbon. Such a reaction represents a degree of decomposition of CFC using the untreated activated carbon. (activated carbon treated with 6 N nitric acid) ??

e. According to research performed at the Centre for Plasma and Laser Engineering, Institute of Fluid Flow Machinery in Poland by Jasinski et al. (2001), CFC11 is destroyed with an efficiency of 80% at a nitrogen flow rate and microwave power delivered to the discharge equal to 2 l/min and 400 W. In this experiment, CFC is mixed with nitrogen using microwave torch plasma. After processing the N_2/CFC11 mixture, byproducts such as carbon, chlorine Cl_2 and fluorine F_2 were identified.

f. Catalytic hydrolysis of CFC-12 using a strong acid such as WO_3/ZrO_2 as a catalyst in the presence of water vapor is another method investigated for the destruction of CFC by Weiming Hua et al.(2004) at the Department of Chemistry, Fudan University, Shanghai, China.

g. A. Sreekumaran Nair et al (2003) studied the reaction of halocarbons with metal nanoparticles such as silver and gold nanoparticles, results in their catalytic destruction forming metal halides and amorphous carbon. This seems to be a promising method to mineralize halocarbons in a reaction such as that presented below:

$2CuO + CCl4 \rightarrow 2CuCl2 + CO2$

h. Khaleel A et al (2002) reported the destruction of CCl_4C by using a high surface area aluminum oxide as a catalytic media. An alumina catalyst was found to destroy carbon tetrachloride with an efficiency >99% at 400 °C. The major product of the reaction is Carbon dioxide while minor products include hydrogen chloride and tetrachloroethylene along with traces of phosgene.

i. Decomposition of halogenated methanes in oxygen-free gas mixtures by the use of a silent electric discharge. (Foglein KA, Szepvolgyi J, Dombi A. From Department of Inorganic and Analytical Chemistry, University of Szeged, H-6701 Szeged, PO Box 440, Hungary.) A silent electric discharge was applied to decompose halogenated methanes including CCl_4, $CHCl_3$, $CFCl_3$, CF_2Cl_2 and CF_3Cl, in argon-containing gas mixtures. The decompositions of the target compounds were studied in static reactors at fixed electric field and room temperature.

2.3.3. Group III (CFC)

Several chemical reactions have been discovered to destroy the CFC molecule, these include;

a. Pyrolysis (a thermal decomposition process) using chemical substances destroys CFCs in a reaction with silicon-compounds at a high temperature via electric heating.
b. Na-naphthalenide in liquid phase at a low temperature of 25-150 °C reacts with CFC molecule destroying it.
c. Na-ammonia destroys CFCs in a reaction with Na dissolved in ammonia. The $NaNH_2$ produced is reused by the reduction to ammonia.
d. Molten metal destroys CFCs in molten sodium.
e. Sodium oxalate destroys CFCs in a reactor containing sodium oxalate at 270 °C.

f. Catalytic types of destruction reactions include; alcohol reduction (FeF_3-$CuCl_2$ / activated carbon), oxidation (PO_4-ZrO_2) and catalytic combustion (WO_3-Al_2O_3).

3. Destruction Technologies

3.1. List of Destruction Technologies approved by the Meeting of the Parties

The *Second Meeting of the Parties* decided in *Dec. II/11* to establish an *Ad Hoc* Technical Advisory Committee on Destruction Technologies to analyze destruction technologies and assess their efficiency and environmental acceptability and develop approval criteria and measurements.

The Task Force on Destruction Technologies developed updated screening criteria. The "screened-in" technologies were then evaluated with emphasis on actual data about ODS destruction performance or efficiency. The Protocol defines destruction efficiency in relation to the input and output of the destruction process itself, not to the destruction facility. The destruction efficiency recommended means that that less than 0.1 g of total ODS will enter the environment from flue gas emissions, liquid effluents, and solid residues, when 1,000 gram ODS are fed into the process.

Of the evaluated technologies, twelve met the recommended criteria for concentrated sources and only two met those for the destruction of foams. Of the recommended technologies, the Parties approved the following technologies listed according to the energy source of destruction:

a. **Thermal oxidation category**
- Liquid injection incineration *[approved by Decision IV/11]*
- Reactor cracking *[approved by Decision IV/11]*
- Gaseous/fume oxidation *[approved by Decision IV/11]*
- Rotary kiln incinerators *[approved by Decision IV/11]*
- Cement kilns *[approved by Decision IV/11]*
- Municipal solid waste incinerators (for foams containing ozone-depleting substances) *approved by Decision V/26]*
- For foam containing ODS: rotary kiln incinerator *[approved by Decision XIV/6]*

b. **Plasma destruction category**
- Radio frequency plasma destruction technology *[approved by Decision VII/35]*
- For CFC, HCFC and halons: argon plasma arc *[approved by Decision XIV/6]*
- For CFC and HCFC: nitrogen plasma arc, microwave plasma, gas phase catalytic dehalogenation and super-heated steam reactor *[approved by Decision XIV/6]*

3.2. Descriptions of the Technologies

A detailed comparative study for a commercially available technology to destroy ODS is not available. Conditions in different countries may require different approaches to deploy destruction technologies in view of the amount of ODS of concern, the infrastructure as well as the need for long distance transportation.

In this section, a short description of 22 commercially available technologies for destruction of ODS is provided. The main sources of information used are the 6th edition of the Handbook for the International Treaties for the Protection of the Ozone Layer produced by the Ozone Secretariat in 2003 and a study carried out by CANTOX ENVIRONMENTAL INC. (CEI) in 2000.

The available technologies are categorized into 3 groups: incineration technologies, plasma technologies and non-incineration technologies. The biological treatment of ODS or biodegradation is another category, which is also examined.

A summary of the advantages and disadvantages of each technology is presented in Annex II to this document. In addition, details on financial cost of the destruction technologies – if available are attached as Annex III to this document.

3.2.1. Incineration Technologies

Nine types of incineration technologies are herewith considered; cement kilns incineration, Container based incineration system, gaseous / fume oxidation, high performance incineration, internaly circulating fluidized bed incineration, liquid injection incineration, municipal solid waste incineration, reactor cracking and rotary kiln incineration.

3.2.1.1. Cement Kiln Incineration

A cement kiln is a kiln that slowly rotates to expose limestone, sand and clay evenly to very high temperatures (1,400-2,000 °C) to make cement clinker. Organic waste can be injected into the kiln with the fuel or directly into the flame. The high temperature and long residence time (6-10 seconds) effectively oxidize the organic waste. Acid gases resulting from organo-chlorine chemicals are supposed to be mostly neutralized by the alkaline cement eliminating the need for a caustic scrubber.

Burning of hazardous industrial wastes in cement kilns is being used for the disposal of hazardous wastes in France and Norway and a number of other European countries.

The principal processes employed in making cement clinker can be broadly classified as either "wet" or "dry" depending on the method used to prepare the kiln feed.

In the wet process the feed material is slurred and fed directly into the kiln. In the dry process the kiln exhaust gases are used to dry the raw meal (a mixture of limestone and other raw materials) while it is being milled.

The capacity is about 500 m^3 for the solid waste and 260 m^3 for fluid waste. (Detailed Review of Selected Non-Incineration and Incineration POPs Elimination Technologies for the CEE Region; Danish Environmental Protection Agency; 2004)

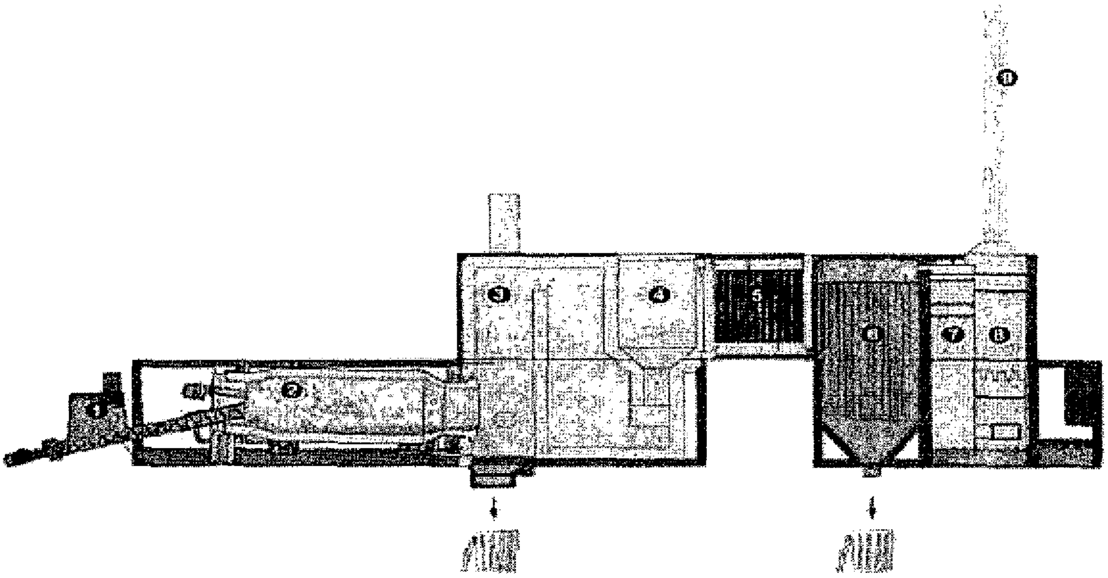
3.2.1.2. Container Based Incineration System

Chemcontrol A/S and Soil Recovery A/S have designed and constructed a mobile Container-based Incineration System (CIS), for high temperature incineration of toxic and hazardous wastes, hospital waste and other industrial wastes, designed on a modular basis to facilitate shipping and erection.

The container-based incineration system is designed for the incineration of solid, pasteous and liquid hazardous waste such as waste oil, organic solvents, paint sludge, lacquers, plastic, synthetic material, rubber halogenated waste, pesticides, PCB, hospital waste and infectious waste (optional). The CIS is a small (mobile) rotary kiln and is just now being tested in Latvia.

The capacity of the plant is 2,000-4,000 ton per year, depending on the bulk density and the heat value of the waste. The incinerator is a turnkey installation consisting of two standard 40 ft. and one 20 ft. containers thus simplifying transportation and installation on site. The unit is complete with feeding system, rotary kiln, secondary combustion chamber, flue gas cooling system, flue gas cleaning, electrical wiring, control system, etc.The CIS has a rotary kiln incineration system with a flue gas cleaning system, and works at an *operating temperature of* 1,100 °C to 1,200 °C.

Picture No. 2: Scheme of Container Based Incineration System



Hazardous waste incinerators have a main chamber for burning wastes and a secondary incineration chamber to achieve maximum destruction of hazardous organic by-products. Air and natural gas are burnt to keep the combustion gases at the appropriate temperature (1,150 °C) for at least two seconds (residence time). Off gases are cooled to approx. 20 °C before entering the gas cleaning processes.

Properly managed incineration can, in principle, destroy pesticide waste with a DRE of 99.99% or higher. Some incinerators even claim DRE values of up to 99.99995%.

Disadvantages of this process include that the effective incineration is complex and depends on many factors, such as: equipment and process design, process control and maintenance of the correct residence time, temperature and turbulence, type of products incinerated, and capacity and effectiveness of air pollution control devices. High temperature incinerators are complex pieces of equipment, which require highly skilled personnel and constant monitoring to maintain stable operating conditions.

Dioxins, which are extremely toxic and persistent in the environment, are formed as the result of a reaction during the cooling of the stack gases. The formation of dioxins has been minimised in modern incinerators either by cooling down in boilers taking out the heat of the flue gas or by quenching off gases quickly to below 250 °C and the release of dioxins, heavy metals and dust are carefully controlled by passing off gases through intensive flue gas cleaning processes.

A disadvantage though is the poor control of the residual products placed as hazardous waste on landfill, which may contain high levels of POPs and other toxic chemicals.

On the other hand, this process enjoys a number of advantages such as; the reduction of the volume of waste from 100% to about 12-13% of slag and 6-7% of fly ash and material from flue gas cleaning; detoxification of many different toxic compounds at the same time especially carcinogens, pathologic materials and all kind of toxic chemicals; reduction of the impact on the environment, e.g. if the alternative is direct land filling where organic and soluble inorganic compounds easy leaks out into the environment; and energy recovery, especially when large amounts of waste are available in a continuous stream from the waste producers.

Finally, the incineration processes at a single process destroys all organic compounds and change their dangerous chemistry radically to something less dangerous. These advantages, in combination with extensive use for municipal waste treatment and combined energy utilisation (distinct heating and electricity utilization) are the background for the very general use of incineration and have made the basis for the development of many different incineration systems.

The DE value for organic carbon is 97-98%. (Detailed Review of Selected Non-Incineration and Incineration POPs Elimination Technologies for the CEE Region; Danish Environmental Protection Agency; 2004)

3.2.1.3. Gaseous / Fume Oxidation

This process uses a refractory-lined combustion chamber for the thermal destruction of waste CFC and HCFC gases. Some of the ODS (e.g. CFC-12, CFC-114, or CFC-115) are gases at ambient temperature and can be destroyed by feeding directly from their pressurized storage into the incinerator. The fume stream is heated using an auxiliary fuel such as natural gas or fuel oil. A combustion temperature near 1,100 ºC is required for most ODS compounds, and the specific unit operates at a temperature from 1,200 to 1,250 ºC. Gaseous residence times in fume incinerators are about 1-2 seconds. Some fume incinerators are equipped with heat exchangers in the flue gas outlet to pre-heat the combustion air and/or the waste fume. These recuperative incinerators are capable of recovering up to 70% of the energy in the flue gas. Fume incinerators are designed for continuous operation and are a simple, proven technology.

The process is reported to achieve a DRE exceeding 99.999% while destroying CFCs and 99.99% destroying halons at feed rates of 165 kg/h and 15 kg/h respectively. The chamber temperature was 1,200 ºC for CFC and 1,250 ºC for halons. The flue gas volume was estimated at 1,200 Nm^3/h, except for the HBr/Br_2 emission that is at 130 Nm^3/h.

Fume incinerators are almost always privately operated and are typically found in fluorine chemical manufacturing plants. A typical dedicated gaseous/fume incinerator, operated by Ineos Fluor Japan Limited in Japan, has a rated capacity of from 15 to 165 kg/hr, depending on whether halons or CFC are being destroyed. These dedicated units are not generally available for use by other parties for the destruction of ODS. However, the technology is not proprietary and could be used in a new facility to destroy ODS for others on a commercial basis. Costs for destruction of ODS waste is expected to be in the range $US 3-5/kg CFC, and somewhat higher for halons because of reduced throughput.

(UNEP Report of the Technology and Economic Assessment Panel, Volume 3B, Report on the Task Force on Destruction Technologies, 2002)

3.2.1.4. High Performance Incineration

High performance incinerators designed specifically to destroy stable organic compounds, such as PCBs and ODS, operate at significantly higher temperatures, generally at 1,200 °C or higher. Such performance incinerators generally achieve 99.9999% destruction. Halogen-containing ODS have a low heat value; therefore, the required high operating temperatures can only be achieved by use of supplementary fuel such as natural gas, fuel oil or propane.

The primary products from the thermal destruction of ODS are carbon dioxide (CO_2), water (H_2O) and hydrochloric and hydrofluoric acids (HCl and HF). Hydrogen bromide (HBr) and/or bromine (Br_2) are produced in the case of the destruction of halons. Products of incomplete combustion (PIC) such as carbon monoxide, hydrocarbons, organic acids and partially degraded products may also be produced, but these PICs are emitted in only small amount from well-designed incineration facilities that provide high temperatures, adequate residence times (1-2 seconds), excess oxygen and good mixing.

A purpose designed system has been installed to facilitate the introduction of ODS into the incinerator in a safe and secure manner. This system employs nitrogen to pressure off the ODS from the shipping container directly into the rotary kiln. The feed rate is regulated to a nominal value of 4 to 5 kg/h although the system capacity is 10 kg/h.

The design of this system offers a number of advantages. For example, the ODS material does not need to be transferred to an intermediate vessel prior to incineration, there are no pumps involved thereby limiting the potential for leakage from seals, the system can be rapidly shutdown locally and through remote interlocks tied into the incinerator control system, the ODS container can be purged with nitrogen at completion and depressurized to atmospheric pressure, the system can accommodate a variety of sizes and configurations of ODS containers. Finally, the entire system is located inside the incinerator feed building that is maintained under a slight negative pressure and is exhausted to atmosphere via a carbon adsorption system

3.2.1.5. Internally Circulating Fluidized Bed Incineration (ICFB)

ICFB incinerators can be fired with any solid, liquid or gas fuel. CFCs and air are blown through the incinerator fluidized bed, and CFCs are broken down by the presence of methane and hydrogen in the reducing atmosphere of the incinerator. Calcium carbonate is also fed into the incinerator to adsorb the corrosive HCl and HF gases formed by the breakdown of the CFCs.

In 1995, a joint effort by Japan's National Institute of Materials & Chemicals Research and the incinerator supplier Ebara Corp. of Tokyo demonstrated CFC destruction in an internally circulating fluidized bed incinerator. The incinerator was modified by attachment of a special nozzle at the bottom of the incinerator to blow CFCs and air through the fluidized bed. Tests using a 30 MT/day incinerator at Ebara's Fujisawa factory have shown that burning with wood chips can destroy more than 99.9998% of CFCs. The main attraction of this approach is its relative simplicity.

3.2.1.6.Liquid Injection Incineration

The waste in burned directly in a combustor or injected into the flame zone of the incinerator chamber through atomizing nozzles. The heating value of the waste is the primary determining factor for the location of the injection point.

Liquid injection incinerators are usually refractory-lined chambers (horizontal or vertical flow, either up or down), generally cylindrical in cross section, and equipped with a primary burner (waste and/or auxiliary fuel fired). Often secondary combustors or injection nozzles are required where low heating value materials such as dilute aqueous-organic waste are to be incinerated.

Liquid injection incinerators operate at temperature levels ranging between 1,000 °C (1,832 °F) and 1,700 °C (3,092 °F). The residence time for the combustion of products in the incinerator may vary from milliseconds to as much as 2.5 seconds. An atomizing nozzle in the burner or the incinerator is a critical part of the system because it converts the liquid waste into fine droplets.

The viscosity of the waste determines whether good atomization of a liquid is possible. Two-fluid atomizers, using compressed air or steam as an atomizing fluid, are capable of atomizing liquid with viscosities up to 70 centistokes (2.7 ft^2/hr).

The physical, chemical, and thermodynamic properties of the waste must be considered in the basic design of any incinerator system. Any commercial facility receiving hazardous waste requires a complete analytical laboratory on site. Most commercial operators require a sample of the waste before they will provide a treatment cost to the generator.

3.2.1.7. Municipal Solid Waste Incineration (MSWI)

MSWI typically employs moving grates for destruction of solid materials including foams containing ODS. Waste is dumped into a refuse pit and then transferred mechanically to a bin that feeds the waste in a controlled manner onto the moving grate. Combustion air is drawn through the refuse pit to control odor, preheated and introduced into the combustion zone through the moving grate. Hot gases from the combustion of the waste are typically cooled in a waste heat boiler and then cleaned either by a spray drier and bag house or by a dry electrostatic precipitator. In order to obtain low dioxin and furan emissions, advanced air pollution control systems use spray-dry scrubbers with activated carbon injection, followed by bag houses. The MSWI is generally kept under negative pressure by a fan that blows the cooled and cleaned flue gas up a stack. Ash from the lower end of the moving grate is discharged to a quench pit and conveyed to discharge for destruction. The combustors may be refractory lined or, as in many newer systems, the walls may be water-cooled to recover additional heat.

The DRE for a municipal solid waste incinerator operating at 850-950 °C is reported as exceeding 99.99%. The total feed was 10,000 kg/h of wet municipal solid waste while the CFC feed rate was 6.5 to 19.5 kg/h. The flue gas volume was estimated at 60,000 m^3/h.

CFC-containing rigid polyurethane foam has been destroyed in Germany together with solid municipal waste in a full-scale roller grate incinerator with a capacity of 10 t/day. Municipal solid waste incinerators are common in Europe and Japan and are used less commonly in North America.

3.2.1.8.Reactor Cracking

The process is used for thermal decomposition of CFC/H-CFC/FC-mixtures in a hydrogen/oxygen flame. Gas hydrofluoric acid of about 55% concentration and hydrochloric acid of about 31% concentration are obtained downstream from the reaction.

The reactor consists of a reaction chamber connected with a special cooler. The cylindrical reaction chamber is protected by a water-jacketed steel shell. A special burner for hydrogen, oxygen and CFC is flanged to the upper end of the reaction chamber. The material of the reaction chamber is graphite and it has to be protected against overheating. The cooling system used is jacket cooling. The cooler flanged directly to the reaction chamber is also made of acid proof graphite and likewise water-jacketed.

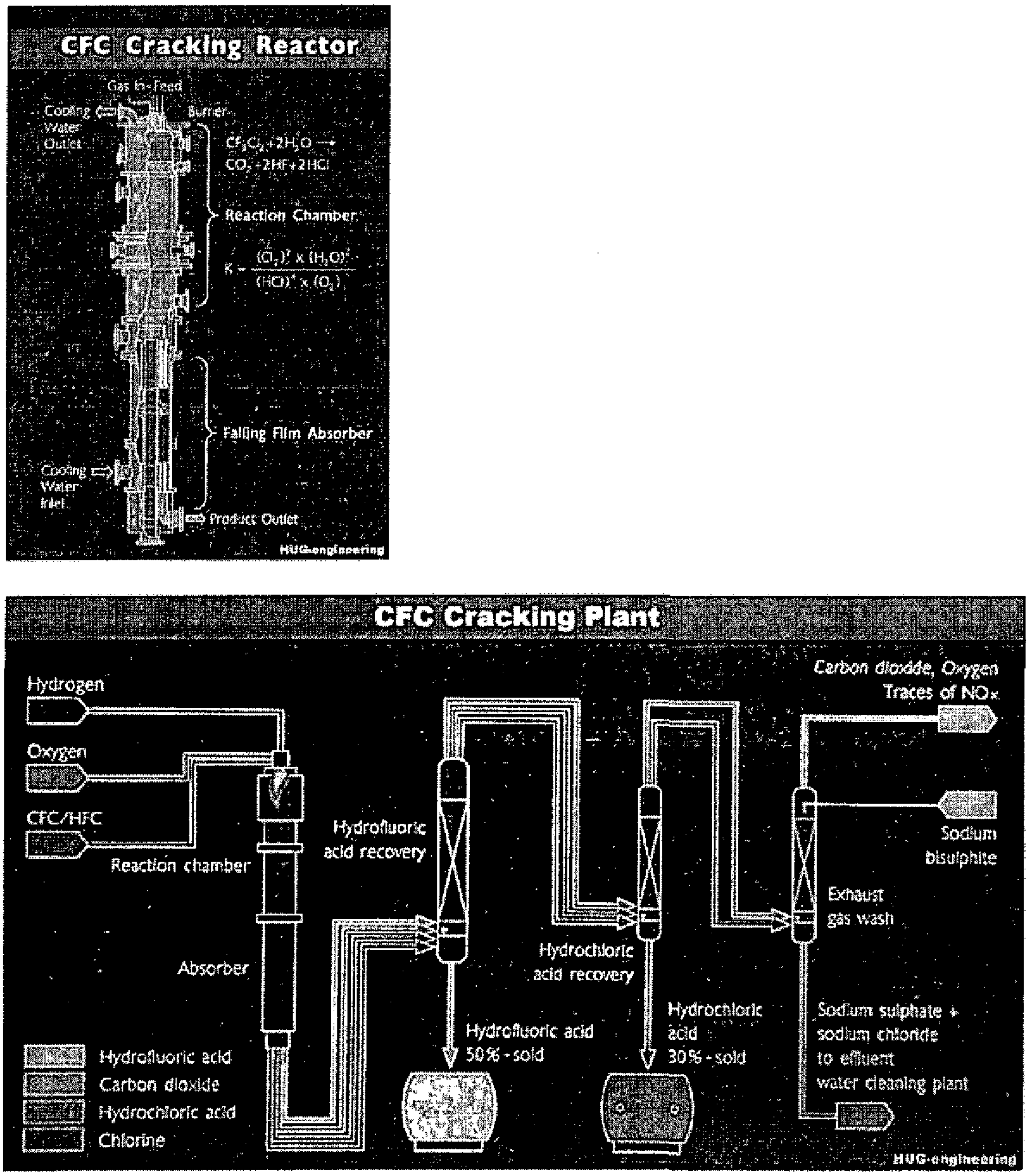
The reaction that takes place is as follows:

$$CCl_2F_2 + O_2 + 2H_2 \rightarrow CO_2 + 2HF + 2HCl$$

The CFCs are decomposed into hydrogen fluoride, hydrogen chloride, carbon dioxide, water and some chlorine. The decomposition products are cooled in the cooler to extend that aqueous hydrofluoric acid of about 55% concentration and the non condensable gases can be withdrawn at the cooler outlet.

In the HF-Recovery-Unit, the hydrogen fluoride is separated from the non condensable gas mixture. Hydrofluoric acid is formed as technical grade quality. The purified gas is then led to the HCl absorption column to recover the hydrogen chloride as hydrochloric acid. This acid is cooled down and pumped to the storage tank.The gas coming from the HCl-absorption is treated in a waste gas scrubber. Any traces of acid are absorbed by water.

The formation of polychlorinated dioxins and furans is reliably prevented by the high cracking temperatures of over 2,000 °C and the subsequent rapid cooling of the decomposition products to about 40 °C. No solid wastes are produced.



Picture No. 3: Scheme of cracking reactor and cracking plant as a whole

http://www.hug-engineering.de/RC_CrackingPlant_01.htm
(http://www.hug-engineering.de/index.htm?DestructionTechniques_01.htm)

3.2.1.9. Rotary Kiln Incineration

The rotary kiln incineration system is commonly a two-stage operation, the first stage being the rotating kiln barrel, and a secondary combustion chamber for completion of the oxidation. The rotating kiln barrel is a refractory-lined cylinder installed at a slight slope to cause the solid material to tumble over itself and travel down the length of the barrel. Rotary kilns can be configured to accept liquid, solid, and sludge wastes. This feature is one of the reasons that rotary kilns have found such wide application in the commercial incineration field.

Combustion gases and volatilized organics from the kiln are then treated in a downstream secondary combustion chamber for complete oxidation. The kiln is typically operated at relatively high temperatures, 700 to 1,300 °C. Tumbling action in the kiln continually exposes fresh waste surface to the high temperature radiant heat from the burner and refractory walls and to the oxygen in the combustion air. Ash and noncombustibles are continuously discharged into an ash handling system. Seals are provided at both ends of the rotating kiln shell to minimize air in leakage.

Rotary kiln incinerators can be designed to operate either in a controlled air or excess air mode. In some large commercial incineration systems, 200 liter drums filled with waste can be fed into the rotary kiln. Design for injection of whole drums rotary kiln is a challenge mechanically and operationally. The operational challenge is maintaining good destruction conditions with the instantaneous input of energy from the volatilization and subsequent combustion of the wastes. Additionally, the drums could damage the refractory as they fall into the kiln. The US Department of Energy operates rotary kiln "mixed" waste incinerators at the Oak Ridge and Savannah River sites.

3.2.2. Plasma Technologies

Five types of plasma technologies are considered here, namely, alternating current plasma, argon plasma, inductively couples radio frequency plasma, microwave plasma and nitrogen plasma arc.

3.2.2.1. Alternating Current Plasma (AC Plasma)

Destruction systems incorporating their patented Plasmatron AC plasma are designed by Scientific Utilization International for the destruction of hazardous wastes. The AC plasma is produced directly with 60 Hz high voltage power but in other respects is similar to the inductively coupled RF plasma. The system is electrically and mechanically simple and is thus claimed to be very reliable. Also, the Plasmatron process can tolerate a wide variety of working gases, including air, and can tolerate oily gases. While some information is available describing the plasma generator and its associated equipment, no information was provided describing the destruction process, but one could envisage a process very similar to the PLASCON process.

DRE and emission of pollutants are expected to be similar to the inductively coupled radio frequency (ICRF) plasma process. The flue gas volume for a 50 kg/h destruction system is estimated at 20 Nm^3/h.

These plasmas have only recently been developed to the stage where they are being applied to hazardous or toxic waste destruction. It has not yet been commercially applied to the destruction of ODS but CFC was destroyed to non-detectable levels in a 500 kW demonstration unit. No cost information was provided but destruction costs are estimated to be comparable to those of the PLASCON process, that is, in the $US 3-5/kg range.

3.2.2.2. Argon Plasma Arc

An argon plasma arc is generated at 10,000 °C using a special 200 kW unit which was developed by Siddons Ramset. The plasma arc atomises the halons or CFC which are then mixed with steam from an electric boiler. The gas mixture is rapidly cooled by an internal primary cooling circuit using a cooling tower mounted off the skid. The cooled gas is then quenched using caustic soda, at a controlled pH, which creates a salt solution. The salt solution is circulated with the caustic quench solution and discharged to sewer in a controlled manner via an effluent tank. The quenched gas is then scrubbed and vented to atmosphere.

3.2.2.3. Inductively Coupled Radio Frequency Plasma

Gaseous CFC and steam are fed through the plasma torch where temperatures of 10,000 °C are achieved in a 185 kW ICRF torch. The gases enter directly into the destruction reactor maintained at about 2,000 °C for about 2 seconds. Subsequently, the gases are cooled and scrubbed with caustic solution to remove acid gases. It is also possible that the radio frequency (RF) approach may lead to increased on-stream time over that observed in the PLASCON process described above. The RF plasma also has a slower gas flow rate and a larger plasma flame that results in higher residence time.

The ICRF plasma process has demonstrated a DRE exceeding 99.99% while destroying CFC at a rate of 50-80 kg/h. The flue gas volume has been estimated at 20 Nm^3/h.

Based on these pilot plant results, a demonstration plant was constructed at Ichikawa City in the Chiba prefecture by a consortium of industrial concerns under the auspices of the Ministry of International Trade and Industry. This process has demonstrated high destruction efficiencies and very low PCDD/PCDF emissions on a commercial scale.

3.2.2.4. Microwave Plasma

This process feeds microwave energy at 2.45 GHz into a specially designed coaxial cavity to generate thermal plasma under atmospheric pressure. The coaxial design is claimed to promote plasma stability. Argon is used to initiate the plasma but otherwise the process requires no gas to sustain the plasma. A mixture of CFC with water vapour is fed to the plasma and is broken down at temperatures exceeding 6,000 °K into the dissociated state, after which HCl, HF, CO and CO_2 are formed. The acid gases are scrubbed in a tower with slaked lime slurry and then the process gas is combusted with air to convert the CO to CO_2.

The DRE for the microwave plasma process is reported to exceed 99.99% while destroying CFC-12 at a rate of 2 kg/h. The flue gas volume has been estimated at 32 Nm^3/h based on the process description and flue gas compositions reported.

The microwave plasma process was developed in Japan by Mitsubishi Heavy Industries, Ltd. The development of the process was started in 1997 by Mitsubishi Heavy Industries, Ltd. and launched in the market in 2000. The plasma approach was selected to provide a very compact design that could be applied at the many sites where CFC was recovered. The CFC feed rate of 2 kg/h was determined.

3.2.2.5. Nitrogen Plasma Arc

Nitrogen plasma-arc technology for destroying solid wastes is in its infancy. In theory, a plasma-arc system consists of a nitrogen plasma-arc torch in a primary chamber, a secondary combustion chamber, exhaust-gas treatment systems, and a waste-handling system. In the primary chamber, high temperatures (2,000 °F) from "an electrical arc" produces highly ionized gases or plasma that causes instant breakdown (pyrolysis) of the waste. The organic waste is volatilized and the inorganic waste is melted into a slag maintained at 3,000 °F. In the secondary chamber, combustion air and fuel oil are added to maintain a temperature of 2,200 °F and ensure complete combustion. The exhaust gases from the secondary chamber are mixed with ambient air and cooled to 570 °F prior to exhaust gas scrubbing. The exhaust-gas system cools and cleans the exhaust gas before releasing it to the atmosphere at a temperature of about 140 °F.

3.2.3. Non-Incineration Technologies

Eight types of non-incineration technologies can be employed for the destruction of ODS are illustrated below; base catalysed dechlorination, gas phase catalytic dehalogenation, gas phase chemical redution, liquid phase chemical conversion, super heated steam reactor, UV Photolysis, vitrification

3.2.3.1. Base Catalysed Dechlorination

Chlorinated organic compounds can be detoxified by reaction with sodium or potassium hydroxide in an oil carrier liquid at temperatures between 300 °C and 350 °C. In the presence of an organic accelerator, which is a source for free radicals in the system, the de-chlorination reaction proceeds to a very high level of completion, within a few hours, leaving a residue that is a suspension of carbon, sodium chloride and unspent sodium hydroxide in the carrier oil. This reaction product usually requires no further treatment.

This process has been patented worldwide by the BCD Group in the USA. Enterra Pty Ltd is a licensee of the BCD Group. Enterra Pty Ltd and the BCD Group are jointly promoting this technology as the BCD process.

The BCD process has the advantage of being able to treat compounds with up to 50% of chlorine (typical concentrations are usually 25-30% chlorine).

The products of the BCD reaction are carbon, sodium chloride (common salt), potassium chloride (where potassium hydroxide is used) and unspent sodium hydroxide (caustic soda) suspended in the oil carrier liquid.

The raw materials used for the Sydney Olympic project are sodium hydroxide, accelerator (a vegetable oil, fatty acid or alcohol) carrier oil and the organo-chlorine compound (i.e. waste), which can be in solid form or often in solution or a slurry in the carrier oil. The reaction process is conducted on-site in a 3 m^3 carbon steel, externally electrically heated vessel equipped with appropriate condensing and vapours treatment systems. The reactor is pressurised and all oxygen is excluded by the introduction of nitrogen gas utilised as a safety blanket.

Reaction mechanism

The chemical reaction that was thought to occur is broadly represented in the following equation. It can be interpreted as a hydro-dechlorination reaction where the chlorine atoms on the aromatic nucleus are replaced by hydrogen atoms. Detailed chemical reaction mechanism can be seen in below.

$$\mathbf{R\text{-}(Cl)_X} \quad + \quad \mathbf{R^1} \quad \xrightarrow[\text{Catalyst}]{\text{NaOH}} \quad \mathbf{R - H} \quad + \ x\,\mathbf{NaCl} \ + \ \mathbf{R^{11}}$$

Where:

$\mathbf{R\text{-}(Cl)_X}$: organo-chlorine compound;
$\mathbf{R^1}$: hydrogen donor (oil);
$\mathbf{R - H}$: hydrogenated organo-chlorine compound, and
$\mathbf{R^{11}}$: dehydrogenated donor.

Whilst the above reaction does occur to some extent, particularly when low concentrations of organo-chlorine compounds are treated, the main product that is observed is carbon. This cannot be explained by the simple hydro-dechlorination reaction mechanism shown above.

$$\mathbf{R\text{-}(Cl)_X} \quad + \quad \mathbf{R^1} \quad \xrightarrow[\text{Catalyst}]{\text{NaOH}} \quad \mathbf{C} \quad + \ x\,\mathbf{NaCl} \ + \ \mathbf{R^{11}}$$

Intermediate products that arise from the sequential dechlorination of an aromatic nucleus are not observed to any significant degree. Thus, for hexachlorobenzene, which contains six chlorine atoms, pentachloro, tetrachloro or other lower chloro substituted benzenes are not detected - the main reaction product is carbon.

The process can be sub-divided in six unit operations:

- Waste or feed *preparation*;
- Caustic preparation;
- Hot oil pre-heating and transfer;
- Caustic and waste injection;
- Reaction, sampling and testing; and
- Treated product transfer.

Disadvantages of this process are the fact that this process can only treat (directly) fluids and also suffers from being a batch process, not a continuous one. This can be partly overcome by erecting several parallel processes, but that might influence the cost per kg treated waste. Furthermore, the process demands the heating up and successive cooling down of bearing oil for the process to run, which is demanding much energy. Finally, the process produces a byproduct that needs conventional incineration, and because of the high load of chloride herein there is an intrinsic risk of dioxin production from this.

Some of the advantages of this method include the destruction of toxic material comprising up to 100% pure chlorinated hydrocarbons in 30 to 90 minutes. This is the big advantage of the BCD - technology compared to incineration technology that can only treat material containing from 2 to 10% chlorine. Furthermore, the gas production from the process is low and seems to be very low in dioxin emission.

The plant is a mobile structure and re-location costs only count for 10% of the initial capital costs. The pricing for re-location is assessed to be higher and follows in line with e.g. GPCR and Semi mobile incineration units (up to 40-50% of investment capital costs).

3.2.3.2. Gas Phase Catalytic Dehalogenation

Hitachi Ltd. of Tokyo, Japan has developed a process in which CFC are destroyed over a proprietary metal oxide catalyst at 400 °C at atmospheric pressure. The HCl and HF produced are absorbed in a lime solution.

The DRE reported for disposing of CFC-12 exceeded 99.99%. A flue gas volume of 15 Nm^3/h was estimated for a system destroying 10 kg/h.

The Hitachi process has been demonstrated to successfully destroy CFC and a similar process has been commercialized for perfluorocarbon decomposition as well as PCB destruction. Commercial destruction of PFC has demonstrated a destruction efficiency exceeding 99%. Hitachi estimates operating costs of about $US 2-3/kg CFC-12 but when depreciation and other fixed costs are applied the destruction cost is more likely to be in the range $US 5-7/kg. Capital costs were estimated at about $US 250,000 for a 1 kg/h system and $US 1 million for a 10 kg/h system.

3.2.3.3. Gas Phase Chemical Reduction (GPCR)

The GPCR technology involves the gas-phase chemical reduction of organic compounds by hydrogen at temperatures of 850 to 900 °C. In contrast to conventional incineration technologies, the GPCR technology uses hydrogen to break down the bonds that hold the molecule together. The technology consists of three main components: the front end system, which heats contaminated solids, liquids or gases, rendering the contaminants into a gaseous form; the GPCR reactor, in which the gaseous contaminants are heated electrically to the reaction temperature and then broken down in less than a second by hydrogen into methane and acid; and the gas scrubbing system, which removes acid from the methane-rich gas product gas. Halogenated hydrocarbons such as CFC are chemically reduced to methane, hydrogen chloride (HCl) and hydrogen fluoride. The methane is recovered and reused as a fuel for the system components, while the acids are neutralized with caustic or lime.

ELI Eco Logic International Inc. (Eco Logic) of Rockwood, Ontario developed and commercialized the ECO LOGIC Gas-Phase Chemical Reduction process. Eco Logic applied for a patent for this core technology in 1986. The proprietary process is a non-incineration technology suitable for destroying organic wastes in all matrices including soil, sediment, sludge, high strength oils, watery wastes and bulk solids such as electrical equipment. The company has destroyed PCB waste and chlorobenzene waste on a commercial scale to DRE exceeding 99.9999%. Eco Logic has also destroyed PCB, DDT and hexachlorobenzene waste on a commercial scale to DRE exceeding 99.9999%. Furthermore, the company has considerable laboratory and field data on many other hazardous wastes including chemical warfare agents. Eco Logic supplies fixed systems and provide treatment services with transportable systems. The GPCR process is reported to destroy ODS at a cost in the range of $US 3-5//kg.

The DRE for a GPCR process designed to destroy 25 kg/h of CFC would exceed 99.9999%. The reported volume of flue gas is 156 Nm^3/h.

3.2.3.4. Liquid Phase Chemical Conversion

This technology uses a liquid-phase chemical conversion process operating at between 80-120°C, where ODS is reacted with a blend of potassium hydroxide and polyethylene glycol. Based on lab-scale demonstrations, the destruction efficiency is greater than 99.7% for CFCs and halons. It has been tested on ODS in pilot-scale tests and is used commercially for PCB wastes. The process is claimed to require and low capital investment and to be almost emission free. No dioxins/furans are generated in this relatively low-temperature process.

This mobile system technology was developed by Ontario Hydro Technologies to destroy a variety of wastes. Two mobile units are currently in operation for PCB destruction. Although commercial destruction of ODS is not currently available using this process. Costs are estimated to be less expensive than incineration for ODS, based on extrapolation from experience with PCB waste disposal.

3.2.3.5. Solvated Electron Decomposition

The process is a batch process involving two simple vessels; one a heated reaction vessel and the other refrigerated ammonia recycle vessel. The ODS compounds are decomposed in the reaction vessel with liquid ammonia and metallic sodium. The process operates at atmospheric pressure. It is expected that no dioxins and furans would be produced by this process since it does not involve oxidation and operates at relatively low temperatures. No atmospheric emissions result from the decomposition of the original ODS material. Only non-toxic waste products are formed: sodium chloride, sodium fluoride, biodegradable organic compounds, and water. Methane and ethane are also produced as by-products. Metallic sodium is consumed in the process and is the major component of operating cost. About 95-98% of the ammonia is recycled and hence does not contribute much to operating cost. The process was demonstrated on a pilot scale to destroy carbon tetrachloride, several CFC, HFC, refrigerant blends and halons at greater than 99.99% efficiency.

Estimated data was provided for a 50 kg/h destruction system. The flue gas volume has been estimated at 80 Nm^3/h based on combustion of the methane/ethane product gas with air.

Commodore Advanced Sciences, Inc. of Albuquerque, New Mexico, developed a process for the destruction of ODS in the early 1990s based on solvated electron solutions formed by dissolving metallic sodium in ammonia. A US patent for the process was issued in 1995. It has been applied successfully to Polychlorinated Biphenyls (PCB) destruction and is currently being applied to the destruction of chemical warfare agents. Finally, operating cost is heavily dependent on the cost of metallic sodium and is reported to exceed $US 7/kg of CFC.

3.2.3.6. Super Heated Steam Reactor

In the super-heated steam reactor process, decomposition of ODS takes place in the gaseous phase at elevated temperatures. CFC, steam, and air are first mixed and then preheated to around 500 °C, before being fed into a tubular-type reactor whose wall is electrically heated at 850-1,000 °C. The decomposition of CFC, mainly by hydration, gives HF, HCl, and CO_2. The exhaust gas is led to a scrubber cooler where the exhaust is quenched by washing with a $Ca(OH)_2$ solution and the acids are neutralized. As a result of the quenching of exhaust, the concentrations of PCDD/PCDF are minimized.

The process is reported to have a DRE exceeding 99.99% while destroying HCFC-22 at a rate of 10.1 kg/h.

The super-heated steam reactor was developed by Ohei Development Industries Co. Ltd, and the patent has been registered (Japan Patent No. 3219686 and No. 3219706). The reactor destroys mainly CFC and HCFC, but has been recently used to decompose HFC. The cost for the destruction slightly varies depending on disposal of neutralized residue, but it is claimed to be in the range of $US 1.1- 1.4/kg-CFC. Destruction costs on all-in basis are more likely to be in the range of $US 2.0-3.0/kg-CFC. The capital cost for the reactor having a capacity of 10 kg/h is about $US 300,000.

(UNEP Report of the Technology and Economic Assessment Panel, Volume 3B, Report on the Task Force on Destruction Technologies, 2002)

3.2.3.7. UV Photolysis

UV-photolysis is the process by which chemical bonds of the contaminants are broken by the energy associated with UV light. When light is incident on an object, the photons may be reflected, transmitted, or absorbed. When UV photons enter a medium (water, for example), they are both transmitted and absorbed by the medium and its constituents (dissolved species including organic and inorganic substances). Photons that are absorbed may initiate a photolysis reaction. In other words, the treatment of a contaminant starts with energy (in the form of photons from a UV light source) being absorbed by a contaminant molecule. A contaminant molecule will undergo the photolysis reaction if the contaminant molecules in water are capable of absorbing UV photons or if the energy holding the chemical bonds in the molecule together is less than the energy of the UV photons absorbed.

In other words, the treatment of a contaminant starts with energy (in the form of photons from a UV light source) being absorbed by a contaminant molecule.

3.2.3.8. Vitrification

A high-temperature vitrification process can convert hazardous waste into a nonhazardous glass/ceramic matrix, which can be used as a commercial product. Organic components in the waste stream are gasified by the system and utilized as an auxiliary energy source. Inorganic components of the waste stream are incorporated into the glass/ceramic matrix. The glass/ceramic matrix is extremely stable and passes typical regulatory leachate tests.

The vitrification system consists of four sections: (1) feed preparation, (2) preheater, (3) vitrifier/converter, and (4) air pollution control/off gas treatment system. The feed preparation system consists of a counter-current rotary drum dryer, batch surge bin to maintain uniform waste feed and allow for the addition of glass formers, and auger feeders to convey the waste to the preheater. The preheater is an indirect gas-fired auger preheater that heats the waste to over 1,100 °F. This temperature effectively gasifies the organic contaminants contained in the waste stream to allow them to be used as fuel. The vitrifier/converter heats the inorganic waste to 2,700 °F in a well-mixed chamber. Oxygen enriched natural gas is the primary energy source for the vitrifier/converter. The molten glass/ceramic exits the vitrifier through a discharge system that allows the molten material to be shaped into useful products. Flue gas from the vitrifier flows through a high temperature heat exchanger. The cooled flue gases pass through a dry baghouse for particulate capture, a wet acid/gas packed tower venturi scrubber, an ammonia scrubber to remove NO_x, and an activated carbon filter to remove any trace organics. Dust from the baghouse is recycled back into the vitrification process.

Benefits of vitrification include its ability to treat a variety of metal contaminated wastes while achieving regulatory leachate and land disposal limit requirements, its ability to process mixed organic/inorganic waste streams in solid and/or sludge forms on a batch or continuous basis. The system is also compact and transportable. Furthermore it uses the energy content of the organic waste contaminants to minimize operating costs and converts hazardous wastes into non-hazardous forms, which can be used to manufacture commercial products and provides a permanent treatment solution.

Capital costs, including installation, range from $2,000,000 for a solid/dust system to $2,500,000 for a sludge system. Both systems process 500-1,000 kilograms per hour of waste material. Operating costs of the vitrification process range from $100 to $420 per ton.

3.2.4. Biodegradation Technology

History of microbial decomposition of ODS was described by Oremland. Lovley and Woodward who demonstrated the bacterial removal of near-atmospheric concentrations of CFC11 and CFC12 during incubation of anoxic soils, sediments, and bacterial cultures. However, the literature suggests that this method is a perspective method for destruction of minor amount of CFC compounds. Degradation by microorganisms is a kinetically exacting process. The reaction itself is realized at low concentrations of these compounds. That is the reason why optimal conditions for realization of such a processes are needed. Criteria have to be developed for:

- Reactor volume
- Process temperature
- Microorganisms used
- Process duration
- Aeration of reaction mixture by oxygen or by air
- Nutrient for microorganisms
- Physical-chemical properties of chemical substances for degradation
- Methods of process controlling
- Regenerativity of microorganisms
- Way of disposal of degraded products

As demonstrated above, biological systems must satisfy a number of variables required for a successful bioprocess. Some of them are technically simple however others can be more difficult for direct application at the commercial scale.

As described earlier, a biological degradation of ODS is among emerging technologies to decompose ODS using microorganisms. These methods are not commercially used for ODS directly but for decontamination of environmental media. Microorganisms are used just for bioremediation of soils or polluted waters. However, this method could be a new contribution on the field of destruction technologies. Further steps should be done in this area of research and progress to find practical applications. In this connection, two types of reactors could be further interest:

- *"Fermentationer"*
  The fermentationer utilizes the principle that if microorganisms are in water phase and substances for biodegradation are anchored in porous material (SiO_2, zeolites, limewashes, activated carbon and the like) – the substances will be adsorbed. Process will take place on the boundary of phases and the metabolites will be in a dilution. For better contact of phases an emulsifiers can be added.
- *"Mediator"*
  This process is opposite one to the previous. Microorganisms will anchor – react with solid phase and degraded substance will be released on the medium or it will be saturated in water.
  In this case process is at work on contact of phases. After adequate quantity of layers of microorganisms, these will get in water phase. A combined process will be running.

Temperature for biodegradation ranges from 20 to 40 °C by type of microorganisms and pH ranges from 5.2 to 7.5.

Nutrient for microorganisms consists of donors of nitrogen, carbon and phosphorus – elements essential for life of microorganisms. For example: sucrose in the form of peeled molasses, methanol, nitrates, and phosphates. Basically it can be said that this process is non-problematic. Problem of regulation of optimal concentration of microorganisms can be solved by nitrate supply or acutely by addition of H_2O_2.

Volume for mobile unit could be approximately 500 l, for stationary one 1,500 l.

Duration of the process is different for individual type of microorganism and for type of chemical substance under the process. However, it should not exceed few weeks. Here we have to consider an amount of chemical compound and also the concentration.

It is possible to use special microorganisms (based on to the literature data) or activated sludge. Combination of both is also possible.

Degraded products – probably HF- are needed to be removed from the reaction environment. They can be simply neutralized by buffering in reaction medium. Another way is neutralization with alkali medium or by addition of fine-grained calcite. This would be removed from medium after filtration and process could continue in a new cycle.

Analytical monitoring should be focused on the conditions in bioreactor: temperature, pH, nutrients, oxygen, volume of products, and volume of decomposed and undecomposed substances.

There is possible biodegradation in some types of substances, in some there is not. These types of chemicals are identified in the literature. But during the research and development of new – also genetically modified –microorganisms it is possible to expand this group of chemicals in the future.

For successful decomposition process it is necessary to choose a proper chemical compound for degradation and at the process conditions certain compromise should be accepted to optimize it for separate substance and microorganism.

3.3. Applications

Special preconditions are required for technologies, which are selected to destroy halons and foams containing ODS.

Destruction technologies for foams

- municipal solid waste incinerators
- rotary kiln incinerator

Destruction technologies for halons and HCFC

- CFC, HCFC and halons: argon plasma arc
- CFC and HCFC: - nitrogen plasma arc, microwave plasma, gas phase catalytic dehalogenation and super-heated steam reactor

4. Legislation

The most significant provisions of the Montreal amendment to the Montreal Protocol adopted by the ninth meeting of the Parties to the Montreal Protocol in 1997 concerns trade with third countries, including bans and restrictions on imports and exports of ODS In this particular document, regulations on the ODS destruction in selected countries are analyzed.

ODS regulations vary noticeably from country to country, both in content and structure. They depend on the legal and administrative structure, available general legislation, the size and type of ODS consumption and on hand information on alternatives at the time when the regulations were enacted.

The progress report (April 2002) of the TFDT under TEAP made a review of the legal instruments addressing ODS in individual countries.

The United States for example requires each producer of a Group I controlled substance (primarily CFC) to report the quantity of controlled substances used in processes that resulted in their transformation or destruction, and the quantity sold for use in processes that resulted in their destruction or transformation. The Resource Conservation and Recovery Act of US lists 85 process wastes and approximately 400 chemicals as hazardous wastes, including CFC and HCFC, which are listed as hazardous wastes from non-specific sources, spent halogenated solvent, and commercial chemical products (e.g., CFC-11 and CFC-12). In 1996, EPA passed the "MACT" rule (maximum achievable control technology) to upgrade the emission standards for dioxins (PCDD), furans (PCDF), mercury, cadmium, lead, particulate matter, hydrochloric acid, chlorine, hydrocarbons, carbon monoxide, and several low-volatile metals produced from hazardous waste combustors. Specifically, this rule affected incinerators, cement kilns, and lightweight aggregate kilns.

The European Union, alternatively, has adopted regulations to reduce emissions of ODS. The new regulation (2037/2000) covers the use, reuse, and disposal requirements for ODS, including virgin and recycled CFC, HCFC, refrigerant blends, halons, 1,1,1-trichloroethane, and carbon tetrachloride. In addition, the regulation mandates the recovery and destruction of blowing agent from domestic and commercial refrigerators. In the EU, it is possible that some waste ODS may be classified as "special waste" and subject to more stringent disposal arrangements than most other wastes. Local Environmental Agencies are responsible for regulating these "special wastes."

Swedish regulations require importers and distributors of refrigerants to take back the refrigerant that they supply for recycling or destruction purposes, at no charge. Industry is responsible for reclamation of recovered refrigerants. To cover these costs, the importers/distributors include a fee in the price of refrigerant sold. Recovered refrigerants that cannot be reused due to excessive contamination must be sent for destruction. Used refrigerants are classified as hazardous waste and must be destroyed according to the Swedish Waste Ordinance. A permit from the Swedish EPA is required for export of recovered/used refrigerants, and as of 1 January 1997, export permits are only issued for the purpose of destruction abroad. The recovery of foam blowing agents from domestic refrigerators has been required since the middle 1990s.

In Switzerland, ODS is classified as a hazardous waste and can only be incinerated in high performance incinerators. Although there is no standard set for Destruction and Removal Efficiency (DRE), the high emission standards guarantee that DRE for incineration is >99.99%.

Australia, New South Wales and Australian Capital Territory have regulations that address destruction of ODS. In practice, all destruction of ODS in Australia occurs at the PLASCON facility at the Australian National Halon Bank in Melbourne, Victoria.

Since 1998, New Zealand has also collected and sent ODS to the Australian National Halon Bank for recycling and destruction. There is a 25% government subsidy for collection, transport, and shipping costs of Halon-1211 sent to Australia for destruction. Since 1995, the refrigeration industry has operated a levy scheme, based on national sales of HCFC, to fund the transport and destruction of "end of life" CFC and HCFC. All fees collected under the levy scheme are for environmentally safe destruction. Although the government of New Zealand strongly endorses the levy scheme, there is no direct government involvement in its operation. To date, over 18,000 kilograms have been exported to Australia for destruction.

The Japanese government has issued manuals, to promote safe and environmentally sound management practices for more than 30 ODS destruction facilities in the country. The manual includes information on how to safely manage six different types of destruction technologies (i.e., waste incineration, manufacturing plant, incineration in water, plasma, catalytic processes, and thermal vaporization). The manual also prescribes the targets for destruction efficiency (99.99%) and emission standards.

Brazilian Government regulations prohibit the destruction of chlorinated compounds in cement kilns. Other than this regulation, there are no Brazilian regulations covering the destruction of ODS. In order to be issued an operation license, destruction facilities must conduct a trial burn to demonstrate that the incinerator meets certain criteria and emission standards.

5. Case Studies

Taking into account the complexity of the problem of ODS destruction and in order to come up with good recommendation, it is necessary to employ experience of countries that reached an adequate technical-logistic level of development in the environmentally sound management of ODS.

Case studies of countries that can service as include Switzerland with its capacity to destroy ODS with help of high-tech incinerator and Australia providing capacities of the National Halon Bank – regional technical center for ODS destruction – not only on the national level but to the whole Asia-Pacific region.

5.1. Switzerland

The Regional Hazardous Waste Incinerator operated by Valorec Services AG (RSMVA) runs a hazardous waste incineration plant in Basel (Switzerland) which is a part of the *Veolia Environnement* group with headquarters in Paris, France. The RSMVA started the commercial incineration of hazardous waste in September 1995.

The RSMVA is a rotary kiln incinerator with secondary combustion chamber and heat recovery, a 6-stage wet gas scrubber and a DeNOx selective catalytic reduction system. All wastewater undergoes physicochemical processing in an appropriate wastewater treatment plant.

Among different types of waste, the facility has the capability to incinerate gases and liquefied gases. Valorec is a major player in the incineration of CFC gases and halons on the Swiss market.

Over the last years Valorec was able to dispose an annual average amount of 100 tons of gases, consisting of CFC (mainly R11 and R12) and halons. However their treatment capacity could be increased up to 500 tons/year. Beside the incineration of liquefied gases delivered in pressurized cylinder (from 1 m^3 to 20 m^3), Valorec also developed an expertise in the treatment of different gases conditioned in gas bottles (up to 50 L).

5.2. Australia

The Australian Halon Management Strategy (AHMS) manages Australia's surplus halon stocks; ensuring supplies of recycled halons continue to be available for essential uses. The Australian National Halon Bank facility in Melbourne safely stores, reclaims and destroys halons and CFCs. The facility in Melbourne has the expertise to provide a range of Ozone Depleting Substances management services to international customers.

The Australian Department of the Environment and Heritage will also develop the National Halon Bank as an Asia-Pacific regional environmental facility to assist Australia and other countries to phase-out their surplus halon stocks while ensuring stocks are maintained to meet their own essential needs.

6. Proposal for Further Steps

There is a wide variety of technologies that fulfills the criteria defined by the Montreal Protocol for the destruction of ODS. Environmental criteria of concern relate mainly to the DE, energy consumption and the emissions. These criteria are therefore quite straightforward and easy to evaluate. However, in order to define economically appropriate technologies for ODS destruction, specific conditions of diverse countries and the amount of chemicals to be destroyed have to taken into account. Both, investment costs and operational costs should be considered as well.

Based on available data, destruction costs are lowest in plasma technologies and the emission levels are relatively low. However, these technologies require a high power consumption.

Non-incineration technologies, on the other side, have low emission rates but their economical feasibility depends on the specific type of ODS and technology to be applied. This is due to the fact that these technologies are chemical reactions specific.

A low energy consumption is required for incineration technologies, yet incineration produces more emissions. The high investment costs pose difficulties for many developing countries.

When choosing a technology for the destruction of ODS, common selection requirements can be applied. Such requirements include;

- low energy consumption
- low emission rates
- applicability for wide variety of ODS wastes
- mobility of destruction unit
- commerciality
- high destruction efficiency
- low cost

Following the information presented in this summary paper, it can be concluded that there is a need to:

- Prepare a comparative study for commercially available technologies taking into account state of the art technologies;
- Develop a Guidance document for disposal of ODS with aim to advice countries based on the specific needs and conditions;
- Give specific attention to the treatment of chemicals based on national vs. regional needs exploring synergies with other environmental conventions
- Investigate the applicability of biological methods for mobile units to address relatively small amounts of ODS at the local level.

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Annexes

Annex I – *Decisions of the Meetings of the Parties to the Montreal Protocol on Destruction*

1) Decision I/12F: Clarification of terms and definitions: Destruction

The *First Meeting of the Parties* decided in *Dec. I/12F* with regard to destruction:

(a) to agree to the following clarification of the definition of Article 1, paragraph 5 of the Protocol: "a destruction process is one which, when applied to controlled substances, results in the permanent transformation, or decomposition of all or a significant portion of such substances";

(b) to request the Panel for Technical Assessment to address this subject for the Parties to return to it at its second and subsequent meetings with a view to determining whether it would be necessary to have a Standing Technical Committee to review and recommend for approval by the Parties methods for transformation or decomposition and to determine the amount of controlled substances that are transformed or decomposed by each method.

2) Decision II/11: Destruction technologies

The *Second Meeting of the Parties* decided in *Dec. II/11* with regard to destruction technologies to establish an *Ad Hoc* Technical Advisory Committee on Destruction Technologies and to appoint its Chairman, who shall appoint in consultation with the Secretariat up to nine other members on the basis of nomination by Parties. The members shall be experts on destruction technologies and selected with due reference to equitable geographical distribution. The Committee shall analyze destruction technologies and assess their efficiency and environmental acceptability and develop approval criteria and measurements. The Committee shall report regularly to meetings of the Parties.

3) Decision III/10: Destruction technologies

The *Third Meeting of the Parties* decided in *Dec. III/10* to note the constitution of the *Ad Hoc* Technical Advisory Committee on Destruction Technologies, established by the Second Meeting of the Parties, and to request the Committee to submit a report to the Secretariat for presentation to the Fourth Meeting of the Parties, in 1992 at least four months before the date set for that meeting; Section 2.3 Decisions of the Meetings of the Parties to the Montreal Protocol (Article 1) 98.

4) Decision IV/11: Destruction technologies

The *Fourth Meeting of the Parties* decided in *Dec. IV/11:*

1. To note the report of the Ad Hoc Technical Advisory Committee on Destruction Technologies and, in particular, the recommendations contained therein;

2. To approve, for the purposes of paragraph 5 of Article 1 of the Protocol, those destruction technologies that are listed in Annex VI to the report on the work of the Fourth Meeting of the Parties which are operated in accordance with the suggested minimum standards identified in Annex VII to the report of the Fourth Meeting of the Parties unless similar standards currently exist domestically;

3. To call on each Party that operates, or plans to operate, facilities for the destruction of ozone-depleting substances:

(a) To ensure that its destruction facilities are operated in accordance with the Code of Good Housekeeping Procedures set out in section 5.5 of the report of the Ad Hoc Technical Advisory Committee on Destruction Technologies, unless similar procedures currently exist domestically; and

(b) For the purposes of paragraph 5 of Article 1 of the Protocol, to provide each year, in its report under Article 7 of the Protocol, statistical data on the actual quantities of ozone-depleting substances it has destroyed, calculated on the basis of the destruction efficiency of the facility employed;

4. To clarify that the definition of destruction efficiency relates to the input and output of the destruction process itself, not to the destruction facility as a whole;

5. To request the Technology and Economic Assessment Panel, drawing on expertise as necessary:

(a) To reassess ozone-depleting substances destruction capacities;

(b) To evaluate emerging technology submissions;

(c) To prepare recommendations for consideration by the Parties to the Montreal Protocol at their annual Meeting;

(d) To examine means to increase the number of such destruction facilities and making available the utilization to developing countries which do not own or are unable to operate such facilities;

6. To list in Annex VI to the report on the work of the Fourth Meeting of the Parties approved destruction technologies;

7. To facilitate access and transfer of approved destruction technologies in accordance with Article 10 of the Protocol, together with provision for financial support under Article 10 of the Protocol for Parties operating under paragraph 1 of Article 5;

5) Decision V/26: Destruction Technologies

The *Fifth Meeting of the Parties* decided in *Dec. V/26,* further to decision IV/11 on destruction technologies:

(a) That there shall be added to the list of approved destruction technologies, which was set out in Annex VI to the report of the work of the Fourth Meeting of the Parties, the following technology:

- Municipal solid waste incinerators (for foams containing ozone-depleting substances);

(b) To specify that pilot-scale as well as demonstration-scale destruction technologies should be operated in accordance with the suggested minimum standards identified in Annex VII to the report of the Fourth Meeting of the Parties unless similar standards currently exist domestically;

6) Decision VII/35: Destruction technology

The *Seventh Meeting of the Parties* decided in *Dec. VII/35:*

1. To note that the Technology and Economic Assessment Panel examined the results of testing and verified that the "radio frequency plasma destruction" technology of Japan meets the suggested minimum emission standards that were approved by the Parties at their Fourth Meeting for destruction technologies;

2. To approve, for the purposes of paragraph 5 of Article 1 of the Protocol, the radio frequency plasma destruction technology and to add it to the list of destruction technologies already approved by the Parties;

7) Decision XII/8: Disposal of controlled substances

The *Twelfth Meeting of the Parties* decided in *Dec. XII/8:*

Noting decisions II/11, III/10, IV/11, V/26 and VII/35 on destruction technologies and the previous work of the Ad Hoc Technical Advisory Committee on Destruction Technologies;

Also noting the innovations that have taken place in the field of destruction technologies since the last report of Advisory Committee;

Recognizing that the management of contaminated and surplus ozone-depleting substances would benefit from further information on destruction technologies and an evaluation of disposal options;

1. To request the Technology and Economic Assessment Panel to establish a task force on destruction technologies;

2. That the task force on destruction technologies shall:

(a) Report to the Parties at their Fourteenth Meeting in 2002 on the status of destruction technologies of ozone-depleting substances, including an assessment of their environmental and economic performance, as well as their commercial viability;

(b) When presenting its first report, include a recommendation on when additional reports would be appropriate;

(c) Review existing criteria for the approval of destruction facilities, as provided for in section 2.4 of the Handbook for the International Treaties for the Protection of the Ozone Layer;

3. To request the Technology and Economic Assessment Panel:

(a) To evaluate the technical and economic feasibility for the long-term management of contaminated and surplus ozone-depleting substances in Article 5 and non-Article 5 countries, including options such as long-term storage, transport, collection, reclamation and disposal of such ozone-depleting substances;

(b) To consider possible linkages to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal and other international treaties as appropriate regarding the issue of disposal;

(c) To report to the Parties on these issues at their Fourteenth Meeting in 2002.

8) Decision XIV/6: Status of destruction technologies of ozone-depleting substances, including an assessment of their environmental and economic performance, as well as their commercial viability

The *Fourteenth Meeting of the Parties* decided in *Dec. XIV/6:*

1. To note with appreciation the Report of the Task Force on Destruction Technologies presented to the twenty-second meeting of the Open-ended Working Group;

2. To note that the Task Force has determined that the destruction technologies listed in paragraph 3 of this decision meet the suggested minimum emission standards that were approved by the Parties at their Fourth Meeting;

3. To approve the following destruction technologies for the purposes of paragraph 5 of Article 1 of the Protocol, in addition to the technologies listed in annex VI to the report of the Fourth Meeting and modified by decisions V/26 and VII/35:

(a) For CFC, HCFC and halons: argon plasma arc;

(b) For CFC and HCFC: nitrogen plasma arc, microwave plasma, gas phase catalytic dehalogenation and super-heated steam reactor;

(c) For foam containing ODS: rotary kiln incinerator;

4. To request the Technology and Economic Assessment Panel to update, in time for consideration by the twenty-third Open-ended Working Group, the Code of Good Housekeeping to provide guidance on practices and measures that could be used to ensure that during the operation of the approved destruction technologies, environmental release of ODS through all media and environmental impact of those technologies is minimized;

5. To consider, at the twenty-fourth meeting of the Open-ended Working Group, the need to review the status of destruction technologies in 2005, including an assessment

of their environmental and economic performance, as well as their commercial viability.

9) Decision XVI/15. Review of approved destruction technologies pursuant to decision XIV/6 of the Parties

Recalling the report of the task force on destruction technologies presented to the Parties at the twenty-second meeting of the Open-ended Working Group,

Noting the need to keep the list of approved destruction technologies up-to-date,

Mindful of the need to minimize any additional workload for the Technology and Economic Assessment Panel,

1. To request the initial co-chairs of the task force on destruction technologies to reconvene in order to solicit information from the technology proponents exclusively on destruction technologies identified as "emerging" in the 2002 report of the task force on destruction technologies;

2. Further to request the co-chairs, if new information is available, to evaluate and report, based on the development status of these emerging technologies, whether they warrant consideration for addition to the list of approved destruction technologies;

3. To request that that report be presented through the Technology and Economic Assessment Panel to the Open-ended Working Group at its twenty-fifth meeting;

Annex II – *Summary of Advantages and Disadvantages of Relevant Destruction Technologies*

Technology	**Advantages**	**Disadvantages**
Incineration Technologies		
Cement Kilns Incineration	* large existing capacities in the world * relatively low cost	* need to control an input rates of fluorine and chlorine * not applicable for destruction of CFC and halon wastes
Container Based Incineration System	* mobile * high DRE	* depending on many factors * high skilled personnel needed * poor control of residual products
Gaseous/Fume Oxidation	* applicable for CFC and halon waste * high DRE * low emissions * relatively low cost	* generally located on fluorocarbon manufacturing site/not available for use of others * not applicable for destruction of CFC in foams
High Performance Incineration	* high DRE	
ICFB	* high DRE * simplicity	
Liquid Injection Incineration	* established and proven technology * relatively low cost	* screening limit for PCDD/PCDF emission not met/relatively high rate of emissions * not applicable for destruction of foams
Municipal Solid Waste Incineration	* technology being used for the destruction of foams containing ODS * faire wide availability * relatively low cost	* potential possibility of exceeding of screening limit for PCDD/PCDF
Reactor Cracking	* large commercial scale/many years * low formation of PCDD/PCDF * relatively low cost	* concern about the availability of an economic source of hydrogen * intolerant process for bromine containing ODS/can not be used for destruction of foams and halons
Rotary Kiln Incineration	* wide variety of liquid and solid wastes/foams and concentrated sources	* very expensive
Plasma Technologies		
AC Plasma	* high DRE/CFC and halons * low emissions * torch electrically simple/mechanically rugged * possible to operate with air/steam/plasma gases * tolerant of oil contamination in ODS	* high energy consumption
Argon Plasma Arc	* non-incineration technology * high DRE/CFC and halons * low emissions of PCDD/PCDF * easily transported	* need to remove oil before destruction * not applicable for destruction of foams
Inductively Coupled Radio Frequency Plasma	* commercial available * high destruction of CFC * low emissions	* high energy consumption
Microwave Plasma	* high destruction efficiency	* production of halide salts

	* low emissions	* high energy consumption
Nitrogen Plasma Arc	* very compact in size/9 m x 4.25 m * mobile by truck/on-site treatment	* limited destruction capacity * production of halide salts * high energy consumption
Other Non-Incineration Technologies		
Base Catalysed Dechlorination	* process being able to treat compounds with up to 50% of chlorine * on-site treatment * low dioxin emissions	* direct processing of fluids only * batch process * high energy consumption
Gas Phase Catalytic Dehalogenation	* high efficiency in destroying of CFC * no PCDD/PCDF emissions * low operating temperature * low mass emissions	* higher destruction cost * production of halide salts
Gas Phase Chemical Reduction	* very high destruction efficiency * low emissions * applicable for solids/potentially including foams * transportability	* lack of experience in destroying of ODS
Liquid Phase Chemical Conversion	* low capital investment * almost emissions free * mobile	* for ODS just tested, not commercially used
Solvated Electron Decomposition	* simplicity * low operating temperature * high destruction efficiency * low emissions	* lack of demonstration of a destruction on a commercial scale * careful attention to operating procedures needed * very expensive
Super Heated Steam Reactor	* *high destruction efficiency* * low emissions * simple design/safe to operate * applicable for mobile destruction/to all but foams * applicable to all but foams	* production of halide salts
UVPhotolysis	* relatively simple	
Vitrification	* compact and transportable technology * minimizing of operating costs	

Annex III - *Cost Information on Relevant Destruction Technologies*

		Technology	Capital cost/USD	Destruction costs USD/kg	Source
1		AC Plasma		3-5	1
2	▨	Argon Plasma Arc			
3		Base Catalysed Dechlorination	0.8 - 1.3 mill.	3.3-6.6	3
4	▨	Cement Kilns Incineration	92* mill.		3
5		Container Based Incineration System	2.6 - 3 mill.	0.3	3
6	▨	Gaseous/Fume Oxidation		3-5	1
7	▨	Gas Phase Catalytic Dehalogenation	1 mill.	2-3	1
8		Gas Phase Chemical Reduction		3-5	1
9		High Performance Incineration			
10		ICFB Incineration			
11	▨	IC RF Plasma			
12	▨	Liquid Injection Incineration			
13		Liquid Phase Chemical Conversion			
14	▨	Microwave Plasma			
15	▨	Municipal Solid Waste Incineration			
16	▨	Nitrogen Plasma Arc			
17	▨	Reactor Cracking	4 mill.		4
18	▨	Rotary Kiln Incineration			
19		Solvated Electron Decomposition		7	1
20	▨	Super Heated Steam Reactor	0.3 mill.	2-3	1
21		UV Photolysis			
22		Vitrification	2-2,5 mill.	0.3	5

* Comprises 24 million USD investments in the cement kiln and 68 million USD for the hazardous waste treatment plant. Both investments are necessary for the correct treatment

Legend:

▨ destruction technologies of ODS recommended by Parties to the Montreal Protocol
☐ destruction technologies of ODS recommended by Cantox Environmental Inc.

1 UNEP Report of the Technology and Economic Assessment Panel, Volume 3B, Report on the Task Force on Destruction Technologies, 2002
2 http://www.pdf.com.au/article.asp?CategoryID=3&TopicID=15&ArticleID=30
3 Detailed Review of Selected Non-Incineration and Incineration POPs Elimination Technologies for the CEE Region; Danish Environmental Protection Agency; 2004
4 http://www.hug-engineering.de/index.htm?DestructionTechniques_01.htm
5 http://www.uneptie.org/ozonaction/library/mmcfiles/multiples/3521-e-file7.pdf

Annex IV - *Ranking of Destruction Technologies of ODS Realized by CANTOX ENVIRONMENTAL, INC (CEI).*

CEI in partnership with the Pioneer Technology Centre (PTC) performed a comparative study on selection of appropriate technologies for destruction of ODS with the aim to develop a Guidance Document for the disposal of surplus CFC and halons in Canada, in consultation with appropriate experts and stakeholders.

In total, 42 ODS disposal technologies were identified and described, then evaluated on the basis of mandatory environmental criteria and commercial availability. Accordingly, the 42 identified technologies were categorized into two main groups:

1. Commercially available and environmentally acceptable technologies.
2. Emerging technologies.

The first group of technologies was then further evaluated based on two different sets of criteria; environmental & technical criteria and commercial & economic criteria.

The Final technical / environmental ranking of ODS disposal technologies selected by CANTOX ENVIRONMENTAL INC. is as follows:

1. Argon Plasma
2. Cement Kiln Incineration
3. Catalytic Dehalogenation
4. Reactor Cracking
5. Vitrification
6. Rotary Kiln Incineration
7. AC Plasma
8. Liquid Injection Incineration
9. Gas/Fume Incineration
10. Liquid Phase Chemical Conversion
11. IC RF Plasma
12. High Performance Incineration
13. Gas Phase Chemical Reduction
14. ICFB Incineration
15. Solvated Electron
16. UV Photolysis

Incineration Technologies

Technology	Liquid Injection Rotary Kiln Gas/Fume ICFB	Cement Kiln	High Performance	Reactor Cracking
Vendor	Generic	Generic	Bovar	Solvay
OperatingTemp (° C)	900 to 1100	1500	1200	2000 to 2600
Residence Time (sec)	1-2	10	2	
DE	99.99% to 99.999%	99.99%	99.9999%	99.999%
PCDD/PCDF	0.1	0.1	0.1	0.1
Effluents	GHG Halide salts	GHG	GHG Halide salts	
Features	Co-incineration	Limited coincineration	Co-incineration	Dedicated HF, HCl recovery
Cost ($/kg CFC)	3.50	3.25	4.00	3.75

Plasma Technologies

Technology		Inductively Coupled RF	DC Argon	AC
Vendor		MITI	SRL Plasma	SUI
OperatingTemp (° C)		2000	3000	
Residence Time (sec)		2	0.020	
Efficiency	**Elec**	95%	95% to 98%	99%
	Thermal	50%	65% to 85%	85% to 90%
DE		99.99%	99.9999%	99.99%
PCDD/PCDF		0.025	0.025	
Effluents		Halide salts	Halide salts	Halide salts
Features		No electrodes enables wide range of gases	Requires inert gas	No need for high frequency AC Tolerates oily gases
Cost ($/kg CFC)		2.50	2.75	2.50

Non-Incineration Technologies (1)

Technology	Solvated Electron	UV Photolytic	Gas Phase Chemical Reduction
Vendor	Commodore Advanced Sciences	Process technologies, Inc.	Eli Eco Logic International Inc.
Process Description	Reaction with liquid ammonia and metallic sodium	UV irradiation of FC in air	Reaction at 850 C under reducing conditions
DE	99.99%	99.7%	99.9999%
PCDD/PCDF	0.01	0.01	0.06
Effluents	Halide salts	Non hazardous	Halide salts

		spent liners	
Features	Methane & ethane byproducts Ammonia recycled	Liner is PTI proprietary mixture	Hydrogen, methane recovered and used as fuel
Cost ($/kg CFC)	11.00	11.00	6.00

Non-Incineration Technologies (2)

Technology	**Gas Phase Catalytic Dehalogenation**	**Liquid Phase Chemical Conversion**	**Vitrification**
Vendor	Hitachi Corp.	Ontario Hydro Technologies	Pure Chem, Inc.
Process Description	Reaction over metal oxide catalyst at 400 °C at atmospheric pressure	Reaction with KOH and polyethylene glycol at 100 °C	Plasma ODS destruction and fixation into glass frit
DE	99.999%	99.7%	99.9999%
PCDD/PCDF	0.01	0.01	0.1
Effluents	Halide salts	Halide salts	Glass frit capable of being returned to commerce
Features	Proprietary catalyst	Mobile systems	Proprietary chemicals used to form glass
Cost ($/kg CFC)	3.60	4.00	3.80

Annex V - *Questionnaire Table with list of Vendors*

Company Name	Country	Contact	Substances that can be destroyed at this facility	Response
Bond Retail Services Ltd	United Kingdom	Garry Hodge Account Manager Bond House, New Road, Sheerness, Kent. ME12 1BB Tel: 01795-668515 Fax: 01795-660206 E-mail: garryh@bond-group.co.uk Brian Hurkett Supervisor Bond House Tel: 07885-055353 Fax: 01795-430673 E-mail: info@bond-group.co.uk Website: www.bond-group.co.uk		
DASCEM Holdings Pty Ltd	Australia	P.O. Box 285, World Trade Centre Melbourne Victoria 3005 Australia +61 3 9649 7405 +61 3 9649 7410 susanne.clarke@dascem.com.au http://www.dascem.com.au/	CFCs Halons HCFCs Other (the process is suitable for destruction of all liquid and gaseous ODS).	
Eco Solutions Ltd	United Kingdom	Yianni Stamataris Managing Director 91, Ware Rd, Hoddesdon, EN119AD Tel: 01992 461229 or 07960 835757 Fax: E-mail: ecosolutions@fsmail.net Website: www.ecosolutionsrecycling.com		

Environcom	United Kingdom	Neil Pattison Enviromental Manager Houghton Road Industrial Estate, Houghton Road, Grantham, Lincolnshire Tel: 01476564942 Fax: 01476564948 E-mail: neilnsue@pattison26.freeserve.co.uk Ian Gray Factory Manager Houghton Road Industrial Estate, Houghton Road, Grantham, Lincolnshire Tel: 01476564942 Fax: 01476564948		
Environcom	United Kingdom	Gary Thomson Sales Elvingstone Science Centre East Lothian EH33 1EH Tel: 07966502288 Fax: 0131 663 2712 E-mail: Gthomson25@aol.com Website:		
Earth Tech Canada Inc.	Canada	Mail Bag 1500 City Swan Hills Alberta T0G 2C0 Canada +1 780-333-4197 +1 780-333-4196 http://www.shtc.ca/	CFCs Halons HCFCs Methyl bromide Foam that ontains ODS	
Ekokem Oy Ab	Finland	PL 181, Kuulojankatu 1 Riihimäki 11101 Finland +358 10 7551 000 +358 10 7551 300 http://www.ekokem.fi/	CFCs HCFCs Halons Foam that contains ozone depleting substances Methyl bromide	

Evans Logistics	United Kingdom	Howard Evans General Inquiries Park Avenue, Aberystwyth, Ceredigion Tel: 01970 626277 Fax: 01970 639042 E-mail: howard		
Global Environmental Recycling Company Ltd	United Kingdom	Bob Shepherd Director Unit D, Maritime Business Park, Campbeltown Road, Birkenhead, Merseyside CH41 9B Tel: 0151 647 2211 Fax: 0151 647 0022 E-mail: robert@shepherdg90.fsnet.co.uk		
Goodearth Recycling Ltd	United Kingdom	George Watts Managing Director 12 Bedehouse Bank, Bourne, Lincs PE10 9JX Tel: 01778 421052 Fax: 01476 576263 E-mail: gw.goodearth@freeuk.com		
HW Martin Waste Ltd	United Kingdom	Steve Pollard General Inquiries Fordbridge Lane, Alfreton, Derbyshire DE55 5JY Tel: 01773 860600 Fax: 01773 813305 E-mail: hwmartinwaste@aol.com		
INDAVER N.V.	Belgium	Poldervliet 5, Haven 550 Antwerp 2030 Belgium +32-3-568.49.11 +32-3-568.49.99 http://www.indaver.com/	CFCs Halons HCFCs Foam that contains ODS	

International Waste Management Group	United Kingdom	John Burnett Director Unit 27, Mayfield Industrial Estate, Dalkeith, Midlothian Tel: 01316631131 Fax: 01316638138 E-mail: iwmg@btconnect.com Website: www.iwmg.co.uk		
JCM Group	United Kingdom	Paul Cynamon General Inquiries Tel: 01642 566003 Fax: 01642 566515 E-mail: fridges@jcm-uk.co.uk		
John Hornby & Sons Ltd	United Kingdom	Stephen Hillas Birkshall Lane, Bradford, BD4 8TB Tel: 01274 390856/01484 652777 Fax: 01484 461460 E-mail: stephen.hillas@refrigerationrecycling.co.uk Website: www.refrigerationrecycling.co.uk		

M Baker Recycling Ltd	United Kingdom	Julie-Ann Adams Client & Marketing Manager Baring House, 6 Baring Crescent, Exeter, Devon, EX1 1TL Tel: 01392-433912 Fax: 01392-411951 E-mail: ja@mbakergroup.co.uk Website: www.weeedirective.co.uk		
New Hartley Recycling	United Kingdom	Geoff Copp 24 Bristol Street, New Hartley, Tyne and Wear NE25 0RJ Tel: 0191 2374661 Fax: 0191 2371262		
NSD Global Ltd	United Kingdom	Harriet Mountford Projects Manager Greetwell Place, Limekiln Way, Greetwell Road, Lincoln, LN2 4US Tel: 0845 090 0027 Fax: 0845 090 0028 E-mail: sales@nsdglobal.com Steven Dipper MD Greetwell Place, Limekiln Way, Greetwell Road, Lincoln, LN2 4US Tel: 0845 090 0027 Fax: 0845 090 0028 E-mail: steve.dipper@nsdglobal.com		
NWP Recycling	United Kingdom	Shane Woods Marketing Manager 55 Cargaclougher Rd, Keady, Co Armagh, BT60 3RA Tel: 028 3753 1591 Fax: 028 3753 9426 E-mail: shane@nwp-recycle.com Website: www.nwp-recycle.com		

Onyx Magyarország Ltd.	Hungary	Bécsi út 131 Dorog Komárom-Esztergom H-2510 Hungary +36 (33) 512-700 +36 (33) 512-857 titkarsag@onyyxmagyarorszag.hu http://www.onyyxmagyarorszag.hu/	Halons	
Overton Recycling Ltd	United Kingdom	Dean Overton Director Alma St, Smethwick, Birmingham B66 2RX Tel: 01869 277998 Fax: 01869 278613 E-mail: fridges@overtonrecycling.com Website: www.overtonrecycling.com		
RAL Quality Assurance Association for the Demanufacturing of Refrigeration Equipment Containing CFCs	United Kingdom	Jeff Weeks UK Director 3 Carlton House, Stamford, Lincs PE9 1XP Tel: 01780 751 017 Fax: 01780 751 018 E-mail: infoUK@RAL-online.org Danik Humbles Co-ordinator 3 Carlton House, Stamford, Lincs PE9 1XP Tel: 01780 751 017 Fax: 01780 751 018 E-mail: infoUK@RAL-online.org Website: www.ral-online.org		

Redibag Recycling Plc	United Kingdom	Enquiries 43 Portland Place, London Tel: 01483 211002 Fax: 01483 479912 E-mail: enquiries@redibagplc.plus.com		
Refrigerator Recycling UK Ltd	United Kingdom	Robert Sant Director Oak Works, Hopton Heath, Craven Arms, Shropshire, SY7 0QD Tel: 01547 530 317 Fax: 01547 530 228 E-mail: robert.sant@refrigeratorrecycling.co.uk Kim Tomkins Enquiries Oak Works, Hopton Heath, Craven Arms, Shropshire, SY7 0QD Tel: 01547 530 317 Fax: 01547 530 228 E-mail: enquiries@refrigeratorrecycling.co.uk Website: www.refrigeratorrecycling.co.uk		
RemTec International Corporate Headquarters	USA	6150 Merger Drive Holland, OH 43528 419/867-8990 419/867-3279 FAX Toll Free: 888/8REMTEC www.remtec.net	CFCs Halons HCFCs HFCs	
Shanks Waste Services Ltd	United Kingdom	Ms Jo Fitzpatrick Dunedin House, Auckland Park, Mount Farm, Milton Keynes, MK1 1BU Tel: 01908 202120 or freefone 0800 0282877 Fax: 01908 202131 E-mail: jo.fitzpatrick@shanks.co.uk John Brewster/Bob Seeley Scotland/Wales Tel: 0141 552 4347/01269 846203Website:www.shanks.co.uk		

Shore Recycling Ltd	United Kingdom	Shore Recycling Ltd Friarton Bridge Park Friarton Road PERTH PH2 8DD Tel. 01738 492950 Fax. 01738 563800 enquiries@shore-recycling.co.uk	CFCs	no destruction
Sims Group UK Limited	United Kingdom	Myles Pilkington Communications Coordinator Long Marston, Stratford-upon-Avon, Warwickshire, CV32 6DL Tel: 01789 720 431 Fax: 01789 720 940 E-mail: mpilkington@uk.sims-group.com Website: www.sims-group.com		no destruction
SimsMetal UK	United Kingdom	Pam Williams South Dock.Newport.Gwent.NP9 2WE Tel: 01633 250 650 Fax: 01633 250 850 E-mail: pwilliams@simsmetal.co.uk Website: www.simsmetal.co.uk		
SOLVAY FLUOR GmbH	Germany	Brüningstr. 50 Frankfurt 65926 Germany 495 118 572 721 495 118 572 178 http://www.solvay-fluor.com/	CFCs HCFCs HFCs	

Sulo MGB Ltd.	United Kingdom	Mrs Terry Brown Project Manager Unit 6 Lincoln Business Park,Lincoln Road, High Wycombe HP12 3RD Tel: 01494 511055 Fax: 01494 511044 E-mail: t.brown@sulo.co.uk		
TdB Incineração Ltda	Brazil	Avenida Ibirama, 518 Taboão da Serra SP 06785-000 Brazil (11) 41388317 (11) 41388311 fsouza@essencis.com.br http://www.essencis.com.br/	CFCs Halons HCFCs Methyl bromide	
Technowaste Limited	United Kingdom	Mark Hadley Director of Technical Services PO Box 27, Dorking, Surrey RH5 5AN Tel: 01306 631911 Fax: 01306 631901 E-mail: mark@technowaste.com Website: www.technowaste.com		
The WS Group	United Kingdom	David.W.Bavaird Operations And Logistics Director Bede House, St Cuthberts Way, Aycliffe Industrial Park, Newton Aycliffe, Dl5 6DX Tel: 01325-379020 Fax: 01325-379036 E-mail: dbavaird@wastesolution.co.uk Website: www.wastesolution.co.uk		

Valorec Services AG	Switzerland	Neuhausstrasse 90, Porte 91, Postfach 118 Basel 4019 Switzerland +41 61 468 86 55 + 41 61 468 86 60 werner.wagner@valorec.com http://www.valorec.ch/	CFCs Halons HCFCs Foam that contains ozone depleting substances Methyl bromide Other (methyl iodide)	Incineration of CFCs
Viromet Ltd	United Kingdom	John Taylor Manager North Lodge, Standon Lane, Ockley, Surrey RH5 5QR Tel: 01306 628068 Fax: 01306 628064 E-mail: sales@viromet.co.uk		
West Herts Recycling	United Kingdom	Nigel/Geoff Partners 1 The Guildhouse Croxley Green Rickmansworth Hertfordshire WD3 3HD Tel: 07870 534335 Fax: 01923 448228 E-mail: nigelc456@hotmail.com		

Numbers of questionareres sent: 37
Number odf answers recieved: 3

Table (appendix) of questionares

TECHNOLOGY/UNIT DATA

		Unit		**Cost**	
	Destruction capacity	**S**	**M**	**Investment**	**Operational**
Chlofofluorocarbons	500 t				
	50 t				
Halons	500 t				
	50 t				
Other Fully Halogenated CFCs	500 t				
	50 t				
Carbon Tetrachloroide	500 t				
	50 t				
Methyl Chloroform	500 t				
	50 t				
Hydro-chlorofluorocarbons	500 t				
	50 t				
Methyl Bromide	500 t				
	50 t				
HFC23	500 t				
	50 t				
Legend to the table:	Unit	S - stationary			
		M - mobile			

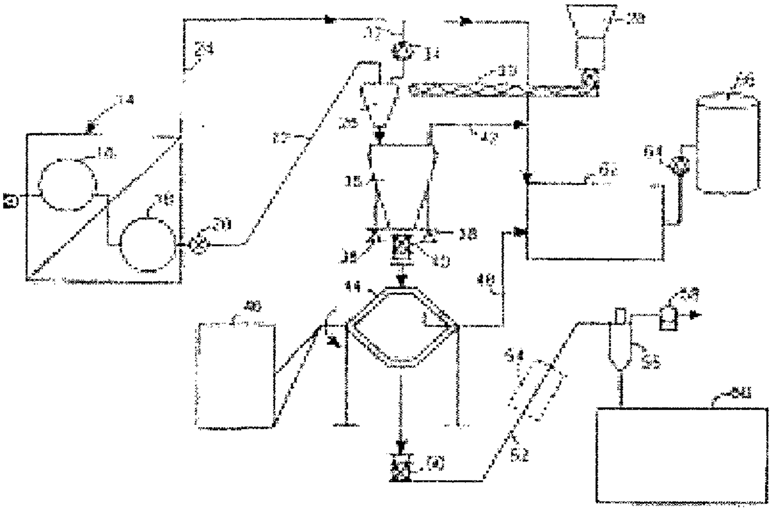
Annex VI - *List of Patents on Destruction Technologies of ODS*

A review was made with the aim of finding patents related to the destruction technologies of ODS. The following results were achieved:

1) EU patents

A method and apparatus for the processing and disposal of foam containing an ozone depleting substance was applied for a patent by Clarke Thomas and Clarke Kenneth from Great Britain in 2003. The present invention relates to the disposal of any foam containing one or more ODS, in particular a method for the environmentally friendly disposal of such foam by adding or encasing same in concrete, the foam preferably being in a fine powder like form on addition to the concrete. The invention also relates to a method of processing such foam to achieve said powder like form, in preparation for the disposal thereof, an apparatus for carrying out said method, and to concrete containing such processed foam.

Picture No. 1: Scheme of ODS destruction process by C. Thomas and C. Kenneth



2) US patents:

U.S. Patents submitted by Commodore Advanced Sciences, Inc. of Albuquerque, New Mexico:

Table No. 3: Existing patents submitted by Commodore Advanced Sciences, Inc.

US Patent Number	Date Issued	Title	Application	Accompanying Foreign Patents
4,702,804	10/27/87	Methods for Electrochemical Reduction of Halogenated Organic Compounds	Dehalogenation by electrochemistry using graphitized carbon	
4,853,040	08/01/89	Processes for Decontaminating Polluted Substrates	Treatment of soils, surfaces, oils, by solvated electron solutions	Canada, Japan
4,968,393	11/06/90	Membrane Divided Aqueous-Nonaqueous System for Electrochemical Cells	Dehalogenation by electrochemistry using divided aqueous/nonaqueous cells	
5,110,364	05/05/92	Processes for Decontaminating Polluted Substrates	Treatment of soils, surfaces, oils, by solvated electron solutions	
5,414,200	5/09/95	Non-Metallized and Substoichiometric Metallized Reactions with Ammonia and Other Weak Bases in the Dehologenation of Refrigerants	CFC destruction by solvated electron and ammonia	
5,497,627	03/12/96	Methods for Purifying Refrigerant Compositions	Aqueous extraction of select refrigerants from mixes allowing recovery of the useful material	
5,559,278	09/24/96	Methods for the Destruction of Ozone Depleting Substances	CFC destruction by solvated electron and ammonia	Australia, New Zealand, Pakistan, South Africa

1. A Method and Apparatus for the Processing and Disposal of Foam Containing an Ozone Depleting Substances
    - by Clarke Thomas (GB), Clarke Kenneth (GB); 2003

2. Destruction of Ozone Depleting Substances with Bases
    - by Mouk Robert W, Abel Albert E, COMMODORE LAB. INC.; 1996

3. Methods for Destroying Ozone Depleting Substances
    - by Mouk Robert W, Abel Albert E; COMMODORE LAB. INC.; 1996

4. Methods and Apparatus for the Decomposition and Re-Use-as-Resource Treatment of Ozone-Layer-Depleting Substances by Application of UV
    - by Othaku Kuninobu (JP), Ohyama Takeshi (JP); TOKYO ELECTRIC POWER CO. (JP);1998

5. Methods for Destroying Ozone Depleting Substances
    - by Mouk Robert W, Abel Albert E; SANDPIPER A.L. CORP. (US); 1995

6. Method for treating Ozone Layer Depleting Substances
    - by Uchiyama Hiroshi (JP); EC CHEM IND. CO. (JP), ITOCHU FINE CHEMICAL CORP. (JP)

ABBREVIATIONS

AC	Alternating Current
AHMS	Australian Halon Management Strategy
BAT	Best Applicable Technologies
BCD	Base Catalysed Dechlorination
BEP	Best Environmental Practices
CFC	Chlorofluorocarbons
CIS	Container Incineration System
DE	Destruction Efficiency
DRE	Destruction and Removal Efficiency
EC	European Commission
EFDT	Environmental Friendly Disposal Technologies
EGM	Expert Group Meeting
GB	Great Britain
GWP	Global Warming Potential
HCFC	Hydrogenchlorofluorocarbons
ICRF	Inductively Coupled Radio Frequency
JP	Japan
MSW	Municipal Solid Waste
MSWI	Municipal Waste Incineration
NHB	National Halon Bank
ODP	Ozone Depletition Potential
ODS	Ozone Depleting Substances
PCB	Polychlorinated Biphenyls
PCDD	Polychlorinated Dibenzo-Dioxin
PCDF	Polychlorinated Dibenzo-Furan
PIC	Products of Incomplete Combustion
RF	Radio Frequency
TAC	Technical Assessment Committee
TEAP	Technology and Economic Assessment Panel
TFDP	Task Force on Destruction Technologies
UNEP	United Nations Environmental Programme
UNIDO	United Nations Industry Development Organization
US	United States
UV	Ultraviolet