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**TITLE**

RECENT CANADIAN EXPERIENCE IN CHEMICAL WARFARE AGENT DESTRUCTION. AN OVERVIEW

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# RECENT CANADIAN EXPERIENCE IN CHEMICAL WARFARE AGENT DESTRUCTION. *AN OVERVIEW*

BY

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Ralston, Alberta

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# RECENT CANADIAN EXPERIENCE IN CHEMICAL WARFARE AGENT DESTRUCTION. *AN OVERVIEW.*

BY

J.M. McANDLESS

## ABSTRACT

A Canadian chemical warfare agent destruction project (Swiftsure) was recently completed in which stockpiles of aged mustard, lewisite, nerve agents and contaminated scrap metal were incinerated or chemically neutralized in a safe, environmentally- responsible manner. The project scope, destruction technologies, environmental monitoring and public consultation programs are described.

# EXECUTIVE SUMMARY

*Introduction*

Project Swiftsure describes a three-year Department of National Defence (DND) project undertaken at the Defence Research Establishment Suffield (DRES) to dispose of old chemical warfare agent waste stored on the DRES Experimental Proving Ground (EPG). Project Swiftsure was created in 1989 following a directive from the Minister of National Defence to accelerate and complete the disposal of remaining chemical agent waste by 1992. This directive was based on the rationale that continued storage of agents represented an unacceptable risk and that Canadian initiatives at the United Nations Conference on Disarmament remained compromised while the agents existed.

*Approaches*

The agent waste inventory, which had been sorted previously and stored at four remote, protected sites on the EPG, included mustard (12 tonnes), lewisite (2.5 tonnes), nerve agents (0.3 tonnes) and contaminated scrap metal material (400 tonnes). DRES destroyed the small nerve agent stockpile in-house by chemical neutralization in early 1989. A contractor was hired to destroy the remaining agent stockpile and contaminated scrap, as well as the secondary waste remaining from the nerve agent neutralization program. This was completed in 1991 by burning mustard agent and neutralized nerve agent waste and by thermally decontaminating the scrap metal in a commercial-design incinerator brought to DRES for this purpose. The contractor also destroyed lewisite in a transportable chemical neutralizer which produced arsenic byproducts. These were readily stabilized in concrete and landfilled. The decontaminated scrap metal was recycled to industry.

During 1990 and prior to commencing disposal operations, the contractor prepared a comprehensive Environmental Protection Plan (EPP) which was reviewed by federal and provincial environmental departments and the district public. DND undertook an extensive public consultation program which offered the public opportunities to directly participate in the development of the EPP and which ensured district communities were fully informed of project aims, approaches and progress. A key element in this program was the formation of a volunteer citizens' advisory committee which became the primary liaison between DRES and the general public as well as the focal point for addressing public concerns.

Environment Canada established project-specific limits for incinerator stack emissions and ambient air quality which were, in some cases, more strict than current regulatory standards. DRES and the incinerator contractor, as well as an independent contractor who was hired to conduct air quality surveys around the incinerator facility and in district communities, carried out an extensive environmental monitoring program to verify that agent destruction operations were being carried out safely with minimal environmental impact.

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*Results*

Destruction of the chemical agents and waste inventory was successfully completed by the end of 1991 without major incident. Preparing and incinerating mustard in solid, frozen form provided a high degree of safety during the destruction of this agent. During destruction operations, the environmental monitoring program confirmed that all project limits were met and that an incinerator of standard commercial design could be successfully used for mustard incineration. Initial public concerns about Project Swiftsure were effectively addressed through public participation in the development of the project EPP and by interaction with the citizen's advisory committee. The committee proved effective for maintaining dialogue, dealing with the technical issues and representing their community interests.

*Significance of Results*

Project Swiftsure was a unique and successful undertaking by the Department of National Defence involving the destruction of chemical warfare agent waste. The project was executed in an open, environmentally-responsible manner and has become an internationally recognized model for conducting controversial waste destruction operations with public participation. The DRES EPG is now cleaner and safer for EPG users. Expertise developed during the course of Project Swiftsure can be readily applied to other DND hazardous waste disposal operations and decommissioning activities. Canadian contractors involved can effectively market their proven agent destruction technology for international chemical demilitarization and site decommissioning projects; for example, in support of the technical implementation of the Chemical Weapons Convention.

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## INTRODUCTION

Project SWIFTSURE describes a three-year undertaking at the Defence Research Establishment Suffield (DRES) to safely destroy old chemical agent waste stored on the DRES Experimental Proving Ground. The project was created in 1989 following an independent review [1] of the Canadian chemical-biological defence research program within the Department of National Defence (DND). This review, known as the "Barton Report", noted that chemical warfare agent stocks, empty contaminated containers, obsolete ordnance and scrap remained to be destroyed as part of an in-house disposal program ongoing since World War II. In response, the Minister of National Defence directed DRES to accelerate and complete the destruction of the chemical agent waste by 1992. This directive was based on the rationale that continued storage was no longer an acceptable risk and that Canadian initiatives at the United Nations Conference On Disarmament remained compromised while the agents existed.

This Suffield Report gives an overview of the scope, the destruction technologies and methods used, and the environmental monitoring and public consultation programs which were undertaken for Project Swiftsure. Technical reports describing Project Swiftsure have been published elsewhere [2,3].

## PROJECT LOCATION

DRES is located at the Canadian Forces Base (CFB) Suffield, approximately 45 km to the northwest of the city of Medicine Hat, Alberta. CFB Suffield incorporates a federal land reserve of 2600 square kilometres (Suffield Military Range) which is used primarily for mechanized training exercises conducted by the Canadian Forces and the British Army. The Experimental Proving Ground (EPG) is located on the southern portion of the range and covers an area of approximately 450 square kilometres. The EPG is dedicated to field trials in support of DRES programs. Most of the EPG may be characterized as gently rolling (or flat), semi-arid short-grass prairie terrain with little surface water and with groundwater located at considerable depth [4]. In general, the EPG contains very few environmentally-sensitive features, except in locations near the South Saskatchewan River. These latter locations are out- of-bounds with respect to DRES field trial activity. The EPG is surrounded by several small (population < 500) and medium-sized (population 10,00 - 50,000) communities, with the nearest community located approximately 5 km from where agent destruction operations were carried out.

## WASTE INVENTORY

The chemical agent waste inventory is listed in Table I. Bulk agents included mustard (bis-2-chloroethyl sulphide, 12 tonnes), lewisite (2-chlorovinyl-dichloro arsine, 2.5 tonnes) and nerve agents in the G- and V-classes (0.3 tonnes). The scrap (400 tonnes) consisted mainly of several thousand empty, mustard-contaminated 210L drums and ordnance casings stored in open pits. All of the lewisite and some of the mustard and nerve agents were stored in 1-ton containers. Nerve agents were also stored in non- explosive ordnance, primarily 105- and 155-mm artillery shells. Mustard which had aged or had been thickened with polymers was also contained in non-explosive ordnance. The waste previously had been sorted by type, collected and stored at four remote, protected sites on the EPG.

## OPERATIONAL CONCEPT

The waste was destroyed using two proven agent destruction methods, *viz*: chemical neutralization and incineration [5]. An on-site disposal operation was selected as this provided maximum safety and minimized environmental risks compared to transportation and destruction of agents elsewhere. At the project outset in 1989, the small nerve agent stockpile was neutralized by DRES staff in a field laboratory over a three-month period. A contractor was subsequently hired to destroy the remaining agent stocks and contaminated scrap, as well as the secondary waste generated from the nerve agent neutralization program. The contractor (Western Research Partnerships[1], Calgary, AB) supplied and operated a transportable incinerator which was used to thermally treat the scrap waste and emptied, decontaminated ordnance items and to burn mustard. Lewisite was chemically destroyed by peroxide oxidation in a transportable facility and the arsenic salt byproducts were stabilized in concrete for on-site disposal in a marked land-fill. Prior to commencing agent destruction, the contractor was required to prepare a comprehensive environmental protection plan (see below). The destruction operations took place in 1991. Project policy prohibited the importation of any additional waste for destruction and excluded the use of commercial facilities for the disposal of final waste products from the destruction processes. Prior to starting destruction operations, a comprehensive public consultation program (see below) was undertaken to address concerns regarding potential safety, health risks and environmental impacts associated with the project. To address public concerns regarding possible post-project uses of the incinerator, DND issued a public statement that the incinerator would be removed upon completion of operations.

[1] Chem-Security Ltd. and Western Research Ltd. Both companies are now a part of BOVARIInc., Calgary.

Table 1

**PROJECT SWIFTSURE WASTE INVENTORY**

| WASTE | DESCRIPTION | QUANTITY (Tonnes) |
|---|---|---|
| Mustard-Contaminated Scrap | 210 L drums<br>ordnance | 400 |
| Neutralized Nerve Agent Solution | alcohol/caustic solution | 4 |
| Bulk Agents:<br>Mustard | ton containers<br>ordnance | 12 |
| Lewisite | ton containers | 2.5 |
| Nerve Agents (GA, GB, VX) | ordnance (non-explosive) | 0.3 |
| Miscellaneous | used protective clothing<br>decontaminating solutions<br>vehicle parts<br>storage containers | 50 |

## PUBLIC CONSULTATION

*Overview*

The public consultation program was carried out during 1990 and before the contractor commenced agent destruction operations. Project Swiftsure was expected initially to generate negative public reaction because: a) chemical warfare agents were being processed, b) incineration was one of the proposed destruction methods, and c) the project proponent was a federal government department. Therefore, the need for a strong public consultation program was identified early during project planning. Less controversy was expected with respect to the highly lethal agents (i.e. nerve agents) as DRES had previously eliminated this small stockpile in a controlled laboratory setting.

*Approaches*

The project proponents adopted the philosophy that the public was "part of the solution, not part of the problem". A variety of public consultation approaches were employed [6], including public information meetings held in district communities, small group meetings and site visits held at DRES, media presentations, distribution of information brochures and newsletters, operation of a toll-free information "hot-line" and the formation of a volunteer citizens' advisory committee.

Information meetings held in early 1990 enabled the scope of public concern to be assessed. At the same time, DND indicated how the project environmental assessment process would be carried out (see below) and how the public could provide input into this process. The key to successful dialogue between the project proponents and the public was the formation of a volunteer advisory group, the Citizens' Environmental Protection Committee (CEPC). This ten-member group, formed initially with the assistance of DRES, was made up of a diverse cross-section of citizens who had expressed concerns or had spoken on behalf of their community at the information meetings. The membership included special interest groups, technical specialists, ranchers and local industry and university representatives. The CEPC set their own terms of reference and held open biweekly meetings which were attended by the media, DRES and contractor representatives. The stated purpose of the CEPC was "to ensure safety to people and environmental integrity remain paramount in the development and implementation of Project Swiftsure" [7]. The Committee became the recognized focal point for community interests and proved effective for maintaining dialogue, for advancing new ideas or for disseminating status reports as plans and programs developed. A key factor which engendered trust between the parties involved was the funding by DRES of a technical consultant who was selected by and reported first to the Committee on project-specific issues.

*Public Concerns*

In general, the main issues arising from the information meetings were as follows:

- Policy: The public was concerned about the fate and usage of the incinerator following Project Swiftsure and whether a formal DND promise to remove the incinerator at the end of the project would change. The public also wanted assurance that wastes, other than those specified in the project plan, would not be incinerated.

- DRES Historical Activities: The public raised concerns regarding potential health and environmental impacts from previous mustard and nerve agent destruction operations and waste disposal activities. There was speculation that military activities and DRES research and development programs might be responsible for certain illnesses or diseases in the district communities.

❖ Environmental Assessment: The public was interested in how they could participate in the environmental assessment process and whether a full public review was necessary. As well, they wanted information on the roles assumed by the environmental regulatory agencies (Environment Canada and Alberta Environment) in the project.

❖ Environmental Protection: The public was concerned about possible contamination of soil and surface water at the waste storage sites and what impact incinerator emissions would have on the environment. The public requested that additional environmental monitoring be carried out by an independent agency and that an independent consultant be hired to review the project environmental assessment documentation.

❖ Health and Safety: The public requested further information on the short- and long-term potential health effects related to incinerator emissions and what emergency response plans were in place to protect workers and the general public in case of accidents.

❖ Technical Issues: Questions were raised on how process residues would be disposed of, how the incinerator was configured and operated and how emissions would be monitored.

The issues described above were addressed during the subsequent development of the project Environmental Protection Plan (see below), with specific responses to the concerns raised provided in the document submitted for public review in the summer of 1990.

## ENVIRONMENTAL ASSESSMENT

### *Overview*

As required under the Canadian Environmental Protection Act, potential health, safety and environmental impacts were examined early during project planning. In 1989 and prior to initiating the public consultation program, DRES completed an initial environmental screening for Project Swiftsure according to the Federal Environmental Assessment Review Process Guideline Orders (EARPGO) [8]. The results of this screening indicated that the project could proceed as all potential environmental impacts resulting from project-related activities could be eliminated or mitigated with known technology, procedures and environmental management practices. However, in anticipation of likely public concern regarding this self-assessment process, DND decided to carry

out a further detailed assessment involving public participation in order to provide the necessary assurance that safety and environmental protection measures were being incorporated during project planning and implementation. That is, a comprehensive risk assessment similar to an Initial Environmental Evaluation [8] which is normally associated with the second stage of the EARPGO was implemented for Project Swiftsure.

The detailed assessment took the form of an Environmental Protection Plan (EPP) which was prepared by Western Research Partnership under the terms of their contract prior to commencing any disposal operations. The EPP was submitted for public review and review by National Defence, Health and Welfare Canada, Environment Canada and Alberta Environment officials.

*Environmental Agencies Roles*

Very early in the environmental assessment process, DND informed Environment Canada and Alberta Environment of the project aims and proposed technical approach. Environment Canada assumed the role as lead regulatory agency for the project since DND, a federal Department, was the project proponent. Project-specific limits were established by Environment Canada for incinerator stack emissions and ambient air quality, as shown in Table II. Certain limits (e.g. particulates) were guidelines which were more stringent than the current regulatory standards. Environment Canada also sent representatives to several public meetings to respond to questions regarding the environmental assessment process and their role in monitoring project performance with respect to environmental protection. Environment Canada did not undertake an active monitoring role in view of the comprehensive monitoring role undertaken by the project proponents and an independent contractor (see below). Instead, this agency reviewed monitoring protocols and monitoring data to ensure the project emission limits were not being exceeded.

*Environmental Protection Plan*

The EPP [4] described the approaches, equipment and procedures to be used by Western Research Partnership in eliminating or mitigating any environmental and health risks with respect to the installation and operation of the agent waste destruction equipment. The following specific topics were addressed:

- ❖ potential public health risks and environmental impacts which might arise off DND property from the agent incineration, waste storage and waste transportation were evaluated. In general, there were no "worst-case" scenarios which could affect the public in the vicinity of the Experimental Proving Ground under the proposed operating plan;

- ❖ emergency response and destruction site safety plans were described, including communications plans, responsibilities and terms of reference for emergency response personnel;

Table 2

## PROJECT-SPECIFIC EMISSION AND ENVIRONMENTAL LIMITS

| PARAMETER | CONCENTRATION LIMIT($mg/m^3$) STACK EMISSIONS | AIR QUALITY | PERIOD (hours) |
|---|---|---|---|
| Particulates | 20 | 0.10 | 24 |
| Mustard[a] | 0.03 | 0.003 | 8 |
| | | 0.0001 | 72 |
| Nitrogen Oxides | 300 | 0.40 | 1 |
| | 0.20 | | 24 |
| Hydrogen Chloride | 75 | 0.10 | 1 |
| Carbon Monoxide | 57 | 15.0 | 1 |
| | | 6.0 | 8 |
| Dioxins/Furans[b] | $12 \times 10^{-6}$ | - | - |

[a] US Department of Health and Human Services long-term exposure limits recommended for protection of workers (8-hour average) and the general public (72-hour average).

[b] Sum of measured dioxin and furan congener concentrations converted to the toxic equivalent concentration of 2,3,7,8- tetrachlorodibenzodioxin (T4CDD)

❖ potential health/safety risks and environmental impacts on EPG sites from operation of the agent destruction equipment were identified. In general, incinerator emissions and their impact on air quality were identified as posing the greatest risks;

❖ specific technologies and procedures employed to prevent or mitigate identified potential impacts were described. Preparing and incinerating mustard agent feedstock in frozen form (see Agent Destruction Operations, below) greatly enhanced project safety and minimized environmental risk;

❖ monitoring programs and technologies for verifying compliance with project-related emission standards were described, including stack monitoring, ambient air quality monitoring, destruction site air monitoring, water sampling and, where necessary, soil sampling.

❖ public consultation programs were outlined, including means to keep the public informed as well as to receive public input during operations.

The EPP also described the local EPG environment where Project Swiftsure was to be conducted, the proposed incinerator technology and general environmental protection and safety measures. Some of these latter measures included:

- ❖ scheduling agent destruction for the winter months to reduce fugitive emissions;

- ❖ using protective clothing and containment systems at the waste storage sites and during transportation of wastes to the incinerator site;

- ❖ designing the incinerator stack to maximize emissions dispersion, and

- ❖ continuously monitoring process parameters, stack emissions and ambient air quality.

*EPP Review Process*

Agency Review: Several government agencies as well as the public were involved in the review of the EPP. Agency review was coordinated by Environment Canada. Staff of Environment Canada, Health and Welfare Canada and Alberta Environment provided written comments and recommendations to DRES. These inputs were then considered and appropriate written responses supplied to the coordinating department for further examination. Ultimately, on behalf of National Defence, DRES received letters of acceptance from the reviewing agencies through Environment Canada stating that the review had been completed and that the agencies were satisfied that the issues had been fully addressed.

The issues raised, comments, recommendations and responses, including the final acceptance letters were collated and included in the Supplementary Information volume of the revised EPP [4].

Public Review: Following the initial public information meetings, the Project Swiftsure Environmental Protection Plan was developed by the contractor and copies of the plan were placed in district libraries in June 1990. The public review process was formally initiated with a presentation of the EPP to a meeting of the citizens' advisory group in June 1990. On behalf of the group, the CEPC technical consultant completed an independent review of the EPP. Specifically, the consultant:

- ❖ examined the EPP to ensure sufficient information had been provided to fully describe potential safety and environmental impacts;

- ❖ assessed proposed incinerator emission standards for protection of human health and wildlife near the selected incinerator site as well as in district communities;

- assessed the adequacy of the emissions dispersion model used;

- assessed the proposed technology options, site selection and processes employed with respect to providing maximum safety and minimal environmental impact;

- reviewed the proposed health, safety and emergency response plans.

The consultant also attended the public EPP review meetings (see below) to assess public response and issues of concern. The consultant's Final Report was also included in the EPP Supplementary Information volume [4].

EPP review meetings open to the public were held in district communities in July-August of 1990. These meetings differed significantly from the earlier information meetings in that a "workshop" format was used where issues could be raised and discussed in a small group setting as opposed to a general panel discussion. Resource personnel from DRES, DND, and Western Research Partnership, as well as members of the citizens' advisory group were in attendance to field questions in their respective areas of expertise. Information hand-outs and source reference materials were also made available to meeting attendees, as follows:

- Information Summary/Project Swiftsure Environmental Protection Plan;

- Copy of an open letter from the Minister of National Defence stating that the incinerator would be removed upon project completion;

- A brochure describing the role of the Project Swiftsure Citizens' Environmental Protection Committee;

- Copies of Environment Canada and Alberta Environment letters requesting information from and the replies provided by the project proponents, and

- List of resource personnel available for consultation at the EPP workshops.

The issues raised and addressed during the EPP workshops along with suggested changes to the agent destruction methods were incorporated into the Supplementary Information volume of the EPP. This, along with the information contained in the original EPP volumes, was then reviewed and subsequently approved by DND. The approved EPP was distributed to district libraries to ensure continued public access to this key document during the course of agent destruction operations.

*EPP Amendments*

Several important modifications to Project Swiftsure and the EPP resulted from reviews by the government agencies, the citizens' committee, and the general public. Where applicable, the contract for the agent destruction operations was amended to be consistent with the EPP changes. The key modifications included:

Lewisite Destruction Process: Rather than incinerate lewisite and its byproducts as originally proposed, the modified plan called for lewisite to be chemically neutralized with the collected arsenate salts and neutralizing solution immediately stabilized in concrete without any incineration. This approach removed concerns regarding the potential for arsenic emissions during incineration.

Dioxins and Furans: A more extensive monitoring program was implemented for these potential products of incomplete combustion. This included using a novel incinerator scrubber fluid analysis method as well as conducting high-volume air sampling surveys near the incinerator.

Incinerator Removal: As a result of public concerns about the possibility of the incinerator being retained and used for further hazardous waste destruction, the Minister of National Defence issued a public statement which required DRES to dismantle and remove the incinerator from CFB Suffield upon completion of Project Swiftsure.

Independent Air Quality Monitoring: Although incinerator emissions were monitored extensively by the contractor, a separate, independent air quality monitoring program (see below) was implemented to verify that emissions were within the limits set for the project.

## ENVIRONMENTAL MONITORING

The EPP included a detailed health risk study based upon highly conservative assessment criteria. This study predicted that no measurable increase in health risks for workers or the general population in district communities would result from the proposed incineration. For example, dispersion models showed that, under worst-case meteorological conditions, maximum ground-level emission concentrations (e.g. $SO_2$, mustard) would be well below project air quality limits and would occur approximately 150 m from the facility, a safe distance from the nearest community (5 km).

In response to public concerns, monitoring programs focused primarily on measuring airborne emissions to determine incinerator performance. Results from the various monitoring programs were reported immediately to the citizens' committee and to the federal and provincial environmental regulatory agencies for review. The environmental agencies opted to forego their own monitoring in view of the extensive project monitoring program.

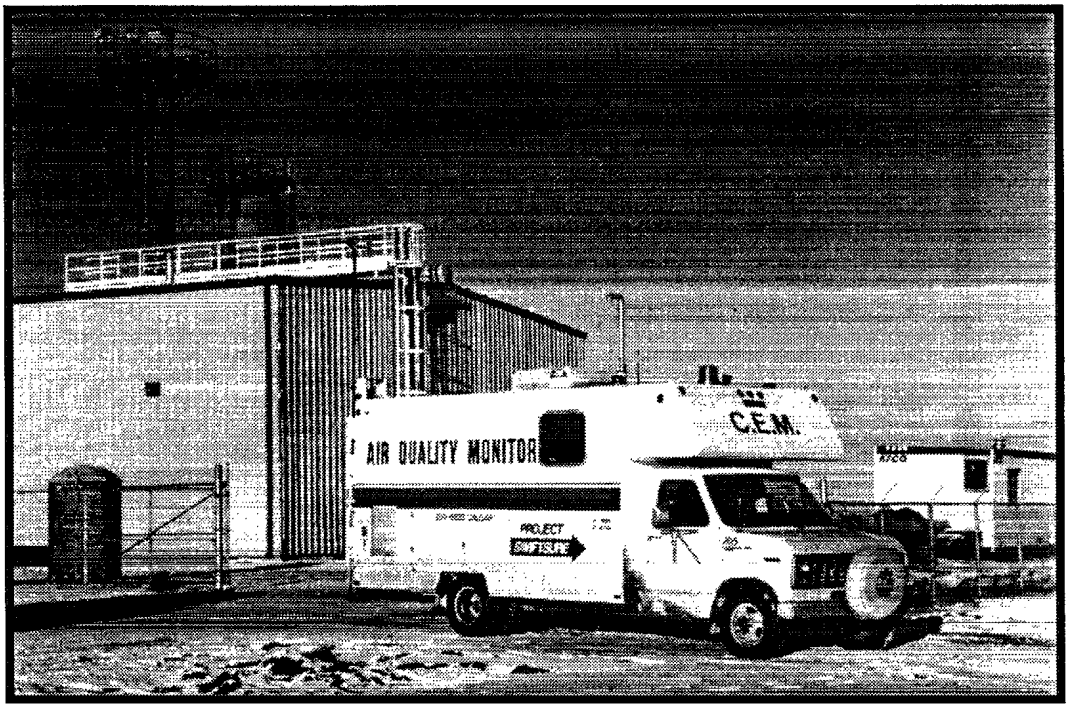
A diverse emissions monitoring program was carried out [9,10] which used retrospective sampling/analysis as well as "real-time", stationary or mobile detection equipment. For example:

❖ Incinerator performance was monitored with a Continuous Stack Emissions Monitoring (CSEM) system which measured concentrations of mustard, particulates, total hydrocarbons and the combustion gases listed in Table II, as well as flue gas oxygen content and other process parameters. During test burns, in-stack samples were taken and analyzed for heavy metals and chlorinated dioxins/furans. Incinerator scrubber fluid batches were analyzed for organics and metals prior to discharge to an on-site holding pond;

❖ Air quality monitoring near the incinerator was carried out using an instrumented trailer which was established downwind of the incinerator in the prevailing wind direction to provide a daily record of meteorological conditions and emissions concentrations. A fixed high-volume sampling array was also installed near the incinerator to collect samples on a periodic basis for trace metal and chlorinated dioxin/furan analyses.

❖ A mobile laboratory (Figure 1) was operated by an independent contractor to monitor air quality near the incinerator facility and in district communities near the DRES EPG.

Figure 1




**Mobile Air Quality Monitoring Laboratory**

## AGENT DESTRUCTION OPERATIONS

*Overview*

Chemical agents other than mustard were destroyed by neutralization prior to incinerating or otherwise disposing of the generated secondary waste. Mustard in all forms was destroyed by direct incineration. This was the only practical choice where the agent had aged to an intractable solid or had been thickened with polymers.

*Nerve Agents*

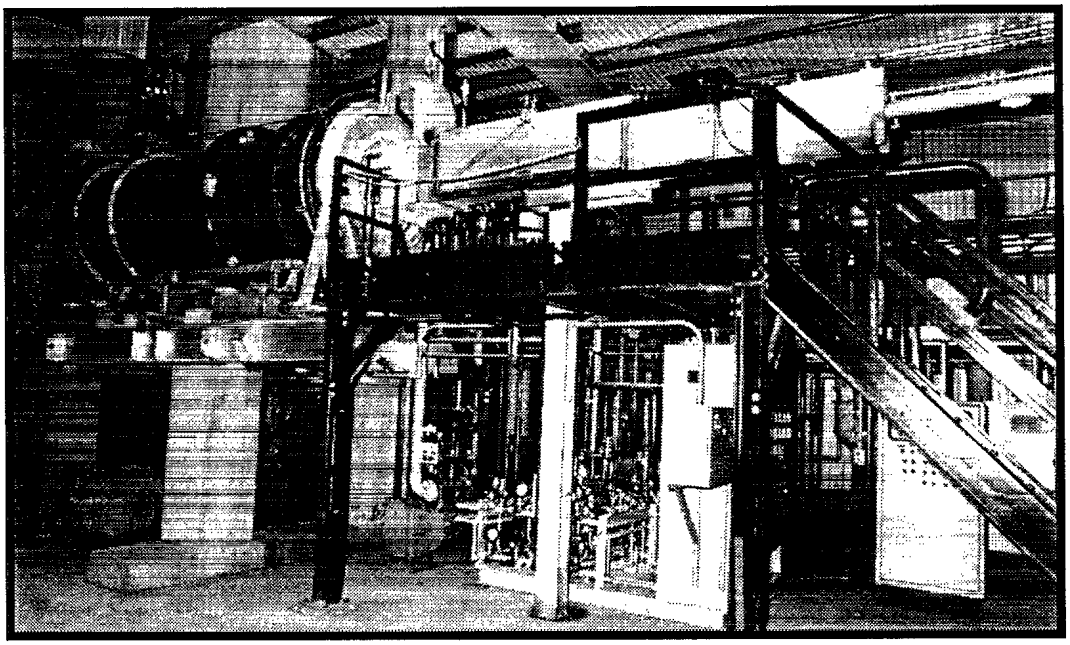
The nerve agent stocks (305 kg), consisting of neat tabun (GA), sarin (GB), VX and experimental G-agent formulations, were processed using a DRES-designed drill and drain apparatus located in a field laboratory equipped with a fume hood and charcoal filter scrubber. Approximately 36 ordnance items could be processed daily using this apparatus. Container contents were drained into a solution of 20% by weight potassium hydroxide in methanol which rapidly and effectively destroyed the agents. The waste methanol solution, containing phosphate salts, cyanides and organic sulphides, was subsequently incinerated along with the used charcoal filters. The drained containers were rinsed with neutralizing solution, then heat-treated by methanol combustion in a vented, enclosed steel tank to render them safe for handling. These containers were eventually processed through the incinerator. During nerve agent destruction, air monitoring was carried out using portable chemical agent monitors (CAMs) within the facility and by periodically monitoring the external charcoal filter housing for signs of agent breakthrough. No fugitive nerve agent emissions were detected except near the drilling apparatus located within the fume hood.

*Mustard*

Mustard is immediately destroyed at temperatures above 500°C to $SO_2$, HCl, $CO_2$ and water vapour. The contractor operated a commercial, transportable 7 MMBtu/h incinerator (Figures 2,3) which could readily achieve an organic destruction efficiency of 99.9999% and which was used to destroy frozen bulk mustard introduced as solid waste and to thermally treat agent-contaminated metal scrap. The incinerator incorporated a two-stage combustion process, *viz*; a rotary kiln (900°C, 1.5 tonnes/hour capacity) and a down-fired secondary combustion chamber (1200°C, 2.5s residence time), backed by a venturi wet flue gas scrubber. System components were erected on a prepared concrete foundation and housed in a pre-fabricated building to provide shelter for the equipment and operators. Natural gas from a nearby well provided a fuel source.

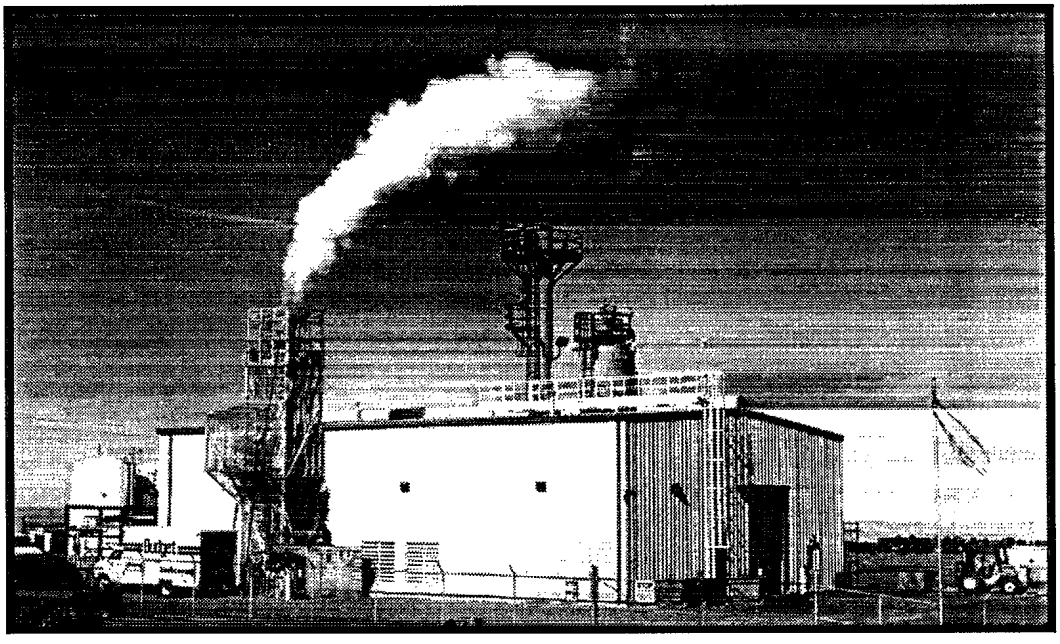
During the winter of 1991, bulk mustard was drained from pre- heated (20°C) 1-ton containers into heavy-walled, polyethylene-lined cardboard boxes and allowed to freeze under cool conditions (< 0°C). The boxes containing frozen mustard were then placed in sealed metal cargo containers and immediately transported to the incinerator site. The boxes were then off-loaded and processed via the rotary kiln solids feed system. All bulk mustard (3tonnes) was destroyed in this manner as part of the incinerator test burn program (see below).

Figure 2



Rotary Kiln and Solids Feed System

Figure 3



Exterior View of Incinerator Facility

Aged and thickened mustard (9 tonnes) contained in non-explosive ordnance items was destroyed following approval of the test burn results. Ordnance was punctured with small explosive perforating charges under cold conditions, sealed with adsorbent (vermiculite) in cardboard boxes and incinerated. The clean ordnance items were recovered from the ash discharge system and sold to a foundry for melting into recyclable metal.

*Lewisite*

Lewisite was processed using a skid-mounted apparatus which could accept bulk liquid metered in from 1-ton cylinders. During October 1991, the agent was destroyed in a three-step neutralization process: 1) conversion of lewisite to lewisite oxide (chlorovinyl arsine oxide) by addition of the agent to aqueous acidic hydrogen peroxide; 2) removal of excess peroxide by catalytic decomposition with manganese dioxide, and 3) conversion of lewisite oxide to arsenate and chloride salts by caustic addition with the production and controlled release of acetylene in a nitrogen-rich atmosphere. The resulting salt solution was mixed with sodium silicate, sodium sulphate and cement to produce a concrete-stabilized product for landfilling. The stabilized product readily passed leachate tests for arsenic-containing waste [5].

*Contaminated Scrap*

Contaminated, empty drums were shredded using a transportable metal shredder, packaged in cardboard boxes and fed into the incinerator via the solids feed system. The clean metal recovered from the ash discharge system was sold to a foundry and melted down into recyclable metal feedstock. Most of the scrap metal processing occurred during the warmer months.

## DESTRUCTION PROCESS PERFORMANCE

The EPP health risk study, which was based on highly conservative assessment criteria, showed that no measurable increase in health risks for workers or the general population in district communities would result from the proposed incineration.

Two separate test burns were conducted in accordance with the EPP to demonstrate that project emission limits could be met. First, sulphur hexafluoride ($SF_6$), a thermally-stable surrogate, was injected and burned to optimize operating conditions and demonstrate thermal destruction efficiency and acid gas removal capabilities. Batches of frozen mustard were then processed under the optimized conditions to establish system performance for regulatory approval. The $SF_6$ and mustard test burn results are summarized in Table III. All performance criteria were readily achieved with the exception of particulate emissions. This latter limit subsequently was met by placing 1-micron filter elements within the wet scrubber system and processing high-solids content waste at a reduced feed rate. The average mustard destruction efficiency (> 99.999987%) was calculated using the lower detection limit of the CSEM mustard analyzer, as no agent was detected by manual stack surveys.

Mustard and contaminated scrap were incinerated out over a ten-month period following approval of the test burns. During this time, the system availability averaged 55%, well below the industry average of 70-75% for solid waste incinerators. The prime cause was the need to perform frequent repairs to the refractory lining as a result of abrasion and impacts from the scrap metal feedstock. When operating, the system capably maintained stack emissions well within project limits and no stack excursions occurred while processing bulk mustard.

Air quality monitoring near the incinerator and in district communities showed [9,10] that measured stack emission concentrations were well within project limits and much lower than previously predicted [4]. For example, mobile monitoring carried out downwind at distances of 100 m, 200 m, 500 m, 1 km, 2 km and 5 km showed that agent incineration had little impact on ambient air quality, as illustrated in Figure 4. Sulphur dioxide and nitrogen dioxide concentrations were usually below the minimum

Table 3

**INCINERATOR TEST BURN RESULTS**

**TEST BURN 1**

$SF_6$ Destruction Efficiency: 99.9999972% (Target 99.9999%)
$SO_2$ Removal Efficiency: 98.3% (Target 95%)

**TEST BURN 2[a]**

| PARAMETER | AVERAGE CONCENTRATION ($mg/m^3$) | EMISSION LIMIT PERCENTAGE (%) |
|---|---|---|
| Particulates | 62.5 | 312.5 |
| $SO_2$ | 29.1 | 11.6 |
| $NO_x$ | 112 | 37.3 |
| HCl | 6.7 | 8.9 |
| CO | 49.6 | 87.0 |
| Mustard[b] | <0.002 | <6.7 |
| Dioxins/Furans[c] | $<0.1 \times 10^{-6}$ | <0.8 |

Average Mustard Destruction Efficiency: >99.999987%
Acid Gas Removal: 99.81% (HCl) 99.06% ($SO_2$)

a Test Burn 2 results are based on averaged stack sampling and continuous stack emission monitoring system data from four separate tests conducted under optimized conditions.

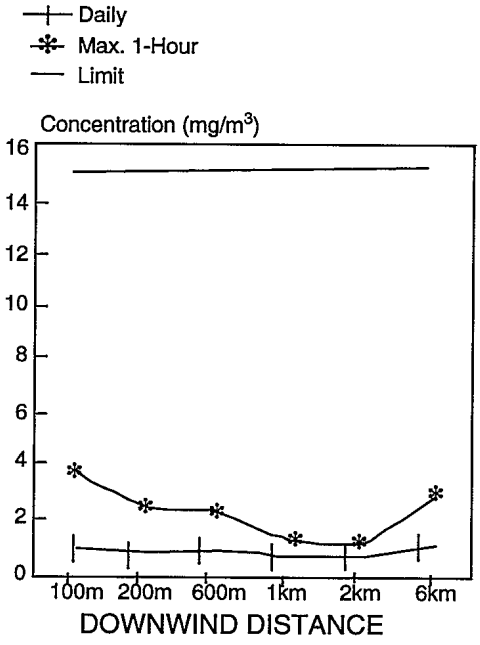
b Results are calculated based on the minimum detection limit of the stack mustard analyzer.

c No dioxins (T4CDD equivalent) detected. Furan concentrations range from 0.01 - 1.1 $ng/m^3$.

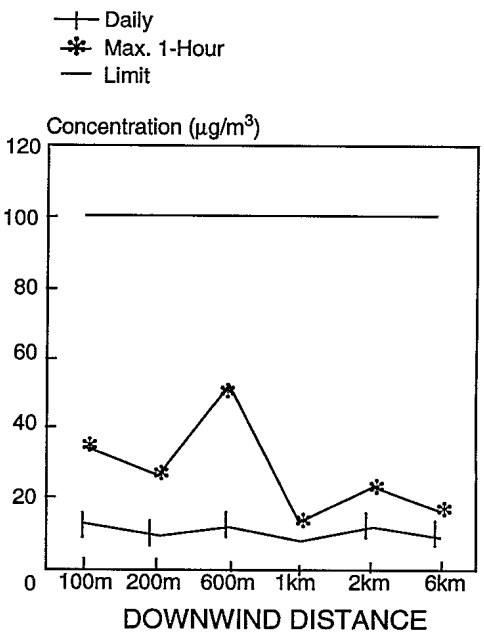
Figure 4

## Examples of Incinerator Emissions Monitoring Surveys

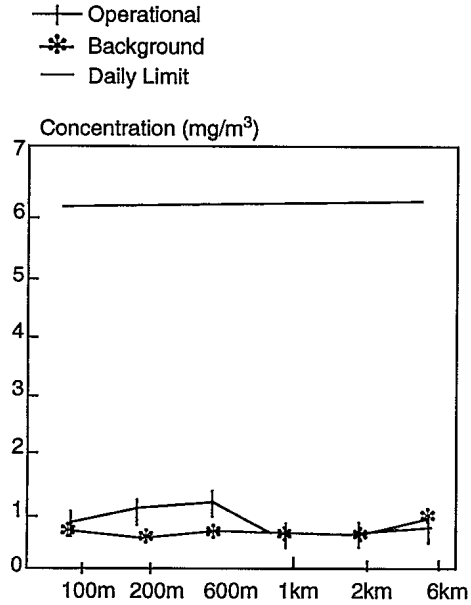
### CO CONCENTRATIONS VERSUS DISTANCE FROM INCINERATOR




### PARTICULATE CONCENTRATIONS VERSUS DISTANCE FROM INCINERATOR

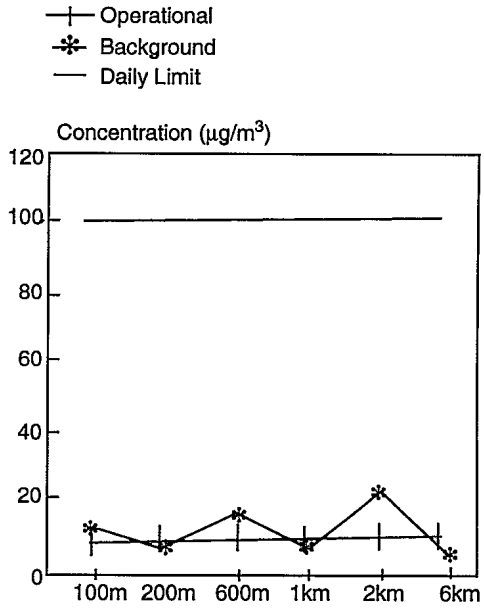



### CO PROFILES VERSUS INCINERATOR OPERATING STATUS




Average Data From All Data

### PARTICULATE PROFILES VERSUS INCINERATOR OPERATING STATUS




Average Data From All Data

the monitoring instrumentation. The concentrations of all parameters measured, including total suspended particulates, were well within air quality limits and could, in many cases, be related to other sources such as blowing dust or vehicular traffic.

Particulate samples collected and analyzed for chlorinated dioxins/furans and metals during incineration showed concentrations several orders of magnitude below current Environment Canada guidelines [11]. Evidence was inconclusive that the incinerator was the sole contributing source of these compounds. Overall, the monitoring programs showed that pre-operational air quality levels for the components measured were not significantly changed during operation of the Swiftsure incinerator.

## DISCUSSION

Project Swiftsure represented a first-case use of transportable incinerator of commercial design for the destruction of a chemical warfare agent (mustard) and agent neutralization products. A high degree of safety was achieved by freezing and packaging the mustard under cool ambient temperatures and processing the frozen mustard through the incinerator solids waste feed system, as opposed to pumping the agent to the incinerator in liquid form.

The comprehensive air quality monitoring program employed during the agent destruction operations confirmed the EPP risk assessment predictions and destruction performance expectations. For example, air quality measurements showed [9] that stack emission concentrations were well within project limits and much lower than previously predicted [4]. Overall, the measurements showed that, for the emissions monitored, normal air quality levels were not significantly changed during operation of the Swiftsure incinerator. This was in accord with the EPP risk assessment and supported the conclusion that the chemical agent wastes had been destroyed in a safe, environmentally responsible manner.

Through the public consultation program, public acceptance for the project goals was gained, effective dialogue was maintained and timely information was disseminated to show that destruction operations were proceeding safely. This program embodied approaches which allowed direct public participation in the development of the project Environmental Protection Plan. This, in turn, led to a more effective environmental assessment in terms of technical approaches and monitoring programs ultimately employed during agent destruction operations. Regulatory agency approval of the project and its proposed environmental protection measures was greatly expedited by addressing public concerns during development of the Environmental Protection Plan itself. This approach avoided the need for a full public (panel) review, a costly, time-consuming process which is usually required by EARPGO for controversial projects. Placing the EPP in district libraries proved an effective means of ensuring full public access to this important document.

Public consultation during agent destruction was maintained, primarily through the citizens' advisory group. Thus, air quality data could be provided to both the public and regulatory agencies in a timely manner which increased public confidence that safety and environmental protection were being implemented in accordance with the Environmental Protection Plan.

## CONCLUSIONS

Project Swiftsure was a unique and successful undertaking in Canada involving the destruction of chemical warfare agent waste using both in-house and contracted resources. Mustard agent in solidified form was destroyed effectively by direct incineration in a transportable, commercial two-stage incinerator system. Specialized chemical neutralization equipment was developed and successfully used for the destruction of small stocks of nerve agents as well as larger quantities of lewisite. A diverse air monitoring program verified that mustard incineration was conducted in a safe and environmentally responsible manner. During planning and subsequent agent destruction operations, a strong public consultation program led to public acceptance of the project goals and approaches.

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