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# AUTHORITY

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REPORT DRXTH-TE-CR-83208

DEVELOPMENT OF NOVEL DECONTAMINATION TECHNIQUES FOR
CHEMICAL AGENTS (GB, VX, HD) CONTAMINATED FACILITIES

Phase I - Identification and Evaluation of
Novel Decontamination Concepts

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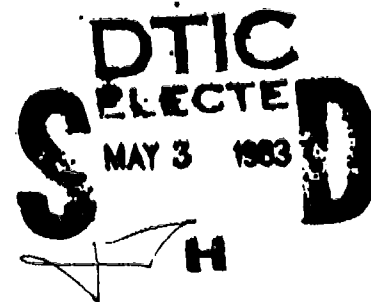
FEBRUARY, 1983

TASK FINAL REPORT FOR THE PERIOD MAY 1982 TO FEBRUARY 1983
VOLUME II OF TWO VOLUMES

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as an official Department of the Army position, policy or
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APPENDIX I

SUSCEPTIBILITY OF BUILDING MATERIALS TO DAMAGE

SUSCEPTIBILITY OF BUILDING MATERIALS TO DAMAGE

An important consideration in the decontamination of a building is the extent of damage to the building materials caused by the decontamination technique. Other than the physical/abrasive decontamination methods, damage can result from two forms of treatment, i.e. thermal and chemical. Thermal damage can result from exposure to the elevated temperatures achieved in thermal decontamination methods. Damage from chemicals can result from exposure to the chemicals used in either the chemical or physical decontamination methods. Each type of building material will have a different stability to thermal and chemical exposure with the extent of damage dependent on either the temperature or the nature of the chemical to which the material is exposed. The following section will discuss the effects of thermal and chemical exposure on specific building materials typical of agent production facilities, i.e. concrete, cement, steel, brick, terra cotta tile, Monel and glass. The major emphasis will be focused on concrete, cement, and steel, as these are the main building constituents.

Cement and Concrete

Thermal Stability

Although concrete is non-combustible, elevated temperatures have a significant influence on the properties of concrete.[1] The high temperature behavior of structural concrete is first observed at a lower boundary temperature of 100 C where free water starts to be driven off. In general, the engineering properties and behavior of concrete up to this temperature vary by only a few percent from those measured at room temperature. As the temperature is increased above 100 C, chemically bound water is progressively released from the hardened cement paste. Above about 150 C, cement dehydration reactions, thermal incompatibilities be-

tween paste and aggregate, and other physiochemical effects lead to thermal stresses, microcracking and a worsening of most structural properties (e.g. compressive strength, flexural strength, etc.).

In the range of 400-600 C dehydration of calcium hydroxide to form calcium oxide takes place. Other dehydration reactions, which are often irreversible, start as soon as desorption of evaporable water is completed and proceed up to a temperature of 800 C. Between 160 and 980 C calcium carbonate breaks down into calcium oxide with release of carbon dioxide. After exposure to sustained temperatures of 650 to 815 C, normal concrete is friable, highly porous, and, after cooling, usually can be taken apart with the fingers.

Thus, an absolute upper limit for non-destructive exposure at sustained temperatures can be taken as 650 C. However, within the allowable temperature range of 100-650 C, a wide variation of structural and thermal properties is expected.

When a concrete structure is exposed to elevated temperatures, the maximum allowable exposure temperature will depend largely on the extent of damage that is permissible. If no damage is permissible, then the allowable temperature range will be quite low. For most concrete structures, minimal damage is expected up to about 150 C. If some damage can be tolerated then the allowable temperature range will be increased. Between 200 and 400 C, most concrete remains substantially intact. However, some cracking may be produced and the flexural strength may be significantly reduced. Above 400 C, a rapid weakening of structurally important properties (e.g. compressive strength) typically occurs. Exposure to temperatures above 600 C results in extensive damage, and should be avoided. It should be noted that these temperature ranges are only approximate, and each specific type of concrete may exhibit different extents of stability. Also, the extent of damages by thermal expansion will depend on the structural configuration and presence of expansion joints.

The following guidelines provide measures to minimize concrete damage at a given temperature.

- Cyclic heating should be avoided.
- The duration of temperature exposure has little effect up to about 24 hours. Beyond this time, the duration should be kept to a minimum.
- Following high temperature exposure, slow cooling should be allowed. Once the concrete has cooled, soaking with water should follow to allow regain of compressive strength, etc.

Chemical Stability

In general, concrete has excellent resistance to chemical attack. There are a few chemical environments, however, than can cause concrete deterioration. In particular, many acid solutions and sulfate solutions are capable of deteriorating concrete. Table I-1 indicates the chemical effects of various materials on unprotected concrete.[2]

The rate of concrete attack in sulfate environments is usually quite slow. For example, aggressive industrial wastes with a high sulfate content have been reported to result in a reduction of wall thickness in concrete sewers of up to 1/4 inch per year.[3] In acid solutions, the rate of attack can be greater. For example, a 5% sulfuric acid solution (pH of 0.2) was reported to cause a 50% loss of weight from progressive surface deterioration after 12 weeks of immersion.[4] For a short term exposure, however, even this rate of attack would probably be permissible.

Thus, for short term exposure to most chemicals, concrete deterioration should not be a serious problem. However, many factors influence the rate of chemical attack, such as concrete type, surface coatings, temperature, concentration of aggressive chemical, etc., and therefore each specific chemical environment that is suspected of causing rapid deterioration should be further characterized.

TABLE I-1. EFFECT OF VARIOUS SUBSTANCES ON PORTLAND CEMENT CONCRETE
(Reference 2)

Material	Effect on Concrete
Acids	
Acetic.	Disintegrates slowly
Acid waters	Natural acid waters may erode surface mortar, but usually action then stops
Carbolic.	Disintegrates slowly
Carbonic.	Disintegrates slowly
Humic	Depends on humus material, but may cause slow disintegration
Hydrochloric.	Disintegrates
Hydrofluoric.	Disintegrates
Lactic.	Disintegrates slowly
Muriatic.	Disintegrates
Nitric.	Disintegrates
Oxalic.	None
Phosphoric.	Attacks surface slowly
Sulfuric.	Disintegrates
Sulfurous	Disintegrates
Tannic.	Disintegrates slowly
Salts and Alkalies (Solutions)	
Carbonates of	
Ammonia	None
Potassium	None
Sodium.	None
Chlorides of	
Calcium	None unless concrete is alternately
Potassium	wet and dry with the solution
Sodium.	
Strontium	
Chlorides of	
Ammonia	Disintegrates slowly
Copper.	Disintegrates slowly
Iron.	Disintegrates slowly
Magnesium	Disintegrates slowly
Mercury	Disintegrates slowly
Zinc.	Disintegrates slowly
Fluorides	None except ammonium fluoride
Hydroxides of	
Ammonia	None
Calcium	None
Potassium	None
Sodium.	None

Material	Effect on Concrete
Salts and Alkalies (Solutions) (Cont.)	
Nitrates of	
Ammonia.	Disintegrates
Calcium.	None
Potassium.	None
Sodium	None
Potassium Permanganate. . . .	None
Silicates.	None
Sulfate of	
Ammonia.	Disintegrates
Aluminum	Disintegrates; however, concrete
Calcium.	products cured in high-pressure
Cobalt	steam are highly resistant to
Copper	sulfates
Iron	
Manganese.	
Nickel	
Potassium.	
Sodium	
Zinc	
Petroleum Oils	
Heavy oils below 35° Baumé.	None
Light oils above 35° Baumé.	None
Benzine.	None
Gasoline	None
Kerosene	None
Naphtha.	None
High-octane gasoline. .	None
Coal-Tar Distillates	
Alizarin	None
Anthracene	None
Benzol	None
Cumol.	None
Paraffin	None
Pitch.	None
Toluol	None
Xylol.	None
Creosote	Disintegrates slowly
Cresol	Disintegrates slowly

TABLE I-1. (Continued)

Material	Effect on Concrete
Miscellaneous	
Alcohol.	None
Ammonia water (ammonium hydroxide). . .	None
Baking soda.	None
Bleaching solution . . .	Usually no effect
Borax, boracic acid, boric acid	No effect
Saltpeter.	None
Sugar.	Dry sugar has no effect on concrete that is thoroughly cured / Sugar solutions attack concrete
Sulfite liquor	Attacks concrete slowly
Trisodium phosphate. . .	None
Vinegar.	Disintegrates (see acetic acid)
Washing soda	None
Wood pulp.	None

Material	Effect on Concrete
Miscellaneous (Cont.)	
Brine (sal-).	Usually no effect on impervious concrete
Charged water	Same as carbonic acid—slow attack
Caustic soda.	None
Cinders	May cause some disintegration
Cyanide solutions . . .	Disintegrate slowly
Formalin.	Aqueous solution of formaldehyde disintegrates concrete
Glucose.	Disintegrates slowly
Glycerine	Disintegrates slowly
Lye	None
Niter	None
Sal ammoniac.	Same as ammonium chloride—causes slow disintegration
Sal soda.	None

Steel

Thermal Stability

Although steel is ncn-combustible, exposure to elevated temperatures can adversely effect its physical properties. From a structural viewpoint, the yield stress of steel is the significant parameter in establishing load carrying capacity. A temperature of about 600 C is normally considered to be the critical temperature.[4] At 600 C, the yield stress in the steel has decreased to about 60% of the 100 C temperature value which is approximately the level normally used as the design working stress. At temperatures above 600 C, the yield stress declines rapidly.

Another property of steel that has an effect upon its performance at elevated temperatures is its coefficient of thermal expansion. The linear coefficient of steel which increases with increasing temperatures affects a building structure in two ways. If the ends of a structural member are axially restrained, the attempted expansion due to the heat causes thermal stresses to be induced in the member. These stresses combine with those of the normal loading causing potential collapse. If the structure is not axially restrained, the increased stresses do not occur; instead, movement takes place. This movement causes the ends of steel columns to be moved laterally, producing an eccentrically loaded column. In other cases, walls can be moved to the point of collapse by expansion of beams. Thus, the maximum allowable temperature in steel members before thermal expansion becomes excessive depends largely on the specific structural configuration.

It should be recognized that the temperature of interest with respect to thermal expansion and yield stress values is the temperature within the steel, and not the ambient or surface temperature. For short term exposures, steel surfaces can be exposed to quite high temperatures without danger of weakening or thermal expansion of the entire member. However, since steel has a high thermal conductivity, it can rapidly at-

tain high internal temperatures and long term exposures at high temperatures should be avoided.

Chemical Stability

Corrosion of steel can occur in many chemical environments. In general, exposure to most acids should be avoided, except for short-term duration. The common alkalies such as caustic soda (NaOH) and caustic potash (KOH) are not particularly corrosive to steel, unless elevated temperatures are employed. Ammonia and ammonia solutions do not present difficult corrosion problems. Most organic solvents have little effect on steel.

Other Building Materials

Many materials other than concrete and steel are commonly used in building construction. Within the scope of the present project, the remaining materials of interest are brick, terra cotta tile, Monel and glass. These materials have widely varying thermal and chemical stability characteristics, and a detailed consideration of each material is not presently warranted. A few general considerations will be discussed, however.

Thermal Stability

Brick and terra cotta tile are quite stable at high temperatures. Monel has a melting point between 1300 and 1450 C. Window glass begins to soften in the 700 to 750 C range, but cracking can occur at much lower temperatures if thermal gradients are imposed.

Chemical Stability

Bricks and terra cotta tile are resistant to most chemical environments, except strong acid solutions. Glass and Monel are resistant to most corrosive chemicals.

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APPENDIX II

COST ANALYSIS

COST ANALYSIS

An order of magnitude cost analysis was performed on those concepts selected as the best concepts. The concepts are Hot Gases, Infrared Heating, Hydroblasting, RadKleen, Steaming, Vapor Circulation, Liquid Reactant, Gaseous Reactant and Volatilization/Aerosol Decontamination.

Several general assumptions were made to provide a basis for cost analysis including:

One site is analyzed. The site is comprised of three hypothetical structures in proximity to each other. Details of the structures are given in Section 3.4.2.

Each building contains a total of five tons of steel as equipment, piping, metal stairs, etc.

A maximum of one month decontamination time per building is allowed.

Capital Cost

Capital equipment costs were estimated from <u>Peterson and Timmerhaus</u> (P&T) (Reference 1) (adjusted to 1982$), <u>Means</u> (Reference 2), the <u>Decommissioning Handbook</u> (Reference 3), the <u>Chemical Marketing Reporter</u> (Reference 4) and in-house estimates. It was assumed that the equipment could be reused at each building.

Operating Costs

Operating costs are:

- Labor at $10/hour,
- Administration and Overhead at 4X labor cost,
- Materials/Other.

The labor cost includes labor for set-up, operation, tear-down, incineration, hauling to landfill, and refinishing building. Several assumptions made for the labor cost include:

- Equipment removal time is 75 percent of set-up time
- Normal clean-up requires 80 hours per building and includes repainting.

Estimates on labor time were also found in the previously cited references (1-3).

Administration and overhead includes purchasing, safety analysis, verification of decontamination, and normal amounts of utilities (steam, electricity, water, sanitary sewage). Large utility usage will be charged:

- Electricity $.06/kwhr.
- Steam $.01/lb.
- Kerosene $2/gal.

Waste disposal costs are assumed part of overhead if no unusual materials are treated. Each facility will be assumed to have a method of disposing of its manufacturing wastes. If unusual materials or quantities are generated, solid debris will be disposed of in either a hazardous landfill or by incineration at $25 per cubic foot. For liquid waste disposal, the facility will have a sanitary sewage treatment plant or access to a municipal plant. If other wastes are generated, a special facility for treatment or evaporation must be built and charged to capital cost or the wastes can be sent to a disposal company.

Materials costs will be the delivered price of the material. The material cost will be estimated from Chemical Marketing Reporter or a specialty chemical catalog.

Protective gear (non-agent) is $1,000. If agent protective gear is required then it is assumed the suit. are non-reusable. At a cost of $100 per suit and a working time of 2 hours, the cost of the suits per manhour is $50.

A summary of the costs and methods used to obtain equipment specifications follows.

Hot Gases

As described in Appendix III, the following equipment is required:

- Direct-Fixed Heater
- Turboblowers (2)
- Fan
- Absorber

Ancillary equipment and materials includes:

- Ductwork
- Kerosene
- Insulation

Direct-Fired Heater

The size of the direct-fired heater which supplies the hot gases can be determined from the heat duty requirements for the three buildings. The following are the heat duty requirements for the buildings.

Building	Total Heat (BTU)	Decontamination Time (hr)	Heavy Duty (BTU/Hr)
Concrete Block	167.2×10^6	40	4.2×10^6
Concrete	167.2×10^6	40	4.2×10^6
Terra Cotta	121.5×10^6	40	3.0×10^6

Thus, a direct fixed heater with a rated output of 10×10^6 BTU/hr would be more than sufficient to supply the required heat duty. A quote of \$25,000 was obtained from a manufacturer.

Turboblower

In order to size the turboblower, the volumetric flow rate of combustion gases must be calculated. Assume kerosene is used as the fuel and that it is composed of 88 wt percent carbon and 12 wt percent hydrogen. Then:

11.53 x wt fraction C + 34.34 x wt fraction H =

(lb air)/(lb fuel) (Stoichiometric)

11.53 x .88 + 34.34 x .12 = 14.27 (lb air)/(lb fuel

CO_2 = 3.66 x wt fraction C = 3.22 (lbs CO_2)/(lb fuel

H_2O = 8.94 x wt fraction H = 1.07 (lbs H_2O/(lb fuel)

Flue gas flow rate is then:

14.27/29 + 3.22/44 + 1.07/18 = 0.625 (lb moles)/(lb fuel)

= 224 ft^3/(lb fuel).

If the direct fired heater is operated at maximum, then with a heat of combustion of kerosene of 120,000 BTU/gal, the fuel requirements are=

10×10^6 BTU/hr x (1 gal)/(120,000 BTU) x 0.13368 ft^3/gal x

48.1 lb/ft^3 = 536 (lb fuel)/hr

The flue gas flow rate is then:

536 x 224 = 121,000 SCFH $\sim$ 2000 SCFM.

Peterson and Timmerhaus (P&T) give a cost of \$8700* for a 3 PSIG maximum pressure discharge, 2000 SCFM capacity turboblower.

Fan

Assume 1 equivalent air change in the building is desired every 5 minutes. Then for a 60x30x25 = 45,000 ft^3 building a 9000 CFM fan is required. The cost from P&T is $2300.*

Absorber

An absorber cost of $10,000 is assumed.

Ductwork

It will be assumed that the direct fired heater and turboblowers are installed, one per site, with ductwork carrying the flue gases being interchanged between buildings. For a 10 MPH output velocity at 2000 CFM:

$$2000 \text{ CFM } / [(10 \text{ MPH})/(60 \text{ minutes}) \times 5280] = 2.2 \text{ ft}^2$$

For an area of 2 ft^2, the cost (P&T) of insulated iron ductwork is about $7.00 per linear foot. Assume 100 feet are required.

Fuel Requirements

The fuel requirements are calculated from the building heat duty requirements as:

$$(167.2 \times 10^6 + 167.2 \times 10^6 + 121.5 \times 10^6) / 0.5 \text{ (efficiency) } /$$
$$120,000 \text{ BTU/gal} = 7600 \text{ gal} \times \$2.00/\text{gal} = \$15,200.$$

---

* Adjusted to 1982 dollars.

Insulation

According to previous calculations, insulation is required. For Metalized Polyester Facing insulation at R=13 (4 inches thick), the cost (Means) is $0.49/ft^2. The insulation will be assumed to be reusable on the three buildings.

Operating Time

Operating times were either obtained from P&T, Means or estimated. During actual decontamination activities it was assumed that two operators and one supervisor were required. A summary of the costs is given in Table II-1.

Infrared Heating

For simultaneous heating on both internal and external building surfaces the following heat duties are required:

Building	Total Heat (BTU)	Decontamination Time (hr)
Concrete Block	153.6x10^6	1/2
Concrete	152.6x10^6	1/2
Terra Cotta	109.7x10^6	1/2

It may not be feasibile to decontaminate the entire building at one time because of the power requirements. Commercially available infrared units rates at 18 KW are available as 1 foot x 5 feet units at a cost of $700 (quote). If 100 units are used then 250 ft^2 can be treated at one time (50 units on both sides of the building).

TABLE II-1.   HOT GASES CONCEPT COST ANALYSIS*

Total Labor Time = 1206 Hours

Labor Cost at $10/Hr:	$ 12,060
Overhead at 4 x Labor Cost:	48,240
Other Operating Costs:	19,300
TOTAL OPERATING COST:	79,600
TOTAL CAPITAL COST:	55,400
TOTAL COST:	$135,000

CAPITAL COST

Equipment Description	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Direct Fired Heater	10×10^6 Btu/hr	$25,000	Quote	1	$25,000
Turboblower	2000 CFM	8,700	P&T	2	17,400
Fan	9000 CFM	2,300	P&T	1	2,300
Absorber System	2000 CFM	10,000	Est.	1	10,000
Iron Ductwork (Insulated)	Linear ft	700	P&T	100	700
			TOTAL CAPITAL COST:		$55,400

OPERATING COST

Operation	Unit Size	Hours/ Unit	Units/ Site	Total Hours	Source
Building Preparation	Bldg	40	3	120	Estimate
Heater Installation	Site	60	1	60	P&T
Blower Installation	Site	70	2	140	P&T
Fan Installation	Bldg	10	3	30	Estimate
Absorber Installation	Site	40	1	40	Estimate
Insulation Installation	Bldg	45	3	135	Means
Ductwork Installation	Bldg	16	3	48	Means
Concrete Building Decontamination	Bldg	40	1	40	Sec. 3.5.6
Concrete Block Decontamination	Bldg	40	1	40	Sec. 3.5.6
Terra Cotta Decontamination	Bldg	40	1	40	Sec. 3.5.6
Equipment Removal	Site	135	1	135	Estimate
Insulation/Ductwork Removal	Bldg	46	3	138	Estimate
Cleanup	Bldg	80	3	240	Estimate
			TOTAL HOURS:	1206	

Other Operating Costs	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Insulation	Sq Ft	$0.49	Means	6300	$ 3,100
Fuel (Kerosene)	Gallon	2.00	Est.	7600	15,200
Protective Gear	--	--	--	--	1,000
			OTHER OPERATING COSTS:		$19,300

* In 1982 dollars.

The power requirements are:

$$(153.5 \times 10^6 + 153.5 \times 10^6 + 109.7 \times 10^6 \text{ BTU})/(3415 \text{ BTU/KWH}) =$$
$$122,000 \text{ KWH}$$

Operating Times

It was assumed that 0.1 hours were required to position each heater and 0.1 hours were required for wiring each time a heater was moved. For a 5 ft^2 heater, the total number of times that heaters must be set-up are

8100 ft^2/building x 3 buildings/site / 5 ft^2/heater = 4860.

It was assumed that two operators and one supervisor was required during actual decontamination. A summary of the costs is given in Table II-2.

Hydroblasting

A basic hydroblaster unit rate at 11 GPM at 10,000 PSIG was quoted from a manufacturer as costing $26,500 plus $6700 for accessories that allows cleaning the inside of tanks, pipes and sumps.

The Decommissioning Handbook (3) cites that a removal depth of 0.74 inches at a rate of 10 ft^2/hr is typical. The time required to decontaminate one building when two shifts are used is

8100 ft^2 / 16 hours/day / 10 ft^2/hr = 51 days.

Thus, two units are required to keep the decontamination time under one month per building.

A pump will be required to continuously remove water from the sumps. At a maximum hydroblasting rate of 11 GPM, a pump capable of 11 GPM and about 20 feet of head is required. The cost from P&T is about $850.

If the water is to be recycled, storage tanks are required. At a rate of 11 GPM x 60 x 16 hrs/day = 10,560 gal/day, a tank holding one

TABLE II-2. INFRARED HEATING CONCEPT COST ANALYSIS*

Total Labor Time = 1962 Hours	
Labor Cost at $10/Hr:	$ 19,620
Overhead at 4 x Labor Cost:	78,480
Other Operating Costs:	8,400
TOTAL OPERATING COST:	106,500
TOTAL CAPITAL COST:	88,000
TOTAL COST:	$194,500

CAPITAL COST

Equipment Description	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Infrared Heaters	18 kw	$800	Quote	100	$80,000
Wiring	--	--	Estimate	--	8,000
			TOTAL CAPITAL COST		$88,000

OPERATING COST

Operation	Unit Size	Hours/ Unit	Units/ Site	Total Hours	Source
Building					
Install IR Heaters	Heater	0.1	4860	486	Estimate
Wiring	Heater	0.1	4860	486	Estimate
Decon Concrete Bldg	250 ft^2	1.5	100	150	Sec. 3.5.6
Decon Block Bldg	250 ft^2	1.5	100	150	Sec. 3.5.6
Decon Terra Cotta Bldg	250 ft^2	1.5	100	150	Sec. 3.5.6
Cleanup	Bldg	80	3	240	Estimate
Equipment					
Install, Wire, Decon, Cleanup	Bldg	100	3	300	
			TOTAL HOURS:	1962	

Other Operating Costs	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Electricity	kwh	$0.06	Estimate	122,000	$7,400
Protective Gear	--	--	--	--	1,000**
			OTHER OPERATING COSTS:		$8,400

* In 1982 dollars

** If either a DPE, level A or level B unit is required, the cost could be as high as 1962 hrs x $50/hr = $98,100.

days supply would be 11,000 gallons. The cost of a mild steel tank, 11,000 gallon in size is $16,000. It is assumed that two tanks are required, one for recycle water to be fed to the hydroblaster and one for storage. If the hydroblaster removes 0.75 inches of surface from all the buildings, then disposal of $0.75/12 \times 8100$ ft^2 x 3 = 1520 ft^3 of debris is needed.

A summary of the costs is given in Table II-3.

RadKleen

In this cost estimate, a spray and vacuum type application method will be costed. An alternative method of application is by spraying. Here, the cost would be comparable to a liquid reactant application.

The cost of a RadKleen unit is estimated to be $45,000 which includes the unit and ancillary equipment such as vacuum/sprayer nozzles (Stanley Steamer®) adaptable to floors, pipes, tanks, walls, etc.

Data has shown that 90 percent decontamination (removal) of agent from cloth in <1 minute, butyl rubber in <2 minutes and webbing in <4 minutes. It is assumed that a 5 minute removal time is required for building materials. For a nozzle that covers an area of 1 ft^2 a building of 60x30x25 feet will require 8100 ft^2 x 5/60 = 675 manhours to clean.

A summary of the costs is given in Table II-4.

Steaming (External)

Assume 100C steam is available at $0.01/lb. Assume one complete changeover of the building atmosphere every two hours (one building volume of steam required every two hours) for a total of 5 days. Then, the steam required is:

(60x30x25 ft^3)/(26.8 ft^3/lb) = 1680 lb every 2 hours = 840 lbs/hr.
840 lb/hr x 120 hrs = 100,800 lbs of steam per building.

TABLE II-3. HYDROBLASTING CONCEPT COST ANALYSIS*

Total Labor Time = 2960 Hours		
Labor Cost at $10/Hr:	$ 29,600	
Overhead at 4 x Labor Cost:	118,400	
Other Operating Costs:	39,000	
TOTAL OPERATING COST:	$187,000	
TOTAL CAPITAL COST:	$ 92,750	
TOTAL COST:	$279,750	

CAPITAL COST

Equipment Description	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Hydroblaster	10,000 psi	$26,500	Quote	2	$53,000
Pipe and Tank Cleaning Accessories	--	6,700	Quote	1	6,700
Sump Pump	11 GPM	850	P&T	1	850
Storage Tank	11,000 Gal	16,100	P&T	2	32,200
				TOTAL CAPITAL COST:	$92,750

OPERATING COST

Operation	Unit Size	Hours/ Unit	Units/ Site	Total Hours	Source
Tanks/Pump Setup	Site	80	1	80	Estimate
Equipment Setup	Day	1	90	90	Estimate
Building Hydroblasting	10 ft^2	1	2430	2430	Ref. 3
Equipment Hydroblasting	Bldg	80	3	240	Estimate
Cleanup (Painting only)	Bldg	40	3	120	Estimate
			TOTAL HOURS:	2960	

Other Operating Costs	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Debris Landfill	ft^3	$25	Estimate	1520	$38,000
Protective Gear	---	---	---	---	1,000**
			OTHER OPERATING COSTS:		$39,000

* In 1982 dollars.

** If either a DPE, level A or level B gear is required, the cost could be as high as $50/hr x 2960 hrs = $148,000.

TABLE II-4. RADKLEEN CONCEPT COST ANALYSIS*

Total Labor Time = 2595 Hours	
Labor Cost at $10/Hr:	$ 25,950
Overhead at 4 x Labor Cost:	103,800
Other Operating Costs:	16,350
TOTAL OPERATING COST:	146,100
TOTAL CAPITAL COST:	45,000
TOTAL COST:	$191,100

CAPITAL COST

Equipment Description	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
RadKleen Unit (Includes Ancillary equipment)	--	$45,000	Estimate	1	$45,000

OPERATING COST

Operation	Unit Size	Hours/ Unit	Units/ Site	Total Hours	Source
Equipment Setup/Teardown	Day	1	90	90	Estimate
Building Decontamination	Bldg	675	3	2025	Estimate
Equipment Decontamination	Bldg	80	3	240	Estimate
Cleanup	Bldg	80	3	240	Estimate
			TOTAL HOURS:	2595	

Other Operating Costs	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Freon 113	Gal	$12	Ref. 4	1000	$12,000
Incineration of Waste— Freon	ft^3	25	Estimate	134	3,350
Protective Gear	--	--	--	--	1,000**
			OTHER OPERATING COSTS:		$16,350

* In 1982 dollars.

** If agent protective gear is required, the cost could be as high as 2595 hrs x 50 = $129,750.

The steam will condense and the water is collected in a 2000 gallon sump. A pump is required to remove the water at a rate of (840 lbs/hr)/(60 lb/ft^3) = 14 ft^3/hr = 2 GPM.

The water is collected in a tank which can hold about one day's supply or 840 lb/hr x 24 hrs / 60 lb/ft^3 = 336 ft^3 = 2500 gal. A 3000 gallon tank is required. The cost from P&T for a 3000 gallon mild steel tank is $8700.

During decontamination it is assumed that one operator and one supervisor are required.

A summary of the costs is given Table II-5.

Vapor Circulation

In order to cost the Vapor Circulation Concept several assumptions must be made:

- Average porosity of building materials is 15%.
- Assume solvent penetrates into all building materials to a depth of 1 inch
- Assume five changes of solvent required and each change requires 24 hours.
- Acetone is the solvent.
- Boiler for acetone operates at 100 C.
- Building is kept at b.p. of acetone (56.2C=133F).
- Mild steel equipment used.

For acetone = M = 58 lb/lbmole

ρ = 49.3 lb/ft^3

ΔH vaporization = 237 BTU/lb

P_{vapor} = 52 PSIA at 100C

TABLE II-5. STEAMING CONCEPT COST ANALYSIS*

Total Labor Time = 1990 Hours
Labor Cost at $10/Hr: $14,900
Overhead at 4 x Labor Cost: 59,600
Other Operating Costs: 4,020
              TOTAL OPERATING COST: 78,520
              TOTAL CAPITAL COST: 11,200
                 . TOTAL COST: $89,720

CAPITAL COST

Equipment Description	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Plumbing	--	--	Estimate	--	$ 2,000
Pump	2 GPM	500	Estimate	1	500
Storage Tank	3000 Gal	$8,700	P&T	1	8,700
				TOTAL CAPITAL COST:	$11,200

OPERATING COST

Operation	Unit Size	Hours/ Unit	Units/ Site	Total Hours	Source
Building Preparation	Bldg	80	3	240	Estimate
Plumbing	Site	250	1	250	Estimate
Equipment Setup	Bldg	40	3	120	Estimate
Cleanup	Bldg	40	3	120	Estimate
Equipment Removal	Site	40	1	40	Estimate
Decontamination	Bldg	240	3	720	Estimate
			TOTAL HOURS:	1490	

Other Operating Costs	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Protective Gear	--	--	--	--	$1,000**
Steam	1 lb	$0.01	Estimate	302,000	3,020
			OTHER OPERATING COSTS:		$4,020

* In 1982 dollars.

** It is anticipated that agent protective gear will not be required.

Acetone Flow Rate

For 1 building decontaminated at a time:

8100 ft^2 x 1/12 ft penetraation x 0.15 porosity = 101 ft^3

= 4979 lbs acetone

If all solvent is exchanged in 24 hours then 4979/24 = 207 lbs/hour = acetone flow rate.

Acetone Supply

At the beginning of operations, the building atmosphere must be permeated with acetone vapor. The quantity of acetone required for the building atmosphere is:

(14.7x144x45,000 ft^3)/[(460 + 133 bp ^{o}R)(1545)] =

104 lbmoles = 6030 lb acetone

For a supply of acetone equivalent to two solvent changes plus the vapor in the room, 2x4979 + 6030 = 16,000 lbs acetone is required.

If the acetone is recycled in one building and then incinerated, a total supply of 16,000x3 bldgs / 49.3 / 0.13368 = 7300 gallons is required.

Acetone Heater

Assume the initial acetone temperature is 70F and it is raised to 212F. Then assuming an average specific heat of 0.55 BTU/lb F, then:

q = m[Cp T + ΔH vaporization]

= 207 lb/hr [0.55 (212-70) + 237 BTU/lb]

= 65,226 BTU/hr

For a 75 percent efficiency, 65300 / 0.75 / 3514 = 25 KW heater is required. The cost from P&T for an immersion heater is $1000.

Heating Tank

For a flow rate of 207 lb/hr and a 10 hour supply a 400 gallon mild steel vessel will be required at a cost of $9000.*

Storage Tank

The tank size required is 16,000 / 49.3 / 0.13368 $\sim$ 2500 gallons. A spherical mild steel, 2500 gallon capacity storage vessel costs about $15,000 (P&T).

Decontamination Time

The total time required for one building is calculated as follows: time to first solvent exchange = (4979 + 6030) / 207 lb/hr = 50 hours. The total time is then 50+24x4 = 146 hours. It is assumed that two operators and one supervisor are required during decontamination.

A summary of the costs is given in Table II-6.

Liquid Reactant

This general cost analysis would be applicable to all of the chemical concepts which use a liquid reactant for decontamination.

Several assumptions must be made prior to evaluation of the cost:

- The liquid is sprayed on.
- Ten applications of the spray are required.
- The liquid would cover 100 ft^2/gallon for concrete and terra cotta.

---

* Note: at 100 PSIG.

TABLE II-6. VAPOR CIRCULATION CONCEPT COST ANALYSIS*

Total Labor Time = 2304 Hours	
Labor Cost at $10/Hr:	$ 23,040
Overhead at 4 x Labor Cost:	92,160
Other Operating Costs:	40,255
TOTAL OPERATING COST:	155,455
TOTAL CAPITAL COST:	29,000
TOTAL COST:	$184,455

CAPITAL COST

Equipment Description	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Acetone Vaporizer System					
--Immersion Heater	25 kw	$ 1,000	P&T	1	$ 1,000
--Heating Vessel	400 gal at 100 psig	9,000	P&T	1	9,000.
Storage Tank	2500 gal	15,000	P&T	1	15,000
Pumps	1 GPM	500	Estimate	2	1,000
Blower	25 CFM	1,000	Estimate	1	1,000
Plumbing	---	2,000	Estimate	1	2,000
				TOTAL CAPITAL COST:	$29,000

OPERATING COST

Operation	Unit Size	Hours/ Unit	Units/ Site	Total Hours	Source
Building Preparation	Bldg	80	3	240	Estimate
Equipment Setup	Site	160	1	160	Estimate
Plumbing	Site	230	1	230	P&T
Building Decontamination	1 hour of decon time	3	438	1314	Estimate
Cleanup	Bldg	80	3	240	Estimate
Equipment Removal	Site	120	1	120	Estimate
			TOTAL HOURS:	2304	

Other Operating Costs	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Acetone	1b	$0.31	Ref. 4	48,000 lb	$14,880
Incineration of Waste					
Acetone	ft^3	$25	Estimate	975 lb	24,375
Protective Gear	--	--	--	--	1,000**
			OTHER OPERATING COSTS:		$40,255

* In 1982 dollars.

** Agent protective gear not anticipated to be required.

- The liquid would cover 25 ft²/gallon for concrete block.
- 50 percent of the spray adheres to or penetrates the building material with the remainder being recycled.
- The spray operation requires one operator and one supervisor.
- An average cost of liquid reactant of $10,00 per gallon.
- The liquid reactant will either permeate through or remove paint.

A summary of the costs is given in Table II-7.

Gaseous Reactant

In this concept gas cylinders are opened and the gas directed into a sealed building. Air is withdrawn from the building and passed through a scrubber until a high gas concentration is achieved. The building is then sealed, allowing the gas to permeate through the building materials for two weeks. Periodic monitoring (4 hours per day) is performed during this period. A summary of the costs is given in Table II-8.

Volatilization/Aerosol Decontamination

For infrared heating of the external building surfaces the following heat duties are required.

	Total Heat (BTU)	Decontamination Time (hr)
Concrete block	68.9×10^6	9.8
Concrete	91.8×10^6	17.4
Terra Cotta	53.1×10^6	14.6
Concrete floors	24.4×10^6	36

TABLE II-7. LIQUID REACTANT CONCEPT COST ANALYSIS*

Total Labor Time = 1454 Hours	
Labor Cost at $10/Hr:	$14,540
Overhead at 4 x Labor Cost:	58,160
Other Operating Costs:	11,000
TOTAL OPERATING COST:	83,700
TOTAL CAPITAL COST:	9,230
TOTAL COST:	$92,930

CAPITAL COST

Equipment Description	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Pressure Sprayer	240 GPH	$3,270	Quote	1	$3,270
Accessories	--	1,960	Quote	1	1,960
Sump Pump	--	500	Estimate	1	500
Storage Tank	1000 gal	3,500	Quote	1	3,500
			TOTAL CAPITAL COST:		$9,230

OPERATING COST

Operation	Unit Size	Hours/ Unit	Units/ Site	Total Hours	Source
Tank, Pump Setup	Site	40	1	40	Estimate
Equipment Setup	Day	1	62	62	Estimate
Spray Application to Building	4000 ft^2	16	62	992	Means
Spray Application to Equipment/Piping	Bldg	40	3	120	Estimate
Cleanup	Bldg	80	3	240	Estimate
			TOTAL HOURS:	1454	

Other Operating Costs	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Liquid Reactant	Gal	$10	Estimate	1000	$10,000
Protective Gear	--	--	--	--	1,000**
			OTHER OPERATING COSTS:		$11,000

* In 1982 dollars.

** If a DPE, level A or B gear is required, then the cost may be as high as 1454 hrs x 50 = $72,700.

TABLE II-8. GASEOUS REACTANT CONCEPT COST ANALYSIS*

Total Labor Time = 1020 Hours	
Labor Cost at $10/Hr:	$10,200
Overhead at 4 x Labor Cost:	40,800
Other Operating Costs:	2,000
TOTAL OPERATING COST:	53,000
TOTAL CAPITAL COST:	8,000
TOTAL COST:	$61,000

CAPITAL COST

Equipment Description	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Turboblower	100 CFM	$1,500	P&T	1	$1,500
Scrubber System	--	5,000	Est.	1	5,000
Gas Regulators	--	150	Est.	10	1,500
			TOTAL CAPITAL COST:		$8,000

OPERATING COST

Operation	Unit Size	Hours/ Unit	Units/ Site	Total Hours	Source
Building Sealing	Bldg	80	3	240	Estimate
Equipment Setup	Bldg	80	3	240	Estimate
Bldg Decontamination	Bldg	100	3	300	Estimate
Cleanup	Bldg	80	3	240	Estimate
			TOTAL HOURS:	1020	

Other Operating Costs	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Gas	--	--	Estimate	--	$2,000

* In 1982 dollars.

Since the power required is within that anticipated to be available at the site, the entire building may be treated at one time. However, at a cost of $800 per heater (Quote), a total of 6300 ft^2 / 5 ft^2 per heater = 1260 heaters x 800 = $1.0 million. Thus, the cost is exorbitant. It will be assumed that 100 heaters are purchased so 500 ft^2 of area can be heated at one time. It will also be assumed that only a supervisor is required during actual decontamination. Other times were taken from the Infrared Concept Cost Analysis (Table III-2).

The total power requirements are:

$(68.9 \times 10^6 + 91.8 \times 10^6 + 53.1 \times 10^6 + 3 \times 24.4 \times 10^6) / 3415 = 84,000$ KWH

The aerosol system will consist of an aerosol generator, blower, sump pump, storage tanks and the necessary piping to allow recycle of the decontaminant. The total cost is estimated to be 10,000.

A summary of the costs is given in Table II-9.

REFERENCES

1. <u>Plant Design and Economics for Chemical Engineers,</u> 3rd Edition, M.S. Peters and K. D. Timmerhaus

2. <u>Means Building Construction Cost Data</u> 1982, 40th Edition, Edited by R. S. Godfrey

3. <u>Decommissioning Handbook DOE/EV/10128-1</u> Prepared by W. J. Manion and T. S. LaGuardia, 1980

4. <u>Chemical Marketing Reporter,</u> October 11, 1982 Issue

TABLE II-9. VOLATILIZATION/AEROSOL DECONTAMINANT
CONCEPT COST ANALYSIS*

Total Labor Time - 2611 Hours	
Labor Cost at $10/Hr:	$ 26,110
Overhead at 4 x Labor Cost:	104,440
Other Operating Costs	16,040
TOTAL OPERATING COST:	146,590
TOTAL CAPITAL COST:	98,000
TOTAL COST:	$244,590

CAPITAL COST

Equipment Description	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Infrared Heaters	18 kw	$800	Quote	100	$80,000
Wiring	--	---	Estimate	--	8,000
Aerosol Generator System	---	--	Estimate	--	10,000
			TOTAL CAPITAL COST:		$98,000

OPERATING COST

Operation	Unit Size	Hours/ Unit	Units/ Site	Total Hours	Source
Building					
Install IR Heaters	Heater	0.1	4860	486	Estimate
Wiring*	Heater	0.1	4860	486	Estimate
Decon Conrete Bldg	500 ft^2	17.4	13	226	Section
Decon Concrete Block Bldg	500 ft^2	9.8	13	127	Sec. 3.5.6
Decon Terra Cotta Bldg	500 ft^2	14.6	13	190	Sec. 3.5.6
Decon Concrete Floor	500 ft^2	36	11	396	Sec. 3.5.6
Aerosol Generation System Setup	Each	160	1	160	Estimate
Cleanup	Bldg	80	3	240	Estimate
Equipment					
Install, Wire, Decon, Cleanup	Bldg	100	3	300	Estimate
			TOTAL HOURS:	2611	

Other Operating Costs	Unit Size	Unit Cost	Source of Cost	Number Required	Total Cost
Electricity	KWH	$0.06	Estimate	84,000	$ 5,040
Protective Gear	--	--	--	--	1,000**
Decontaminating Solution	Gal	$10	Estimate	1,000	10,000
			OTHER OPERATING COSTS:		$16,040

* In 1982 dollars.

** It is anticipated that agent protective gear will not be required.

APPENDIX III

CONCEPT DESCRIPTIONS

THERMAL DECOMPOSITION USING FLASHBLASTING

1.0 General Description

1.1 Summary of Idea
The flashblast device consists of a high intensity Xenon-quartz strobe light which can be focused onto a contaminated surface. The high energy light pulse produces enough heat to remove paint and rust and to thermally decompose surface contaminants.

1.2 Origination of Idea
Developed by Dr. John Asmus of Maxwell Laboratories. (Johnson, 1982).

1.3 Obvious Advantages and Disadvantages
Advantages. Prior paint removal not necessary. Less clean-up as compared with abrasive removal techniques. Volatilization of agent is not anticipated.

Disadvantages. Only effective as a surface treatment. Not easily adaptable to intricate surface areas.

1.4 Variations of Idea
None.

1.5 Sketch
None.

2.0 Chemical Decomposition Treatment
See general discussion of thermal decomposition.

2.1 Chemical Reactions
GB, HD and VX undergo thermal decomposition by either pyrolysis in inert atmospheres or oxidation (combustion) in excess air.

<u>GB Pyrolysis</u> (325-900 C)

$$CH_3-\overset{O}{\underset{OC_3H_7}{\overset{\|}{P}}}-F \longrightarrow CH_3-\overset{O}{\underset{OH}{\overset{\|}{P}}}-F + CH_2 = CHCH_3$$

<u>GB Oxidation/Combustion</u> (250-1050 C)

$$2\ CH_3-\overset{O}{\underset{OC_3H_7}{\overset{\|}{P}}}-F + 13O_2 \longrightarrow 8CO_2 + 9H_2O + P_2O_5 + 2HF$$

<u>HD Pyrolysis</u> (180-900 C)

Main Reaction: $S(CH_2CH_2Cl)_2 \longrightarrow H_2S + 2CH_2=CHCl$

HD Oxidation/Combustion (250-1000 C)

$$S(CH_2CH_2Cl)_2 + \frac{13}{2} O_2 \longrightarrow 4CO_2 + 3H_2O + 2HCl + SO_2$$

VX Pyrolysis
See general discussion.

VX Oxidation/Combustion (600-1200 C)

$$2C_{11}H_{26}O_2PSN + \frac{79}{2} O_2 \longrightarrow P_2O_5 + 2NO_2 +$$

$$22CO_2 + 26H_2O + 2SO_2$$

2.2 Hazardous Products
The oxidation/combustion products of the agents are relatively non-toxic gaseous and volatile species. However, reports of potentially hazardous pyrolysis products of the agents have been reported for HD including: Ethyl Mercaptan; Diethyl Sulfide; and Vinyl Chloride.

2.3 Destruction Efficiency, Residue Level
Complete decomposition of the agents is anticipated if the agent can be maintained at the decomposition temperature for the prescribed period of time. For example, complete decomposition of GB by pyrolysis was observed after heating at 150 C for 2-1/2 hours (Anonymous, 1974)

2.4 Reaction Rate/Kinetics

$$- \frac{d(Vx)}{dt} = [9.6 \times 10^8 \exp (-14,000/T(°K)](VX)$$

$$- \frac{d(GB)}{dt} = [1.5 \times 10^8 \exp (-11,700/T(°K)](GB)$$

$$- \frac{d(HD)}{dt} = [1.8 \times 10^9 \exp (-12,632/T(°K)](HD)$$

where (VX), (GB), (HD) = concentration of the
the respective agent
t = time (sec)
T = temperature (°K)

2.5 Supplementary Treatment
Supplementary treatments may be required to remove and/or decompose the thermal decomposition products of HD, GB and VX if pyrolysis rather than oxidation occurs.

2.6 State-of-the-Art
Several studies have been performed on the pyrolysis and

oxidation/combustion of agents including several references
(Pugh, 1970; Hildebrandt, 1972; Lapp, 1962; Sass, 1972;
Tomlinson, 1980; Williams, 1947; Reeves, 1954; Brooks 1979).
See general discussion of state-of-the-art.

3.0 Physical Treatment
   Not applicable.

4.0 Applicability

   4.1 Agent Applicability
       Potentially applicable to all agents.

   4.2 Isolated Building Material Applicability
       Applicable to all building materials of interest.

       4.2.1 Impact of Substrate on Chemistry
             The adsorption of contaminant on particular substrates
             may inhibit decomposition, but it is anticipated that
             this effect will be small.

       4.2.2 Removal or Reaction of Contaminant from Surface
             Surface reaction is highly probable. Extent of
             reaction per blast is uncertain. Numerous blasts may
             be required for complete destruction.

       4.2.3 Removal or Reaction of Contaminant from Interior
             Only shallow penetration is possible.

       4.2.4 Damage to Material
             Minimal damage anticipated.

   4.3 Practical Applicability to Building

       4.3.1 Building Preparation
             None required.

       4.3.2 Practical Physical Limitations/Methods to Overcome
             Not well suited to intricate surface areas.
             Restricted to line of sight locations.

       4.3.3 Secondary Decontamination Treatment
             Subsurface treatment using an alternative method will
             be necessary.

       4.3.4 Clean-up Requirements
             Removal of surface char may be necessary.

   4.3.5 Waste Treatment and Disposal
             None anticipated.

4.4 State-of-the-Art

The method has never been used for building decontamination.
It has been successfully employed as a surface cleaning
technique in a variety of applications, including removal of
slime from submarine hulls and removal of paint and rust from
metals (Johnson, 1982).

5.0 Engineering

5.1 Process Description

5.1.1 Main process

| FLASH BLASTER SET-UP | → | FLASH BLAST DECONTAMINATION | → | CHAR REMOVAL (CLEAN-UP) | → | SECONDARY DECONTAMINAT |
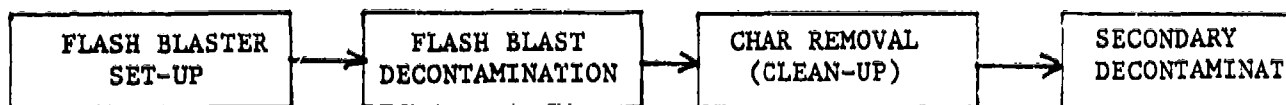
5.1.1.1 Flashblast treatment

The flashblast device would be applied to
conveniently sized sections in an orderly
manner so that all accessible areas would be
decontaminated.

5.1.1.2 Char removal

Painted surfaces will become charred, so char
removal will be necessary.

5.1.2 Variations

Remote operation may be possible.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

5.2.1.1 Flashblast device

The flashblast device consists of water
cooled Xenon-quartz lamps contained in a
planar array. A three-phase power line feeds
a bank of capacitors, which accumulate the
electrical charge required for each blast.
The lamps turn on for as little as 1
millisecond, and generate enough heat to
raise the temperature to 1800 C at
approximately 3/4 of an inch away. Typical
units range from 2 x 12" to 7 x 7" in size.
An expanded unit (36 x 36" for example) could
be designed for large areas, with possible
adaption for remote control (Johnson, 1982).

5.2.1.2 Char removal equipment

Surface char can be readily removed by water
wash and/or abrasive scrubbing.

5.2.2 Reliability, Availability and Maintainability
Typically the lamps are good for a half-million blasts.

5.3 Decontamination Time

5.3.1 Set-up
Involves installation of electrical connectors, water cooling and accessories, and possibly a remote control system.

5.3.2 Application Time

5.3.2.1 Personnel
Operation of flashblast device would require substantial labor involvement unless a remote control system is employed.

5.3.2.2 Decontamination
The time interval between blasts and number of blasts required per unit area need to be determined. Lengthy decontamination times are anticipated because only small sections are decontaminated at one time.

5.3.2.3 Verification
Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Removal of electrical connections and accessories, and remote control system (if employed) would be rapid.

5.3.3.2 Clean-up
Char removal would require low to moderate time.

5.4 Safety Requirements

5.4.1 Process Hazards
None anticipated.

5.4.2 Personnel Hazards
Burns, high intensity light, toxic vapors.

5.4.3 Protective Methods
Wear heat resistant clothing, safety glasses, gloves, etc.

Use adequate ventilation or respiratory equipment.
Avoid exposure by remote operation.

6.0 Economics

6.1 Building Damage - Repair Costs
None anticipated.

6.2 Developmental Costs
Testing of flashblasting on a variety of substrates and contaminants.
Design and construction of large area flashblast unit.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Electrical requirements may be substantial.

6.3.2 Equipment Cost
Cost of flashblast unit and accessories.

6.3.3 Material Cost
None anticipated.

6.3.4 Manpower Cost
High labor cost. Involves flashblast operation, either manual or remote operation.

7.0 Future Work Required

7.1 Knowledge Gaps

Extent of surface reaction per blast.

7.2 Resolution
Experimental testing.

THERMAL DECOMPOSITION USING ELECTRICAL RESISTANCE CONTACT HEATING

1.0 General Description

1.1 Summary of Idea
This is a method of thermally decomposing and/or volatilizing agents within building materials. The resistance heat would be applied to the surface and would penetrate to the interior of the building material. By adjusting the temperature, the thermal decomposition of contaminants present could be achieved, within the constraints of the building materials's thermal durability.

1.2 Origination of Idea
Novel Processing Project Team.

1.3 Obvious Advantages and Disadvantages
Advantages. This approach may be better for subsurface treatment than most other thermal methods because of the possibility for greater temperature control, less extreme temperature gradients, and capability for vacuum removal of degassed components.

Disadvantages. Not easily adaptable to intricate surface areas. Building materials may suffer damage from thermal effects. Temperature gradient may volatilize agents and cause vapors to penetrate deeper into the building material by thermal diffusion.

1.4 Variations of Idea
For large, obstruction free surface areas, heating plates (with vacuum as required) could be directly applied. For intricate surface areas, heating plates could be placed at a convenient distance or heating type could be directly applied, although under these conditions vacuum application would probably not be feasible. Diffusion of volatilized agents outward may be overcome by heating the material from both sides (if accessible) or by heating very slowly to minimize the temperature gradient. Alternatively, a vacuum system could be employed to remove volatiles.

1.5 Sketch
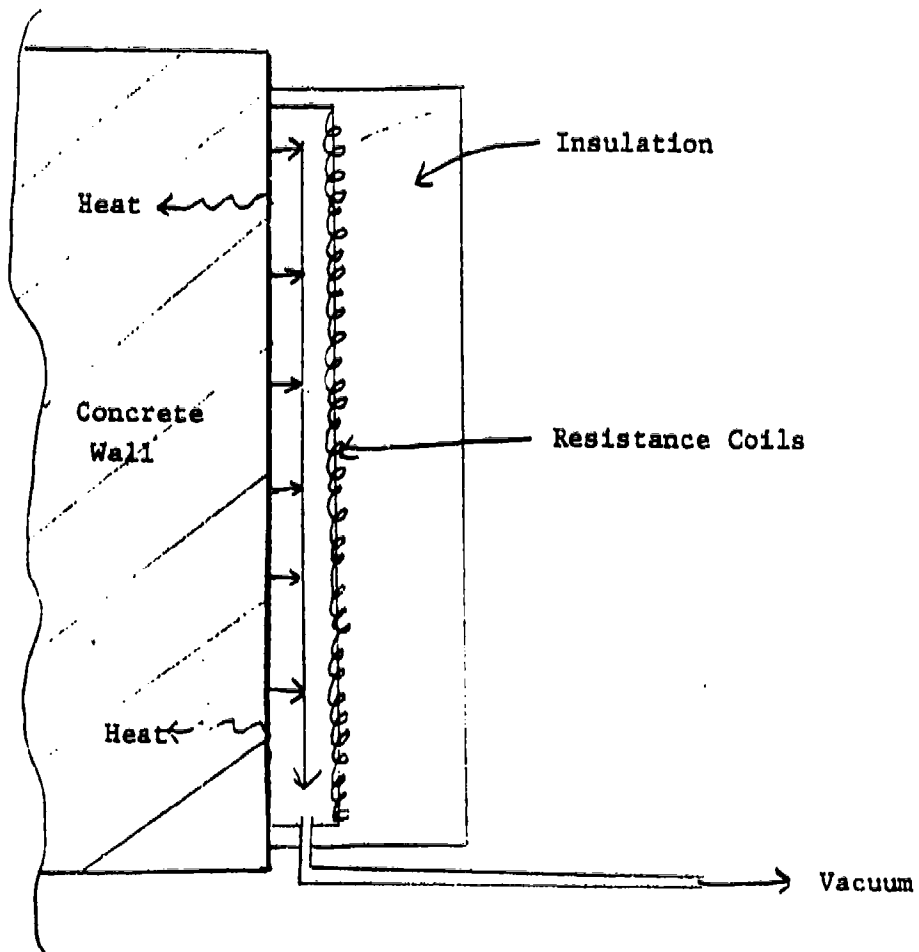See page III-8.

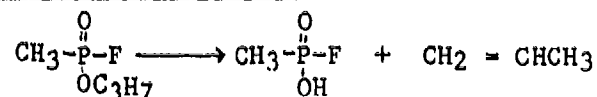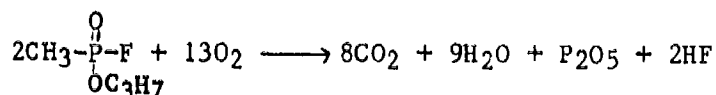2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions
GB, HD and VX undergo thermal decomposition by either pyrolysis in inert atmospheres or oxidation (combustion) in excess air.

Contact Heating with Vacuum

GB Pyrolysis (325-900 C)

$$CH_3-\overset{\overset{O}{\|}}{\underset{OC_3H_7}{P}}-F \longrightarrow CH_3-\overset{\overset{O}{\|}}{\underset{OH}{P}}-F + CH_2 = CHCH_3$$

GB Oxidation/Combustion (250-1050 C)

$$2CH_3-\overset{\overset{O}{\|}}{\underset{OC_3H_7}{P}}-F + 13O_2 \longrightarrow 8CO_2 + 9H_2O + P_2O_5 + 2HF$$

HD Pyrolysis (180-900 C)

Main Reaction: $S(CH_2CH_2Cl)_2 \longrightarrow H_2S + 2CH_2=CHCl$

HD Oxidation/Combustion (250-1000 C)

$$S(CH_2CH_2Cl)_2 + \frac{13}{2} O_2 \longrightarrow 4CO_2 + 3H_2O + 2HCl + SO_2$$

VX Pyrolysis
See general discussion.

VX Oxidation/Combustion (600-1200 C)

$$2C_{11}H_{26}O_2PSN + \frac{79}{2} O_2 \longrightarrow P_2O_5 + 2NO_2 +$$

$$22CO_2 + 26H_2O + 2SO_2$$

2.2 **Hazardous Products**

The oxidation/combustion products of the agents are relatively non-toxic gaseous and volatile species. However, reports of potentially hazardous pyrolysis products of the agents have been reported for HD including: Ethyl Mercaptan; Diethyl Sulfide; and Vinyl Chloride.

2.3 **Destruction Efficiency, Residue Level**

Complete decomposition of the agents is anticipated if the agent can be maintained at the decomposition temperature for the prescribed period of time. For example, complete decomposition of GB by pyrolysis was observed after heating at 150 C for 2-1/2 hours (Anonymous, 1974).

2.4 **Reaction Rate/Kinetics**

$$-\frac{d(Vx)}{dt} = [9.6 \times 10^8 \exp(-14,000/T(^oK)](VX)$$

$$-\frac{d(GB)}{dt} = [1.5 \times 10^8 \exp(-11,700/T(^oK)](GB)$$

$$-\frac{d(HD)}{dt} = [1.8 \times 10^9 \exp(-12,632/T(^oK)](HD)$$

where (VX), (GB), (HD) = concentration of the
the respective agent
t = time (sec)
T = temperature (°K)

2.5 Supplementary Treatment

Supplementary treatments may be required to remove and/or decompose the thermal decomposition products of HD, GB and VX if pyrolysis rather than oxidation occurs and to decompose volatilized undecomposed agent.

2.6 State-of-the-Art

Several studies have been performed on the pyrolysis and oxidation/combustion of agents including several references (Pugh, 1970; Hildebrandt, 1972; Lapp, 1962; Sass, 1972; Tomlinson, 1980; Williams, 1947; Reeves, 1954; Brooks, 1979).

3.0 Physical Treatment

Not applicable.

4.0 Applicability

4.1 Agent Applicability

Potentially applicable to all agents.

4.2 Isolated Building Material Applicability

Applicable to all unpainted surfaces of interest. May not be applicable to most painted surfaces.

4.2.1 Impact of Substrate on Chemistry

The adsorption of contaminant on particular substrates may inhibit decomposition, but it is anticipated that this affect will be small.

4.2.2 Removal or Reaction of Contaminant from Surface

Easily achieved for unpainted surfaces.

4.2.3 Removal or Reaction of Contaminant from Interior

Good potential applicability.

4.2.4 Damage to Material

Damage depends largely on decomposition temperature required, time of exposure, and depth of thermal penetration. Concrete is subject to cracking and dehydration at high temperatures. Metals are readily oxidized at high temperatures.

4.3 Practical Applicability to Building

4.3.1 Building Preparation

Paint removal may be necessary because the heating equipment is in direct contact with the surface. The

building should be sealed during decontamination to prevent potential release of volatilized agent.

4.3.2   Practical Physical Limitations/Methods to Overcome
Not well suited to intricate surface areas. Heating plates could be applied at a convenient working distance instead of in direct contact with the surface. Alternatively, heating tape could be employed, but direct vacuum application would not be feasible and labor requirements would be substantial. Properly positioned hoods may overcome the vacuum application difficulty.

4.3.3   Secondary Decontamination Treatment
A secondary decontamination treatment may be required to remove hazardous products of reaction and to decompose volatilized undecomposed agent.

4.3.4   Clean-up Requirements
Wash down of dehydrated cement may be advantageous to allow regain of strength.

4.3.5   Waste Treatment and Disposal
All volatilized agents will need to be collected and treated. Alternatively the decomposition product vapors could be vented to the atmosphere (in accordance with EPA regulations), if no volatilized agent is present and the gaseous decomposition products are non-hazardous.

4.4   State-of-the-Art
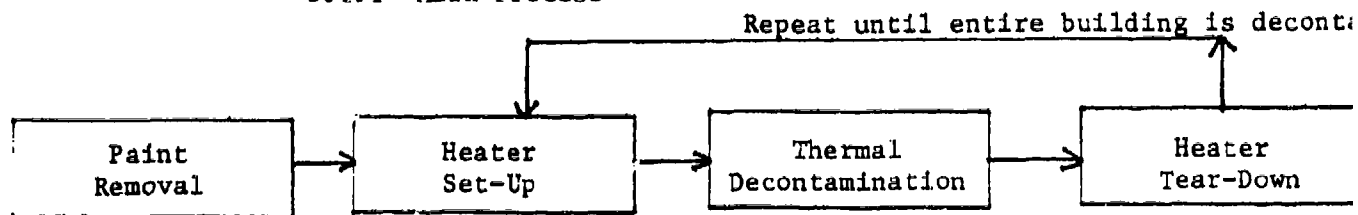The method has never been used for building decontamination.

5.0   Engineering

5.1   Process Description

5.1.1   Main Process

Repeat until entire building is deconta

| Paint Removal | → | Heater Set-Up | → | Thermal Decontamination | → | Heater Tear-Down |

5.1.1.1   Paint Removal
Sandblasting, paint stripping solvents or flaming could be employed, depending on the building material.

5.1.1.2 Heat Treatment

Plate heaters and/or heating tape are applied to a building section (e.g. part or all of a wall). Heating is continued unil decontamination is complete. The equipment is then dismantled and moved to a different subsection. This is repeated until all accessible areas have been decontaminated.

5.1.1.3 Gaseous Products Collection

Volatiles could be collected by vacuum application.

5.1.1.4 Gaseous Products Treatment

Toxic vapors will need to be contained and treated to minimize safety hazards.

5.1.2 Variations

Omit steps 5.1.1.1, 5.1.1.3, and 5.1.1.4 or combinations thereof. Allow resistance heat to remove paint. Implement heating from the outside using an aerosol cloud of decontaminant to decompose volatilized agent inside the building. Heat simultaneously from both sides to contain volatilized agent for thermal decomposition.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

5.2.1.1 Paint Removal Equipment

Sandblast. Use standard commercial sandblasting equipment. Best for porous materials (concrete, brick, etc.)
Paint Stripper. Apply solvent by brush or spray. Best for impervious materials (metals).
Flaming. Use standard paint removal torches.

5.2.1.2 Heat Treatment Equipment

Use specially designed electrical plate heater with hooded enclosure for vacuum application. The perimeter seal would have to withstand high temperatures. Several different size units would probably be required. Preliminary estimates indicate that a 30 kW power capacity could treat approximately 10 square feet at a 600 C surface temperature. Thermocouples could be utilized to maintain the surface temperature at the desired level and to measure the

subsurface temperature.

Use commercially available high temperature heating tape for intricate surface area application.

5.2.1.3 Gaseous Product Collection Equipment
The vapors from the hooded enclosure could be suctioned using a fan. To maintain a one inch of water pressure differential, preliminary estimates indicate an approximate 100 cfm capacity fan would be required.

5.2.1.4 Gaseous Product Treatment Equipment
The heated vapors would have to be cooled before passing through the fan. A scrubber system could serve the dual function of cooling the vapor stream and removing toxic vapors. Adsorption filters or other treatment systems could also be employed.

5.2.2 Reliability, Availability and Maintainability
Expected to be high because of use of relatively simple equipment.

5.3 Decontamination Time

5.3.1 Set-up
Involves all or some of the following: paint removal, electrical wiring and heating element installation, and sealing building. Generally low set-up time.

5.3.2 Application Time

5.3.2.1 Personnel
Requires movement and set-up of heaters throughout the building and temperature monitoring during heating and cooling. Expected to be moderate to high.

5.3.2.2 Decontamination
Heating time is dependent on the temperature, type of material and depth of penetration. Cooling will probably be achieved by natural convection, and again will depend on temperature, type of material and depth of penetration. It is anticipated to be moderate to lengthy (hours to days).

5.3.2.3 Verification
Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Involves removal of heating tape, electrical connections. Generally much less than set-up time.

5.3.3.2 Clean-up
Short to moderate time for removal of surface char and wash down of dehydrated cement.

5.4 Safety Requirements

5.4.1 Process Hazards
None anticipated.

5.4.2 Personnel Hazards
Burns, electrical shocks, toxic vapors.

5.4.3 Protective Methods
Wear heat resistant clothing for protection from burns.
Avoid exposure by remote operation during heating.
Wear respiratory equipment in cases where toxic vapors are present.
Level A or B gear will probably be required if workers required in building during heating.

6.0 Economics

6.1 Building Damage - Repair Costs
Possible damage to concrete blocks from heating. Expansion joints may alleviate stresses from thermal expansion.

6.2 Developmental Costs
Testing of temperature requirements.
Design and/or specification of plate heaters.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Electrical requirements may be substantial but are expected to be a small part of the total cost.

6.3.2 Equipment Cost
Cost of plate heaters.
Cost of fan/vacuum system.
Cost of scrubber/filter system.

6.3.3 Materials Cost
Decon solution for aerosol, if necessary.

6.3.4 Manpower Cost
High labor cost. Involves paint removal (if necessary), heater operation, and char removal, and wash down of dehydrated cement.

7.0 Future Work Required

7.1 Knowledge Gaps
Extent of damage to porous building materials and methods to minimize building damage.
Applicability to painted surfaces. Extent of volatile penetration from thermal diffusion.
Effect of substrate on decomposition temperature of contaminant.

7.2 Resolution
Experimental testing.

THERMAL DECOMPOSITION USING HOT PLASMA

1.0 General Description

 1.1 Summary of Idea
 This method is based on the use of a hot plasma
 (2500-20,000K) to thermally and/or chemically decompose
 contaminants. Thermal decomposition would be obtained by
 heat transfer from the hot plasma to the contaminant.
 Chemical decomposition may be obtained by reaction of ionized
 gases and electrons contained in the plasma with contam-
 inants. The mode of application could take the form of a
 plasma torch which would resemble conventional flaming
 techniques.

 1.2 Origination of Idea
 Novel Processing project team.

 1.3 Obvious Advantages and Disadvantages
 Advantages. Complete and rapid destruction of contaminants.

 Disadvantages. Potential high utility cost. High
 temperature is likely to cause extensive damage to building
 materials. Volatilization of agent may occur.

 1.4 Variations of Idea
 The plasma torch could be generated using either a high
 intensity arc jet or an induction plasma torch. The torching
 could be accomplished either manually with a hand held unit
 or remotely.

 1.5 Sketch
 An arc plasma spray gun is depicted on page III-17.

2.0 Chemical Decomposition Treatment

 2.1 Chemical Reactions
 GB, HD and VX undergo thermal decomposition by either
 pyrolysis in inert atmospheres or oxidation (combustion) in
 excess air.

 GB Pyrolysis (325-900 C)

$$CH_3-\overset{O}{\underset{OC_3H_7}{P}}-F \longrightarrow CH_3\ \overset{O}{\underset{OH}{P}}-F\ +\ CH_2 = CHCH_3$$

 GB Oxidation/Combustion (250-1050 C)

$$2CH_3-\overset{O}{\underset{OC_3H_7}{P}}-F\ +\ 13O_2 \longrightarrow 8CO_2\ +\ 9H_2O\ +\ P_2O_5\ +\ 2HF$$
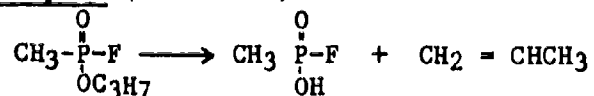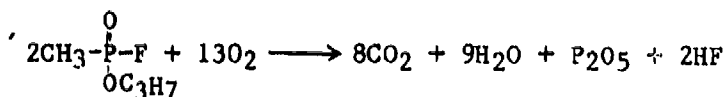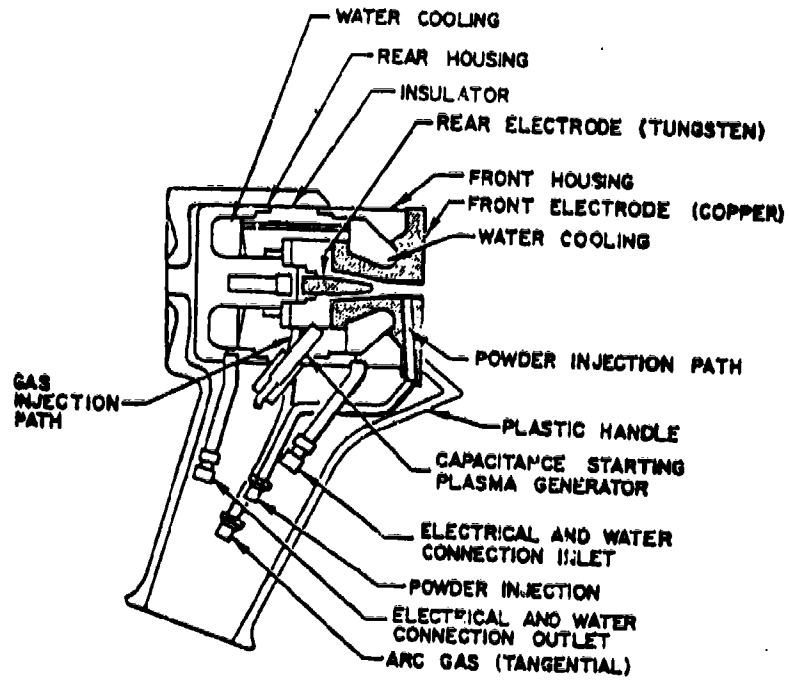
Plasma spray gun.

<u>HD Pyrolysis</u> (180-900 C)

Main Reaction: $S(CH_2CH_2Cl)_2 \quad H_2S + 2CH_2=CHCl$

<u>HD Oxidation/Combustion</u> (250-1000 C)

$S(CH_2CH_2Cl)_2 + \frac{13}{2} O_2 \quad 4CO_2 + 3H_2O + 2HCl + SO_2$

<u>VX Pyrolysis</u>
See general discussion.

<u>VX Oxidation/Combustion (600-1200 C)</u>

$2C_{11}H_{26}O_2PSN + \frac{79}{2} O_2 \quad P_2O_5 + 2NO_2 + 22CO_2 + 26H_2O + 2SO_2$

2.2 Hazardous Products

The oxidation/combustion products of the agents are relatively non-toxic, gaseous and volatile species. However, reports of potentially hazardous pyrolysis products of the agents have been reported for HD including: Ethyl Mercaptan; Diethyl Sulfide; 2,2'Dichlorodiethylsulfide, and Vinyl Chloride.

2.3 Destruction Efficiency, Residue Level

Complete decomposition of the agents is anticipated if the agent can be maintained at the decomposition temperature for the prescribed period of time. For example, complete decomposition of GB by pyrolysis was observed after heating at 150 C for 2-i/2 hours (Anonymous, 1974).

2.4 Reaction Rate/Kinetics

$$- \frac{d(Vx)}{dt} = [9.6 \times 10^8 \exp(-14,000/T(^\circ K)](VX)$$

$$- \frac{d(GB)}{dt} = [1.5 \times 10^8 \exp(-11,700/T(^\circ K)](GB)$$

$$- \frac{d(HD)}{dt} = [1.8 \times 10^9 \exp(-12,632/T(^\circ K)](HD)$$

where (VX), (GB), (HD) = concentration of the
the respective agent
t = time (sec)
T = temperature (°K)

2.5 Supplementary Treatment

Supplementary treatments may be required to remove and/or

decompose the thermal decomposition products of HD, GB and VX
if pyrolysis rather than oxidation occurs.

2.6 State-of-the-Art
Several studies have been performed on the pyrolysis and
oxidation/combustion of agents including several references
(Pugh, 1970; Hildebrandt, 1972; Lapp, 1962; Sass, 1972;
Tomlinson, 1980; Williams, 1947; Reeves, 1954; Brooks, 1979).
See general discussion of state-of-the-art.

3.0 Physical Treatment
Not applicable.

4.0 Applicability

4.1 Agent Applicability
Applicable to all agents.

4.2 Isolated Building Material Applicability
Painted and unpainted concrete and metals.

4.2.1 Impact of Substrate on Chemistry
The adsorption of contaminant on particular substrates
may inhibit decomposition, but it is anticipated that
this effect will be small. Substrate may compete for
reaction with ionized gases.

4.2.2 Removal or Reaction of Contaminant from Surface
Surface reaction is highly probable.

4.2.3 Removal or Reaction of Contaminant from Interior
Potentially applicable, but will depend on the ability
to control heat conduction from the surface without
establishing a large temperature gradient.

4.2.4 Damage to Material
Damage is highly probable, but the extent of damage
will depend on the plasma temperature and dwell time.
Cement and concrete are subject to cracking and
dehydration at high temperatures. Metals are oxidized
or melted at high temperatures. Refer to general dis-
cussion of temperature stability of building mate-
rials. (Appendix I)

4.3 Practical Applicability to Building

4.3.1 Building Preparation
All combustible materials would have to be removed
prior to treatment. The building may require sealing
to prevent release of agent.

4.3.2 Practical Physical Limitations/Methods to Overcome

All areas must be accessible to the plasma torch. Obstructions to the line-of-sight of the torch may require removal unless heat conduction is relied on for heat transfer. A trade off exists between depth of thermal penetration and damage to building materials.

4.3.3 Secondary Decontamination Treatment

Secondary decontamination treatments may be required to remove interior contaminants if short dwell times of the torch are used

4.3.4 Clean-up Requirements

May need to remove surface char. Rewetting of dehydrated cement may be advantageous to restore strength.

4.3.5 Waste Treatment and Disposal

All material removed from the building may be decontaminated chemically or by incineration. Decomposition product gases may need to be collected and treated. Volatilized agent would have to be contained and treated chemically or by incineration.

4.4 State-of-the-Art

Plasma torches are industrially employed for welding, cutting, and shaping of high melting point materials. Plasma spray guns are industrially used to deposit refractory coatings on materials such as glass, metals, plastics and ceramics.

5.0 Engineering

5.1 Process Description

Remove Combustibles	→	Remove Obstructions	→	Remote Plasma Torching	→	Hand-Held Plasma Torching
↓		↓				↓
Incinerate		Decontamination				Char/Debris Removal
						↓
						Secondary Decontamination
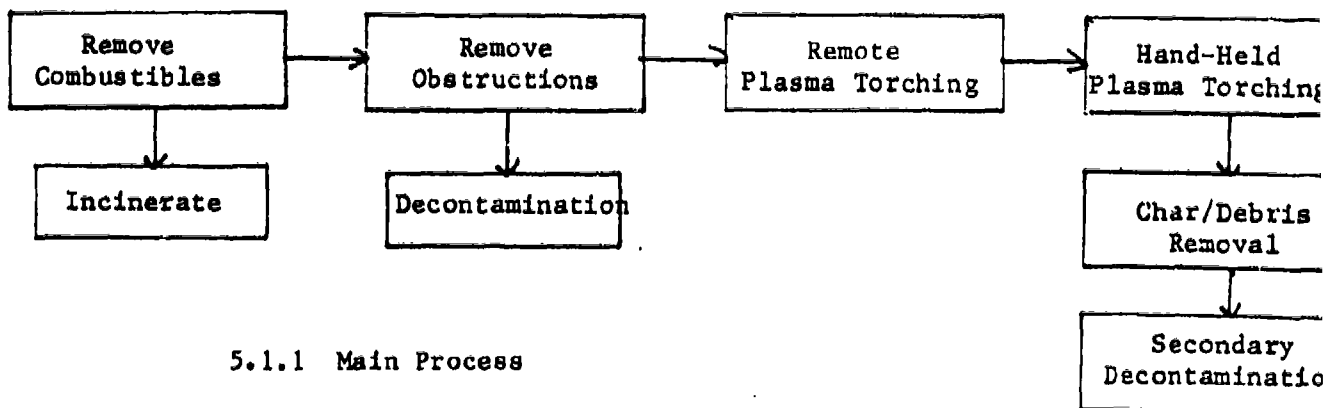
5.1.1 Main Process

5.1.1.1 Remove Combustibles and Obstructions

5.1.1.2 Remote Torching

5.1.1.3 Hand-Held Torching

5.1.2 Variations
An automatic remote torch could be employed.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
The main component of the process is the plasma torch.
Two types of plasma torches are available:
1) the arc plasma jet and 2) the induction plasma
torching. The arc plasma jet is produced by injecting
a carrier gas (usually inert) into a high intensity
arc chamber. With an induction torch the energy is
inductively coupled with the plasma.

5.2.2 Reliability, Availability and Maintainability
Arc electrodes need periodic replacement.

5.3 Decontamination Time

5.3.1 Set-up
Dependent on amount of obstructions and combustible
material which require removal. Sealing the building,
if required, to prevent release of volatilized agent.

5.3.2 Application Time

5.3.2.1 Personnel
Long time for hand-held operation. Shorter
time for remote operation.

5.3.2.2 Decontamination
Very short per treated area, but entire
building treatment would be lengthy.

5.3.2.3 Verification
Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Short time to remove torching equipment.

5.3.3.2 Clean-up
Low to moderate time to remove char from
surfaces and to rehydrate cement.

5.4 Safety Requirements

5.4.1 Process Hazards
None anticipated.

5.4.2 Personnel Hazards
      Burns, toxic vapors.

5.4.3 Protective Methods
      Wear heat resistant clothing, eye protection and
      possibly respiratory gear. Level A or B clothing may
      also be required. Use remote operation/shielding
      barriers and a hood to withdraw product gases. Pre-
      vention of release of agents to uncontaminated areas,
      may be accomplished by either repeated spray of decon
      solution or use of an aerosol decontaminant.

6.0 Economics

6.1 Building Damage - Repair Costs
    Depends on depth of thermal penetration. Potentially quite
    severe, but can be minimized by short surface exposure.

6.2 Developmental Costs
    Design of remote operating equipment.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
      Minimal.

6.3.2 Equipment Cost
      Cost of plasma torch units and accessories might be a
      major capital investment.

6.3.3 Material Cost
      Inert gas (e.g. N_2, He) would be fairly
      inexpensive, but significant quantitites may be
      required.

6.3.4 Manpower Cost
      Substantial labor involvement, especially if hand-held
      torching is largely required.

7.0 Future Work Required

7.1 Knowledge Gaps
    Extent of damage ot building materials by plasma.
    Verification requirements need development.
    Cost effectiveness compared with other thermal methods.
    Degree of agent volatilization.

7.2 Resolution
    Experimental testing.

THERMAL DECOMPOSITION BY MICROWAVES

1.0 General Description

    1.1 Summary of Idea
        Microwave heating employs the use of microwaves to heat
        dielectric building materials (concrete, brick, etc.) to the
        decomposition temperature of the agent contaminants. A quick
        heat-up rate may be employed to minimize volatilization of
        agents.

    1.2 Origination of Idea
        Novel Processing project team.

    1.3 Obvious Advantages and Disadvantages
        Advantages. Microwaves will penetrate concrete, and brick
        causing heating throughout the materials (i.e. heat conduc-
        tion plays only a minor role in heat transfer). Quick heat-
        up rates can be obtained. One report stated that concrete
        became molten after 15 minutes of irradiation with microwaves
        (O'Kress, 1975). Microwaves may also directly decompose agents.

        Disadvantages. Sheet metal or closely spaced metal pipes
        will reflect the radiation without being heated. Building
        materials may be damaged by thermal effects. Volatilization
        of agent to uncontaminated areas may occur.

    1.4 Variations of Idea
        Concrete or brick can be saturated with water followed by
        intense microwave radiation to cause spalling of the concrete
        surface as a result of explosive force developed by rapid
        generation of steam (physical removal method). An aerosol
        may be generated and contained inside the building in order
        to decompose agent which had volatilized. Microwave heating
        may be used as a supplemental heating process.

    1.5 Sketch

Microwave Generator → | Building | ← Copper Gauze Protective Screen

2.0 Chemical Decomposition Treatment

    2.1 Chemical Reactions
        GB, HD and VX undergo thermal decomposition by either
        pyrolysis in inert atmospheres or oxidation (combustion) in
        excess air.

GB Pyrolysis (325-900 C)$_2$

$$CH_3-\underset{\underset{OC_3H_7}{|}}{\overset{\overset{O}{\|}}{P}}-F \longrightarrow CH_3-\underset{\underset{OH}{|}}{\overset{\overset{O}{\|}}{P}}-F + CH_2 = CHCH_3$$

GB Oxidation/Combustion (250-1050°C)

$$2CH_3-\underset{\underset{OC_3H_7}{|}}{\overset{\overset{O}{\|}}{P}}-F + 13O_2 \longrightarrow 8CO_2 + 9H_2O + P_2O_5 + 2HF$$

HD Pyrolysis (180-900°C)

Main Reaction: $S(CH_2CH_2Cl)_2 \longrightarrow H_2S + 2CH_2 = CHCl$

HD Oxidation/Combustion (250-1000°C)

$$S(CH_2CH_2Cl)_2 + \frac{13}{2}O_2 \longrightarrow 4CO_2 + 3H_2O + 2HCl + SO_2$$

VX Pyrolysis
        Confidential

VX Oxidation/Combustion (600-1200°C)

$$2C_{11}H_{26}O_2PSN + \frac{79}{2}O_2 \longrightarrow P_2O_5 + 2NO_2 + 22CO_2 + 26H_2O + 2SO_2$$

2.2 Hazardous Products

The oxidation/combustion products of the agents are relatively non-toxic gaseous and volatile species. However, reports of potentially hazardous pyrolysis products of the agents have been reported for HD including: Ethyl Mercaptan; Diethyl Sulfide; 2,2'Dichlorodiethylsulfide, and Vinyl Chloride.

2.3 Destruction Efficiency, Residue Level

Complete decomposition of the agents is anticipated if the agent can be maintained at the decomposition temperature for the prescribed period of time. For example, complete decomposition of GB by pyrolysis was observed after heating at 150°C for 2-1/2 hours (Anonymous, 1974).

2.4 Reaction Rate/Kinetics

$$-\frac{d(Vx)}{dt} = [9.6 \times 10^8 \exp(-14,000/T(°K)](VX)$$

$$-\frac{d(GB)}{dt} = [1.5 \times 10^8 \exp(-11,700/T(°K)](GB)$$

$$-\frac{d(HD)}{dt} = [1.8 \times 10^9 \exp(-12,632/T(°K)](HD)$$

where (VX), (GB), (HD) = concentration of the
the respective agent

t = time (sec)

T = temperature ($^\circ$K)

2.5 Supplementary Treatment

Supplementary treatments may be required to remove and/or decompose the thermal decomposition products of HD, GB and VX if pyrolysis rather than oxidation occurs.

2.6 State-of-the-Art

Several studies have been performed on the pyrolysis and oxidation/combustion of agents including several references (Pugh, 1970; Hildebrandt 1972; Lapp, 1962; Sass, 1972; Tomlinson, 1980; Williams, 1947; Reeves, 1954; Brooks, 1979). See general discussion of state-of-the-art.

3.0 Physical Treatment

Not applicable.

4.0 Applicability

4.1 Agent Applicability

Microwave heating is applicable to the thermal decomposition of all agents.

4.2 Isolated Building Material Applicability

Applicable to all materials of interest.

4.2.1 Impact of Substrate on Chemistry

There is a potential for the agent to be adsorbed on the surface or pores of the substrates. Microwave radiation may supply enough energy to overcome the desorption activation energy as a result of direct heating of the substrate or by microwave interactions with agent.

4.2.2 Removal or Reaction of Contaminant from Surface

Complete decomposition of the agents on the surfaces of dielectric materials (paint, concrete, brick, etc.) is anticipated. Decomposition of agents on metal surfaces (e.g. plates or tanks) may occur despite their reflective properties toward microwave radiation by direct interaction of the microwaves with the agent residues. Metal pipes may be decontaminated if they are insulated because the microwaves will cause heating of the insulation. The heat could then be conducted to the metal pipes.

4.2.3 Removal or Reaction of Contaminant from Interior

Complete decomposition of the agents in the interior

of cement, concrete, and brick is anticipated. However, reinforced concrete may cause attentuation of the microwaves preventing direct heating of material behind them.

4.2.4 Damage to Material

Slight damage to building materials such as paint charring, concrete dehydration and cracking of cement may be expected. Different radiation intensities and frequencies may be employed on different materials to minimize damage. See general discussion of temperature stability of building material.

4.3 Practical Applicability to Building

4.3.1 Building Preparation

All metal plate arrays of closely aligned pipe and tanks may require removal if obstructing the source of microwaves. A copper gauze screen must be set up outside the building opposite the microwave source. The building must be adequately sealed to prevent release of volatilized agent.

4.3.2 Practical Physical Limitations/Methods to Overcome

Optics (microwave reflectors) can be employed to direct microwaves to behind steel plates, etc. Also the microwave heaters can be set up on both sides of the building (internal and external). Microwaves do not work directly with glass.

4.3.3 Secondary Decontamination Treatment

Materials not heated by microwaves may be treated by another technique. A secondary treatment may be required to remove hazardous decomposition products.

4.3.4 Clean-up Requirements

Wash down and repainting is all that is required.

4.3.5 Waste Treatment and Disposal

Venting of the gaseous decomposition products and volatiles to a scrubber may be necessary.

4.4 State-of-the-Art

Industrial microwave processes include drying and cooking of food and sealing of plastics. Microwave has also been demonstrated to be effective in curing concrete, cracking concrete slabs and destroying fungus and woodworm in timber by thermal heating. (Okress, 1975).

5.0 Engineering

5.1 Process Description

```
┌─────────────────┐   ┌─────────────┐   ┌─────────────────┐   ┌──────────────────┐
│     Remove      │   │   Install   │   │    Install      │   │     Thermal      │
│   Obstructions  │──▶│  Microwave  │──▶│  Optics System  │──▶│  Decontamination │
│  (if necessary) │   │   Heaters   │   │  (if necessary) │   │                  │
└─────────────────┘   └─────────────┘   └─────────────────┘   └──────────────────┘
                            ▲                                            │
                            │                                            ▼
                            │                                   ┌──────────────┐
                            └───────────────────────────────────│  Tear Down   │
                                                                └──────────────┘
                         Repeat cycle until                             │
                         entire building is                             ▼
                         decontaminated                         ┌──────────────┐
                                                                │   Clean-Up   │
                                                                └──────────────┘
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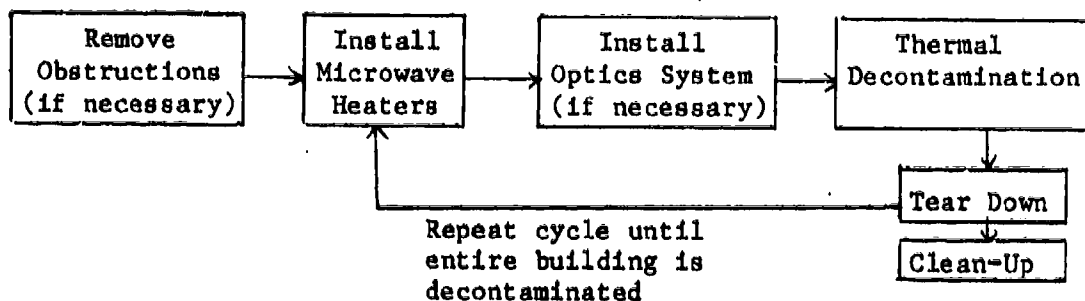
5.1.1 Main Process

The microwave heaters are set-up inside and/or outside the building after all obstructions to microwaves are removed. Optic systems are then installed to direct microwaves. A protective metal sheet or copper gauze is set-up to prevent personnel exposure to microwaves outside of the area being decontamined. The building is then sealed to prevent release of volatilized agents. The units are then turned on and allowed to run until the section or building is decontaminated by thermal decomposition of the agent residing. The equipment is then moved to decontaminate another area.

5.1.2 Variations

Enough microwave heaters can be set up to treat the entire building at once. In this case the power load may be above that which could be obtained from the area utilities. Since workers need not be present during decontamination, the building could be filled with an aerosol to allow decomposition of volatilized agent.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

Microwave heaters.
Protective screen-sheet metal or copper gauze.
Scrubber system, if necessary, to treat decomposition products.
Aerosol generator, if desired.

5.2.2 Reliability, Availability and Maintainability

Expected to be high because of minimal amount of complex equipment that is required.

5.3 Decontamination Time

5.3.1 Set-up

Dependent on microwave heater and configuration and size of materials in the building. Small amount of time if only several heaters required. Extensive time if building is decontaminated by sections. Setup of protection equipment, if required, to prevent release of volatilized agent (e.g. sealing a building).

5.3.2 Application Time

5.3.2.1 Personnel

Personnel required for set-up, tear-down and routine monitoring. Expected to be low to moderate.

5.3.2.2 Decontamination

Decontamination time is dependent on the agent, building materials and heat-up rates. Heat-up rates should be rapid (less than one hour) as possibile to limit volatilization of agents.

5.3.2.3 Verification

Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal

Tear down time is dependent on the amount of equipment set-up and number of decontamination cycles performed. It is expected to require less time than set-up.

5.3.3.2 Clean-up

Clean-up is anticipated to be minimal involving wash down with decon solution and painting.

5.4 Safety Requirements

5.4.1 Process Hazards

Potential for a fire when combustible material is heated may be either eliminated by removal of all combustible material in the building or by using an inert atmosphere.

5.4.2 Personnel Hazards

Microwave radiation exposure to personnel. Burns from hot surface. Volatized agent.

5.4.3 Protective Methods

Sheet metal or copper gauze can be placed one-quarter wavelength from the walls to eliminate the possibility of radiation exposure to personnel outside the building during decontamination. Personnel may not be required to be inside building during decontamination. Microwave units react instantaneously to control adjustments. Hoods may be used to ventilate decontamination areas. Prevention of release of agents, if volatilized undecomposed, may be accomplished by either repeated spray with decon solution or use of an aerosol decontamination.

6.0 Economics

6.1 Building Damage - Repair Costs

Slight to none if heating rate is low, may be moderate if high heating rate employed. Expansion joints may alleviate stresses from thermal expansion.

6.2 Developmental Costs

Microwave heaters and reflector systems may require special design. Optimum temperatures, reaction times and microwave interferences (i.e. reinforced concrete) must be investigated prior to equipment selection.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost

Utilities are expected to be a small part of the overall cost.

6.3.2 Equipment Cost

Expected to be higher than most other heating equipment (IR, contact heaters).

6.3.3 Material Cost

The protective barrier - steel sheets or copper gauze and supports are not expected to be expensive and may be reusable - decon solution for washdown.

6.3.4 Manpower Cost

Moderate because of remote operation of microwave units and because only routine maintenance is required. Most cost will be involved in setup.

7.0 Future Work Required

7.1 Knowledge Gaps

The time and temperature required to decompose the agents under consideration in various building materials with various microwave frequencies must be determined. The effect of direct interaction of microwaves on agents should be considered.

7.2 Resolution

Parametric experiments using various microwave frequencies, various agents, and various building configurations must be made.

THERMAL DECOMPOSITION BY FLAMING

1.0 General Description

1.1 Summary of Idea
Flaming entails the use of a flame to in-situ thermally decontaminate building materials containing agents.

1.2 Origination of Idea
Rockwell International. Literature (Lillie, 1981).

1.3 Obvious Advantages and Disadvantages
Advantages. Complete and rapid destruction of all agent residues contacted by the flame.

Disadvantages. Primarily a surface decontamination technique. Interior decontamination of building materials may be achieved but extensive damage to the material would probably result. Potential for high fuel cost. Volatilization of undecomposed agent may occur.

1.4 Variations of Idea
Flaming may either be accomplished by a hand-held flamer or by a remotely operated flamer. The use of a remotely operated flamer is restricted to expansive open surfaces whereas hand-held flames are required for complex areas, niches, cracks, etc.

1.5 Sketch
See pages III-32,33.

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions
GB, HD and VX undergo thermal decomposition by either pyrolysis in inert atmospheres or oxidation (combustion) in excess air.

GB Pyrolysis (325-900°C)

$$CH_3-\overset{O}{\underset{OC_3H_7}{\overset{\|}{P}}}-F \longrightarrow CH_3-\overset{O}{\underset{OH}{\overset{\|}{P}}}-F + CH_2 = CHCH_3$$

GB Oxidation/Combustion (250-1050°C)

$$2CH_3-\overset{O}{\underset{OC_3H_7}{\overset{\|}{P}}}-F + 13O_2 \longrightarrow 3CO_2 + 9H_2O + P_2O_5 + 2HF$$

HD Pyrolysis (180-900°C)

Main Reaction: $S(CH_2CH_2Cl)_2 \longrightarrow H_2S + 2CH_2 = CHCl$
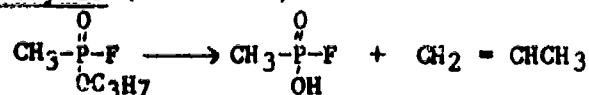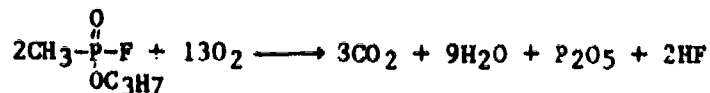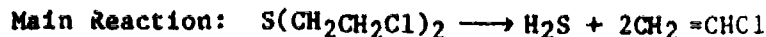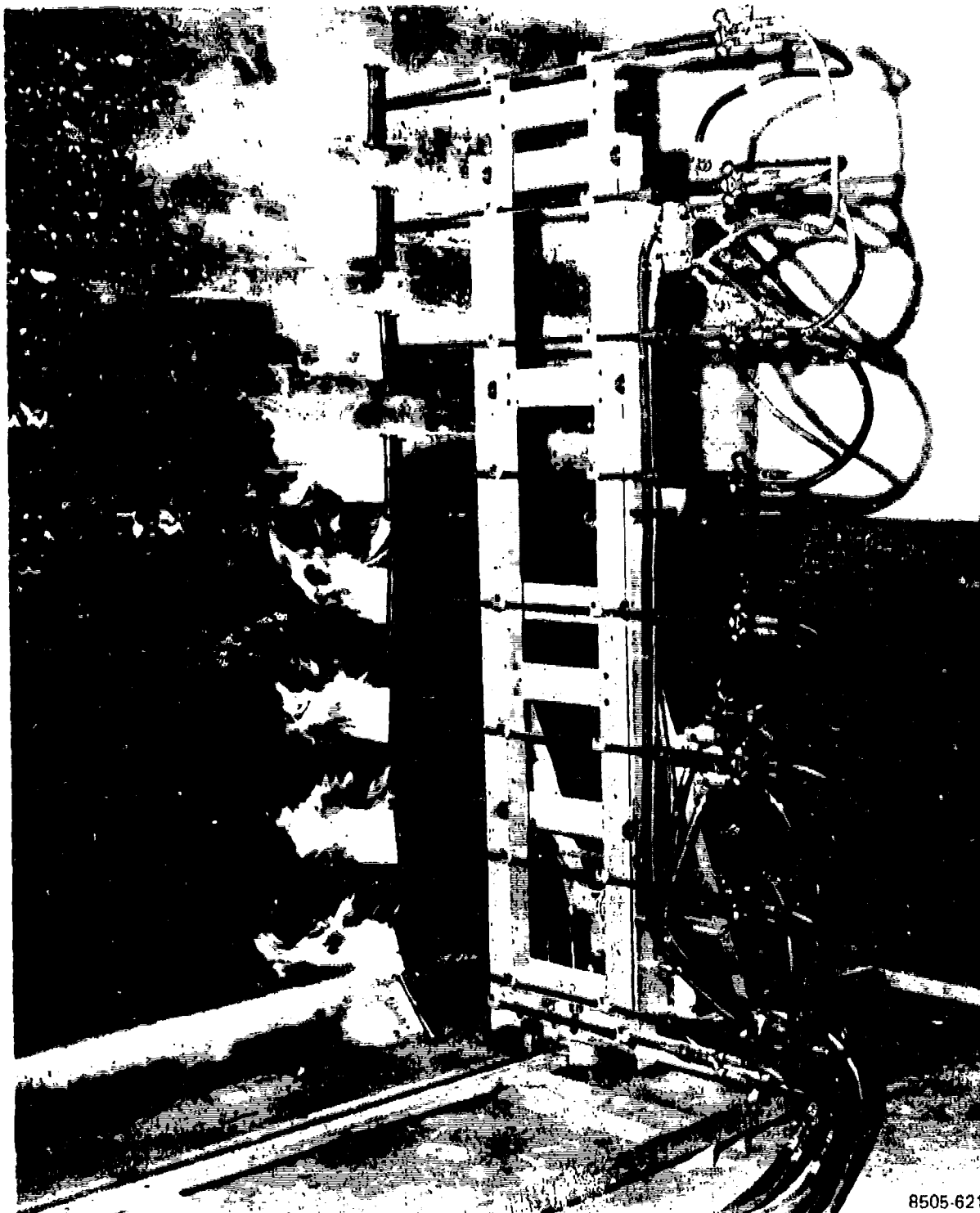
8505-621

Wall Flamer in Action (torches automatically offset at end of
travel - same as floor flamer
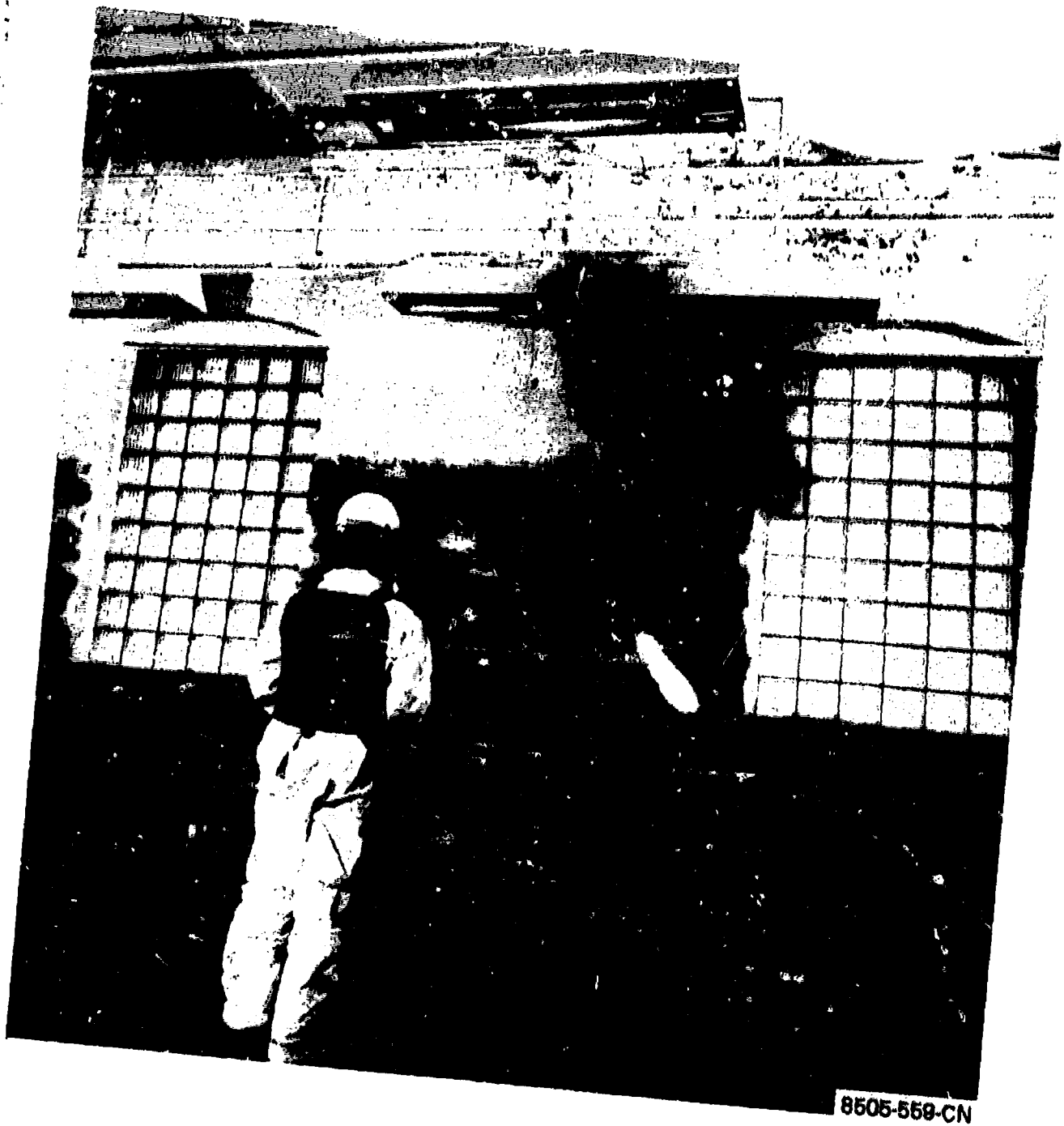
8505-559-CN

Hand Flaming in Progress

HD Oxidation/Combustion (250-1000 C)

$$S(CH_2CH_2Cl)_2 + 13/2\ O_2 \longrightarrow 4CO_2 + 3H_2O + 2HCl + SO_2$$

VX Pyrolysis
        Confidential

VX Oxidation/Combustion (600-1200 C)

$$2C_{11}H_{26}O_2PSN + 79/2\ O_2 \longrightarrow P_2O_5 + 2NO_2 +$$

$$22CO_2 + 26H_2O + 2SO_2$$

2.2 **Hazardous Products**
The oxidation/combustion products of the agents are relatively non-toxic gaseous and volatile species. However, reports of potentially hazardous pyrolysis products of the agents have been reported for HD including: Ethyl Mercaptan; Diethyl Sulfide; 2,2'Dichlorodiethylsulfide, and Vinyl Chloride.

2.3 **Destruction Efficiency, Residue Level**
Complete decomposition of the agents is anticipated if the agent can be maintained at the decomposition temperature for the prescribed period of time. For example, complete decomposition of GB by pyrolysis was observed after heating at 150 C for 2-1/2 hours (Anonymous, 1974).

2.4 **Reaction Rate/Kinetics**

$$-\frac{d(Vx)}{dt} = [9.6 \times 10^8 \exp(-14,000/T(^oK)](VX)$$

$$-\frac{d(GB)}{dt} = [1.5 \times 10^8 \exp(-11,700/T(^oK)](GB)$$

$$-\frac{d(HD)}{dt} = [1.8 \times 10^9 \exp(-12,632/T(^oK)](HD)$$

where (VX), (GB), (HD) = concentration of the
                                    the respective agent
                    t = time (sec)
                    T = temperature (^oK)

2.5 **Supplementary Treatment**
Supplementary treatments may be required to remove and/or decompose the thermal decomposition products of HD, GB and VX if pyrolysis rather than oxidation occurs.

2.6 State-of-the-Art
Several studies have been performed on the pyrolysis and oxidation/combustion of agents including several references (Pugh, 1970; Hildebrandt, 1972; Lapp, 1962; Sass, 1972; Tomlinson, 1980; Williams, 1947; Reeves, 1954; Brooks, 1979).

3.0 Physical Treatment
Not applicable.

4.0 Applicability

4.1 Agent Applicability
The flaming process would be applicable to all agents.

4.2 Isolated Building Material Applicability
Applicable to painted and unpainted concrete and metals.

4.2.1 Impact of Substrate on Chemistry
The adsorption of the contaminant on a particular substrate may inhibit the decomposition reaction. However this effect is anticipated to be small.

4.2.2 Removal or Reaction of Contaminant from Surface
It is anticipated that complete destruction of agents on surfaces can be achieved.

4.2.3 Removal or Reaction of Contaminant from Interior
Because of the high temperature of the flame, the dwell time of the flame should be held to a minimum to minimize material damage. Thus, decomposition is not facilitated in the interior of building materials.

4.2.4 Damage to Material
Minimal damage of the building materials is anticipated except for paint charring. If interior decontamination of building materials is required, then the dwell time of the flame should approach 10 minutes or longer (time is dependent on material). This may cause excessive damage of the building materials.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Combustible material would have to be removed prior to flaming.

4.3.2 Practical Physical Limitations/Methods to Overcome
All areas must be accessible to the flame front. Obstructions to the flame would require removal in order to achieve complete surface decontamination. Heat conduction to inaccessible areas would be

dependent on the building material and flame dwell
time.

4.3.3 Secondary Decontamination Treatment
Secondary decontamination treatments may be required
to remove interior contaminants if short dwell times
of the flame are used and/or to remove decomposition
products.

4.3.4 Clean-up Requirements
Removal of surface paint char may be required prior to
painting. Washdown of concrete may be required.

4.3.5 Waste Treatment and Disposal
All materials removed from the building may be
decontaminated chemically or by incineration. Venting
product gases to a scrubber may be required.

4.4 State-of-the-Art
Flaming is the state-of-the-art technique for explosive
installation restoration. The technique has been applied to
the decontamination of Frankford Arsenal. Flaming has not
been used for agent installation restoration. However,
flaming agent contaminated equipment is the state-of-
the-art.

5.0 Engineering

5.1 Process Description

5.1.1 Main Process
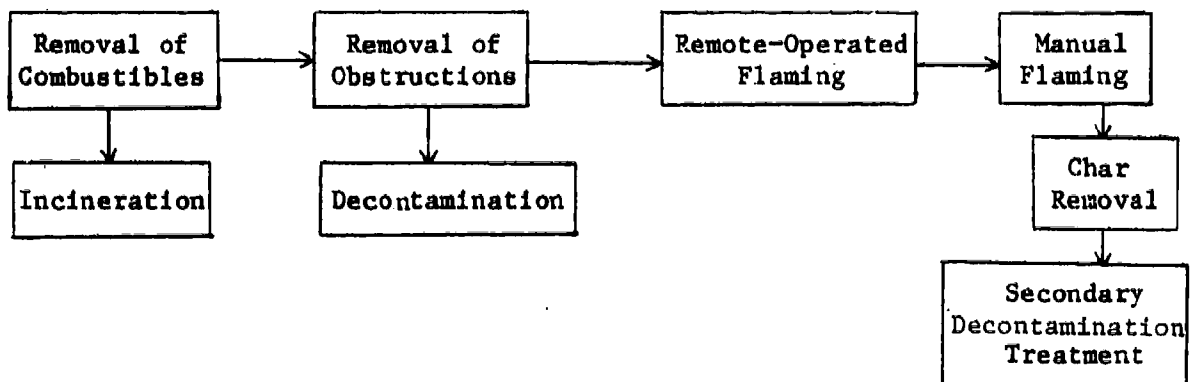
5.1.2 Variations
If the building has large open, continuous surface
areas, then a remote-operated flamer would be
preferred. Otherwise, a hand-held flamer is
preferred.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
Torch (hand held and remotely operated).
Fuel source, hoses, regulators
Fire extinguishers
Tools to remove obstructions and
    combustible material

5.2.2 Reliability, Availability and Maintainability
The RAM is expected to be low for the remotely
operated flamer because of the complexity of the
device. For a hand-held flamer the RAM is expected to
be high.

5.3 Decontamination Time

5.3.1 Set-up
Dependent on amount of obstructions and combustible
material which requires removal prior to flaming as
well as the amount of protective equipment required to
be set up (e.g. aerosol generator, etc.).

5.3.2 Application Time

5.3.2.1 Personnel
Long time if hand-held flamer extensively
employed. Short time if remotely operated
flamer extensively employed.

5.3.2.2 Decontamination
Very short (for surface treatment). The decon-
tamination time of agents exposed to 5600 F heat
will be a fraction of seconds.

5.3.2.3 Verification
Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
None if hand held flamer is exclusively used,
otherwise moderate.

5.3.3.2 Clean-up
Removal of char from the wall will not
be very consuming.

5.4 Safety Requirements

5.4.1 Process Hazards

Thermal decomposition of agents will produce gases which may require scrubbing to prevent release to the atmosphere. The gases may also contain volatilized agent.

5.4.2 Personnel Hazards

There is the possibility of burns from the flames or hot surfaces. If lead paint was used in the building, lead vapors would be formed during flaming. Volatilization of undecomposed agent may be possible.

5.4.3 Protective Methods

Shielding, safety glasses, fire extinguishers, non-static clothing, respirators and remotely operated equipment may be employed to reduce potential safety hazards. Hoods may be used to vent gases and collect lead vapors. Level A or B clothing may be required by operators.

6.0 Economics

6.1 Building Damage - Repair Costs

Building damage is expected to be minimal if flaming is employed as a surface decontamination technique; otherwise damage is expected to be extensive.

6.2 Developmental Costs

None required for process. The determination of building material agent concentrations on the interior is required to optimize the dwell time of the flamer.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost

Requires a large supply of gas (propane or acetylene and either oxygen or air).

6.3.2 Equipment Cost

Hand held flamers may be obtained as off-the-shelf equipment. Remotely operated flamers could be modeled after Rockwell design.

6.3.3 Material Cost

Decon solution for wash down.

6.3.4 Manpower Cost

Labor intensive especially if hand-held flaming is performed to a large extent.

7.0 Future Work Required

7.1 Knowledge Gaps
　　Selection of secondary treatment if surface flaming is
　　performed. In any case, concentration gradients of agents in
　　building materials must be determined.

7.2 Resolution
　　Experimental testing.

THERMAL DECOMPOSITION BY HOT GASES

1.0 General Description

    1.1 Summary of Idea

        The hot gas concept employs the use of heated gases such as burner exhaust gases to thermally decompose agent residues. The circulation of hot gases in a building may allow the building to behave like an oven. Toxic gases will be vented to a scrubber. The system will be operated until the desired time-at-temperature is attained to ensure agent decomposition. The outside walls and roof of the building may be wetted with a decon solution to prevent release of volatilized agent.

    1.2 Origination of Idea

        Novel Processing project team/Battelle ISDS (Internal Surface Decontamination System) Program (Stanford, 1981).

    1.3 Obvious Advantages and Disadvantages

        Advantages. Low cost burner exhaust gases may be employed to supply the heat duty. Inert atmosphere would minimize the fire risk. Low labor cost. Workers not directly involved in decontamination. All interior areas in a building (including intricate surfaces) will be simultaneously heated.

        Disadvantages. Potential need for long decontamination time. Building materials may be damaged.

    1.4 Variations of Idea

        Use flue gas from an on-site fossil fuel power plant, for example. Employ either electrical heating of air (probably not cost effective) or hand-held blower (not cost effective, safety risks). Add vaporized decontaminant to the inlet gas stream to assist decomposing volatilized agents.

    1.5 Sketch

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions

GB, HD and VX undergo thermal decomposition by either pyrolysis in inert atmospheres or oxidation (combustion) in excess air.

GB Pyrolysis (325-900 C)

$$CH_3-\overset{O}{\underset{OC_3H_7}{P}}-F \longrightarrow CH_3-\overset{O}{\underset{OH}{P}}-F + CH_2=CHCH_3$$

GB Oxidation/Combustion (250-1050 C)

$$2CH_3-\overset{O}{\underset{OC_3H_7}{P}}-F + 13O_2 \longrightarrow 8CO_2 + 9H_2O + P_2O_5 + 2HF$$

HD Pyrolysis (180-900 C)

Main Reaction: $S(CH_2CH_2Cl)_2 \longrightarrow H_2S + 2CH_2=CHCl$

HD Oxidation/Combustion (250-1000 C)

$$S(CH_2CH_2Cl)_2 + 13/2 \ O_2 \longrightarrow 4CO_2 + 3H_2O + 2HCl + SO_2$$

VX Pyrolysis
Confidential

VX Oxidation/Combustion (600-1200 C)

$$2C_{11}H_{26}O_2PSN + \frac{79/2}{2} O_2 \longrightarrow P_2O_5 + 2NO_2 + 22CO_2 + 26H_2O + 2S$$
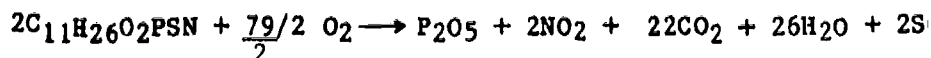
2.2 Hazardous Products

The oxidation/combustion products of the agents are relatively non-toxic gaseous and volatile species. However, reports of potentially hazardous pyrolysis products of the agents have been reported for HD including: Ethyl Mercaptan; Diethyl Sulfide; 2,2'Dichlorodiethylsulfide, and Vinyl Chloride. A significant problem is the volatilization of intact agents below their decomposition temperatures.

2.3 Destruction Efficiency, Residue Level

Complete decomposition of the agents is anticipated if the agent can be maintained at the decomposition temperature for the prescribed period of time. For example, complete decomposition of GB by pyrolysis was observed after heating at 150 C for 2-1/2 hours (Anonymous, 1974).

2.4 Reaction Rate/Kinetics

$$-\frac{d(VX)}{dt} = [9.6 \times 10^8 \exp(-14{,}000/T(^oK)](VX)$$

$$-\frac{d(GB)}{dt} = [1.5 \times 10^8 \exp(-11{,}700/T(^oK)](GB)$$

$$-\frac{d(HD)}{dt} = [1.8 \times 10^9 \exp(-12{,}632/T(^oK)](HD)$$

where (VX), (GB), (HD) = concentration of the
the respective agent
t = time (sec)
T = temperature (^oK)

2.5 Supplementary Treatment
Supplementary treatments may be required to remove and/or decompose the thermal decomposition products of HD, GB and VX if pyrolysis rather than oxidation occurs.

2.6 State-of-the-Art
Several studies have been performed on the pyrolysis and oxidation/combustion of agents including several references (Pugh, 1970; Hildebrandt, 1972; Lapp, 1962; Sass, 1972; Tomlinson, 1980; Williams, 1947; Reeves, 1954; Brooks, 1979). See general discussion of state-of-the-art.

3.0 Physical Treatment
Not applicable.

4.0 Applicability

4.1 Agent Applicability
The hot gas concept has potential applicability to all agents.

4.2 Isolated Building Material Applicability
All materials except some plastics.

4.2.1 Impact of Substrate on Chemistry
The agents may be adsorbed on the surface or in pores of the substrates. While adsorption of the contaminant on particular substrates may inhibit or catalyze the decomposition reaction the effect will probably be small.

4.2.2 Removal or Reaction of Contaminant from Surface
Complete decontamination of all surfaces may be achieved.

4.2.3 Removal or Reaction of Contaminant from Interior
If time is allowed for the building materials to heat up to the decomposition temperature of the agent, complete decontamination is anticipated.

4.2.4 Damage to Material
The hot gas method is expected to provide a slow building heat up rate. Thus, only slight damage to building materials such as paint charring, concrete dehydration and, possibly cracking of cement is anticipated. See discussion on thermal stability of materials (Appendix I).

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Removal of all plastics from the building may be required prior to heating. Insulation of windows, sealing of cracks between doors would be necessary to minimize heat loss and prevent release of volatilized agent.

4.3.2 Practical Physical Limitations/Methods to Overcome
There are no physical limitations because of the use of a gas. All areas including cracks, crevices, and interstitial wall spaces should be thermally decontaminated.

4.3.3 Secondary Decontamination Treatment
A secondary treatment may be required to remove hazardous decomposition products.

4.3.4 Clean-up Requirements
Wash down and repainting is all that is anticipated.

4.3.5 Waste Treatment and Disposal
Venting of the product gases from the building will require scrubbing prior to release to the environment to remove volatilzed agent, product gases etc. Combustible material removed from the building may be decontaminated chemically or by incineration.

4.4 State-of-the-Art
No reports could be found as to the decontamination of a building contaminated with agents using hot gases. However, work has been performed on using vehicle exhaust gases to volatilize agents from interiors of vehicle.
[Battelle ISDS (Internal Surface Decontamination System), Stanford, 1981].

5.0 Engineering

5.1 Process Description

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┌──────────────┐      ┌──────────────┐      ┌──────────────────┐
│  Insulate/   │ ───▶ │  Equipment   │ ───▶ │                  │
│ Seal Building│      │   Set-up     │      │ Decontamination  │
└──────────────┘      └──────────────┘      └──────────────────┘
                                                     │
                                                     ▼
                      ┌──────────────┐      ┌──────────────────┐
                      │              │ ◀─── │    Equipment     │
                      │   Clean-Up   │      │    Tear-Down     │
                      └──────────────┘      └──────────────────┘
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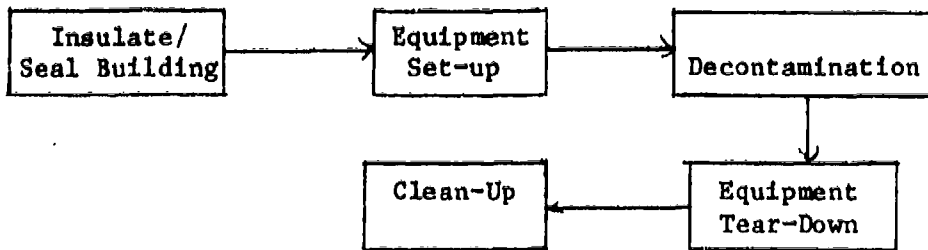
5.1.1 Main Process

Kerosene, for example, is combusted in a burner and the exhaust gases vented into the building with the aid of a blower. The gases supply heat to the building after which they are vented from the building with the aid of a blower, through a scrubber and released to the atmosphere. During decontamination, the outside surfaces of the building may be kept wet with a decon solution to prevent release of volatilized agent.

5.1.2 Variations

Flue gas from an on-site power plant is passed through ducts to the buildings. Air is electrically heated and passed into the building.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

Burner for kerosene, propane or other fuel. Blower to force burner exhaust into building. Fan to circulate gas in building. Blower to force spent gas from building to scrubber. Scrubber to clean exhaust gas.

5.2.2 Reliability, Availability and Maintainability

Off the shelf equipment can be employed so RAM is high.

5.3 Decontamination Time

5.3.1 Set-up

Set-up requires connection of ductwork and equipment and removal of plastic from the building. Burner, blowers and scrubber may be skid mounted to aid transportation and set-up. Set-up time may also involve sealing the building and other protective methods to prevent release of volatilized agent to the atmosphere.

5.3.2 Application Time

5.3.2.1 Personnel
Personnel required for equipment set-up and tear-down as well as routine maintenance on the blowers and burner during operation. Workers also required to periodically wet the outside surfaces of the building. Not a labor intensive operation.

5.3.2.2 Decontamination
The time is expected to be hours to days.

5.3.2.3 Verification
Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Short time if equipment is skid mounted.

5.3.3.2 Clean-up
Wash down and clean-up is all that is anticipated.

5.4 Safety Requirements

5.4.1 Process Hazards
None anticipated since use of required equipment is well known. Fire risks inside building are minimal because the inert atmosphere from the burner exhaust gases will be used as heating source.

5.4.2 Personnel Hazards
Since workers will not be in building during decontamination, the degree of personnel hazard is minimal (e.g. burns from hot gas ducts or burner or exposure to volatilized agent).

5.4.3 Protective Methods
Prevention of release of agents to the atmosphere may be accomplished by wetting the outside surfaces of the building during decontamination.

6.0 Economics

6.1 Building Damage - Repair Costs
Slight if heating rate is low. However, cracking of cement, brick and concrete may occur. Expansion joints may alleviate stresses developed from thermal expansion.

6.2 Developmental Costs
None for the process since off the shelf equipment is employed. However, temperatures and reaction times must be stipulated for the building materials under consideration prior to equipment selection.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Relatively inexpensive fuels such as kerosene may be employed.

6.3.2 Equipment Cost
Relatively inexpensive off-the-shelf equipment (blowers, burner) can be employed.

6.3.3 Materials Cost
Decon solution.

6.3.4 Manpower Cost
Low because of remote operation of burner and blowers requires only routine maintenance.

7.0 Future Work Required

7.1 Knowledge Gaps
Time and temperature required to decompose the agents in various building materials (brick, concrete, etc.)

7.2 Resolution
Experimental testing.

THERMAL DECOMPOSITION USING SOLVENT SOAK/CONTROLLED BURNING

1.0 General Description

1.1 Summary of Idea
This method consists of soaking a contaminated, porous material with a flammable solvent followed by controlled combustion of the soaked area. Before ignition, the solvent would be allowed to dissolve subsurface contaminants. After ignition, the contaminated solvent would diffuse to the surface to feed the flame and would, by combustion, thermally decompose dissolved contaminants.

1.2 Origination of Idea
Novel Processing project team.

1.3 Obvious Advantages and Disadvantages
Advantages. The method combines solvent extraction with thermal decomposition. Potentially applicable to both surface and subsurface contamination.

Disadvantages. The solvent diffusion may be too slow to maintain surface combustion. Open fire could cause damage to surrounding areas. It may be difficult to control combustion resulting in personnel hazards. Volatilization of undecomposed agent may occur.

1.4 Variations of Idea
Flaming could be used to maintain combustion if diffusion rate of solvent from the material is slow.

1.5 Sketch
None.

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions
GB, HD and VX undergo thermal decomposition by either pyrolysis in inert atmospheres or oxidation (combustion) in excess air.

<u>GB Pyrolysis</u> (325–900 C)

$$CH_3-\overset{O}{\underset{OC_3H_7}{P}}-F \longrightarrow CH_3-\overset{O}{\underset{OH}{P}}-F + CH_2 = CHCH_3$$

<u>GB Oxidation/Combustion</u> (250–1050 C)

$$2CH_3-\overset{O}{\underset{OC_3H_7}{P}}-F + 13O_2 \longrightarrow 8CO_2 + 9H_2O + P_2O_5 + 2HF$$

__HD Pyrolysis__ (180-900 C)

Main Reaction: $S(CH_2CH_2Cl)_2 \rightarrow H_2S + 2CH_2=CHCl$

__HD Oxidation/Combustion__ (250-1000 C)

$$S(CH_2CH_2Cl)_2 + \frac{13}{2} O_2 \rightarrow 4CO_2 + 3H_2O + 2HCl + SO_2$$

__VX Pyrolysis__
Confidential

__VX Oxidation/Combustion__ (600-1200 C)

$$2C_{11}H_{26}O_2PSN + \frac{79}{2} O_2 \rightarrow P_2O_5 + 2NO_2 +$$

$$22CO_2 + 26H_2O + 2SO_2$$

2.2 **Hazardous Products**
The oxidation/combustion products of the agents are relatively non-toxic gaseous and volatile species. However, reports of potentially hazardous pyrolysis products of the agents have been reported for HD including: Ethyl Mercaptan; Diethyl Sulfide; 2,2'Dichlorodiethylsulfide, and Vinyl Chloride.

2.3 **Destruction Efficiency, Residue Level**
Complete decomposition of the agents is anticipated if the agent can be maintained at the decomposition temperature for the prescribed period of time. For example, complete decomposition of GB by pyrolysis was observed after heating at 150 C for 2-1/2 hours (Anonymous, 1974).

2.4 **Reaction Rate/Kinetics**

$$- \frac{d(Vx)}{dt} = [9.6 \times 10^8 \exp (-14,000/T(^\circ K)](VX)$$

$$- \frac{d(GB)}{dt} = [1.5 \times 10^8 \exp (-11,700/T(^\circ K)](GB)$$

$$- \frac{d(HD)}{dt} = [1.8 \times 10^9 \exp (-12,632/T(^\circ K)](HD)$$

where (VX), (GB), (HD) = concentration of the
the respective agent
t = time (sec)
T = temperature ($^\circ K$)

2.5 **Supplementary Treatment**
Supplementary treatments may be required to remove and/or

decompose the thermal decomposition products of HD, GB and VX
if pyrolysis rather than oxidation occurs.

2.6 State-of-the-Art

Several studies have been performed on the pyrolysis and
oxidation/combustion of agents including several references
(Pugh, 1970; Hildebrandt, 1972; Lapp, 1962; Sass, 1972;
Tomlinson, 1980; Williams, 1947; Reeves, 1954; Brooks, 1979).
See general review of the state-of-the-art.

3.0 Physical Treatment

Although the solvent aids in physical removal of contaminants, the
main decontamination process is via thermal decomposition (i.e.
combustion). Thus analysis of the physical treatment aspects is
not necessary if it assumed that a flammable solvent of adequate
solubility and diffusivity properties is available.

4.0 Applicability

4.1 Agent Applicability

Potentially applicable to all agents.

4.2 Isolated Building Material Applicability

Applicable mainly to non-combustible porous materials (e.g.,
concrete, cement block, bricks), although metal surfaces
could also be treated. Possibly applicable to painted
surfaces.

4.2.1 Impact of Substrate on Chemistry

None anticipated.

4.2.2 Removal or Reaction of Contaminant from Surface

Surface reaction is highly probable.

4.2.3 Removal or Reaction of Contaminant from Interior

May require repeat applications. Complete
decontamination is dependent on diffusion of solvent
laden with agent from the porous material to the
flame.

4.2.4 Damage to Material

Depends on flame temperature, burning time and,
necessity of flaming to maintain surface combustion.
Cement and concrete are subject to cracking and
dehydration at high temperatures. Metals are readily
oxidized at high temperatures. Refer to general dis-
cussion of temperature stability of materials.

4.3 Practical Applicability to Building

4.3.1 Building Preparation

Paint removal may be necessary to allow diffusion of

solvent into and out of building materials. Sealing
of the building to prevent release of volatilized
agent may be required. All combustible materials
should be removed.

4.3.2 Practical Physical Limitations/Methods to Overcome
Would be difficult to use on ceilings. Should be
applied to only small sections at a time to avoid
uncontrolled fire hazards.

4.3.3 Secondary Decontamination Treatment
None anticipated unless diffusion of solvent from the
porous materials is slow or incomplete (i.e. residual
solvent remains fillowing treatment).

4.3.4 Clean-up Requirements
Clean-up of char, smoke residues and soot. Washing
of concrete with decon solution may be required.

4.3.5 Waste Treatment and Disposal
Controlled ventilation and treatment of flue gas may
be necessary. Combustible materials will require
separate decontamination.

4.4 State-of-the-Art
The method has never been used for building decontamination.

5.0 Engineering

5.1 Process Description

```
┌──────────────┐     ┌──────────┐     ┌──────────────┐     ┌──────────────┐
│   Remove     │ - ->│ Solvent  │ - ->│  Controlled  │ - ->│ Char Removal/│
│ Combustibles │     │   Soak   │     │   Burning    │     │  Clean-Up    │
└──────────────┘     └──────────┘     └──────────────┘     └──────────────┘
        │                  ▲                  │
        ▼                  │                  │
┌──────────────┐          │                  │
│ Decontaminate│          │                  │
└──────────────┘          │                  ▼
                     ┌──────────────────────────┐
                     │  Repeat Until Entire      │
                     │  Building is Decontaminated│
                     └──────────────────────────┘
```
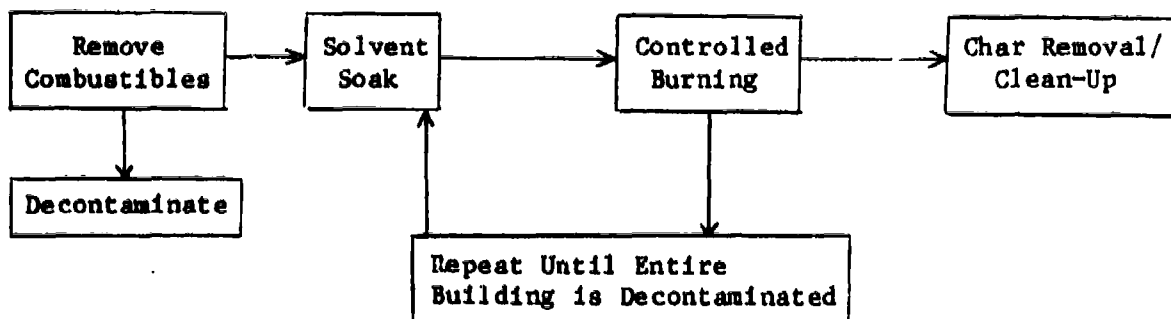
5.1.1 Main Process

5.1.1.1 Paint Removal (If necessary)
Sandblasting or paint stripping solvents
could be employed.

5.1.1.2 Solvent Soak
A flammable organic solvent capable of

solubilizing agents of interest is required.
Possible choices include toluene, methyl
cellosolve, or diethylene glycol. The
solvent could be applied by spray or brush
and allowed to soak in. Only a small
section of the building should be treated at
one time.

5.1.1.3 Controlled Burning
The solvent would be ignited remotely by a
hot wire or similar device. The burning
would be supported by an igniter, if
necessary.

5.1.1.4 Gas Collection
Volatiles would be collected via portable
hoods.

5.1.1.5 Gas Treatment
Flue gas may need to be contained and
treated.

5.1.2 Variations
Omit steps 5.1.1.1, 5.1.1.4 and 5.1.1.5 or com-
binations thereof. Allow solvent and/or burning to
remove paint, and allow vapors to naturally vent.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

5.2.1.1 For paint removal standard commercial sand-
blasting equipment could be employed. Paint
stripping solvents could be applied by brush or
spray.

5.2.1.2 Spray or brush system for solvent application.

5.2.1.3 Remote ignition device for initiation of
burning flamer may be necessary.

5.2.1.4 Fan for vapor collection/suction.

5.2.1.5 Scrubber, adsorption filter or similar system
for vapor treatment.

5.2.2 Reliability, Availability and Maintainability
Very high.

5.3 Decontamination Time

5.3.1 Set-up

Remove all combustible material (e.g., plastic). May
need to remove paint. Time dependent on amount
of material requiring removal. Setup of protection
equipment, if required, against the release of
volatilized agent (e.g. aerosol generator).

5.3.2 Application Time

5.3.2.1 Personnel
Moderate time to apply solvent to each
section, ignite solvent, maintain and monitor
combustion.

5.3.2.2 Decontamination
Depends on depth of contamination and number
of applications required to solubilize all of
agent. It will probably take a few days.

5.3.2.3 Verification
Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Minimal.

5.3.3.2 Clean-up
Moderate time for char, smoke residue and
soot clean-up.

5.4 Safety Requirements

5.4.1 Process Hazards
Uncontrolled combustion, explosions.

5.4.2 Personnel Hazards
Burns, toxic vapor. Flammable solvents, volatilized
agent.

5.4.3 Protective Methods
Have fire fighting equipment on stand-by. Wear heat
resistant clothing. Respiratory equipment required in
all cases because of oxygen deprivation. Use remote
operation/shielding barriers and hoods to withdraw
smoke and toxic vapors. Level A or B clothing may be
required. Use an aerosol to decontaminate volatilized
agent.

6.0 Economics

6.1 Building Damage - Repair Costs
Probable damage to concrete, cement blocks from flames.
Expansion joints may reduce damage from thermal stresses.

6.2 Developmental Costs
  Testing of flame maintainability and selection of solvent.

6.3 Treatment Costs

  6.3.1 Utilities and Fuel Cost
      Depends on necessity for flaming apparatus, but would
      be quite small (cost of solvent considered under
      material cost).

  6.3.2 Equipment Cost
      Relatively low. Costs include:
        spray or brush system
        flamer
        portable hood
        scrubber/filter system

  6.3.3 Material Cost
      Solvent cost - depends on type of solvent, but may be
      high because of amount required.

  6.3.4 Manpower Cost
      Substantial labor involvement.

7.0 Future Work Required

  7.1 Knowledge Gaps
      Degree of volatilization of agent.
      Necessity of flaming to maintain combustion.
      Necessity of prior paint removal.
      Extent of damage to building materials.
      Building preparation depends on necessity of prior paint
        removal and necessity of expansion joints.
      Solvent selection

  7.2 Resolution
      Experimental testing.

THERMAL DECOMPOSITION BY RADIANT (INFRARED) HEATING

1.0 General Description

1.1 Summary of Idea
Radiant heating employs the use of fuel or electrically powered radiant heaters to heat building materials to the decomposition temperature of the agent. Off-the-shelf commercial radiant heaters may be employed. Heating external and internal surfaces simultaneously may prevent volatilization of agent to uncontaminated areas.

1.2 Origination of Idea
Novel Processing project team.

1.3 Obvious Advantages and Disadvantages
Advantages. Efficient process (at least 67% of energy supplied to heater is converted to infrared radiation). No contact between heater and wall is required. Not necessary to heat air in the room. (Summer, 1965).

Disadvantages. Heating complex surface areas in a building may be difficult only because of configurations of radiant heaters. Building materials may be damaged. Volatilization of agent to uncontaminated areas.

1.4 Variations of Idea
None

1.5 Sketch
See pages III-55,56.

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions
GB, HD and VX undergo thermal decomposition by either pyrolysis in inert atmospheres or oxidation (combustion) in excess air.

GB Pyrolysis (325-900 C)

$$CH_3-\overset{O}{\underset{OC_3H_7}{P}}-F \longrightarrow CH_3-\overset{O}{\underset{OH}{P}}-F + CH_2 = CHCH_3$$

GB Oxidation/Combustion (250-1050 C)

$$2CH_3-\overset{O}{\underset{OC_3H_7}{P}}-F + 13O_2 \longrightarrow 8CO_2 + 9H_2O + P_2O_5 + 2HF$$
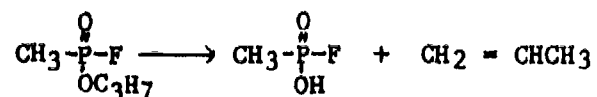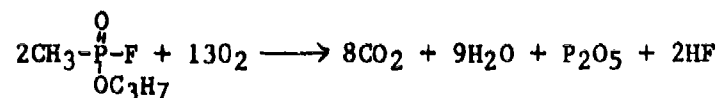
Types CPL and CPH—wide area-flat surface sections
0.5 to 3.6 kW/FT²
2.5 to 7.9 micron wave length
200°F to 1600°F emitter temperatures

Ratings

Dimensions (In.) A Overall Length	B Overall Width	Volts	Phase	KW	Watt Density Watts/ Sq. In.	Therm owell	Chromalox Catalog No.	PCN	Approx. Weight
6	12	120/240	1	1.1	15	Yes	CPL-0612T	223790	3
6	12	240/480	1	1.8	25	Yes	CPH-0624T	223802	3
12	12	240/480	1	2.2	15	Yes	CPL-1224T	223810	6
12	12	240/480	1	3.6	25	No	CPH-1224	223829	6
12	12	240/480	1	3.6	25	Yes	CPH-1224T	223837	6
24	12	240/480	1	4.3	15	Yes	CPL-2424T	223845	12
24	12	240	3	7.2	25	No	CPH-2423	223853	12
24	12	240	3	7.2	25	Yes	CPH-2423T	223861	12
24	12	480	3	7.2	25	No	CPH-2443	223870	12
24	12	480	3	7.2	25	Yes	CPH-2443T	223888	12
48	12	240	3	8.6	15	Yes	CPL-4823T	223896	24
48	12	480	3	8.6	15	No	CPL-4843	223909	24
48	12	480	3	8.6	15	Yes	CPL-4843T	223917	24
48	12	240	3	14.4	25	Yes	CPH-4823T	223925	24
48	12	480	3	14.4	25	Yes	CPH-4843T	223933	24
60	12	480	3	10.8	15	Yes	CPL-6043T	223941	30
60	12	240	3	18.0	25	Yes	CPH-6023T	223950	30
60	12	480	3	18.0	25	Yes	CPH-6043T	223968	30

Construction

U.S. Patent Pending

Features

☐ **Uniform radiation pattern assured** with a wide flat infrared surface versus the line pattern given in normal radiant heaters. This eliminates uneven heating of the work and allows uniform heating of a stationary surface such as in an indexing process.

☐ **Lower operating cost** with up to 80% of the input energy transmitted to and absorbed by the work material. The maximum amount of radiant energy is transferred to the work with very low heater convection losses. Typical installation two-four inches from the work surface reduces significantly the energy input.

☐ **Costly down-time minimized.** There is no deterioration of the output radiation level with heater life and no reflectors to clean which could cause down-time and increased maintenance costs. The unit is resistant to vibration because of the compact homogeneous construction.

☐ **Easy to install.** The light weight building block approach allows for a modular installation which is easily expandable. It is lightweight in construction, less than seven pounds per square foot, can typically be applied two-four inches from the work surface simplifying heater mounting and minimizing construction costs.

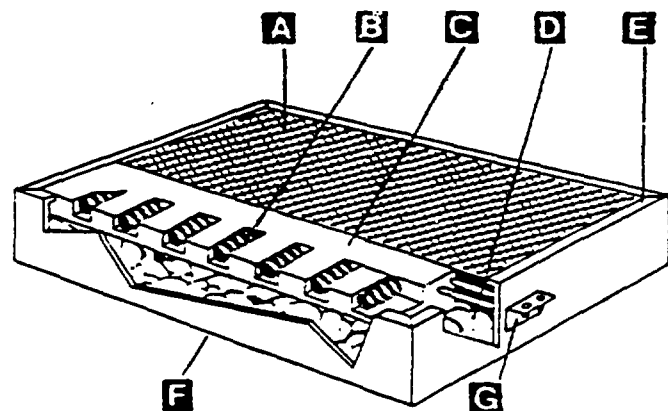☐ **Repeatable process performance assured.** Used with closed loop control, the system automatically compensates for ambient temperature ranges and line voltage fluctuations. Maximum energy transfer requires matching the peak wave length output to the specific material absorption characteristics. Because the peak wave lengths of the flat surface heater are repeatable and adjustable the quality output of the process is assured.

☐ **Easy to control.** The use of time proportioning control with closed loop feedback, such as Chromalox Series 3800 temperature controllers, Chromalox magnetic contactors or CSCR power controllers assure easy and dependable system control. Thermowells in two locations in the heater interior suitable to accept Chromalox standard thermocouples, sense the emitter temperature insuring accurate wave length emission. Fast response time of the unit reduces thermal lag.

🅰 **Emission Surface**—Woven refractory cloth with black ceramic coating for high radiant energy transfer.

🅱 **Heater Element**—Precision iron base resistance wire, designed to give extended life and uniform emission over entire radiating surface.

🅲 **Heater Element Support**—Fibrous ceramic material, specially developed for high insulation qualities, durability, shock resistant and asbestos free.

🅳 **Insulation**—Fiberglass insulation to minimize heat loss out the back of the heater.

🅴 **Frame**—Heavy gauge, heat resistant, aluminized steel.

🅵 **Terminals**—Stainless steel terminals are provided in a standard 4" x 4" junction box for easy hookup.(not shown)

🅶 **Thermowell**—Quality tubular quartz thermowell, with strain relief, to accept a Chromalox C-700JU or C-700KU thermocouple on units with suffix "T" in catalog number.

Stocked LN and LW oven sections, with built-in air spaces for insulation and terminal block for bus bar, will accept 1, 2 or 3 heating elements. Designed for use with locally available hardware, they provide great flexibility in radiant sources and housings, for a single heater section or a complete oven.

Chromalox supplies oven sections, heating elements, frame wireways, controls and wiring. Framing hardware and brackets must be obtained from local suppliers.

Single heater mountings

Angle iron brackets

Threaded rod and continuous-slot metal framing

Formed strap iron

Flat heater banks

Angle iron
and chain.

Angle iron

Continuous-slot metal framing
and metal wireway

Large oven sections

Straight and formed angle iron

Angle iron frame,
strap-iron brackets
and sheet aluminum
sides

Formed ovens

Angle iron frame and
strap-iron brackets

Formed strap iron bolted
to machine frame

Angle iron or
continuous-slot framing

Curved strap iron
and angle iron

Danger—Hazard of fire—Avoid direct contact of heater case with any combustible surfaces. Energized heaters should be spaced so that no combustible surfaces exceed 194°F.

HD Pyrolysis (180-900°C)

Main Reaction: $S(CH_2CH_2Cl)_2 \longrightarrow H_2S + 2CH_2=CHCl$

HD Oxidation/Combustion (250-1000°C)

$S(CH_2CH_2Cl)_2 + \frac{13}{2} O_2 \longrightarrow 4CO_2 + 3H_2O + 2HCl + SO_2$

VX Pyrolysis

Confidential

VX Oxidation/Combustion (600-1200°C)

$2C_{11}H_{26}O_2PSN + \frac{79}{2} O_2 \longrightarrow P_2O_5 + 2NO_2 +$

$22CO_2 + 26H_2O + 2SO_2$

2.2 Hazardous Products

The oxidation/combustion products of the agents are relatively non-toxic gaseous and volatile species. However, reports of potentially hazardous pyrolysis products of the agents have been reported for HD including: Ethyl Mercaptan; Diethyl Sulfide; 2,2'Dichlorodiethylsulfide, and Vinyl Chloride.

2.3 Destruction Efficiency, Residue Level

Complete decomposition of the agents is anticipated if the agent can be maintained at the decomposition temperature for the prescribed period of time. For example, complete decomposition of GB by pyrolysis was observed after heating at 150 C for 2-1/2 hours (Anonymous, 1974).

2.4 Reaction Rate/Kinetics

$-\dfrac{d(Vx)}{dt} = [9.6 \times 10^8 \exp(-14,000/T(°K)](VX)$

$-\dfrac{d(GB)}{dt} = [1.5 \times 10^8 \exp(-11,700/T(°K)](GB)$

$-\dfrac{d(HD)}{dt} = [1.8 \times 10^9 \exp(-12,632/T(°K)](HD)$

where (VX), (GB), (HD) = concentration of the
the respective agent
t = time (sec)
T = temperature (°K)

2.5 Supplementary Treatment

Supplementary treatments may be required to remove and/or decompose the thermal decomposition products of HD, GB and VX if pyrolysis rather than oxidation occurs.

2.6 State-of-the-Art
Several studies have been performed on the pyrolysis and oxidation/combustion of agents including several references (Pugh, 1970; Hildebrandt, 1972; Lapp, 1962; Sass, 1972; Tomlinson, 1980; Williams, 1947; Reeves, 1954; Brooks 1979). A review of the state-of-the-art is given Section 4.4.

3.0 Physical Treatment
Not applicable.

4.0 Applicability

4.1 Agent Applicability
The radiant heating concept has the potential applicability to all agents.

4.2 Isolated Building Material Applicability
All materials compatible with the required decomposition temperature.

4.2.1 Impact of Substrate on Chemistry
The agent may be adsorbed on the surface or pores of the substrate while adsorption of the contaminant on particular substrates may inhibit or catalyze the decomposition reaction the effect will be probably small.

4.2.2 Removal or Reaction of Contaminant from Surface
Complete decontamination of all surfaces is expected.

4.2.3 Removal or Reaction of Contaminant from Interior
The infrared radiation will primarily heat the surface. Heat conduction from the surface will heat the interior of the building material to the decomposition temperature of the agent. However, long wave IR may be employed to heat some materials from their center to the periphery.

4.2.4 Damage to Material
Some damage to building materials such as concrete dehydration and, possibly, cracking of cement is expected. See Appendix I for discussion of thermal stability of materials. Different radiation intensities may be employed on different materials to minimize damage.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Removal of plastic and other combustibles may be required.

4.3.2 Practical Physical Limitations/Methods to Overcome

Heat transfer from the infrared source is by radiation which heats only the surface. However, the subsurfaces of the building material will be heated by conduction. Thus, no limitations are expected.

4.3.3 Secondary Decontamination Treatment

A secondary treatment may be required to remove hazardous decomposition products.

4.3.4 Clean-up Requirements

Wash down and repainting is all that is anticipated.

4.3.5 Waste Treatment and Disposal

Combustible material removed from the building may be decontaminated chemically or by incineration. Venting of any volatilized agent and product gases to a scrubber unit will be necessary.

4.4 State-of-the-Art

Although radiant heating has not been applied to heating building materials for thermal decomposition of agents, radiant heating has been used for paint drying plastic moulding, in the leather and tire industry, clay drying (long wave radiation penetrates into the clay to cause drying from the inside out), and metal heating. (Summer, 1965)

5.0 Engineering

5.1 Process Description

```
┌──────────┐     ┌──────────────┐     ┌──────────┐     ┌──────────┐
│ Radiant  │     │   Thermal    │     │          │     │          │
│ Heater   │ ──► │Decontamination│ ──► │Tear-Down │ ──► │ Clean-Up │
│ Set-Up   │     │              │     │          │     │          │
└──────────┘     └──────────────┘     └──────────┘     └──────────┘
      ▲                                      │
      └──────────────────────────────────────┘
```

Repeat Cycle Until Building is Decontaminated
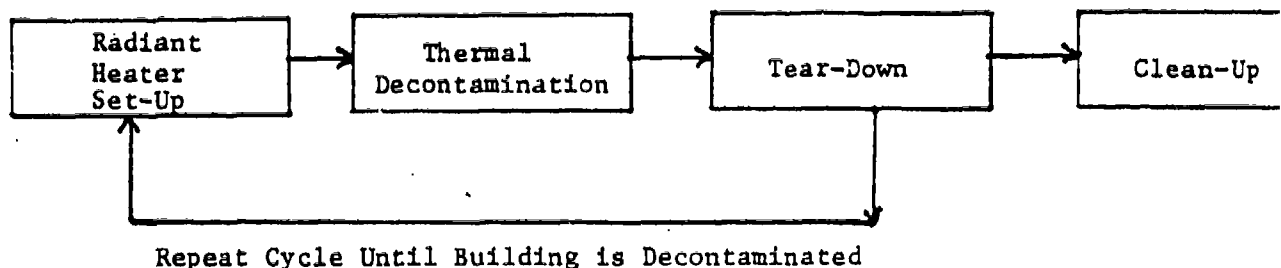
5.1.1 Main Process

The radiant heaters are set up in a series of banks in a section of the building and operated until it is decontaminated. The equipment is then moved to another section of the building and the process repeated until all areas of the building are decontaminated.

5.1.2 Variations
Enough IR heaters may be supplied so as to treat the entire building simultaneously.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
Infrared (radiant) heaters. Scrubber system (including blower), if necessary, to remove volatilized agent and product gases.

5.2.2 Reliability, Availability and Maintainability
Expected to be high because of off-the-shelf equipment that will be used.

5.3 Decontamination Time

5.3.1 Set-up
Set-up time may be relatively long especially if there are complex areas in the building. Set-up for straight wall should be simple. Set-up time may also involve protection against release of volatilized agent, if necessary, such as sealing the building, set-up of an aerosol decontaminant generator, etc.

5.3.2 Application Time

5.3.2.1 Personnel
Required primarily in equipment set-up and tear-down; otherwise only routine maintenance and monitoring will be required.

5.3.2.2 Decontamination
Decontamination time is dependent on the agent building materials and heat-up rates. It is expected to take several minutes to hours.

5.3.2.3 Verification
Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Removal time is expected to require less time than set-up.

5.3.3.2 Clean-up
Cleanup will be primarily repainting.

5.4 Safety Requirements

5.4.1 Process Hazards

Potential for a fire when combustible materials (e.g. plastics) are heated. This may be reduced if either moderate heat-up rates are employed or if an inert atmosphere maintained in the building during decontamination or if the materials are removed prior to heating.

5.4.2 Personnel Hazards

Burns from hot equipment or building. Volatilized agent.

5.4.3 Protective Methods

Personnel may not be required to be inside building during decontamination. Hoods may be used to ventilate decontamination areas. Level A or B clothing may be required. Preventing release of agents to uncontaminated areas, if volatilized undecomposed, may be accomplished by either spraying surfaces with decon solution or by use of an aerosol decontaminant.

6.0 Economics

6.1 Building Damage - Repair Costs

Building stresses from thermal process may cause cracking of concrete, cement or bricks. Expansion joints may alleviate stresses resulting from thermal expansion.

6.2 Developmental Costs

None for the process since off the shelf equipment is employed. However, temperatures and heating times must be stipulated for the series of building materials under consideration prior to equipment selection.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost

Utilities are expected to be a small part of the overall costs.

6.3.2 Equipment Cost

Off-the-shelf equipment can be employed and reused at several sites. Some initial electrical wiring may be required.

6.3.3 Material Cost

None anticipated.

6.3.4 Manpower Cost

Moderate manpower cost because of set-up and tear-down times.

7.0 Future Work Required

7.1 Knowledge Gaps

Time and temperature required to decompose the agents while minimizing volatilization in various building materials (brick, concrete, etc.) must be determined.

7.2 Resolution

Experimental testing.

THERMAL DECOMPOSITION USING CO_2 LASER

1.0 General Description

1.1 Summary of Idea
This method would utilize a CO_2 laser to direct an infrared laser beam onto a contaminated building surface. Surface contaminants would be thermally decomposed directly; sub-surface contaminants could be thermally decomposed by heat conduction from the irradiated surface.

1.2 Origination of Idea
Novel Processing project team.

1.3 Obvious Advantages and Disadvantages
Advantages. The laser could be centrally located in a room and operated by computer control for ease of operation.

Disadvantages. Limited to line-of-sight locations. A highly complex beam guidance system would be necessary. Decontamination rate may be substantially restricted by small laser beam diameter. Building materials may suffer damage from thermal effects. High capital cost. Volatilization of agent may occur.

1.4 Variations of Idea
None.

1.5 Sketch
None..

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions
GB, HD and VX undergo thermal decomposition by either pyrolysis in inert atmospheres or oxidation (combustion) in excess air.

GB Pyrolysis (325-900 C)

$$CH_3-\overset{\overset{O}{\|}}{\underset{OC_3H_7}{P}}-F \longrightarrow CH_3\ \overset{\overset{O}{\|}}{\underset{OH}{P}}-F\ +\ CH_2 = CHCH_3$$

GB Oxidation/Combustion (250-1050 C)

$$2CH_3-\overset{\overset{O}{\|}}{\underset{OC_3H_7}{P}}-F\ +\ 13O_2 \longrightarrow 8CO_2\ +\ 9H_2O\ +\ P_2O_5\ +\ 2HF$$

HD Pyrolysis (180-900 C)

Main Reaction: $S(CH_2CH_2Cl)_2 \longrightarrow H_2S\ +\ 2CH_2 = CHCl$

HD Oxidation/Combustion (250-1000 C)

$$S(CH_2CH_2Cl)_2 + \frac{13}{2} O_2 \longrightarrow 4CO_2 + 3H_2O + 2HCl + SO_2$$

VX Pyrolysis
      Confidential

VX Oxidation/Combustion (600-1200 C)

$$2C_{11}H_{26}O_2PSN + \frac{79}{2} O_2 \longrightarrow P_2O_5 + 2NO_2 + 22CO_2 + 26H_2O + 2SO_2$$

2.2 Hazardous Products

The oxidation/combustion products of the agents are relatively non-toxic gaseous and volatile species. However, reports of potentially hazardous pyrolysis products of the agents have been reported for HD including: Ethyl Mercaptan; Diethyl Sulfide; 2,2'Dichlorodiethylsulfide; and Vinyl Chloride.

2.3 Destruction Efficiency, Residue Level

Complete decomposition of the agents is anticipated if the agent can be maintained at the decomposition temperature for the prescribed period of time. For example, complete decomposition of GB by pyrolysis was observed after heating at 150 C for 2-1/2 hours (Anonymous, 1974).

2.4 Reaction Rate/Kinetics

$$- \frac{d(Vx)}{dt} = [9.6 \times 10^8 \exp (-14,000/T(^\circ K)](VX)$$

$$- \frac{d(GB)}{dt} = [1.5 \times 10^8 \exp (-11,700/T(^\circ K)](GB)$$

$$- \frac{d(RD)}{dt} = [1.8 \times 10^9 \exp (-12,632/T(^\circ K)](HD)$$

where (VX), (GB), (HD) = concentration of the
                        the respective agent
          t = time (sec)
          T = temperature ($^\circ K$)

2.5 Supplementary Treatment

Supplementary treatments may be required to remove and/or decompose the thermal decomposition products of HD, GB and VX if pyrolysis rather than oxidation occurs.

2.6 State-of-the-Art

Several studies have been performed on the pyrolysis and

oxidation/combustion of agents including several references (Pugh, 1970; Hildebrandt, 1972; Lapp, 1962; Sass, 1972; Tomlinson, 1980; Williams, 1974; Reeves, 1954; Brooks 1979). See the general section reviewing the state-of-the-art.

3.0 Physical Treatment
Not applicable.

4.0 Applicability

4.1 Agent Applicability
CO_2 laser concept has the potential applicability to all agents.

4.2 Isolated Building Material Applicability
All materials compatible with the required decomposition temperature for surface decontamination.

4.2.1 Impact of Substrate on Chemistry
The agent may be adsorbed on the surface or pores of the substrate. While adsorption of the contaminant on particular substrates may inhibit or catalyze the decomposition reaction the effect will be probably small.

4.2.2 Removal or Reaction of Contaminant from Surface
Complete decontamination of all surfaces is expected.

4.2.3 Removal or Reaction of Contaminant from Interior
Potentially applicable, but will depend on the ability to control heat penetration from the surface.

4.2.4 Damage to Material
Extent of damage depends on the laser beam intensity and dwell time. Cement and concrete are subject to cracking and dehydration at high temperatures. Metals are readily oxidized at high temperatures. Refer to general discussion of temperature stability of building materials. (Appendix I)

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Removal of paint and other combustible material may be necessary. The building should be sealed during decontamination to prevent release of volatilized agent.

4.3.2 Practical Physical Limitations/Methods to Overcome
Restricted to line-of-sight locations. This could be partially overcome by movement of mirrors to different perspectives within a given room.

4.3.3 Secondary Decontamination Treatment
Treatment of regions that are inaccessible to the laser may be required.

4.3.4 Clean-up Requirements
Removal of surface char, and wash down needed.

4.3.5 Waste Treatment and Disposal
Decomposition product vapors may need to be collected and treated. Properly positioned hoods could collect the vapors and any volatilized agent, and treatment could be achieved using either a scrubber, absorption filter, or similar system. All combustible material removed would require decontamination by either chemical means or by incineration.

4.4 State-of-the-Art
The method has never been used for building decontamination.

5.0 Engineering

5.1 Process Description

Laser Set-up	→	Thermal Decontamination	→	Laser Tear-down	→	Clean-up	→	Secondary Decontamination Treatment (if necessary)
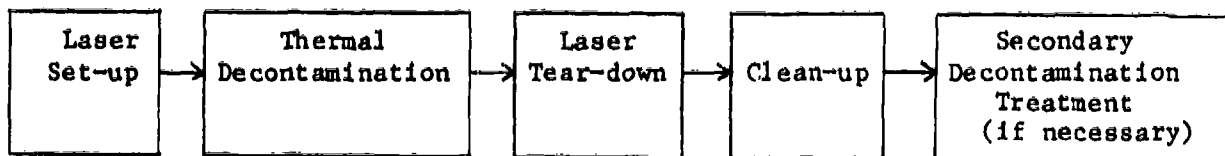
5.1.1 Main Process

5.1.1.1 Paint removal
Sandblasting, paint stripping solvents or flaming could be employed, depending on the building material.

5.1.1.2 Laser treatment
A continuous wave CO_2 laser source would be positioned in a stationary location inside a building or room. A complex network of mobile mirrors and lenses would be required to direct and focus the beam onto a contaminated surface. A computer control system would be required to move the mirrors so that a large surface area could be scanned. The beam intensity, beam size, angle of incidence, and scan rate, would all have to be manipulated to achieve the desired surface temperature and depth of heat penetration.

5.1.1.3 Gas collection
Volatiles could be collected by properly positioned hoods.

5.1.1.4 Gas treatment
Vapors may need to be treated to minimize
safety hazards and air pollution.

5.1.2 Variations
Omit Steps 5.1.1.1, 5.1.1.3 and 5.1.1.4 or
combinations thereof. Allow laser to remove paint.
Allow vapors to vent naturally.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

5.2.1.1 Paint removal equipment
Sandblast. Use standard commercial
sandblasting equipment. Best for porous
materials (concrete, brick, etc.).
Paint Stripper. Apply solvent by brush or
spray. Best for impervious materials
(metals).
Flaming. Use standard paint removal torches.
May be suitable for metal.

5.2.1.2 Laser equipment
The main component would be a CO_2 laser with
power intensity in the range of 1-5
kilowatts. Accessories include mirrors,
lenses, remote control equipment, computer
hardware and software.

5.2.1.3 Gas collection equipment
Portable hood.

5.2.1.4 Gas treatment
Toxic vapors may be treated in a scrubber,
absorption filter or similar system.

5.2.2 Reliability, Availability and Maintainability
Very low because of the complexity of the laser system.

5.3 Decontamination Time

5.3.1 Set-up

5.3.1.1 Very long set up time. In addition to possible
paint removal, a complex beam guidance system
may be required. This would involve installa-
tion of the laser source in an appropriate
location, installation of a complex network of

mobile mirrors and lenses, and computer inter-
facing and programming.

5.3.2 Application Time

5.3.2.1 Personnel
System monitoring and maintenance is
anticipated but would·be minimal.

5.3.2.2 Decontamination
Decon time will depend on the beam size, scan
rate and the complexity of the guidance
system (e.g., can the entire room be treated
with a single network configuration or will
it require maneuvering). Generally, decon
may take days.

5.3.2.3 Verification
Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Removal of laser source and beam guidance
system would proceed quickly.

5.3.3.2 Clean-up
Short time for removal of surface char and
wash down of dehydrated cement.

5.4 Safety Requirements

5.4.1 Process Hazards
None anticipated.

5.4.2 Personnel Hazards
Burns from reflected laser beam and volatilized agent.

5.4.3 Protective Methods
Wear heat resistant clothing.
Wear eye protection.
Use remote operation/shielding barriers.
Level A or B clothing may be required to be worn
by personnel entering the building.

6.0 Economics

6.1 Building Damage - Repair Costs
Depends on depth of thermal penetration and beam intensity.
Potentially quite severe, but can be minimized by short
surface exposure or cutting expansion joints.

6.2 Developmental Costs
   Testing of temperature requirements.
   Design and construction of beam guidance system.
   Computer programming and interfacing requirements
   specification.

6.3 Treatment Costs

   6.3.1 Utilities and Fuel Cost
      Electrical requirements may be substantial.

   6.3.2 Equipment Cost
      Substantial, including cost of:
      CO_2 laser.
      Beam guidance system.
      Computer system (microprocessor).

   6.3.3 Material Cost
      None anticipated.

   6.3.4 Manpower Cost
      High labor cost including paint removal (if
      necessary), system set-up and tear-down, system
      monitoring.

7.0 Future Work Required

   7.1 Knowledge Gaps
      Extent of damage to porous building materials.
      Extent of volatile penetration via thermal diffusion.
      Applicability to painted surfaces.
      Effect of substrate on decomposition temperature of
      contaminant.

   7.2 Resolution
      Experimental testing.

HYDROBLASTING

1.0 General Description

1.1 Summary of Idea
A high pressure (500-20,000 psi) water jet impacts the surface removing the contaminated surface. Surface debris and water is then collected and thermally or chemically decontaminated.

1.2 Origination of Idea
Novel Processing project team.

1.3 Obvious Advantages and Disadvantages
Advantages. Hydroblasting offers a relatively inexpensive, non-hazardous surface decontamination technique using off-the-shelf (commercial) equipment. Hydroblasting can very easily incorporate variations such as hot or cold water, abrasives, solvents, surfactants, and varied pressures. Many manufacturers produce a wide range of hydroblasting systems and high pressure pumps.

Disadvantages. Hydroblasting may not effectively remove contaminants that have penetrated the surface layer. Large amounts of water will have to be collected and treated.

1.4 Variations of Idea
Remote operated hydroblasting rigs could be designed and used on walls or floors. Surfactants, caustic solutions, and commercial cleaners can be added to the water to decrease surface tension and increase cleaning, rate of hydrolysis, and possibly the depth of penetration.

Other solvents could be used in combination with water (water/acetone) to replace water all together, to take advantage of agent solubility. Sand or other abrasives can be used to increase the abrasive surface removal (add-on attachments are available from the manufacturers).

1.5 Sketch
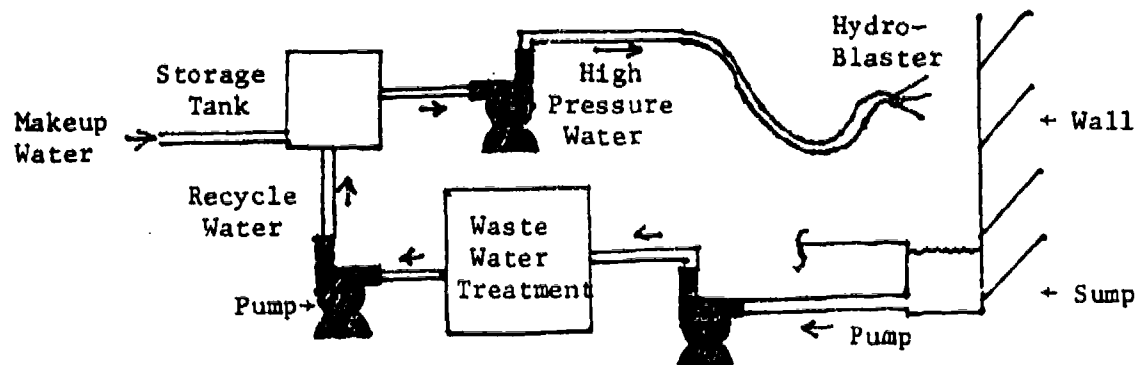
2.0 Chemical Decomposition Treatment
Caustic solutions should aid the hydrolysis of GB and VX and, to a minor extent, HD, but the principal interest here is physical removal.

3.0 Physical Treatment

3.1 Removal Efficiency, Residue Level
Complete removal of surface contamination is anticipated. High pressures (10,000-20,000 psi) and chemical additives may enable removal of contaminants from below the surface.

3.2 Hazardous Wastes
The removed debris still contains the active agent. Spent water may contain agents and therefore requires waste treatment prior to recycle or discharge.

3.3 Supplementary Treatment(s)
Other physical, chemical or thermal methods may be required to either remove or react with agents that have penetrated the surface layer through cracks or pores.

3.4 Waste Recovery and Disposal
The removed surface debris and spent water needs to be collected in a sump system. Water may be recycled to blaster following agent removal. Surface debris will need to be periodically removed from the sump and decontaminated.

3.5 State-of-the-Art
Hydroblasting has been used to decontaminate nuclear facilities (Manion, 1980) and military vehicles (Bless, 1980).

4.0 Applicability

4.1 Agent Applicability
Hydroblasting is applicable to all agents.

4.2 Isolated Building Material Applicability
Applicable to concrete, cement, brick, metal, etc.

4.2.1 Impact of Substrate on Chemistry
None anticipated.

4.2.2 Removal or Reaction of Contaminant from Surface
Complete removal of contaminant from the surface is expected.

4.2.3 Removal or Reaction of Contaminant from Interior
Chemical additives or solvent other than water may allow contaminants to be removed from sub-surface layer. High pressures (10,000 - 20,000 psi) and/or

added abrasives can physically remove surface layers enabling contaminant to be removed from sub-surface layers.

4.2.4 Damage to Material
Minimal - water may damage insulation or other types of materials but most building materials will be undamaged.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Existing sump/water collection systems will have to be checked for leaks. Installation of sumps and external water storage tanks may be necessary.

4.3.2 Practical Physical Limitations/Methods to Overcome
None anticipated - all areas of a building could be accessible to water sprays.

4.3.3 Secondary Decontamination Treatment
Other methods may need to be employed to remove/ decontaminate agents that may have penetrated the surface through cracks and pores.

4.3.4 Clean-up Requirements
Minimal - the collection system and sumps will have to be thoroughly cleaned to remove any remaining debris and agent residue. The spent wash water will have to be treated and disposed of. All surface debris will have to be collected for decontamination and disposal.

4.3.5 Waste Treatment and Disposal
All removed agents will have to be separated from or treated in large quantities of water. The surface debris will have to be separated from the water (using settling for example) and decontaminated.

4.4 State-of-the-Art
Hydroblasting has been employed to commercially clean bridges, building, heavy machinery, highways, ships, metal coatings, railroad cars, heat exchanger tubes, reactors, piping, etc. Off-the-shelf equipment is available from many manufacturers and distributors. (Manufacturer's brochures)

5.0 Engineering

5.1 Process Description

```
┌──────────────┐     ┌──────────────┐     ┌──────────────┐     ┌──────────────────┐
│  Equipment   │────▶│ Hydroblasting│────▶│  Equipment   │◀────│    Secondary     │
│   Set-Up     │   ┌▶│              │     │  Tear Down   │────▶│  Decontamination │
└──────────────┘   │ └──────┬───────┘     └──────────────┘     │     Treatment    │
                   │        │                                  └──────────────────┘
                   │        ▼
                   │ ┌──────────────┐     ┌──────────────────┐
                   │ │Water Treatment│    │     Debris       │
                   └─│     and       │───▶│  Decontamination │
                     │Debris Separation│  │   and Disposal   │
                     └──────────────┘     └──────────────────┘
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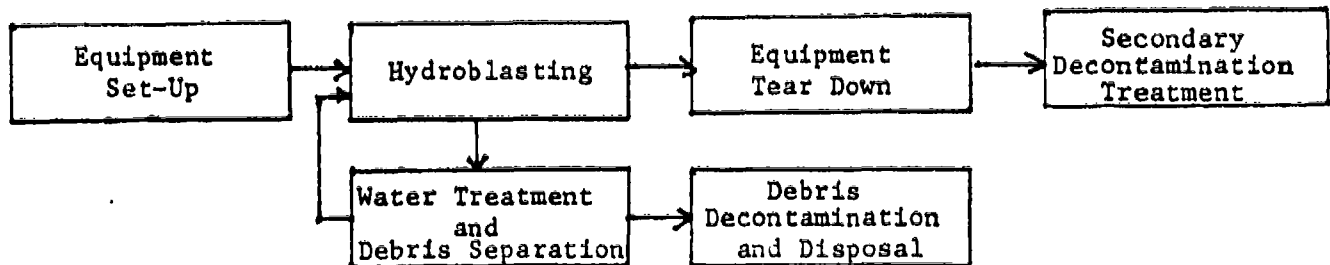
5.1.1 Main Process

Manual or automated water blasting equipment is employed to physically remove/clean all building surfaces. Water and debris are collected in a sump system. Water is treated (if necessary) and recycled. Debris is removed from water, decontaminated and disposed of.

5.1.2 Variations

Surfactants, solvents, or abrasives can be added to the hydroblasting equipment to aid in surface penetration and/or surface removal. An organic solvent could replace water in the blasting scheme.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

Water blasting system consisting of high pressure pump hoses and nozzles.
Water collection sumps
Water storage tanks
Conventional water pumps

5.2.2 Reliability, Availability and Maintainability

Off-the-shelf equipment is employed and the system is quite simple so the RAM is high.

5.3 Decontamination Time

.5.3.1 Set-up

Minimal - inspection of existing sump systems and possible installation of such a system.

5.3.2 Application Time

5.3.2.1 Personnel

Could be extensive - all surfaces must be treated. Automated hydroblasting systems will decrease personnel time but increase equipment cost.

5.3.2.2 Decontamination
Dependent upon the technique chosen for the decontamination of debris and secondary treatments (if necessary) - anticipated to be moderate to long.

5.3.2.3 Verification
Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Minimal.

5.3.3.2 Clean-up
Low to moderate - The collection system will need to be rinsed of debris and the spent water treated.

5.4 Safety Requirements

5.4.1 Process Hazards
None anticipated.

5.4.2 Personnel Hazards
No serious hazards are present although high pressure water lines are a potential hazard.

5.4.3 Protective Methods
Protective clothing should be worn.

6.0 Economics

6.1 Building Damage - Repair Costs
Minimal - The surface left on some materials may require painting or other finishing methods.

6.2 Developmental Costs
Minimal - hydroblasting technology is well developed.
Water and debris treatment systems will have to be selected.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Moderate - hydroblaster can be powered by gas, electric, or diesel fuel.

6.3.2 Equipment Cost
A 10,000 psi, 10 gpm diesel powered pump, with trailer $27,138 and wet sandblast mixing head $542. 5000 psi, 10 gpm diesel powered pump, with trailer $19,125. (Manufacturer's brochures).

6.3.3 Material Cost
Solvents, surfactants or abrasives, if added.

6.3.4 Manpower Cost
Could be extensive - automated systems can decrease manpower cost but will increase equipment cost.

7.0 Future Work Required

7.1 Knowledge Gaps
Selection of a treatment technique to remove or decompose small quantities of agent from a large quantity of water. Decontamination and disposal technique for removed surface debris.

7.2 Resolution
Experimental testing.

ACID ETCH/NEUTRALIZATION

1.0 General Description

   1.1 Summary of Idea
       Acid is applied to a surface to promote corrosion.
       Neutralization of acid and removal of the surface layer
       follows. The debris is then neutralized and disposed.
       However thermal or chemical decontamination of removed
       material may be required.

   1.2 Origination of Idea
       Novel Processing project team.

   1.3 Obvious Advantages and Disadvantages
       Advantage. Probably will cause decomposition of the agent as
       the material is corroded from the surface.

       Disadvantages. Removal of a portion of the "metal", may
       weaken the structure. Hazardous operation. Requires special
       application equipment. Primarily applicable to metals which
       will readily corrode. Large material requirement.

   1.4 Variations of Idea
       The acid can either be applied as a mixture in steam or the
       acid can be sprayed or brushed on at ambient or elevated
       temperatures.

   1.5 Sketch
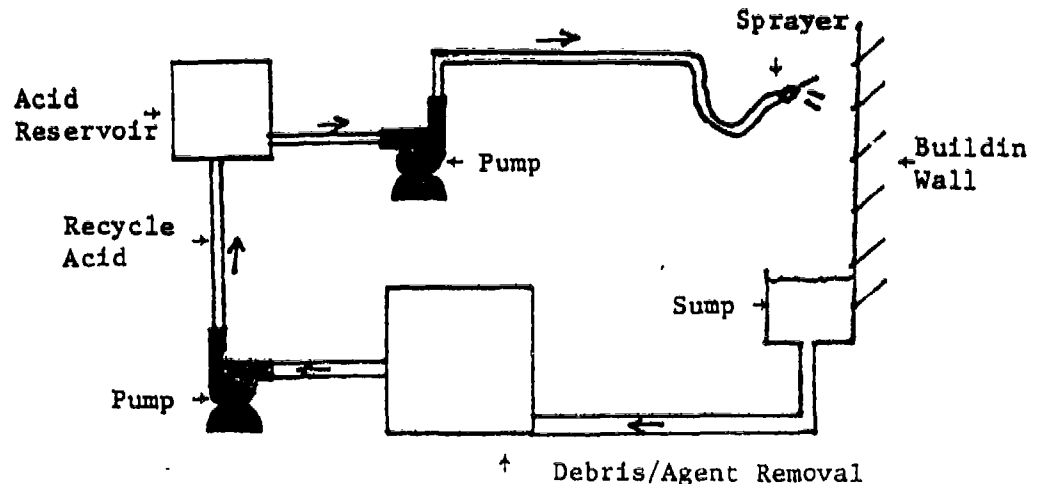
2.0 Chemical Decomposition Treatment
       Not applicable.

3.0 Physical Treatment

   3.1 Removal Efficiency, Residue Level
       Very effective and complete removal of metal surfaces such as
       mild steel. May also be effective on concrete, brick
       structures and some plastic materials.

3.2 Hazardous Wastes
   Residual agent may remain in the waste. Spent acid should be considered hazardous.

3.3 Supplementary Treatment(s)
   Secondary methods (physical, chemical and/or thermal) required to decontaminate/remove contaminants that have penetrated the surface layer through cracks and pores.

3.4 Waste Recovery and Disposal
   Removal of the layers of metal oxides formed on steel by, for example, sand blasting may be required. Spent acid may be recycled followed by removal of agent residues.

3.5 State-of-the-Art
   Corrosivity of various acids to building materials is known.

4.0 Applicability

   4.1 Agent Applicability
      Method applies to all agents.

   4.2 Isolated Building Material Applicability
      Applicable primarily to mild steel.

      4.2.1 Impact of Substrate on Chemistry
         None anticipated.

      4.2.2 Removal or Reaction of Contaminant from Surface
         Method removes contaminants from metal surfaces; may be ineffective on other surfaces such as concrete.

      4.2.3 Removal or Reaction of Contaminant from Interior
         Ineffective on interior of building materials.

      4.2.4 Damage to Material
         May weaken the material depending on the number of applications and its initial thickness.

   4.3 Practical Applicability to Building

      4.3.1 Building Preparation
         Paint removal may be required if paint is corrosion resistant.

      4.3.2 Practical Physical Limitations/Methods to Overcome
         Acid can be sprayed on equipment and pipes (inside and out) so no physical limitations anticipated.

      4.3.3 Secondary Decontamination Treatment
         Other materials not affected by the acid treatment will require decontamination.

4.3.4 Clean-up Requirements
May need to remove residual oxide coatings from metal surfaces. Neutralization and water wash.

4.3.5 Waste Treatment and Disposal
Insoluble metal oxides and salts require treatment such as filtration. Disposal of a large amount of soluble salts requires concentration before they can be placed in a land fill.

4.4 State-of-the-Art
Has not been used to decontaminate buildings.

5.0 Engineering

5.1 Process Description

```
┌─────────────┐     ┌─────────────┐     ┌─────────────────┐          ┌──────────────┐
│             │     │             │     │  Spent Acid/    │          │  Seconda⌐    │
│  Acid Spray │ ──> │ Water Wash  │ ──> │ Debris Collection│         │  Decontamin⌐ │
│             │     │             │     │                 │          │              │
└─────────────┘     └─────────────┘     └─────────────────┘          └──────────────┘
      ↑                                          │                           ↑
      │                                          ↓                           │
      │                                ┌──────────────────┐          ┌──────────────┐
      └────────────────────────────────│  Waste Treatment │ ───────> │ Sand Blast⌐  │
         Recycle Acid                   └──────────────────┘          │ (For exampl⌐ │
                                                                      └──────────────┘
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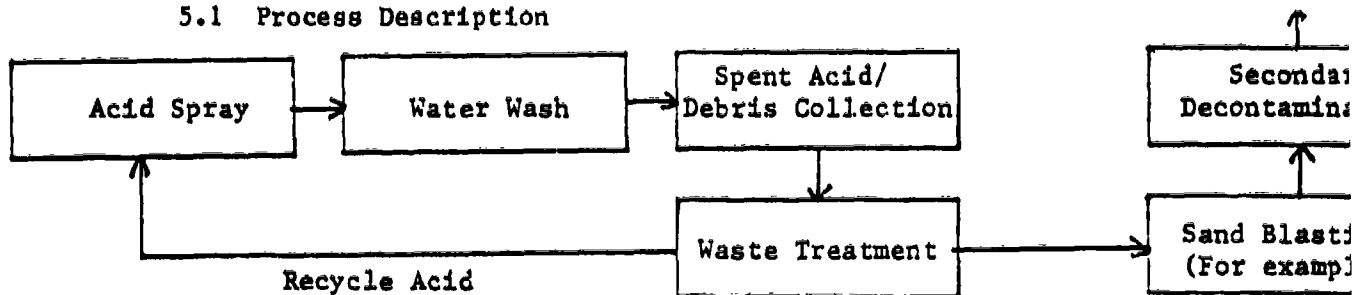
5.1.1 Main Process
The acid is applied onto the surface, and is allowed to induce corrosion. The surface is neutralized and finally washed with water. A secondary decontamination treatment may then be required to remove contaminants from concrete, brick, etc.

5.1.2 Variations
The application can be by spraying, brushing on, or with a gas, for example, HCl gas.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
Acid neutralizer; spraying equipment and pump; water spraying equipment (hose); acid source; steam source (optional).

5.2.2 Reliability, Availability and Maintainability
Equipment is available, but may not be corrosion resistant. Equipment will probably require substantial maintenance and periodic replacement.

5.3 Decontamination Time

5.3.1 Set-up
      Paint removal may be required before treatment.

5.3.2 Application Time

    5.3.2.1 Personnel
        Personnel required only for spraying and cleanup. . The process may be time consuming to ensure all surfaces are treated and if repeated applications are required.

    5.3.2.2 Decontamination
        Decontamination time may be long due to slow reaction rate.

    5.3.2.3 Verification
        Knowledge gap.

5.3.3 Tear-Down Time

    5.3.3.1 Equipment Removal
        Equipment removal should not take very long.

    5.3.3.2 Clean-up
        Substantial time anticipated. All the acid must be completely washed off the equipment to avoid corrosion. Sand blasting and collection of spent acid may be required.

5.4 Safety Requirements

5.4.1 Process Hazards
      Acid.

5.4.2 Personnel Hazards
      Acid burns.

5.4.3 Protective Methods
      Personnel protection required (rubber suit/boots/ gloves) eye protection and breathing protection. Safety shower should be readily available.

6.0 Economics

6.1 Building Damage - Repair Costs
    Metal parts will be damaged but concrete may be undamaged.

6.2 Developmental Costs
    Modest - developmental cost including testing effectiveness.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Low cost. Power for spraying pump.

6.3.2 Equipment Cost
Corrosion resistant equipment.

6.3.3 Material Cost
Low cost although a large quantity will be required.

6.3.4 Manpower Cost
Moderate to high cost because of application and clean-up time.

7.0 Future Work Required

7.1 Knowledge Gaps
Secondary decontamination treatment must be stipulated. Effectiveness of acid removal of agents must be established.

7.2 Resolution
Experimental testing.

SANDBLASTING

1.0 General Description

    1.1 Summary of Idea
        Sandblasting is an abrasive surface removal technique in
        which an abrasive such as steel pellets are used to uniformly
        remove building material surface layers containing the
        contaminants.

    1.2 Origination of Idea
        Literature (Plaster, 1964).

    1.3 Obvious Advantages and Disadvantages
        Advantages. Sandblasting is a widely used surface removal
        technique. It can simultaneously and readily remove paint
        and contaminants in close proximity to the surface.

        Disadvantages. Large amount of agent laden dust and debris
        generated. Only effective as a surface treatment. Requires
        personnel to wear potective (level A or B) gear.

    1.4 Variations of Idea
        Alumina oxide, glass beads or steel shot may
        be used as the abrasive instead of sand.

    1.5 Sketch
        See page III-86.

2.0 Chemical Decomposition Treatment
    Not applicable.

3.0 Physical Treatment

    3.1 Removal Efficiency, Residue Level
        Complete removal of surface and near surface contaminants can
        be achieved.

    3.2 Hazardous Wastes
        Sandblasting will generate debris, dust and abrasive contam-
        inated with agents.

    3.3 Supplementary Treatment(s)
        Drilling and spalling or other techniques may need to be
        employed to remove contaminants that have penetrated the
        surface layer through cracks and pores.

    3.4 Waste Recovery and Disposal
        The removed surface and spent abrasive must be collected (by
        vacuum or other means) and disposed of by incineration, for
        example. Vacuuming or water spraying with decon solution of
        surfaces will also be required to remove remaining dust.

3.5 State-of-the-Art

Sandblasting has been employed since 1870 to remove surface layers from metallic and ceramic surfaces, and is currently used extensively throughout industry.

4.0 Applicability

4.1 Agent Applicability

Applicable to all agents (HD, VX and GD).

4.2 Isolated Building Material Applicability

Applicable to all materials of interest.

4.2.1 Impact of Substrate on Chemistry

None anticipated.

4.2.2 Removal or Reaction of Contaminant from Surface

Complete removal of contaminant from surface for all building materials is anticipated.

4.2.3 Removal or Reaction of Contaminant from Interior

Ineffective for depths grater than about 1/8 to 1/2 inch.

4.2.4 Damage to Material

Minimal because only surface layer removed.

4.3 Practical Applicability to Building

4.3.1 Building Preparation

None required.

4.3.2 Practical Physical Limitations/Methods to Overcome

Corners may not be sandblasted effectively. Obstructions (e.g., pipes bolted to a wall) may require removal. Since abrasive is a "sprayed" method is applicable to many hard-to-reach areas (ceilings, behind equipment, etc.)

4.3.3 Secondary Decontamination Treatment

Drilling and spalling or other techniques may need to be employed to remove contaminants that have penetrated the surface layers through cracks or pores.

4.3.4 Clean-up Requirements

All material removed and spent abrasives will have to be collected for decontamination and disposal. Vacuuming and wash with decon solution as a final clean-up.

4.3.5 Waste Treatment and Disposal

The mixture of contaminated surface debris and spent abrasive material will have to be decontaminated (possibly by incineration) and disposed of. Large amount of debris anticipated because abrasive is not recycled.

4.4 State-of-the-Art

A large number of sandblast equipment manufacturers and contractors are available. The technology is well developed.

5.0 Engineering

5.1 Process Description

```
┌──────────────┐     ┌──────────────┐     ┌──────────────┐
│ Obstructions │ ──▶ │  Equipment   │ ──▶ │ Sand Blasting│
│   Removal    │     │   Set-Up     │     │              │
└──────────────┘     └──────────────┘     └──────┬───────┘
                                                  │
                                                  ▼
        Debris  ┌──────────────┐     ┌──────────────┐     ┌──────────────┐     ┌──────────────
      ┌─────────│  Over/Under  │ ◀── │Collect Debris│ ──▶ │  Vacuum and  │ ──▶ │   Secon
      │         │   Separator  │     │ and Abrasive │     │  Wash Down   │     │   Deconta
      │         └──────┬───────┘     └──────────────┘     └──────────────┘     └──────────────
      ▼                │                                                              │
┌──────────────┐      ▼                                                               ▼
│ Incineration │   Abrasive
└──────────────┘
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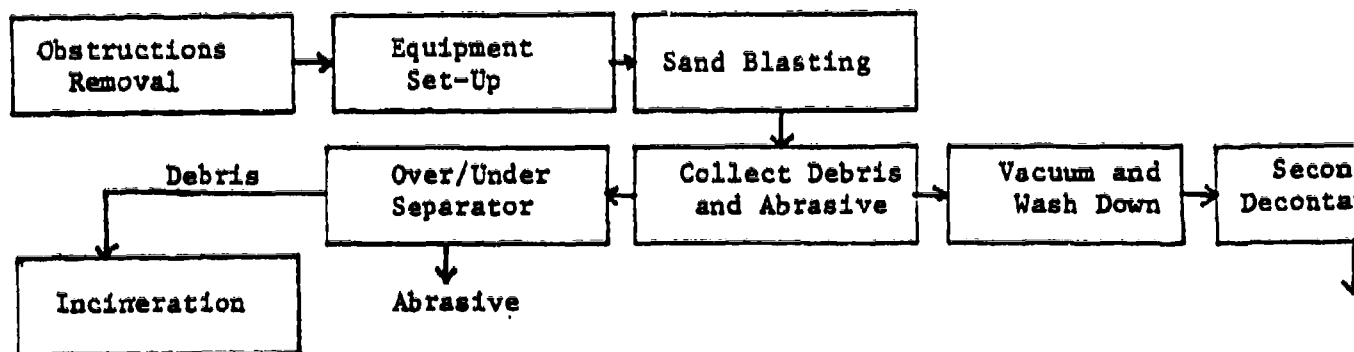
5.1.1 Main Process

After all obstructions are removed, the equipment is set-up and the building sandblasted. The debris and abrasive is collected, packaged, and transported to the waste incinerator. The building is then cleaned by vacuuming and/or decon solution wash. A secondary decontamination is then performed, if necessary, to remove contaminants which have penetrated building materials.

5.1.2 Variations

A chemical method may be employed to decontaminate the generated debris. Remote control sandblaster.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

Sandblasting equipment including blast-gun, pressure liner, abrasive. Air compressor. Debris/dust collection systems.

5.2.2 Reliability, Availability and Maintainability

Very good because technology is well developed.

5.3 Decontamination Time

5.3.1 Set-up

Minimal but dependent on whether obstructions require removal.

5.3.2 Application Time

5.3.2.1 Personnel
Sandblasting, collection of debris, transport of debris to waste processor and clean-up - labor intensive. Remote control units may decrease labor time but at the expense of capital cost.

5.3.2.2 Decontamination
Dependent on size and interior configuration of building but probably long.

5.3.2.3 Verification
Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Minimal - removal of blasting equipment.

5.3.3.2 Clean-up
Vacuum or spray walls with decon solution. Collect all removed material and spent abrasive. Possible transport to decontamination site.

5.4 Safety Requirements

5.4.1 Process Hazards
None anticipated.

5.4.2 Personnel Hazards
Inhalation of dust laden with agent, dust explosion if combustible material sandblasted.

5.4.3 Protective Methods
Face hoods and protective clothing (level A or B) required. Wash down area with decon solution to minimize dust. Use an aerosol decontaminant to minimize dust and potential for dust explosion.

6.0 Economics

6.1 Building Damage - Repair Costs
None anticipated.

6.2 Developmental Costs
Dust control/collection systems.

6.3 Treatment Costs

    6.3.1 Utilities and Fuel Cost
        Electricity or fuel for air compressors and vacuum
        systems.

    6.3.2 Equipment Cost
        Sandblaster, air compressor, debris collection system,
        dust suppression system.

    6.3.3 Material Cost
        Abrasive, decon solution.

    6.3.4 Manpower Cost
        Labor intensive (manual operation) sandblast,
        collection, waste disposal, clean-up.

7.0 Future Work Required

    7.1 Knowledge Gaps
        Waste recovery and disposal method, dust suppression system
        and selection of decon agent.

    7.2 Resolution
        Engineering development of decontamination methods for
        treatment of waste materials.

ESSENTIAL COMPONENTS OF A SUCCESSFUL SANDBLAST OPERATION

Points to Check

1. Large Compressor
2. Large Air Hose and Couplings
3. Portable High Production Sandblast Machines
4. Large Size Sandblast Hose with External Couplings
5. Large Orifice Venturi Nozzle
6. Remote Control Valves
7. Moisture Separators
8. High Nozzle Air Pressure
9. Proper Sandblasting Abrasive
10. Safety Air Fed Helmet
11. Training of Operators
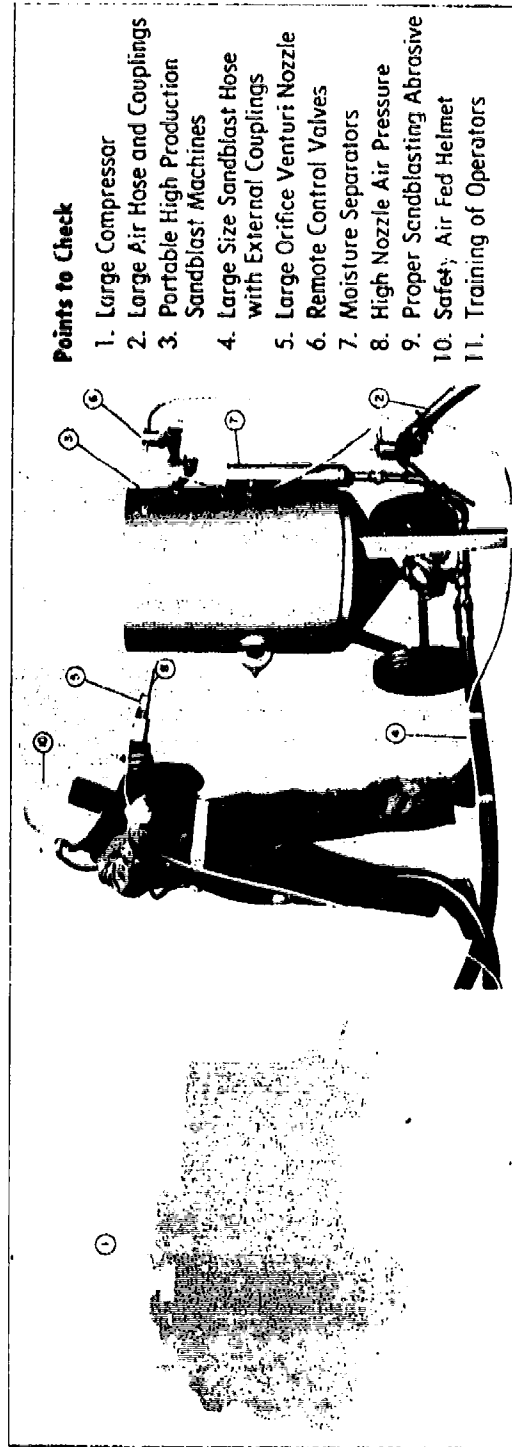
Manufacturer's brochure

DEMOLITION

1.0 General Description

    1.1 Summary of Idea
        Mechanical demolition involves manual total destruction of a building.

    1.2 Origination of Idea
        Employed for Nuclear Facility decontamination. Described in detail in the Decommissioning Handbook (Manion, 1980).

    1.3 Obvious Advantages and Disadvantages
        Advantages. Demolition allows for decontamination of buildings materials that have completely permeated by agents.
        Disadvantages. The building is destroyed. Huge quantities of debris must be decontaminated. Airborne contamination may occur.

    1.4 Variations of Idea
        Demolition of part of a building. For example, reinforced concrete walls may be required to be torn down in order to completely decontaminate.

    1.5 Sketch
        None.

2.0 Chemical Decomposition Treatment
    Not applicable.

3.0 Physical Treatment

    3.1 Removal Efficiency, Residue Level
        Total decontamination can be achieved.

    3.2 Hazardous Wastes
        The destroyed building/debris has not been decontaminated, so a hazard still exists.

    3.3 Supplementary Treatment(s)
        None required.

    3.4 Waste Recovery and Disposal
        All debris must be decontaminated (possibly using kiln incineration) which may involve transporting huge amounts of material as well as high fuel costs if the building is composed of non-combustible materials.

III-88

3.5 State-of-the-Art
Many types of demolition techniques have been successfully used in the demolition of Nuclear Facilities (Manion, 1980). Demolition is used extensively by the construction industry.

4.0 Applicability

4.1 Agent Applicability
Demolition could be used on any building and therefore is applicable to all agents. However, if the building is permeated with agents, safety factors (dust laden with agent) may prevent its use.

4.2 Isolated Building Material Applicability
Applicable to all building materials.

4.2.1 Impact of Substrate on Chemistry
None.

4.2.2 Removal or Reaction of Contaminant from Surface
Complete.

4.2.3 Removal or Reaction of Contaminant from Interior
Complete.

4.2.4 Damage to Material
Complete destruction.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Wash-down with agent decontaminating solution to minimize dust.

4.3.2 Practical Physical Limitations/Methods to Overcome
None.

4.3.3 Secondary Decontamination Treatment
None required.

4.3.4 Clean-up Requirements
Extensive - The entire building material/debris will have to be collected/contained for treatment.
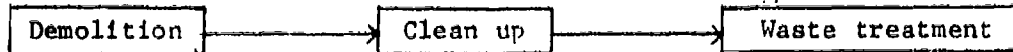
4.3.5 Waste Treatment and Disposal
Extensive - Debris must be decontaminated (possibly using incineration) and disposed of in landfills.

4.4 State-of-the-Art
Demolition technology is well developed.

5.0 Engineering

5.1 Process Description

```
┌─────────────┐        ┌──────────────┐        ┌──────────────────┐
│ Demolition  ├───────▶│  Clean up    ├───────▶│ Waste treatment  │
└─────────────┘        └──────────────┘        └──────────────────┘
```

5.1.1 Main Process
Controlled blasting, wrecking balls, hydraulic rams, flame cutters or other methods may be employed to demolish the building. The debris must then be collected/contained for decontamination (possible incineration) and disposal.

5.1.2 Variations
Demolition of part of a building such as removal of transite walls or concrete barriers in the building.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
Demolition equipment, backhoe/clean-up equipment.

5.2.2 Reliability, Availability and Maintainability
Good - The technology is well developed.

5.3 Decontamination Time

5.3.1 Set-up
Dependent on demolition technique; however, set-up should require little time.

5.3.2 Application Time

5.3.2.1 Personnel
Could be extensive - demolition techniques may be slow and require extensive manpower, especially if building has agent in it.

5.3.2.2 Decontamination
Dependent upon the decontamination technique chosen (days).

5.3.2.3 Verification
KNOWLEDGE GAP

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Dependent on demolition technique however this should require little time.

5.3.3.2 Clean-up

Extensive – Clean-up time may constitute the
largest portion of the total time required.

5.4 Safety Requirements

5.4.1 Process Hazards
Use of heavy machinery.

5.4.2 Personnel Hazards
High noise and dust levels, agent laden dust and
debris.

5.4.3 Protective Methods
Proper eye, ear and clothing protection should
be worn. Maintain a wet environment.

6.0 Economics

6.1 Building Damage – Repair Costs
The building is completely destroyed. Replacement may be
necessary.

6.2 Developmental Costs
None – The technology is well developed.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Moderate to high – fuel to operate the demolition and
clean-up equipment as well as the incinerator for
debris treatment.

6.3.2 Equipment Cost
Dependent on demolition technique chosen.

6.3.3 Material Cost
Decontaminating solution for washdown.

6.3.4 Manpower Cost
High – extensive manpower will be required for
clean-up, decontamination, and disposal.

7.0 Future Work Required

7.1 Knowledge Gaps
A technique will have to be selected for the decontamination
of the building material.

7.2 Resolution
Experimental testing.

VACU-BLAST

1.0 General Description

    1.1 Summary of Idea
        Vacu-blasting entails removal of the surfaces of a building
        through a sandblasting technique where all dust, debris and
        used abrasive are vacuum returned to an over/under particle
        separator and the abrasive continuously recycled.

    1.2 Origination of Idea
        Novel Processing project team.

    1.3 Obvious Advantages and Disadvantages
        Advantages. Vacu-blasting is a widely used surface removal
        technique. It can simultaneously remove paint and contam-
        inants from surface layers. All dust, debris and abrasive
        are contained using a vacuum system. The abrasive is
        separated from the debris and reused.

        Disadvantages. Only effective as a surface treatment.
        Collected debris must then be decontaminated and disposed of.

    1.4 Variations of Idea
        Specially designed cleaning heads are available for cleaning
        intricate surfaces such as right angles and pipe exteriors.

    1.5 Sketch
        See pages III-92, 93.

2.0 Chemical Decomposition Treatment
    Not applicable.

3.0 Physical Treatment

    3.1 Removal Efficiency, Residue Level
        Complete removal can be obtained for contaminant located in
        close proximity of the surface of metals, concrete and brick.
        No removal of contaminants from the interior of building
        material is expected.

    3.2 Hazardous Wastes
        The vacu-blasting process will generate agent laden debris
        which requires further treatment.

    3.3 Supplementary Treatment(s)
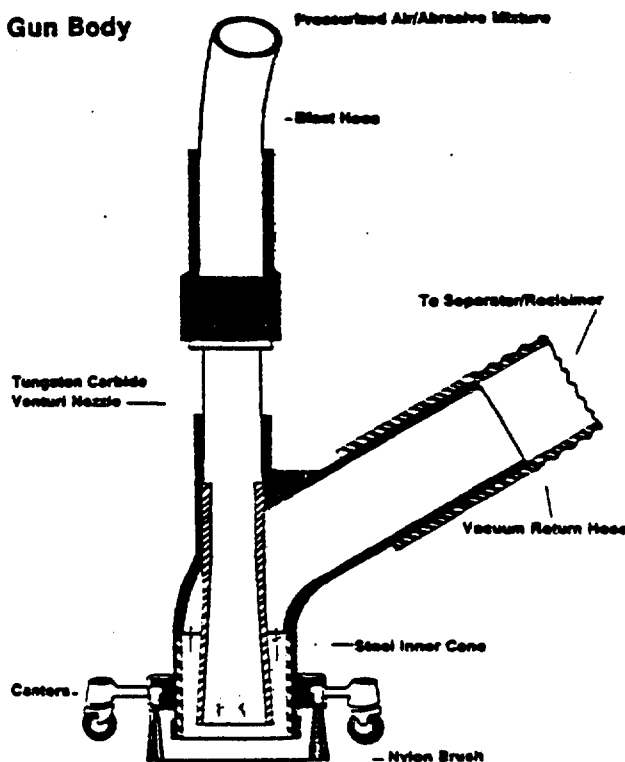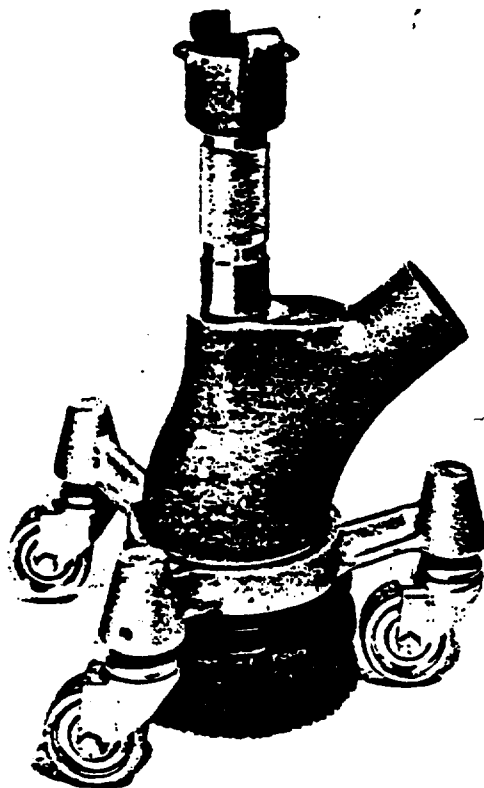   Other techniques may be needed to remove contaminants that
        have deeply penetrated the surface.

    3.4 Waste Recovery and Disposal
        All dust, debris and abrasive from the blasting are contained
        in the blast gun body and continuously vacuum retrieved for

BIG BOSS VR-3A

Big Boss Gun Body

Pressurized Air/Abrasive Mixture
Blast Hose
To Separator/Reclaimer
Tungsten Carbide Venturi Nozzle
Vacuum Return Hose
Steel Inner Cone
Casters
Nylon Brush

FEATURES

The Pauli & Griffin Big Boss VR-3A is a portable dust free blast machine which features a powerful pressure system with total dust control for in-plant blasting. It also offers a sophisticated abrasive recycling system, and portability for hard-to-reach areas.

Fast and powerful — with the speed and force available only from a direct pressure machine, the Big Boss attacks heavy in-plant maintenance and production jobs with deep cleaning, etching and peening.

Completely dust free — all dust, debris and abrasive generated during blasting are retained in the blast gun body and continuously conveyed out by special vacuum return action for recycling. Thus, time consuming shielding of plant equipment and messy clean up are not needed. And the operator does not require cumbersome respiratory equipment. The powerful dust collection system removes all dust and light fines, so you maintain a pollution free environment. Noise pollution is also minimized by a large 55" muffler.

Efficient and economical — the Big Boss incorporates a total abrasive reclaiming system which cleans and recycles such expensive, durable abrasives as steel grit and shot. This reduces abrasive waste, insures consistent finishes.

Portable — a compact design with two sets of wheels and remote controls allows blasting wherever needed. Spot blasting, awkward or unwieldly locations present no problems with the maneuverable

Vacuum Return Blast Gun
The Big Boss features a uniquely designed blast gun with special vacuum return action. Made of lightweight aluminum with steel inner cone, the blast gun directs a pressurized stream of abrasive at the work surface, but retains all dust, debris and used media inside the gun body. Continuous suction action of the vacuum return hose conveys all material back to the machine body for reclaiming. A nylon brush surrounds the gun body to prevent the escape of dust and abrasive. Three casters facilitate movement along work surfaces. A smaller gun assembly is also available for blasting in hard-to-reach areas.

Automatic Abrasive Cleaning & Reclaiming
The automatic abrasive cleaning and reclaiming system on the Big Boss insures that only uniform, reusable abrasive is used in blasting. This ends waste of costly media, and insures consistent finishes. During the blast cycle, the vacuum return hose sends all used abrasive, dust and debris to a cyclone separator. The cyclone centrifugally sends dust and lightweight particles over to the dust collector while reusable abrasive and heavy debris falls onto a vibrating screen for further classification. Only clean, reusable abrasive falls through the screen into the hopper, and then into the pressure vessel for use over and over until it breaks down.

Efficient Dust Collector
A powerful 320 cfm dust collection system solves the difficult problem of dust removal on the Big Boss. Dirty air is pulled through the cyclone over to the dust collector where seven highly efficient tubular dust bags provide 35 sq. feet of filtration. Instead of a single large exposed bag, the Big Boss dust bags are located in a totally enclosed bag housing. This meets all government regulations for pollution control and provides additional protection against dust escaping in the event of a bag breaking. When blasting stops, the dust falls into a compartment at the base of the dust collector for easy disposal. The air driven blower which provides vacuum for this process is mounted on the "clean" side of the dust collector for

Big Boss VR-3A Abrasive Reclaimer Dust Collector

Diagram labels: Enclosed Bag Housing, Air Powered Vacuum Pump, Cyclone Separator, Vibrating Screen, Abrasive Hopper, ASME Pressure Vessel, Silencer, Moisture Separator, Pressure Gauge, Dust Bin, Blast Hose, Vacuum Hose, Blast Gun, Nylon Brush, Feathertouch® Remote Control

APPLICATIONS

Tungsten Carbide Venturi Nozzle
A venturi nozzle with long-lasting tungsten carbide lining provides extra acceleration of the abrasive/air mixture for supersonic blasting speeds.

Moisture Separator & Pressure Gauge
A moisture separator helps keep abrasive dry and free from oil. The pressure gauge allows monitoring of air flow for maximum efficiency.

ASME Pressure Vessel
One cubic foot ASME-coded pressure vessel holds up to 300 lbs. of steel grit.

OPERATION

Depressing the Feathertouch® safety release switch starts pressurization. Abrasive falls from the ASME pressure vessel into the blast stream below where it combines with air and is propelled through the blast hose.

At the blast head, the tungsten carbide venturi nozzle blasts the air/abrasive mixture onto the work surface.

After blasting, used media, dust and debris remain contained within the blast head by the brushes which provide a seal with the work surface.

The vacuum hose then conveys all used abrasive, dust and debris from the surface back to an airwash cyclone. Centrifugal cyclone action separates light and heavy particles. Finer material is pulled off to the dust collector. Heavier material falls onto a vibrating screen which traps larger debris for easy removal later. Only good abrasive falls through to the hopper for reuse in the pressure vessel and blast stream. The pressure vessel is automatically refilled from the hopper when the Feathertouch® switch is released.

The Big Boss VR-3A is ideal for in-plant maintenance work because it puts an end to flying dust and abrasive, maski plant equipment and messy clean up. It also cleans more efficiently than hand tools.

In-Plant Maintenance — Cleans large and bulky machiner roof trusses without interrupting production.

Floors — Blasts away hard-to-remove coatings and leave surface for applying new coatings such as epoxy. Remov markings.

Chemical Plants — Quickly cleans process tanks in preps coatings. Spot blasts to white metal for repair of coatings linings.

Heavy Equipment Maintenance — Ideal for spot cleaning construction equipment or other large vehicles prior to cc

Nuclear Power Plants — Especially useful where pollutio problem and maximum cleanliness must be maintained.

Steel Fabrication Plants — Highly recommended for clea weldments.

Gear Manufacturers — Shot peens for added strength wh are in place.

Textile Mills — Cleans and peens calendar rolls while sti production equipment.

abrasive recycle. Cyclones are used to centrifugally sep-
arate the dust and debris from reusable abrasive. The debris
would require decontamination (by incineration or other
techniques) and disposal.

3.5 State-of-the-Art
Vacu-blast systems have been employed for building material
surface removal since the 1950's and are widely used through-
out industry today (Plaster, 1964).

4.0 Applicability

4.1 Agent Applicability
Applicable to all agents.

4.2 Isolated Building Material Applicability
Applicable to all relevant materials.

4.2.1 Impact of Substrate on Chemistry
Not applicable.

4.2.2 Removal or Reaction of Contaminant from Surface
Complete removal of contaminant from a surface and
near-surface layers of all building materials is
anticipated.

4.2.3 Removal or Reaction of Contaminant from Interior
Not possible for depths greater than 1/8 to 1/2 inch.

4.2.4 Damage to Material
Minimal.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
None required.

4.3.2 Practical Physical Limitations/Methods to Overcome
Vacu-blasting of corners or other hard to reach areas
may be accomplished with specially designed nozzles.
However, certain areas may remain inaccessible (e.g.
behind pipes bolted to a wall). Physical removal of
the obstruction may then be required.

4.3.3 Secondary Decontamination Treatment
Other techniques may be required to remove contamin-
ants that have penetrated the surface.

4.3.4 Clean-up Requirements
Minimal - vacuuming or wash down with either water or
decon solution to remove and decontaminate loose dust
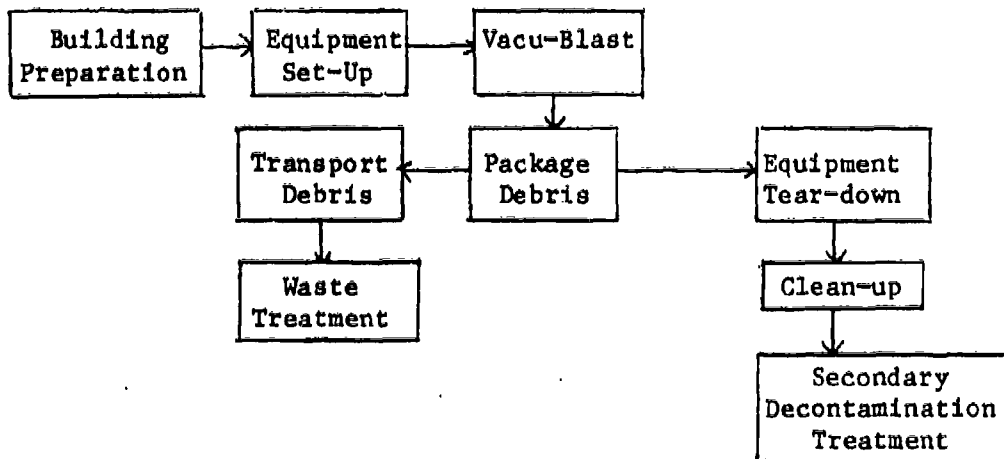and debris.

4.3.5 Waste Treatment and Disposal

All debris collected may have to be decontaminated (by incineration or other techniques) and disposed of.

4.4 State-of-the-Art

Vacu-blasting has been employed in the cleaning of ship hulls, metal molds, and pre-welding applications as well as various building surfaces. There are a number of equipment manufacturers and contractors available.

5.0 Engineering

5.1 Process Description

```
┌──────────┐    ┌──────────┐    ┌──────────┐
│ Building │───▶│Equipment │───▶│Vacu-Blast│
│Preparation│    │  Set-Up  │    │          │
└──────────┘    └──────────┘    └──────────┘
                                      │
                                      ▼
┌──────────┐    ┌──────────┐    ┌──────────┐
│ Transport│◀───│ Package  │───▶│Equipment │
│  Debris  │    │  Debris  │    │Tear-down │
└──────────┘    └──────────┘    └──────────┘
     │                               │
     ▼                               ▼
┌──────────┐                    ┌──────────┐
│  Waste   │                    │ Clean-up │
│Treatment │                    └──────────┘
└──────────┘                         │
                                     ▼
                              ┌──────────────┐
                              │  Secondary   │
                              │Decontamination│
                              │  Treatment   │
                              └──────────────┘
```

5.1.1 Main Process

Vacu-blasting - the system abrasively blast-cleans all surfaces while containing all dust and debris. A vacuum system continuously returns all debris to a cyclone which separates the debris from the reusable abrasive. Decontamination - all collected debris must then be decontaminated. Secondary decontamination is then performed, if necessary, to remove contaminants which have penetrated building materials.

5.1.2 Variations

Steel grit is the most commonly used abrasive but steel shot and aluminum oxide may also be employed. Sand and other non-durable abrasives are not recommended due to rapid break-down after one or two cycles. Remote control vacu-blaster.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
Vacu-blast system including blast gun, vacuum and pressure lines, cyclone separator, abrasive, dust collection bags/compartment. Compressor.

5.2.2 Reliability, Availability and Maintainability
Very good since technique is well developed and off-the-shelf equipment is available.

5.3 Decontamination Time

5.3.1 Set-up
May be labor intensive depending on accessibility of building areas (i.e. may require removal of pipes or other equipment).

5.3.2 Application Time

5.3.2.1 Personnel
May be high since entire surface area needs to be covered. Obstructions - Dependent upon size of building and amount of equipment in the building. A remote control unit may be used to cut down on operator time but may not be cost effective unless large unrestricted surface areas are present.

5.3.2.2 Decontamination
Dependent on method used to decontaminate debris.

5.3.2.3 Verification
Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Minimal - removal of blasting equipment.

5.3.3.2 Clean-up
Minimal - dust removal, wash down with decon solution.

5.4 Safety Requirements

5.4.1 Process Hazards
None anticipated.

5.4.2 Personnel Hazards
Minimal - majority of dust and debris picked up by vacuum system. Volatile agents may be entrained in the outlet air.

5.4.3 Protective Methods
Eye protection and protective clothing (e.g. level B) should be worn by operators. A dust suppression system such as periodic wash down with a decon solution may be required.

6.0 Economics

6.1 Building Damage - Repair Costs
None anticipated.

6.2 Developmental Costs
None anticipated.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Minimal.

6.3.2 Equipment Cost
Vacu-blast system. Conventional air compressors. Dust suppression unit (if required).

6.3.3 Material Cost
Abrasive cost - steel grit most commonly used. Decon solution.

6.3.4 Manpower Cost
Vacu-blast operators. (Labor intensive - Moderate to high.

7.0 Future Work Required

7.1 Knowledge Gaps
Selection of waste recovery and disposal method as well as the secondary decontamination method, if required.

7.2 Resolution
Experimental testing.

CRYOGENICS

1.0 General Description

1.1 Summary of Idea
The surface of the material is exposed to cryogenic
temperatures in order to make it brittle. The surface
is then chipped or scraped off.

1.2 Origination of Idea
Novel Process project team.

1.3 Obvious Advantages and Disadvantages
Advantages. The cold surfaces are very brittle and therefore
may be removed easily. The cold will limit evaporation of
agents.
Disadvantages. Potential for uneven surface removal. Dif-
ficult application on hard-to-reach areas. High cost of cry-
ogenic fluid (large quantitites required). Labor intensive.

1.4 Variations of Idea
Cryogenic paint removal.

1.5 Sketch
None.

2.0 Chemical Decomposition Treatment
Not applicable.

3.0 Physical Treatment

3.1 Removal Efficiency, Residue Level
Complete removal of contaminated surface is anticipated.

3.2 Hazardous Wastes
Material removed still contains the contaminant, thus it must
be decontaminated.

3.3 Supplementary Treatment(s)
Other methods may be required to decontaminate materials into
which agents have penetrated.

3.4 Waste Recovery and Disposal
Chemical or thermal methods may be employed to decontaminate
the material removed.

3.5 State-of-the-Art
Building materials are known to be brittle at low temper-
atures.

4.0 Applicability

4.1 Agent Applicability
Should be applicable to all agents.

4.2 Isolated Building Material Applicability
Applicable to paint removal on all surfaces. Applicable to surface removal of concrete.

4.2.1 Impact of Substrate on Chemistry
None anticipated.

4.2.2 Removal or Reaction of Contaminant from Surface
Complete removal of the surface (especially paint) containing the contaminant is anticipated. However, the technique will leave a very coarse finish on the surface.

4.2.3 Removal or Reaction of Contaminant from Interior
None anticipated.

4.2.4 Damage to Material
Either a concrete cap or secondary abrasive method must be employed to refinish the coarse surface produced.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Removal of obstructions required unless method directed only towards paint removal.

4.3.2 Practical Physical Limitations/Methods to Overcome
Not applicable to hard-to-reach areas. All obstructions must be removed. However, since paint may fall off when exposed to cryogenic temperatures, no physical limitations are anticipated for a paint removal method.

4.3.3 Secondary Decontamination Treatment
A secondary decontamination treatment will be required for subsurface contaminant removal.

4.3.4 Clean-up Requirements
Removal of debris, refinishing of rough surfaces.
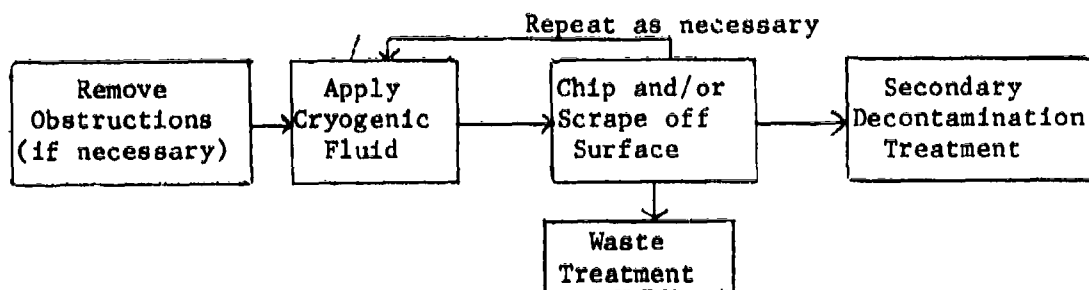
4.3.5 Waste Treatment and Disposal
The contaminated materials removed (chipped surface and paint) will require treatment to decompose agent residues by either a chemical or a thermal method.

4.4 State-of-the-Art
Building materials are known to be brittle at low temperatures.

5.0 Engineering

5.1 Process Description

Repeat as necessary

```
┌──────────────┐   ┌──────────┐   ┌──────────────┐   ┌──────────────────┐
│   Remove     │   │  Apply   │   │ Chip and/or  │   │    Secondary     │
│ Obstructions │──▶│Cryogenic │──▶│ Scrape off   │──▶│ Decontamination  │
│(if necessary)│   │  Fluid   │   │   Surface    │   │    Treatment     │
└──────────────┘   └──────────┘   └──────────────┘   └──────────────────┘
                                          │
                                          ▼
                                   ┌──────────────┐
                                   │    Waste     │
                                   │  Treatment   │
                                   └──────────────┘
```

5.1.1 Main Process
The surfaces are exposed to a cryogenic material (e.g. liquid N_2). The surface is then removed by scraping. The chips are collected and incinerated. A secondary decontamination method is then employed to remove/decompose subsurface contaminants.

5.1.2 Variations
A cryogenic material can be applied to concrete followed by manual or remotely operated chipping to remove the surface layers.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
Cryogenic fluid supply. Concrete chipper and/or paint scraper.

5.2.2 Reliability, Availability and Maintainability
High because of simplicity of equipment.

5.3 Decontamination Time

5.3.1 Set-up
May be extensive if a lot of obstructions require removal, otherwise low to none.

5.3.2 Application Time

5.3.2.1 Personnel
Extensive labor involvement for application of cryogenic fluid and chipping/scraping of surface.

5.3.2.2 Decontamination
Probably extensive since a secondary decontamination method is required.

5.3.2.3 Verification
Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
None.

5.3.3.2 Clean-up
Extensive if refinishing of chipped-off
concrete surfaces required.

5.4 Safety Requirements

5.4.1 Process Hazards
None anticipated.

5.4.2 Personnel Hazards
Cryogenic burns, flying chips, asphyxiating atmo-
sphere, exposure to agent associated with debris.

5.4.3 Protective Methods
Insulated clothing, goggles and respirator required.

6.0 Economics

6.1 Building Damage - Repair Costs
Extensive refinishing of uneven surfaces may be required.

6.2 Developmental Costs
A process must be developed.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
None unless powered concrete chipper and/or scraper
employed.

6.3.2 Equipment Cost
Low - concrete chipper and/or paint scraper.

6.3.3 Material Cost
High - although liquid N_2 is relatively inexpensive,
a large quantity is required.

6.3.4 Manpower Cost
Large manpower cost to apply the cryogenic fluid and
chip the concrete and/or scrape the paint off.

7.0 Future Work Required

7.1 Knowledge Gaps
   Operating parameters required for optimum removal of paint and/or concrete.

7.2 Resolution
   Experimental removal of surfaces of various building materials by cryogenics.

SCARIFIER

1.0 General Description

1.1 Summary of Idea
The scarifier technique is capable of removing approximately 1 inch of surface layer from concrete or similar materials. The scarifier tool consists of pneumatically operated piston heads that strike a surface causing concrete to chip off. The piston heads consist of multi-point tungsten carbide bits.

1.2 Origination of Idea
Decommissioning Handbook (Nuclear Facilities) (Manion, 1980).

1.3 Obvious Advantages and Disadvantages
Advantages. Can achieve a deeper penetration (removal) of surface as compared with most other surface removal techniques. Suitable to both large open areas and small area application.

Disadvantages. The treated surface retains a rough appearance that would probably require resurfacing. Substantial amounts of contaminated debris are generated which require further processing. Only effective as a near surface removal technique. Dust laden with agent is generated.

1.4 Variations of Idea
Wall, floor and hand-held models available. The units may be modified to include a filtered vacuum exhaust system to capture contaminated dust.

1.5 Sketch
See pages III-104, 105.

2.0 Chemical Decomposition Treatment - Not applicable.

3.0 Physical Treatment

3.1 Removal Efficiency, Residue Level
Complete removal can be obtained for surfaces contaminated to a depth of approximately one inch.

3.2 Hazardous Wastes
The debris removed from the surface will contain toxic contaminants.
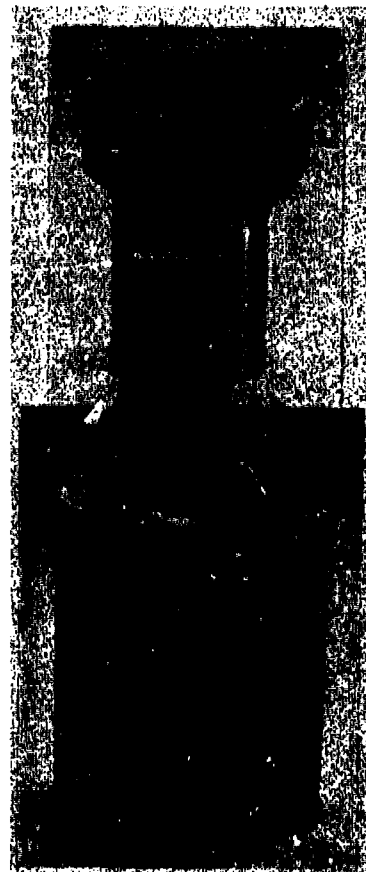
3.3 Supplementary Treatment(s)
Drilling and spalling or other techniques may have to be employed to remove contaminants that have penetrated the

Wall Model

Floor Model

Scabbler Bits

FLOOR AND WALL SCABBLERS

(Manion, 1980)

Scarifiers

When tough, labor-intensive surface maintenance or renovation jobs come along, you need TENNANT scarifiers. These hard-working machines can help you remove imbedded grime, grease, traffic-hardened dirt—even paint—more easily than you thought possible. Equipped with special cutting tools they can rout or score concrete, level bumps, do many jobs. No hand scraping needed. No water, soap or chemicals either. Resulting smooth, level surfaces mean plant trucks use less power, have better traction, move with less damage to wheels and bearings, and make less noise.

These machines are engineered for outstanding performance in even the most rugged applications. They are constructed of welded steel plate and heavy duty components.
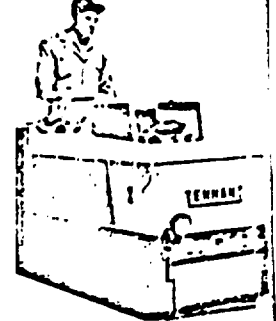
Shears off buildup
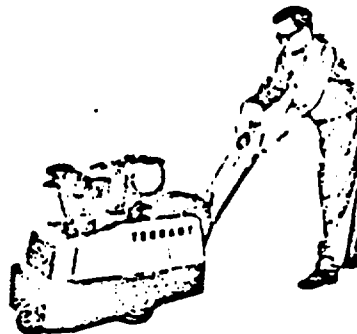
K-4 Covers 500-1,500 sq. ft. per hour. Faster and cleaner than a work crew. Leaves floor clean, smooth, ready for traffic. Removes grime, shears paint, sands, levels, scores grooves for overlays.
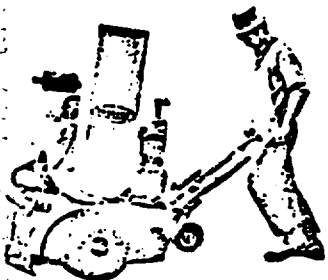
Removes deposits fast
III-10

L-2 Covers nearly 9,0 sq. ft. per hour. Powerful cleaning for heavily soiled floors. Removes imbedded grime, hurls it into 2cu capacity hopper. Machine leaves clean, dry, smooth surface.

Removes concrete; cleans cracks

G Cleans joints, routs winding cracks. Removes extruded material. Scores surface. Levels pavement bumps. Erases thermoplastic traffic lines. Prepares concrete for re-topping.

Roof scraper

RS Scrapes 12-28 squares per hour to within 1½" of flashing, parapets, walls. Often pays for itself in a single job. Splits in 2 sections for easy hoisting. Optional tool removes felts, insulation. 9 hp. engine.

Traffic line remover

TLR Removes 6" line permanently. Erases nearly 600 ft. of markings per hour. No chemical, sand or masking. Provides ideal bonding surface for new paint. Propels itself. Portable.

Scarifier Tools

Tennant Company scarifier tools tailor machines to specific applications. Cutters and patterns vary from light deposit and paint removal to aggressive concrete grinding. Hardened steel cutters give fast cleaning and removal action—thousands of impacts per second. In addition, wire brushes are available to shear away traffic-packed grease, dirt and metal cuttings. There are also special purpose tools for roof scraping and concrete routing operations.

3 easy ways to put a TENNANT machine to work for you.

Leasing

If you're interested in a machine now but don't want to use your current working capital, consider the Tennant Company Leasing Program. There are terms from 1 to 3 years with options to purchase or renew.

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If you want to own your machine and conserve cash or normal credit lines, use the Tennant Company Time Purchase Plan. Contract terms are from 3 months to 3 years.

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When you want to have the use of your machine before your capital budget is approved, look into the Tennant Company Rental Plan. Rent a new machine and part of the payments apply to machine purchase at a later date.

For more information on leases, time purchases and rentals, contact your Tennant Company representative.

Tennant Company, Minneapolis, MN
(R & F () 17)

surface deeper than 1 inch through cracks or pores. Other techniques are required to decontaminate metals, etc.

3.4 Waste Recovery and Disposal
The removed surface must be collected (by vacuum or other means) and decontaminated and disposed of.

3.5 State-of-the-Art
The scarifier technique has been used in the decommissioning of nuclear facilities. The tool is marketed under the trade name of "Scabbler" by the MacDonald Air Tool Company, New Jersey.

4.0 Applicability

4.1 Agent Applicability
Applicable to all agents (HD, VX and GB).

4.2 Isolated Building Material Applicability
Applicable to concrete (not concrete block) and cement only.

4.2.1 Impact of Substrate on Chemistry
None.

4.2.2 Removal or Reaction of Contaminant from Surface
Complete removal can be obtained from surface layer of concrete.

4.2.3 Removal or Reaction of Contaminant from Interior
The scarifier technique is only useful for depths up to 1 inch of concrete.

4.2.4 Damage to Material
Large degree of damage - Surface layer is chipped off leaving a course finish (1/4 to 1/2 inch peak-to-valley height). For smooth finish a concrete cap could be applied.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Obstructions to the scarifier may require removal.

4.3.2 Practical Physical Limitations/Methods to Overcome
Not suitable to hard-to-reach areas such as behind pipes and equipment. (Applicability dependent on interior building configuration.)

4.3.3 Secondary Decontamination Treatment
Drilling and spalling or other techniques may be required for contaminants that have penetrated the

surface deeper than 1 inch through cracks or pores.
Scarifier technique can only be applied to concrete
so other treatments must be employed for treatment of
metal.

4.3.4 Clean-up Requirements

Large amounts of contaminated debris will have to be
collected. A concrete cap may be needed to cover
rough surfaces.

4.3.5 Waste Treatment and Disposal

The contaminated debris will have to be packaged for
decontamination and disposal which may entail, for
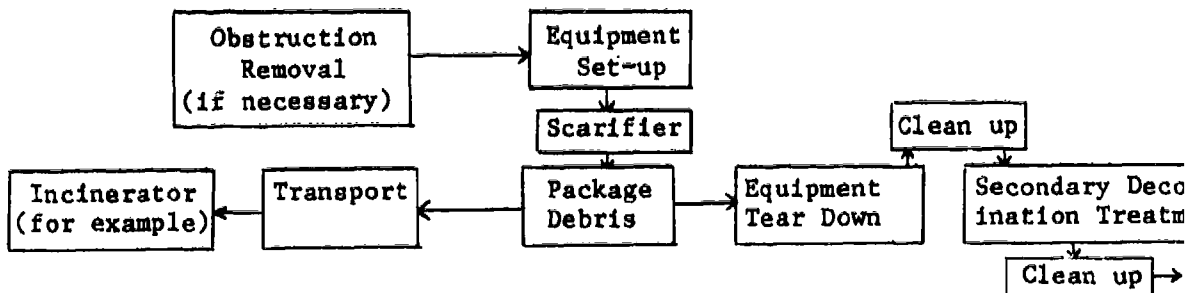example, incineration.

4.4 State-of-the-Art

This technique was used on concrete surfaces in the
decommissioning of nuclear facilities.

5.0 Engineering

5.1 Process Description

5.1.1 Main Process

```
┌──────────────┐        ┌──────────────┐
│ Obstruction  │ -----> │ Equipment    │
│ Removal      │        │ Set-up       │
│ (if necessary)│       └──────────────┘
└──────────────┘              │
                              ▼
                        ┌──────────┐              ┌──────────┐
                        │ Scarifier│              │ Clean up │
                        └──────────┘              └──────────┘
                              │                    ▲       │
┌──────────────┐ ┌──────────┐ ▼           ┌──────────────┐ ▼
│ Incinerator  │<│ Transport│<│ Package  │<│ Equipment    │ │ Secondary Deco
│ (for example)│ └──────────┘ │ Debris   │ │ Tear Down    │ │ ination Treatm
└──────────────┘              └──────────┘ └──────────────┘ └──────────┘
                                                               ▼
                                                         ┌──────────┐
                                                         │ Clean up │→
                                                         └──────────┘
```

Surface removal - The pneumatic scarifier is employed
to chip the surface away with its tungsten carbide
bits. Decon solution is used to keep dust down.
Debris Collection - The removed contaminated debris
must be collected by using a vacuum or other systems
and packaged for decontamination by incineration or
other techniques. Transport may be necessary. A
secondary decontamination treatment is then employed
to remove contaminants from metal, etc. and contami-
inants that have penetrated deep into concrete (more
than 1 inch).

5.1.2 Variations

Floor and wall models could be fitted with dust
collection systems. Hand-held models could be
developed for corners or other hard to reach area.
Use remote operated scarifier rig.

5.2 Equipment/Support Facilities Needed

    5.2.1 Description
        Scarifier unit requires pressurized air source.
        Portable generator and air compressors would be
        necessary to furnish the supply of compressed air.
        Debris collection/packaging system.

    5.2.2 Reliability, Availability and Maintainability
        Good - The concept is quite simple. The
        tungsten-carbide bits have an average working life of
        80 hours under normal conditions. Specially designed
        units are available for corners and other hard to
        reach places.

5.3 Decontamination Time

    5.3.1 Set-up
        Minimal time required unless obstructions (pipes or
        other equipment) require removal.

    5.3.2 Application Time

        5.3.2.1 Personnel
            Manhour requirements will be high since
            removing the surface layer is quite time
            consuming. Depends on size of building and
            amount of equipment/obstruction in the
            building. A remote control unit may decrease
            labor time but may be cost prohibitive unless
            large open surface areas are present.

        5.3.2.2 Decontamination
            Probably long since large amounts of material
            will have to be processed.

        5.3.2.3 Verification
            KNOWLEDGE GAP

    5.3.3 Tear-Down Time

        5.3.3.1 Equipment Removal
            Minimal

        5.3.3.2 Clean-up
            Considerable time will be required to remove
            all debris.

5.4 Safety Requirements

5.4.1 Process Hazards
None anticipated.

5.4.2 Personnel Hazards
Noise levels will be high. Dust laden with agent and flying chips could be hazardous.

5.4.3 Protective Methods
Protective clothing (level A or B) and eye wear as well as ear protection may be required. A dust suppression system such as periodic wash down with decon solution is recommended.

6.0 Economics

6.1 Building Damage - Repair Costs
Could be high. Very course surface will be obtained which may have to be capped with concrete or covered with other materials.

6.2 Developmental Costs
Dust control systems will probably have to be designed for all scarifier systems. Secondary treatment methods may need to be identified.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Low to moderate considering the cost of electricity or portable power generation.

6.3.2 Equipment Cost
Cost of scarifier. Tungsten-carbide replacement bits.

6.3.3 Material Cost
None anticipated.

6.3.4 Manpower Cost
Probably high since the removal rate will probably be quite slow.

7.0 Future Work Required

7.1 Knowledge Gaps
Selection of secondary treatment method. Waste recovery and disposal method.

7.2 Resolution
An engineering study.

ELECTROPOLISHING

1.0 General Description

1.1 Summary of Idea
Electropolishing is a commonly used electrochemical process that has been effectively employed for decontamination purposes. A contaminated <u>metal</u> object serves as the anode in an electrolytic cell. The passage of electric current results in the anodic dissolution of the surface material and, with proper operating conditions, a progressive smoothing of the surface. Contaminants on the surface or entrapped within surface imperfections are removed and released into the electrolyte by this surface dissolution process. The production of a polished surface also facilitates the removal of residual electrolyte by rinsing.

1.2 Origination of Idea
Developed in part by Battelle Pacific Northwest Laboratories (Allen, 1979) - for purposes of nuclear facility decontamination. Described in detail in the Decommissioning Handbook (Manion, 1980).

1.3 Obvious Advantages and Disadvantages
Advantages. Highly effective in removing contaminants from metal surfaces.

Disadvantages. Limited to metallic materials. Metal surface must be unpainted. May not be as cost effective as just allowing the item to soak in a tank.

1.4 Variations of Idea
Remote Tank Electropolishing: This may be suitable for small metal objects (equipment tools, etc.). <u>In situ</u> Electropolishing: Contact devices have been developed that would permit direct surface application. A system for electropolishing the inside of pipes has also been developed.

1.5 Sketch
See pages III-116, 117, 118.

2.0 Chemical Decomposition Treatment
Not applicable.

3.0 Physical Treatment

3.1 Removal Efficiency, Residue Level
Reduces radiation contamination to background levels, so complete removal of agents is highly probable.

3.2 Hazardous Wastes
Agents contained in the electrolyte may remain hazardous, although a strongly acidic electrolyte would tend to decompose the agents (e.g., VX).

3.3 Supplementary Treatment(s)
   Rinsing of metal surface with, for example, water.

3.4 Waste Recovery and Disposal
   Purification of the electrolyte will probably be necessary.
   Contaminant residues separated from the electrolyte may
   require further treatment and disposal.

3.5 State-of-the-Art
   Electropolishing is a very well developed electrochemical
   process used in both laboratory and industrial applications.

4.0 Applicability

4.1 Agent Applicability
   Applicable to all agents.

4.2 Isolated Building Material Applicability
   Unpainted metals only.

   4.2.1 Impact of Substrate on Chemistry
      None.
   4.2.2 Removal or Reaction of Contaminant from Surface
      Surface removal highly probable.

   4.2.3 Removal or Reaction of Contaminant from Interior
      Removal from interior of metals is not possible.

   4.2.4 Damage to Material
      Negligible.

4.3 Practical Applicability to Building

   4.3.1 Building Preparation
      Paint removal from metals is necessary.

   4.3.2 Practical Physical Limitations/Methods to Overcome
      Adaption to complex metal surfaces (e.g. structural
      networks) would be difficult.

   4.3.3 Secondary Decontamination Treatment
      Decontamination of non-metals will be necessary.

   4.3.4 Clean-up Requirements
      Rinsing of metal surfaces.

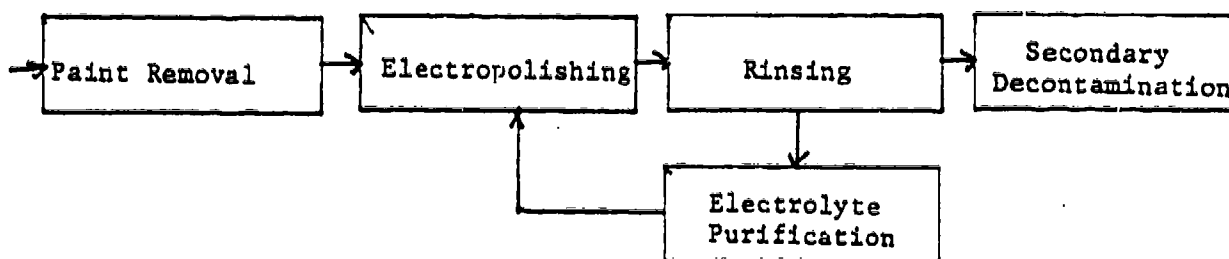   4.3.5 Waste Treatment and Disposal
      Contaminant residue separated from the electrolyte can
      be treated by incineration or chemical neutralization
      if not already decomposed.

4.4 State-of-the-Art
Electropolishing is currently under development for large scale decontamination of metal surfaces in nuclear facility decommissioning operations. (Allen, 1/1979, 3/1979, 5/1979, 11/1979, 11/1978).

5.0 Engineering

5.1 Process Description

```
          ┌──────────────┐   ┌──────────────┐   ┌──────────────┐   ┌──────────────┐
  ─────▶  │Paint Removal │─▶ │Electropolishing│─▶│   Rinsing    │─▶│  Secondary   │
          └──────────────┘   └──────────────┘   └──────────────┘   │Decontamination│
                                    ▲                 │            └──────────────┘
                                    │                 ▼
                                    │          ┌──────────────┐
                                    └──────────│  Electrolyte │
                                               │ Purification │
                                               └──────────────┘
```

5.1.1 Main Process

    5.1.1.1 Paint Removal
        Sandblasting or paint stripping solvents could be employed.

    5.1.1.2 Electropolishing treatment
        The contaminated metal is interfaced with electrolyte (typically 40-80% phosphoric acid) to establish a complete circuit and electrical current is applied.

    5.1.1.3 Rinsing
        The electrolyte is removed from the decontaminated metal surface by rinsing with water.

    5.1.1.4 Electrolyte purification
        The electrolyte is purified and recycled.

5.1.2 Variations
Several different types of electropolishing systems can be employed, depending on the size and geometry of the contaminated metal. These include a remote tank electropolishing system (applicable to small metal objects), a direct surface contact device and a system for electropolishing the inside of pipes.

5.2 Equipment/Support Facilities Needed

  5.2.1 Description

    5.2.1.1 Paint removal equipment. Standard commercial sandblasting equipment could be employed. Paint stripping solvents could be applied by brush or spray.

    5.2.1.2 Electropolishing equipment.
    The remote tank electropolishing system consists of the following: electropolishing tank, one or more rinse tanks, DC power supply, heating and agitation equipment and a ventilation system.

    The contact type device consists of an insulated fixture that holds the cathode at a fixed distance from the anode (component being decontaminated) surface. Electrolyte is pumped through the unit while maintaining a slightly negative pressure to contain the electrolyte.

    The internal pipe electropolishing system consists of a movable cathode pipe that is inserted inside a contaminated pipe. Electrolyte is pumped through the cathode into the pipe and returned to an external electrolyte reservoir.

    5.2.1.3 Rinsing equipment.
    Rinse tanks or water spray system could be employed.

    5.2.1.4 Electrolyte purficiation equipment
    A mobile mounted system for spent acid solidification has been developed by Chem-Nuclear.

  5.2.2 Reliability, Availability and Maintainability
  Depends on specific electropolishing system. Remote tank system would be quite high, but the in situ devices would rate lower.

5.3 Decontamination Time

  5.3.1 Set-up
  Paint removal from metals is time dependent on extent of detailed structural networks.

  5.3.2 Application Time

5.3.2.1 Personnel
Remote tank system - loading and unloading of small items would proceed rapidly. Placement and operation of contact device on a contaminated section would be rapid, but overall time to treat all surfaces would be long.

5.3.2.2 Decontamination
Typically, one-half hour is sufficient per treated area.

5.3.2.3 Verification
Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Removal of electropolishing system would proceed rapidly.

5.3.3.2 Clean-up
Clean-up of spills.

5.4 Safety Requirements

5.4.1 Process Hazards
Electrolyte leaks.

5.4.2 Personnel Hazards
Acid burns, possible contact with agent contaminated solution.

5.4.3 Protective Methods
Wear protective clothing, safety goggles. Level A or B may not be required.

6.0 Economics

6.1 Building Damage - Repair Costs
Negligible.

6.2 Developmental Costs
Demonstration of effectiveness on metals contaminated with agents.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Electrical input cost for DC power supply would be moderate.

6.3.2 Equipment Cost
    A large tank system capable of supplying 500 to 1500 A/m^2 is expected to cost \$100,000 (Manion, 1980). Cost of _in situ_ devices is unknown.

6.3.3 Material Cost
    Cost of phosphoric acid.

6.3.4 Manpower Cost
    Substantial labor involvement.

7.0 Future Work Required
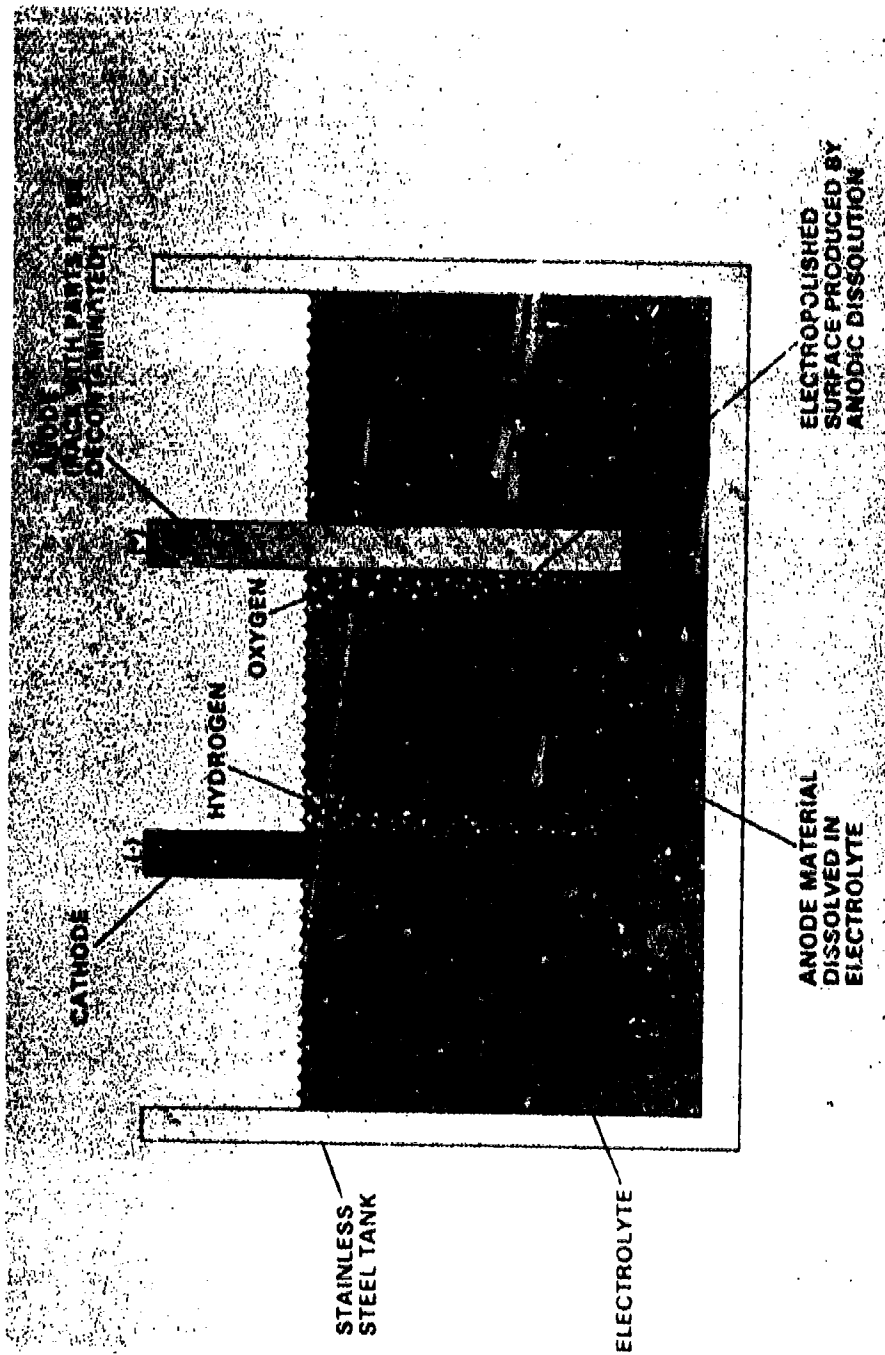
7.1 Knowledge Gaps

    5.3.2.3 Verification requirements need development.

    6.0 Economics.
        The method has been proven quite effective in decontamination.
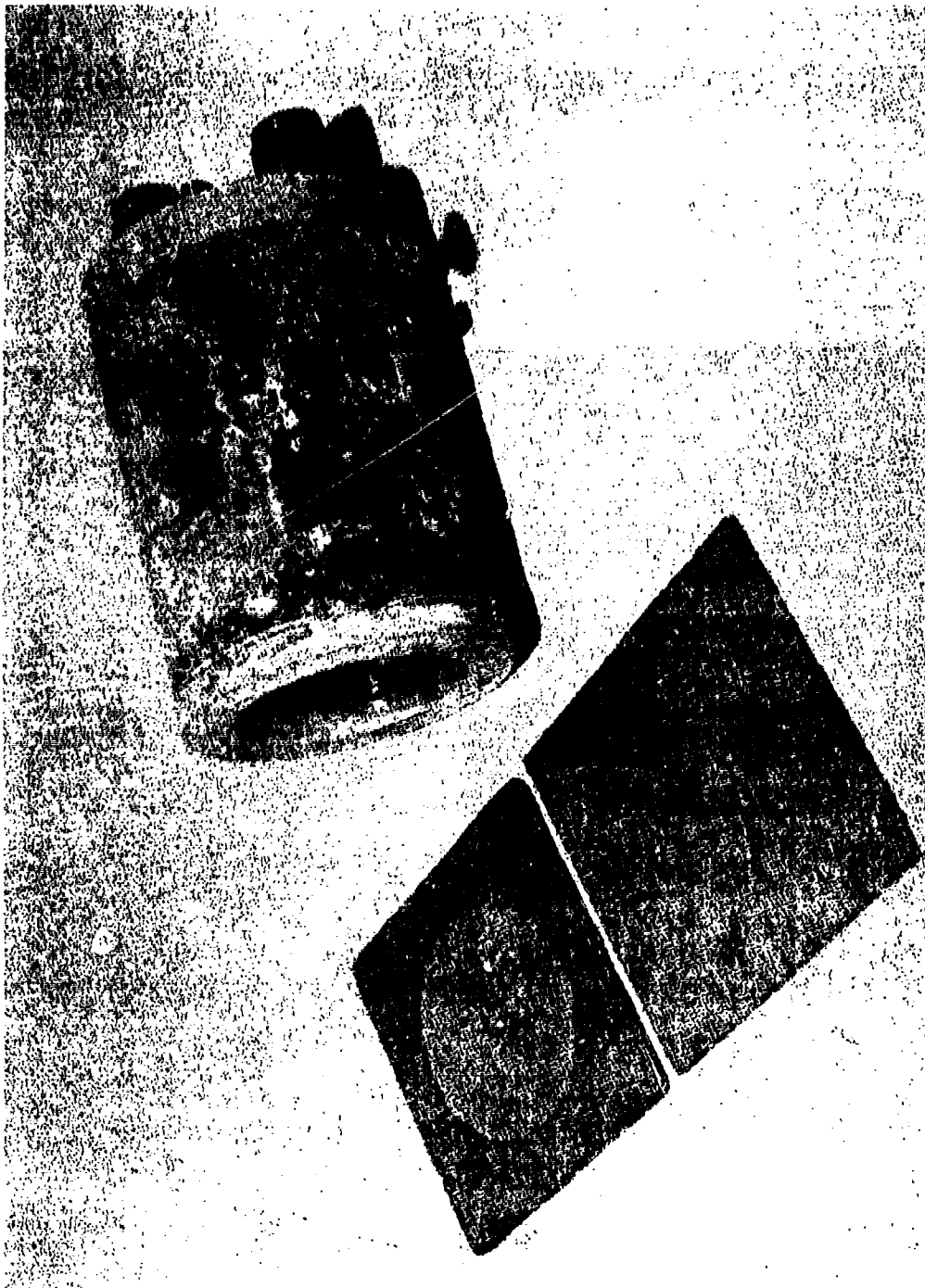
7.2 Resolution
    Economic analysis, experimental testing.
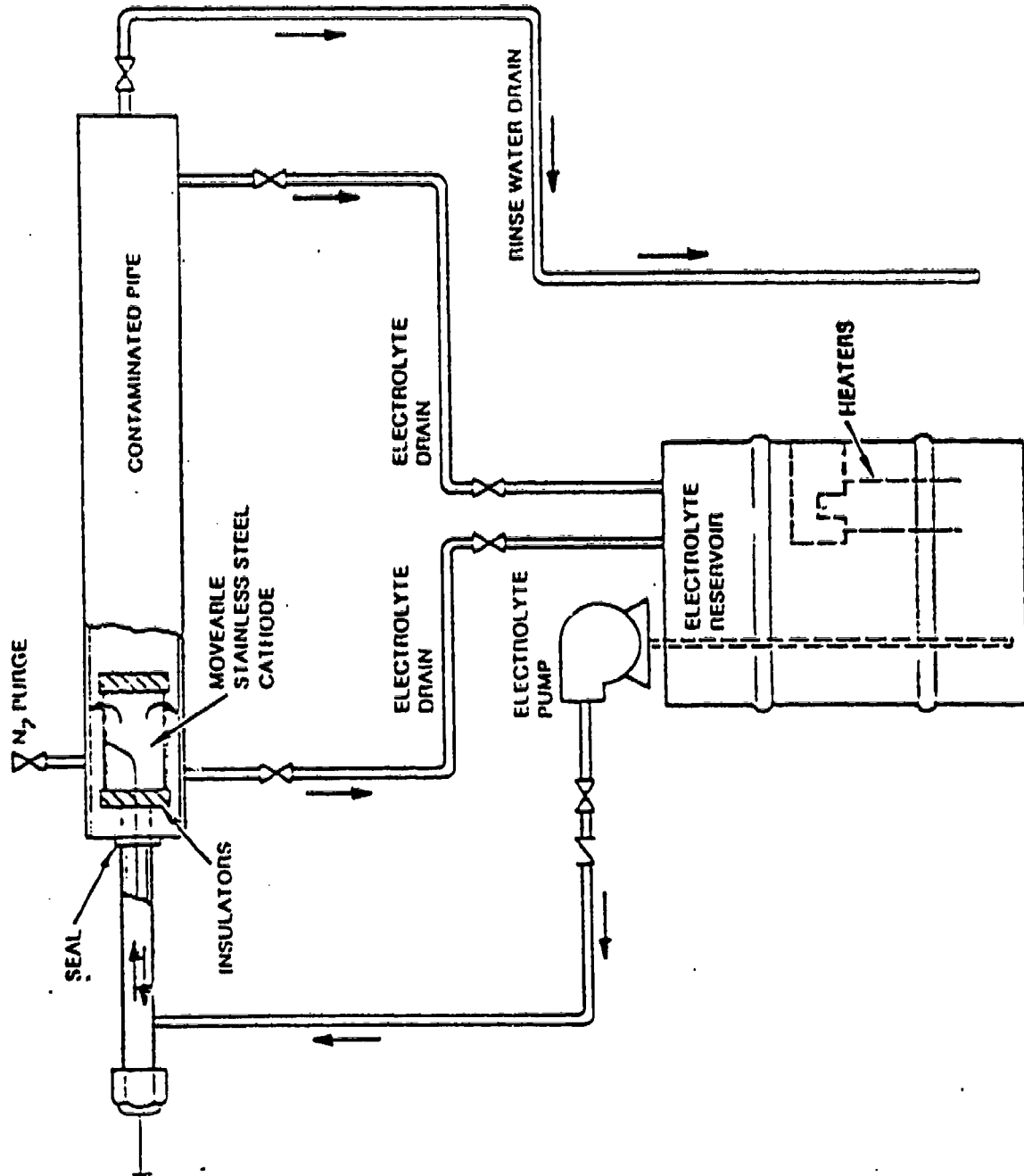
ELECTROPOLISHING CELL

(Manion, 1980)

IN-SITU ELECTROPOLISHING CONTACT DEVICE

(Manion, 1980)

SCHEMATIC DIAGRAM OF MOVABLE ELECTROPOLISHING IN CORROSION TEST LOOP

DRILL AND SPALL

1.0 General Description

1.1 Summary of Idea
The drill and spall technique is capable of removing approximately 2 inches. of surface layer from concrete or similar materials. The technique consists of drilling holes (1 to 1-1/2 inches diameter) approximately 3 inches deep into the surface. The spalling tool bit is inserted into the hole and hydraulically spreads to spall off the contaminated concrete.

1.2 Origination of Idea
Decommissioning Handbook (Nuclear facilities) Literature (Manion, 1980).

1.3 Obvious Advantages and Disadvantages
Advantages. The technique can achieve deeper preparation (removal) of surfaces as compared with other surface removal. techniques. Good for large scale application.

Disadvantages. Only effective as a near surface treatment of concrete. The treated surface retains a very rough appearance that would necessitate resurfacing. Substantial amounts of contaminated debris requires processing.

1.4 Variations of Idea
Vacuum filter systems as well as water sprayers (spray decon solution) can be employed during operation to control dust laden with agent.

1.5 Sketch
See pages III-124, 125.

2.0 Chemical Decomposition Treatment
Not applicable.

3.0 Physical Treatment

3.1 Removal Efficiency, Residue Level
Complete removal can be obtained for contamination within 2 inches of concrete surface.

3.2 Hazardous Wastes
The removed concrete is still contaminated and is therefore a hazard.

3.3 Supplementary Treatment(s)
Other techniques may have to be employed if contaminants have penetrated the surface to depth greater than 2 inches. Other techniques are required to decontaminate metals, etc.

3.4 Waste Recovery and Disposal
The concrete removed must be collected for decontamination
(e.g. incineration) and disposal.

3.5 State-of-the-Art
Drilling and spalling was used in the decommissioning of
Nuclear facilities. (Manion, 1980).

4.0 Applicability

4.1 Agent Applicability
Applicable to all agents.

4.2 Isolated Building Material Applicability
Applicable to concrete (not concrete block) and cement only.

4.2.1 Impact of Substrate on Chemistry
None.

4.2.2 Removal or Reaction of Contaminant from Surface
Complete removal can be obtained from the surface
layer of concrete and cement.

4.2.3 Removal or Reaction of Contaminant from Interior
Complete removal of concrete is obtainable for depth
up to 2 inches.

4.2.4 Damage to Material
High - a very coarse surface is left behind which
would have to be capped with concrete or otherwise
finished to a smooth surface. Reinforcement bars may
become exposed.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
None required.

4.3.2 Practical Physical Limitations/Methods to Overcome
Not suitable for hard to reach areas such as behind
pipes and equipment (applicability dependent on
interior building configuration).

4.3.3 Secondary Decontamination Treatment
Other techniques will be required to treat
contaminants that have penetrated the surface deeper
than 2 inches as well as for other materials (brick,
concrete block, etc.)

4.3.4 Clean-up Requirements

Large amounts of concrete debris will need to be collected for decontamination and disposal. A concrete cap must be made to cover rough surfaces.
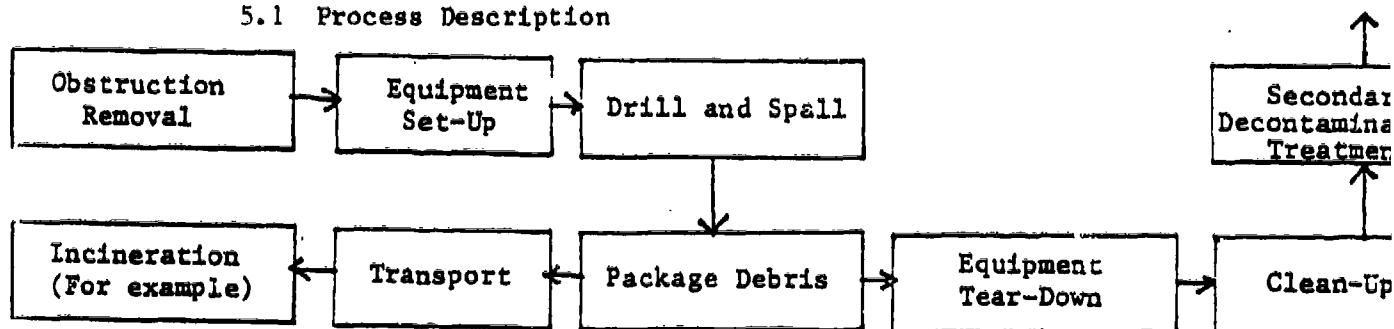
4.3.5 Waste Treatment and Disposal

The removed concrete/debris will have to be decontaminated (possibly through incineration) and disposed.

4.4 State-of-the-Art

A drilling and spalling rig is being designed and tested by Battelle Pacific Northwest Laboratories to increase the concrete removal rate (Manion, 1980). See attachments.

5.0 Engineering

5.1 Process Description

```
┌──────────────┐    ┌──────────────┐    ┌──────────────────┐                                    ┌──────────────┐
│ Obstruction  │───▶│  Equipment   │───▶│ Drill and Spall  │                                    │   Secondar   │
│   Removal    │    │   Set-Up     │    │                  │                                    │ Decontamina  │
└──────────────┘    └──────────────┘    └──────────────────┘                                    │   Treatmer   │
                                                 │                                              └──────────────┘
                                                 ▼                                                      ▲
┌──────────────┐    ┌──────────────┐    ┌──────────────────┐    ┌──────────────┐    ┌──────────────┐
│ Incineration │◀───│  Transport   │◀───│  Package Debris  │───▶│  Equipment   │───▶│   Clean-Up   │
│(For example) │    │              │    │                  │    │  Tear-Down   │    │              │
└──────────────┘    └──────────────┘    └──────────────────┘    └──────────────┘    └──────────────┘
```

5.1.1 Main Process

One to 1-1/2 inch diameter holes approximately 3 inches deep and 12 inches on center are drilled into the concrete surface. Hydraulically operated spalling tools are inserted into the holes. The spalling tool bit is an expansible tube of the same diameter as the hole. A tapered mandril is hydraulically forced into the hole to spread the fingers and spall off the concrete. The removed concrete must then be collected for decontamination and disposal. A secondary treatment is then performed to remove contaminants which have penetrated deeper than 2 inches as well as for the other materials (brick, etc.).

5.1.2 Variations

Vacuum filter systems or water sprayers may be employed for dust control. Use remote operated drill and spalling rig.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
Drill and Spall Rig
Scaffolding/hydraulic positioning system.
Clean-up equipment.

5.2.2 Reliability, Availability and Maintainability
Good - the technique is relatively simple.

5.3 Decontamination Time

5.3.1 Set-up
Minimal - scaffolding will have to be assembled for wall treatment as well as removal of obstructions (if necessary).

5.3.2 Application Time

5.3.2.1 Personnel
Extensive - this is a relatively slow process. A remote control device may decrease labor time but may not be cost effective. Battelle Pacific Northwest reports that its drilling and spalling rig has an average removal rate of 7.5 cubic yd/hr for standard concrete (Manion, 1980).

5.3.2.2 Decontamination
Anticipated to be extensive because of slow process as well as requirement of secondary treatment.

5.3.2.3 Verification
Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Minimal.

5.3.3.2 Clean-up
Extensive - large quantities of concrete will have to be collected. Surfaces may require wash down.

5.4 Safety Requirements

5.4.1 Process Hazards
None anticipated.

5.4.2 Personnel Hazards

Dust level (laden with agent) and noise level may be high. High pressure air lines and flying debris.

5.4.3 Protective Methods
Eye, ear and clothing protection (e.g. level A or B) should be worn. A dust suppression system such as periodic wash down with decon solution may be required.

6.0 Economics

6.1 Building Damage - Repair Costs
The spalled surface is very rough and will require concrete capping or other treatment to yield smooth surfaces. Cost expected to be high.

6.2 Developmental Costs
Secondary treatment method. Dust control systems.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Relatively low to moderate.

6.3.2 Equipment Cost
Drill and spall rig without positioning equipment cost approximately $10,000 (1980 dollars) (Manion, 1980).

6.3.3 Material Cost
Decon solution.

6.3.4 Manpower Cost
High - the concrete removal rate is relatively slow and clean-up time is large.

7.0 Future Work Required

7.1 Knowledge Gaps
Decontamination - A technique must be selected to treat contaminated concrete. Practical physical limitations - dust control systems need to be designed. The drilling and spalling technique will have to be modified or another technique chosen to decontaminate block, brick, wood and other building materials. Selection of secondary treatment.
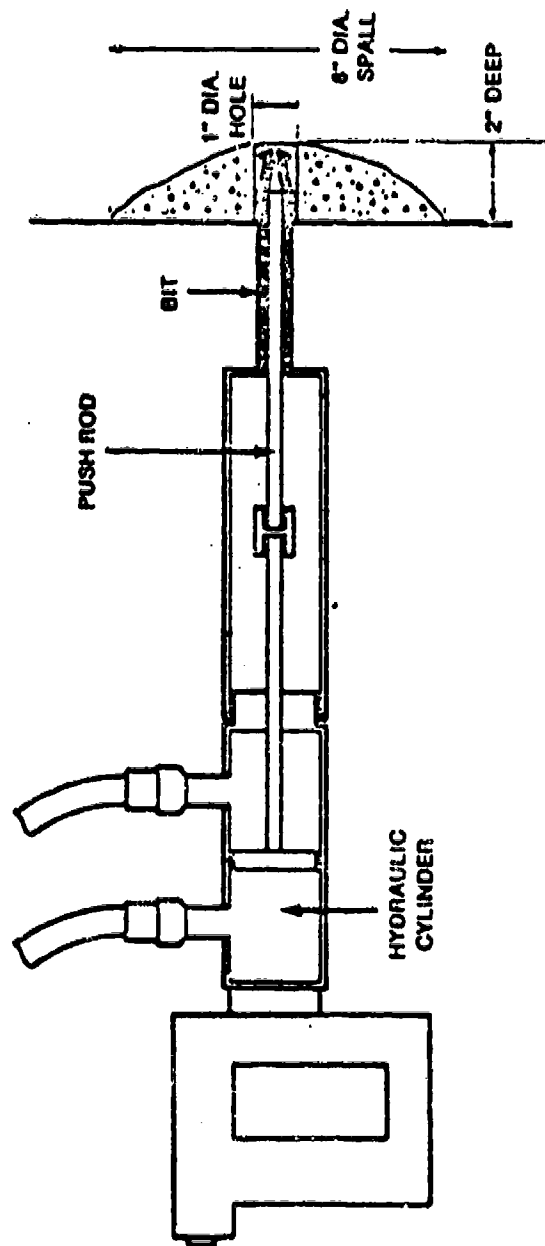
7.2 Resolution
Engineering analysis of treatment of spalled concrete.
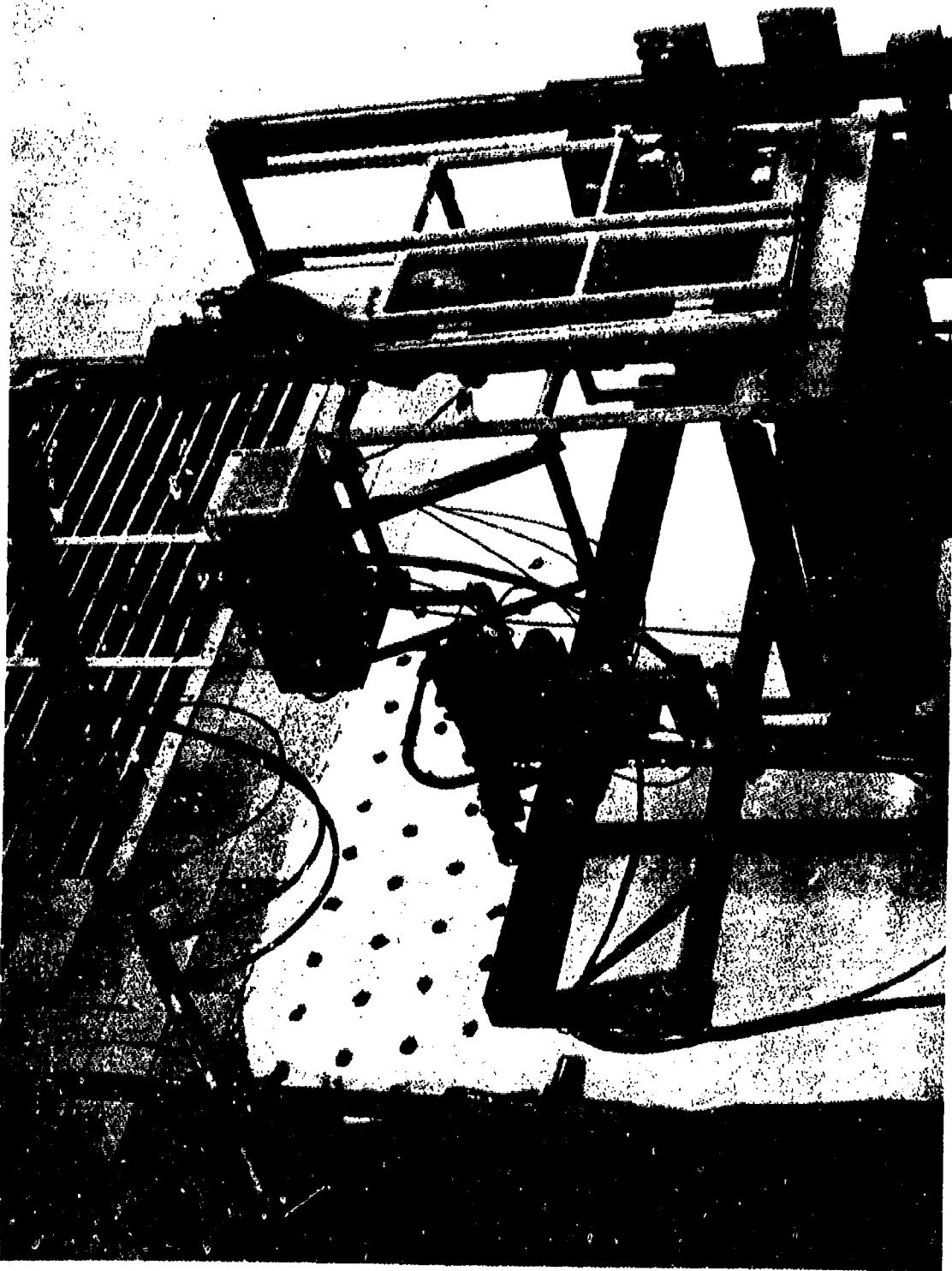
DRILL AND SPALL RIG

(Manion, 1980)

CONCRETE SPALLER

ULTRASONIC EXTRACTION

1.0 General Description

 1.1 Summary of Idea
  Ultrasonic cleaning is a surface scrubbing technique that can be employed to remove surface contaminants. Small equipment would be removed and loaded into ultrasonic cleaning tanks. Specially designed scrubbers would then be used to clean the walls and floors. An ultrasonic cleaning system typically consists of an ultrasonic generator, a transducer, a cleaning tank, a liquid couplant/solvent and a heater. The generator converts line power from 60 Hz to a higher frequency (from 18 to 90 KHz.) The transducer converts these high frequency impulses to low amplitude mechnical energy of the same frequency. The warm liquid coupling agent (150-170 F) serves to transmit this energy to the object to be cleaned. The compression-rarefaction-compression wave cycle transmitted by the generator causes the liquid to cavitate and implode creating minute quantities of energy with tremendous localized force. Pressures and temperatures are approximately 10^4 psi and 10^4 °C. These imploding cavities serve to scrub the surface being decontaminated causing spalling and descaling.

 1.2 Origination of Idea
  Used in the decontamination of nuclear facilities and described in detail in the Decommissioning Handbook (Manion, 1980). It is also commercially used for cleaning electronic components electronic and plating industries.

 1.3 Obvious Advantages and Disadvantages
  Advantages. Potentially applicable to all building materials. Paint removal is not required prior to cleaning. Localized high temperature may cause decomposition of some explosives.

  Disadvantages. Only known to be effective as a surface removal technique. The coupling agent may carry the contaminant deeper into porous materials. The cleaning liquid and removed surface must be decontaminated and disposed.
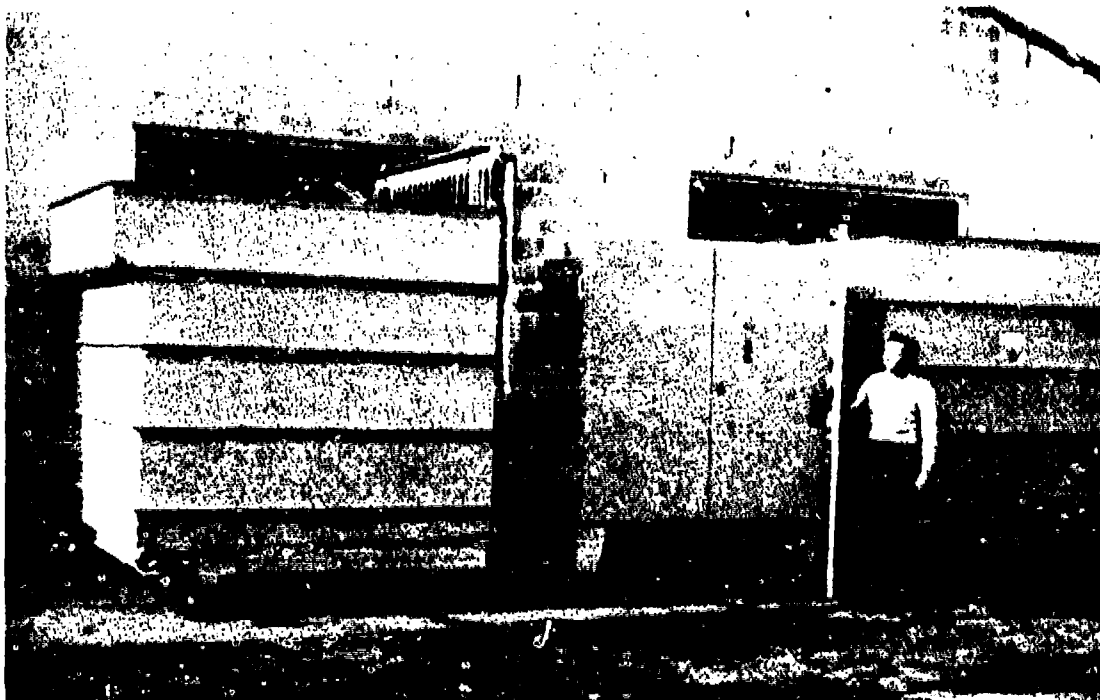
 1.4 Variations of Idea
  Phosphoric, citric or other acids may be used as coupling agent/solvents in the cleaning tank. Decontamination solutions may also be used. Ultrasonics may be used with other techniques to allow enhanced penetration of solution into building material.

 1.5 Sketch
  See page III-127.

Interior View of a Decontamination Tank

Exterior View of Decontamination Tanks

ULTRASONIC DECONTAMINATION TANKS

(Manion, 1980)

2.0 Chemical Decomposition Treatment
   Not applicable.

3.0 Physical Treatment

   3.1 Removal Efficiency, Residue Level
      Complete removal of surface contaminants is anticipated.

   3.2 Hazardous Wastes
      The liquid cleaning solution will become contaminated with agents and must therefore be treated as hazardous.

   3.3 Supplementary Treatment(s)
      Another technique may need to be employed to remove contaminants that have penetrated the surfaces of building materials through cracks and pores.

   3.4 Waste Recovery and Disposal
      Liquid cleaning solution will have to be contained and treated for decontamination of contaminants.

   3.5 State-of-the-Art
      Ultrasonics have been employed in Nuclear decontamination. A commercial ultrasonic tank measuring 10 ft x 3 ft x 3 ft with an ultrasonic power rating of 18 KW has been in service for about 8 years at Bettis Atomic Power Laboratory (Manion, 1980). Specially designed hand-held wall cleaners and a floor cleaner have been designed for Argonne National Laboratories to decontaminate flame-sprayed zinc on hot cell liners. (Manion, 1980). Ultrasonic baths are used to clean electric circuit boards on a commercial basis.

4.0 Applicability

   4.1 Agent Applicability
      Potentially applicable to the removal of all agents.

   4.2 Isolated Building Material Applicability
      Potentially applicable to all building materials.

      4.2.1 Impact of Substrate on Chemistry
         Removal of adsorbed agents may be accomplished by this method.

      4.2.2 Removal or Reaction of Contaminant from Surface
         Complete removal anticipated.

      4.2.3 Removal or Reaction of Contaminant from Interior
         Ultrasonic cleaning has only been demonstrated to be an effective surface decontamination technique.

4.2.4 Damage to Material
Minimal - the surface layer will probably be removed but without structural damage.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Disassembly of small equipment for cleaning in ultrasonic tanks. Removal of pipes, pumps and other obstruction for cleaning in tanks.

4.3.2 Practical Physical Limitations/Methods to Overcome
Special units may need to be designed to clean corners, and other complex geometrics. Liquid collection systems may need to be designed.

4.3.3 Secondary Decontamination Treatment
Other techniques may need to be employed to remove contaminants that have penetrated the surface through cracks and pores.

4.3.4 Clean-up Requirements
Surfaces may require a water/solvent rinse to remove remaining debris. Rinse water must be contained and decontaminated.

4.3.5 Waste Treatment and Disposal
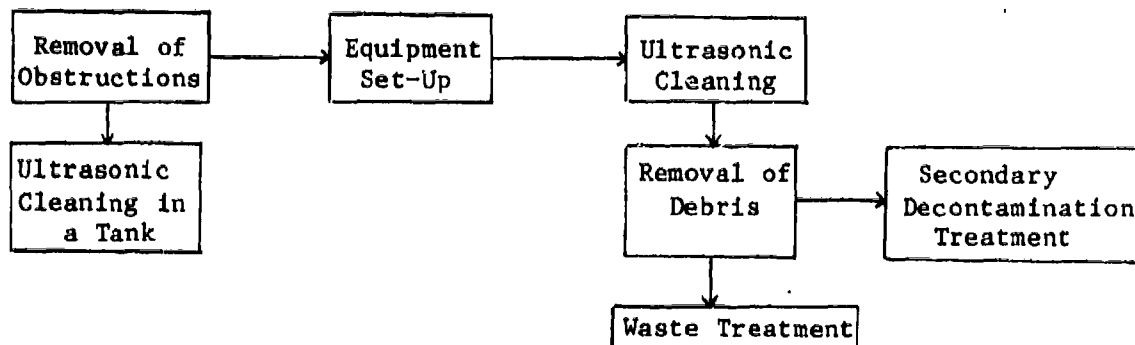The proper technique will need to be chosen to treat the spent cleaning liquid and removed debris.

4.4 State-of-the-Art
Ultrasonic cleaning via a cavitating fluid has been used to clean many intricate parts (see page III-127). However, ultrasonic cleaning has never been employed for large scale cleaning of an entire building.

5.0 Engineering

5.1 Process Description

```
Removal of      Equipment      Ultrasonic
Obstructions -> Set-Up    ->   Cleaning
     |                              |
     v                              v
Ultrasonic                     Removal of   ->  Secondary
Cleaning in                    Debris           Decontamination
a Tank                             |             Treatment
                                   v
                              Waste Treatment
```

5.1.1 Main Process

The generator converts line power from 60 Hz to a high frequency of from 18 to 90 Hz. The transducer converts these high frequency impulses to low amplitude mechanical energy of the same frequency. The liquid coupling agent transmits this energy to the surface or object to be cleaned. Liquid coupling agent is then treated to remove surface debris and recycled.

5.1.2 Variations

Many types of cleaning liquids could be used such as acids or solvents. Instead of a cleaning fluid, a decontaminating solution may be used.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

Electricity. Waste liquid treatment facility/capabilities.

5.2.2 Reliability, Availability and Maintainability

The ultrasonic tank cleaners are commercially available.

5.3 Decontamination Time

5.3.1 Set-up

Connection of power to generator, heaters. Removal of small equipment and obstruction for cleaning in ultrasonic tanks.

5.3.2 Application Time

5.3.2.1 Personnel

Could be extensive - all surfaces would have to be manually treated with hand-held units. Remotely operated units may be used but at a much higher capital cost. If a short decontamination time could be achieved, the method would be similar to painting.

5.3.2.2 Decontamination

This technique has never been employed on agents. The localized high pressures and temperatures may also decompose as well as remove agents.

5.3.2.3 Verification

Knowledge gap.

5.3.3 Tear-Down Time

    5.3.3.1 Equipment Removal
        Minimal - removal of the ultrasonic generator
        and support equipment.

    5.3.3.2 Clean-up
        Average - surfaces may require a water or
        solvent rinse to remove remaining debris.
        All removed debris and spent cleaning liquid
        needs to be gathered for decontamination and
        disposal.

5.4 Safety Requirements

    5.4.1 Process Hazards
        None anticipated.

    5.4.2 Personnel Hazards
        None anticipated if non-toxic, non-corrosive cleaning
        solutions used. Precaution should be taken to operate
        outside the audible range. Solution will be contam-
        inated with agent.

    5.4.3 Protective Methods
        Ear projection and gloves should be worn.

6.0 Economics

6.1 Building Damage - Repair Costs
    Damage to the building should be minimal since this is only a
    surface removal technique.

6.2 Developmental Costs
    Specially designed units may need to be designed to handle
    large scale decontamination efforts.

6.3 Treatment Costs

    6.3.1 Utilities and Fuel Cost
        High electrical power usage may be required.

    6.3.2 Equipment Cost
        10 ft x 3 ft x 3 ft 18 KW tank with generator and
        transducer are $60,000. Small hand-held wall cleaner
        and a floor cleaner are $3,000. 26 in^3, 6KW tank
        with removable/disposable liner is $35,000.

    6.3.3 Material Cost
        Minimal - unless special liquids such as acids are
        used as cleaning fluids.

6.3.4 Manpower Cost
    Could be high (dependent on decontamination time) –
    the wall and floor scrubbers may need to be manually
    operated. Automation could be employed to decrease
    manpower cost at the expense of equipment investment.
    It depends on required decomposition time.

7.0 Future Work Required

7.1 Knowledge Gaps
    Conventional ultrasonic cleaning systems may need modifi-
    cations to handle the decontamination of an entire building.
    Spent liquid treatment systems may also need to be developed
    to handle the spent liquid which contains removed surfaced
    debris and removed contaminants.

7.2 Resolution
    Experimental testing.

ULTRASONIC DECOMPOSITION

1.0 General Description

1.1 Summary of Idea
High energy sound waves could be used to decompose contaminants contained in building materials. A generator is used to convert standard 60 Hz line power to low frequency, long wavelength energy which would travel through a small air layer and penetrate the building surface, destroying the contaminants.

1.2 Origination of Idea
Novel Process project team.

1.3 Obvious Advantages and Disadvantages
Advantages. Ultrasound could effectively penetrate building materials to any desired depth. Building preparation and damage would be minimal.

Disadvantages. The effectiveness of ultrasonic waves upon agent is not known.

1.4 Variations of Idea
Ultrasonic cleaning tanks could be employed to clean small pieces of equipment (valves, pump parts, etc.). A direct contact liquid interface system could be used to clean the surface via cavitation.

1.5 Sketch
Ultrasonics may be used as a supplementary treatment to other methods (i.e chemical) to potentially enhance reaction rates.
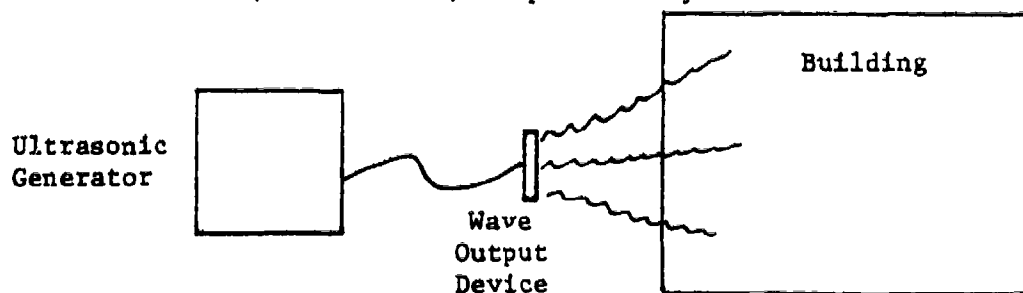
Ultrasonic Generator

Wave Output Device

Building

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions
Knowledge gap.

2.2 Hazardous Products
Knowledge gap.

2.3 Destruction Efficiency, Residue Level
Complete destruction may be possible since the ultrasonic waves can penetrate to any depth in the building material.

2.4 Reaction Rate/Kinetics
Knowledge gap.

2.5 Supplementary Treatment
Knowledge gap.

2.6 State-of-the-Art
In the decommissioning of nuclear facilities liquid
cavitation cleaning systems have been employed (Manion,
1980). Non-liquid, air interface systems of this type
have never been used in decontamination efforts; however,
ultrasonic horns are available and have been commercially
used (Boucher, 1961; Weissler, 1969).

3.0 Physical Treatment
Not applicable.

4.0 Applicability

4.1 Agent Applicability
Potentially applicable to agents.

4.2 Isolated Building Material Applicability
Potentially applicable to all building materials.

4.2.1 Impact of Substrate on Chemistry
The substrate will dictate the wavelength and
frequency required for penetration. The effect of
ultrasonic waves on adsorbed agents is unknown.

4.2.2 Removal or Reaction of Contaminant from Surface
Complete decomposition may be possible.

4.2.3 Removal or Reaction of Contaminant from Interior
Complete decomposition may be possible since ultra-
sonic waves can penetrate building materials to any
depth.

4.2.4 Damage to Material
None anticipated.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
None anticipated.

4.3.2 Practical Physical Limitations/Methods to Overcome
The correct wavelength and frequency that will
penetrate all of the building material and destroy the
contaminants will have to be determined.

4.3.3 Secondary Decontamination Treatment
None anticipated.
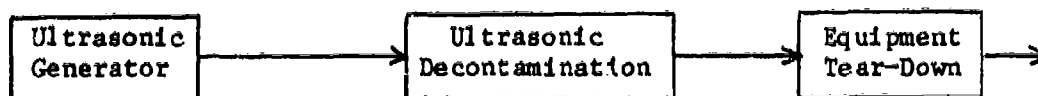
4.3.4 Clean-up Requirements
None anticipated.

4.3.5 Waste Treatment and Disposal
None anticipated.

4.4 State-of-the-Art
Ultrasonics have found many uses in industry including flow detection in metals, emulsification and dispersion in liquids, diagnostic medical equipment, welding equipment, etc. Liquid systems have been employed in nuclear decontamination and cleaning of electronic components but non-liquid air interface systems have never been employed for cleaning purposes.

5.0 Engineering

5.1 Process Description

```
┌──────────────┐      ┌──────────────────┐      ┌──────────────┐
│ Ultrasonic   │────→ │ Ultrasonic       │────→ │ Equipment    │────→
│ Generator    │      │ Decontamination  │      │ Tear-Down    │
└──────────────┘      └──────────────────┘      └──────────────┘
```

5.1.1 Main Process
An ultrasonic wave generator would be used to produce a high energy, long wavelength wave that would be directed towards the surface to be cleaned. The wave penetrates to the desired depth (complete penetration, if necessary) and destroys the contaminants.

5.1.2 Variations
Small equipment is first disassembled and decontaminated in liquid filled ultrasonic tanks via cavitation. A liquid film would be maintained between the wall and the ultrasonic device and surface cleaning would be achieved via cavitation of the liquid.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
Electricity. Ultrasonic generator.

5.2.2 Reliability, Availability and Maintainability
RAM is expected to be high due to the simplicity of the decontaminating scheme.

5.3 Decontamination Time

5.3.1 Set-up
Should be low since no prior building treatment is required.

5.3.2 Application Time

5.3.2.1 Personnel
Routine monitoring of equipment and wave generator adjustments as well as placement of wave output device.

5.3.2.2 Decontamination
Dependent on building material, wavelength/frequency of wave, and contaminant.

5.3.2.3 Verification
Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Minimal - the removal of equipment should require little time.

5.3.3.2 Clean-up
None-anticipated.

5.4 Safety Requirements

5.4.1 Process Hazards
None anticipated.

5.4.2 Personnel Hazards
Ultrasonics have the potential for being in the audible ranges when operated under certain circumstances.

5.4.3 Protective Methods
Ear protection.

6.0 Economics

6.1 Building Damage - Repair Costs
Minimal - little, if any, damage to the building should results.

6.2 Developmental Costs
Could be high - this large scale application will require considerable experimental work in equipment specification as well as determining the effect of ultrasonic waves on agents.

6.3 Treatment Costs

    6.3.1 Utilities and Fuel Cost
        Could be high - large amounts of electricity will
        probably be required.

    6.3.2 Equipment Cost
        Moderate - the ultrasonic generator will be the major
        cost.

    6.3.3 Material Cost
        None required.

    6.3.4 Manpower Cost
        Low to moderate - personnel required only for
        equipment set-up/tear-down and routine
        monitoring/maintenance.

7.0 Future Work Required

    7.1 Knowledge Gaps
        Equipment specification. Wavelength specification for each
        material. Effect of ultrasonic waves on agents.

    7.2 Resolution
        Experimental testing.

RADKLEEN

1.0 General Description

1.1 Summary of Idea
RadKleen involves the use of Freon® 113 solvent extraction of contaminated materials. The solvent is sprayed onto the substrate under pressure, then collected, treated and recycled.

1.2 Origination of Idea
Health Physics Systems Inc. (HPSI) designed RadKleen as a radioactive decontamination unit. Modifications include decontamination scrubbers suggested by Novel Processing Team.

1.3 Obvious Advantages and Disadvantages
Advantages. Freon 113 is a stable, non-polar organic solvent suitable for extracting organic compounds. The solvent is nontoxic, nonflammable and noncarcinogenic. Low surface tension permits rapid wetting of the surfaces. Low viscosity and easy particulate separation. Can be easily reclaimed if used in a closed system.

Disadvantage. A secondary treatment is required to decompose the solubilized agent. Complete extraction of agents from subsurfaces may be difficult to accomplish. Diffusion may limit application rate.

1.4 Variations of Idea
System using an additive to decontaminate the agent simultaneously with extraction. System which passes the solvent through a reactive bed (e. g. activated carbon) for disposal of agent.

1.5 Sketch
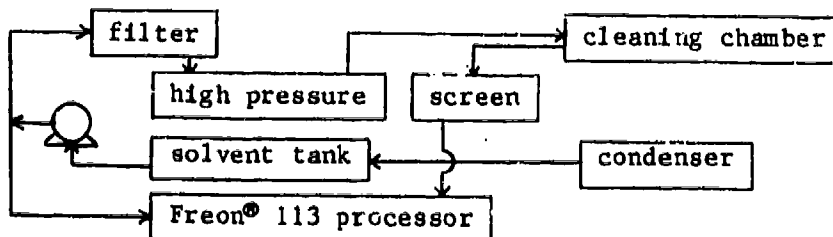
2.0 Chemical Decomposition Treatment – Not applicable

3.0 Physical Treatment

3.1 Removal Efficiency, Residue Level
Experimental values obtained on some clothing. 95% of HD and GD are removed from polyester-cotton, rubber and Nomex cloth. HPSI claims it is very effective with radioactive materials. The removal efficiency from porous building materials is unknown. Pocrofke, 1970 has shown that Freon because of its low surface tension and high density tends to displace organic residues from surfaces.

3.2 Hazardous Wastes
The material removed has not been deactivated and thus is still a hazard.

3.3 Supplementary Treatment(s)
None anticipated.

3.4 Waste Recovery and Disposal
Waste solvent can be reclaimed following removal of contaminants. Contaminants may be incinerated.

3.5 State-of-the-Art
RadKleen is currently used for cleaning radioactive material from various surfaces. It has been applied to removal of agents from small objects and thus has demonstrated feasibility. Studies have been conducted for agent-contaminated clothing materials, such as polyester-cotton, Nomex® cloth, butyl rubber gloves, webbing and charcoal impregnated cloth.

4.0 Applicability

4.1 Agent Applicability
Should be applicable to all agents.

4.2 Isolated Building Material Applicability
It may be used with all building materials: metals, concrete, tile, and brick either on painted or unpainted surfaces. Since Freon® 113 is electrically nonconductive and compatible with electrical and electronic components, it allows decontamination of operating electrical/electronic equipment.

4.2.1 Impact of Substrate on Chemistry
Adsorbed agents may be difficult to extract.

4.2.2 Removal or Reaction of Contaminant from Surface
Should provide complete removal of contaminant from surface.

4.2.3 Removal or Reaction of Contaminant from Interior
Freon should readily penetrate into porous materials. The diffusion rate of the Freon laden with agent from the building material and the extraction efficiency from porous materials are unknown.

4.2.4 Damage to Material
No damage to material expected. Paint films may be affected.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
None necessary.

4.3.2 Practical Physical Limiations/Methods to Overcome
Radkleen should be used in an enclosed area to allow
containment and recovery of solvent for recycle. No
physical limitations are anticipated because spraying
allows accessibility of Freon to all areas of a build-
ing including pipes, tanks and sumps.

4.3.3 Secondary Decontamination Treatment
None anticipated.

4.3.4 Clean-up Requirements
Wash down or heat to remove traces of Freon.

4.3.5 Waste Treatment and Disposal
The agents and other wastes must be removed from the
solvent and decomposed.

4.4 State-of-the-Art
RadKleen has not been proven useful for removal of agents in
building environments although it has been used for removal of
agent from clothing. High pressure Freon cleaning has been
shown to be effective in removing radioactive contaminants
from tools and porous items (McVey, 1981).

5.0 Engineering

5.1 Process Description

5.1.1 Main Process
The solvent (Freon® 113) is sprayed under pressure
(200-2150 psi) on the building surfaces. The solvent
dissolves the contaminating material and the solvent
is then collected, filtered and distilled for reuse.
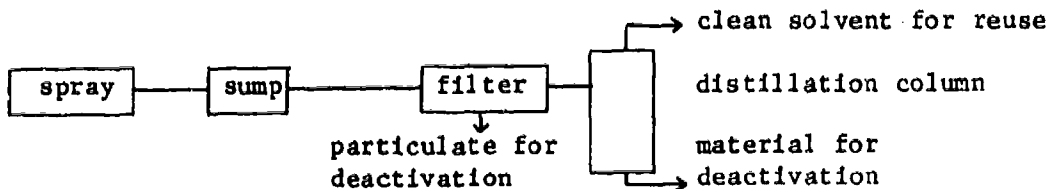
5.1.2 Variations
Can have the solvent boiling and permeating the walls
at atmospheric pressure.
May have an additive (e.g. MEA for HD) to react with
the compounds and destroy them simultaneously with
extraction.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

Pump, spray system, collection tank, filters, distillation column, enclosure, and electricity

5.2.2 Reliability, Availability and Maintainability
Readily available and HPSI claim it is easy to maintain and clean up.

5.3 Decontamination Time

5.3.1 Set-up
Time may be required to seal the building to prevent release of vapors.

5.3.2 Application Time

5.3.2.1 Personnel
Personnel are required to apply the spray. However, the method can potentially be semi-automatic.

5.3.2.2 Decontamination
Removal of agent in 5-10 minutes from complex surface geometry.

5.3.2.3 Verification
KNOWLEDGE GAP

5.3.3 Tear-Down Time
Minimal - remove the enclosure for the buildings.

5.3.3.1 Equipment Removal
Minimal

5.3.3.2 Clean-up
Wash down is all that is anticipated.

5.4 Safety Requirements

5.4.1 Process Hazards
High pressure fluids

5.4.2 Personnel Hazards
Because of the high vapor pressure of Freons at ambient conditions, a suffocating atmosphere may be present during spray application.

5.4.3 Protective Methods
Respiratory protection for personnel inside structure.

6.0 Economics

6.1 Building Damage - Repair Costs
No building damage is anticipated.

6.2 Developmental Costs
Demonstration of applicability to building environment needed.
Evaluation of cost of recovering used solvent and disposal
of residues is required.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Minimal.

6.3.2 Equipment cost
Moderate to provide for recycle of solvent.

6.3.3 Material cost
Low due to recyclibility.

6.3.4 Manpower cost
Manpower cost may be substantial depending on how
much automation is possible.

7.0 Future Work Required

7.1 Knowledge Gaps
Develop recycle requirements.

7.2 Resolution
Engineering development of recycle system.

SURFACTANTS

1.0 General Description

1.1 Summary of Idea
A surfactant is added to a water washing solution to decrease its surface tension providing an increased solubility of the agents in the water. Further decontamination of the solubilized agents is required.

1.2 Origination of Idea
Novel Processing project team, literature (Gibson, 1967; Mankowich, 1970).

1.3 Obvious Advantages and Disadvantages
Advantages. The surfactant may allow increased solubility of the agent in the water by lowering the surface tension.

Disadvantages. Only effective as a surface decontamination technique. Low solubility of mustard in aqueous media.

1.4 Variations of Idea
Steam could be used to enhance solubility. A supplemental additive could be used to react with the contaminant in situ.

1.5 Sketch
None.

2.0 Chemical Decomposition Treatment
Not applicable.

3.0 Physical Treatment

3.1 Removal Efficiency, Residue Level
Complete removal of contaminants from the surface may be possible. Nacconal can be used for HD, VX, and GD (Stanford, 1981)

3.2 Hazardous Wastes
The washing solution will contain agents which need to be decontaminated prior to disposal.

3.3 Supplementary Treatment(s)
Treatment of the wash solution by incineration or chemical treatment. Other methods will need to be employed on the building to remove agents that have penetrated the surface.

3.4 Waste Recovery and Disposal
All spent liquids including clean-up rinses must be collected in a sump system and disposed of.

3.5 State-of-the-Art
Surfactants are commonly used in industrial cleaning applications to enhance the cleaning power of water.

4.0 Applicability

   4.1 Agent Applicability
       Applicable to all agents (Stanford, 1981).

   4.2 Isolated Building Material Applicability

       4.2.1 Impact of Substrate on Chemistry
              None expected.

       4.2.2 Removal or Reaction of Contaminant from Surface
              Should effectively remove contaminants from the
              surface of building materials.

       4.2.3 Removal or Reaction of Contaminant from Interior
              Probably not effective as a building material interior
              cleaning technique.

       4.2.4 Damage to Material
              None anticipated.

   4.3 Practical Applicability to Building

       4.3.1 Building Preparation
              Paint removal may be required.

       4.3.2 Practical Physical Limitations/Methods to Overcome
              Method is applicable to hard to reach and complex
              areas of a building if a spraying application method
              is used.

       4.3.3 Secondary Decontamination Treatment
              Other techniques will need to be employed to remove
              contaminants that have penetrated the surface through
              cracks and pores.

       4.3.4 Clean-up Requirements
              A water rinse of all surfaces may be desirable.
              Spent surfactant solutions need to be collected.

       4.3.5 Waste Treatment and Disposal
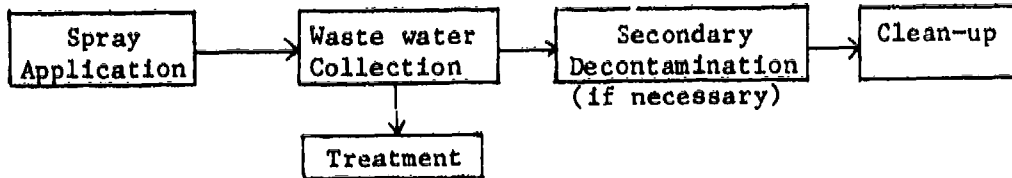   All waste solutions collected in the sump system must
              be treated to destroy agent residues.

   4.4 State-of-the-Art
       Most industrial cleaners have metered dispensing devices for
       adding surfactant to cleaning water/solvent. Therefore,
       off-the-shelf cleaning devices could be employed.

5.0 Engineering

5.1 Process Description

```
┌─────────────┐   ┌─────────────┐   ┌──────────────────┐   ┌──────────┐
│   Spray     │──▶│ Waste water │─▶ │    Secondary     │─▶ │ Clean-up │
│ Application │   │ Collection  │   │ Decontamination  │   │          │
└─────────────┘   └─────────────┘   │  (if necessary)  │   └──────────┘
                         │          └──────────────────┘
                         ▼
                  ┌─────────────┐
                  │  Treatment  │
                  └─────────────┘
```

5.1.1 Main Process

A surfactant is added to water (or another solvent) to enhance the solvent's cleaning ability. This cleaning solution is sprayed on all surfaces. The washings are collected in a sump and incinerated.

5.1.2 Variations

Automated spray systems could be used to cut manpower requirements.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

Conventional cleaners/sprayers with metered surfactant addition systems.

5.2.2 Reliability, Availability and Maintainability

Should be high since technique is simple and off-the-shelf equipment can be employed.

5.3 Decontamination Time

5.3.1 Set-up

Sump systems and waste collection systems must be installed if non-existent. Paint removal is required.

5.3.2 Application Time

5.3.2.1 Personnel

Could be extensive since all surfaces must be treated and repeat applications may be necessary. Paint removal is probably required.

5.3.2.2 Decontamination

Dependent on the effectiveness of the method in removing surface and interior contaminants.

5.3.2.3 Verification

Knowledge Gap.

5.3.3 Tear-Down Time

      5.3.3.1 Equipment Removal
                 Minimal - remove spray systems.

      5.3.3.2 Clean-up
                 A water wash is all that is anticipated.

5.4 Safety Requirements

5.4.1 Process Hazards
None.

5.4.2 Personnel Hazards
None anticipated.

5.4.3 Protective Methods
Minimal protective clothing is recommended.

6.0 Economics

6.1 Building Damage - Repair Costs
No damage to building is anticipated.

6.2 Developmental Costs
An effective waste treatment technique will need to be specified as well as determining the effectiveness of the method in removing contaminants.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Electricity for mixer and pumping systems.

6.3.2 Equipment Cost
Convential spray systems are quite inexpensive.

6.3.3 Material Cost
The cost of the surfactant.

6.3.4 Manpower Cost
Could be high. Dependent on number of applications necessary, secondary treatment required and waste treatment technique.

7.0 Future Work Required

7.1 Knowledge Gaps
Depth of surfactant solution penetration must be determined. Effectiveness of waste treatment system to destroy contaminant must be determined.

7.2 Resolution
Experimental testing.

STRIPPABLE COATING

1.0 General Description

1.1 Summary of Idea
Compounds which bind with agents could be included in a polymer, applied to a contaminated surface, and removed for subsequent decontamination.

1.2 Origination of Idea
Novel Processing project team.

1.3 Obvious Advantages and Disadvantages
Advantages. Strippable coatings contain the contaminant for easier handling and disposal.

Disadvantages. The agent may still be active. The polymer may bind not only to the agent but to the wall or item on which it is applied (strippability depends on its properties and the substrate surface).

1.4 Variations of Idea
Add a chemical reactant to the polymer which would react with the agent in situ and circumvent the need for secondary decontamination.

1.5 Sketch
None.

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions
Chemical treatment/reactions would depend on what kind of reagent that is added to the polymer.

3.0 Physical Treatment

3.1 Removal Efficiency, Residue Level
A strippable coating should remove all the agent it comes in contact with. There is a potential for the coating not to reach all surface if it has a high surface tension or if the polymer molecules are too large to fit in the pores.

3.2 Hazardous Wastes
The agent may still be active, although contained.

3.3 Supplementary Treatment(s)
Dependent on how effective the polymer is in removing the agent.

3.4 Waste Recovery and Disposal
The waste generated (the contaminated polymer) would have to be treated to decompose the agent and dispose of the polymer. Some polymers are sensitive to radiation, chemicals or bio-degradation while some must be burned or landfilled.

3.5 State-of-the-Art
Polymer coating technology has been studied extensively, but agent removal efficiency is unknown.

4.0 Applicability

4.1 Agent Applicability
The method should be applicable to all agents of interest.

4.2 Isolated Building Material Applicability
The method should be applicable to all materials. A different polymer formulation may be required for various materials. Painted surfaces may require paint removal prior to treatment.

4.2.1 Impact of Substrate on Chemistry
None anticipated.

4.2.2 Removal or Reaction of Contaminant from Surface
Method should remove contaminants from surfaces especially smooth surfaces.

4.2.3 Removal or Reaction of Contaminant from Interior
It is probably not an interior treatment although the presence of the coating may enhance diffusion to the surface.

4.2.4 Damage to Material
No damage to the material is expected.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Paint should be removed.

4.3.2 Practical Physical Limitations/Methods to Overcome
None anticipated. Polymer can be sprayed on intricate surfaces.

4.3.3 Secondary Decontamination Treatment
Even if agents are completely removed from the surface, a secondary treatment may be required to remove penetrated contaminants. No secondary treatment is expected on metals.

4.3.4 Clean-up Requirements

Clean-up involves removal of the strippable coating from all surfaces.

4.3.5 Waste Treatment and Disposal

The contaminated polymer may need treatment to decompose the agent. If a chemical were added to the polymer to react with the agent then the waste treatment would depend on the particular chemistry.
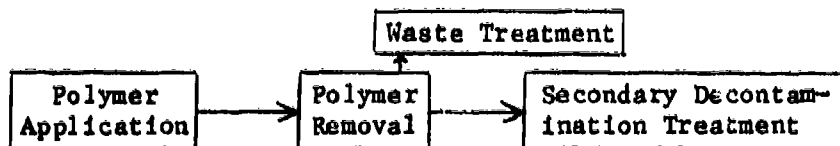
4.4 State-of-the-Art

Needs development in these areas:
1. Polymer formulation
2. Applicability to various surfaces (coverage, stripability).

5.0 Engineering

5.1 Process Description

```
                          ┌─────────────────┐
                          │ Waste Treatment │
                          └─────────────────┘
                                  ▲
   ┌─────────────┐      ┌──────────┐      ┌──────────────────────┐
   │  Polymer    │ ──▶  │ Polymer  │ ──▶  │ Secondary Decontam-  │
   │ Application │      │ Removal  │      │ ination Treatment    │
   └─────────────┘      └──────────┘      └──────────────────────┘
```

5.1.1 Main Process

A polymer mixture is applied into the surface, allowed to react (polymerize) and coat the surface. As it polymerizes the agent becomes entrained in the lattice or attached to the polymer molecules. The polymer layer is peeled off removing the agent.

5.1.2 Variations

A chemical to decompose the agent may be added to the mixture.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

For the main process tanks for storage of either polymer mixture or components of the mixture; spraying, brushing or other application equipment; and scraping or peeling equipment. Heating equipment may be needed to activate the polymer (initiate the reaction).

5.2.2 Reliability, Availability and Maintainability

The RAM is expected to be high.

5.3 Decontamination Time

5.3.1 Set-up

No more set up time than that for painting expected.

5.3.2   Application Time

     5.3.2.1   Personnel
            Application should be similar to painting.

     5.3.2.2   Decontamination
            Decontamination will be dependent on the
            polymerization time, nature of reactants
            in the coating and contaminants diffusion
            rates.

     5.3.2.3   Verification
            Knowledge Gap.

5.3.3   Tear-Down Time

     5.3.3.1   Equipment Removal
            Minimal.

     5.3.3.2   Clean-up
            Remove strippable coating for disposal
            destruction.

5.4   Safety Requirements

5.4.1   Process Hazards
       None anticipated.

5.4.2   Personnel Hazards
       No unusual personnel hazards expected although the
       personnel should wear protective clothing and avoid
       contact with the polymer.

5.4.3   Protective Methods
       Protective clothing, eye protection recommended.

6.0   Economics

6.1   Building Damage - Repair Costs
     No damage to building is expected.

6.2   Developmental Costs
     Substantial developmental costs are expected for formulation
     of feasible strippable decontamination coatings.

6.3   Treatment Costs

6.3.1   Utilities and Fuel Cost
       Minimal.

6.3.2   Equipment Cost
       Equipment available and low cost.

6.3.3 Material Cost
Should be in the range of the cost of paints.

6.3.4 Manpower Cost
Man power should be similar to that required for painting for application. Additional manpower required for stripping and decontamination/destruction of coatings.

7.0 Future Work Required

7.1 Knowledge Gaps
Formulation of polymer coating, application method, application times and the removal efficiencies must be determined.

7.2 Resolution
Experimental work.

VAPOR PHASE SOLVENT EXTRACTION

1.0 General Description

    1.1 Summary of Idea
        An organic solvent such as chloroform or freon is heated
        to its boiling point and the vapors allowed to circulate
        in a building. The vapors permeate into porous building
        materials where they condense, solubilize the agent and
        diffuse outward. The driving force for the outward move-
        ment of agent is a concentration gradient in the liquid
        phase once the building material temperature has reached
        an equilibrium. The liquid solvent laden with contaminants
        is collected in a sump and treated to allow recycle of solvent.

    1.2 Origination of Idea
        Novel Processing project team.

    1.3 Obvious Advantages and Disadvantages
   Advantages. Method well suited to all areas of a building
        including intricate structures. Solvent permeability and
        diffusivity enhanced by using vapor phase. Removal of
        contaminated paint is possible if the proper solvent is
        selected. Depending on the solvent-contaminant match,
        may be a very efficient removal system. Enhanced solubility
        of agents in heated solvent.

        Disadvantages. Outward diffusion of solvent laden with agent
        may require long treatment times. The solvent may tend to
        carry the agent farther into the wall before outward movement
        occurs. Volatilization of agent may occur.

    1.4 Variations of Idea
        A solvent/decontaminant system may be employed. Supplemental
        heating (e.g. microwaves) may be employed to maintain boiling
        of the solvent in the building materials.

    1.5 Sketch
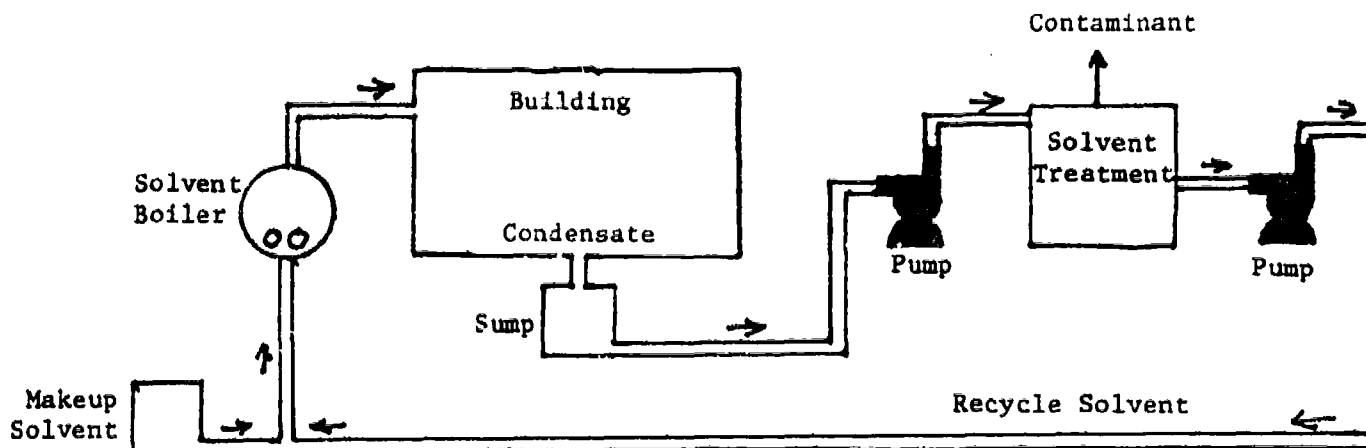
2.0 Chemical Decomposition Treatment
    Not applicable.

3.0 Physical Treatment

    3.1 Removal Efficiency, Residue Level
        If the proper solvent is used it should dissolve most or all of the contaminants it contacts. The primary difficulty is to achieve an outward flux of solvent contaminated with agents from the porous building materials. It is unknown whether this may be accomplished within a realistic period of time.

    3.2 Hazardous Wastes
        If neat solvent is used the agent will still be active. The solvent may be flammable or toxic.

    3.3 Supplementary Treatment(s)
        Solvent will be continuously recycled until the optimum removal efficiency is obtained. A secondary decontamination treatment may be necessary to remove any residual contaminants not removed by the solvent.

    3.4 Waste Recovery and Disposal
        The recovered solvent has to be treated for agent contaminants. If the solvent is incinerated, pollution standards must be observed. If a chemical treatment is employed, the products may require detoxification.

    3.5 State-of-the-Art
        Agents are miscible in most organic solvents.

4.0 Applicability

    4.1 Agent Applicability
        Depending on choice of solvent, method can be applied to all agents of interest.

    4.2 Isolated Building Material Applicability

        4.2.1 Impact of Substrate on Chemistry
            Adsorbed agents may be difficult to extract.

        4.2.2 Removal or Reaction of Contaminant from Surface
            Complete removal of the contaminant from surfaces is anticipated.

4.2.3 Removal or Reaction of Contaminant from Interior
May not remove agent from the interior of building materials. Although solvent penetration into porous materials (e.g. concrete) is expected, reverse diffusion of contaminant solvent may require a long time.

4.2.4 Damage to Material
No damage to building materials is expected. Paint films may be damaged/removed.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
The building must be sealed to prevent undue release of solvent vapors. Windows may require insulation. Pipes and tanks should be opened to allow penetration of solvent vapors.

4.3.2 Practical Physical Limitations/Methods to Overcome
None anticipated since solvent vapors can permeate throughout the building including tanks and sumps.

4.3.3 Secondary Decontamination Treatment
May require a secondary treatment to remove residual agents and/or solvent laden with agents from the building materials.

4.3.4 Clean-up Requirements
May need water or water/soap wash after decontamination to remove the solvent contained in porous materials. Heating may also be employed to volatilize residual solvent.
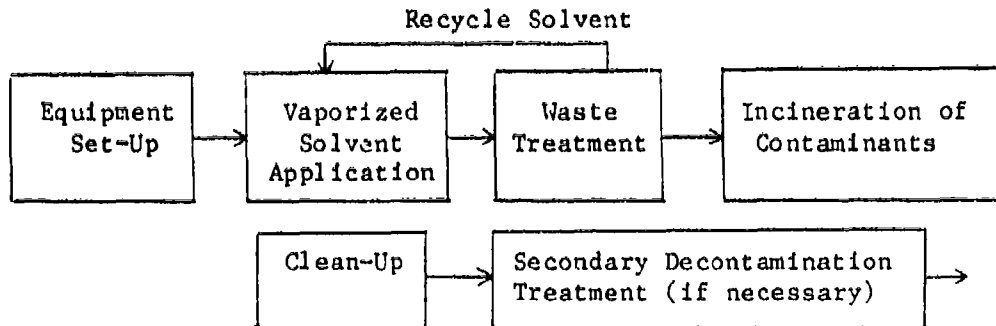
4.3.5 Waste Treatment and Disposal
The waste (contaminated solvent) may have to be chemically treated or incinerated to decompose the contaminants. If a chemical method or adsorption does not remove the contaminant to allow recycle of the solvent, then a thermal method (i.e. incineration) must be employed.

4.4 State-of-the-Art
This technique has not yet been applied to building decontamination, however, Brock, 1975 cited use of an ethanol/Freon mixture volatilized in a similar method to the one described here as a degreaser.

5.0 Engineering

5.1 Process Description

Recycle Solvent

```
┌──────────┐     ┌──────────┐   ┌──────────┐   ┌────────────────┐
│ Equipment│     │ Vaporized│   │  Waste   │   │ Incineration of│
│  Set-Up  │ ──> │ Solvent  │──>│ Treatment│──>│  Contaminants  │
│          │     │Application│   │          │   │                │
└──────────┘     └──────────┘   └──────────┘   └────────────────┘
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```
          ┌──────────┐   ┌────────────────────────────┐
          │ Clean-Up │──>│ Secondary Decontamination  │ ──>
          │          │   │ Treatment (if necessary)   │
          └──────────┘   └────────────────────────────┘
```

5.1.1 Main Process

Solvent is vaporized in a boiler external to the building. A series of insulated pipes feeds the vapor into the building. The solvent permeates through the building and cools to below the boiling point. The liquid solvent, laden with contaminants, is collected in a sump from which it is pumped to a waste treatment system where the contaminants are removed. The solvent is then recycled to the boiler.

5.1.2 Variations

Microwave heaters may be employed to maintain the solvent at its boiling point in the building.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

Pumps, solvent boiler, and waste treatment system.

5.2.2 Reliability, Availability and Maintainability

The RAM is expected to be high because of the simplicity of the equipment.

5.3 Decontamination Time

5.3.1 Set-up

Low to moderate time to set-up boiler, seal building, etc.

5.3.2 Application Time

5.3.2.1 Personnel

Probably low to moderate - extensive involvement in set-up and tear-down but basically a passive process (monitors required only during decontamination).

5.3.2.2 Decontamination

Dependent on diffusion and number of applications required (hours to days).

5.3.2.3 Verification
Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Low to moderate time.

5.3.3.2 Clean-up
Wash with decon agent or water or heating to volatilize the residual solvent may be required.

5.4 Safety Requirements

5.4.1 Process Hazards
Explosion or fire hazards from flammable solvents.

5.4.2 Personnel Hazards
Toxicity of solvent. Volatilization of agents.

5.4.3 Protective Methods
If flammable solvent is used "explosion proof equipment" is required. Personnel must wear protective clothing. Cooling coils may be installed on the ceiling to prevent escape of solvent (Brock, 1975).

6.0 Economics

6.1 Building Damage - Repair Costs
No damage to buildings is anticipated.

6.2 Developmental Costs
Low to moderate development cost - selection of equipment and solvent and designation of optimum operating parameters (e.g. temperature).

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Low to moderate cost for fuel for boiler and pumps.

6.3.2 Equipment Cost
Low to moderate cost for boiler, ductwork, and pumps. However, it is dependent on the complexity of the solvent recovery/recycle system.

6.3.3 Material Cost
Moderate high material cost (solvent) depending on recovery system. (i.e., high cost if solvent cannot be recovered and recycled).

6.3.4 Manpower Cost
Low to moderate cost for equipment set-up and teardown
as well as monitoring the boiler, etc. during decon-
tamination.

7.0 Future Work Required

7.1 Knowledge Gaps
Specification of equipment and process designation -
application, recovery, collection, efficiency (surface
and interior), solvent selection, temperature and time.

7.2 Resolution
Experimental testing.

SOLVENT CIRCULATION

1.0 General Description

   1.1 Summary of Idea
         An organic solvent such as acetone is circulated across the
         surface of a building solubilizing the contaminants. The
         spent solvent is thermally or chemically treated to decon-
         taminate the agents. The solvent may be recycled if no
         degradation of the solvent occurs during treatment.

   1.2 Origination of Idea
         Novel Processing project team.

   1.3 Obvious Advantages and Disadvantages
         Advantages. Removal of contaminated paint is possible if the
         proper solvent is selected. Depending on solvent-agent
         match, this may be very efficient removal system.

         Disadvantages. Method not suited for intricate structures.
         Penetration of solvent into material matrix followed by
         outward diffusion may require long times. Residual solvent
         in building material may require removal and/or decomposi-
         tion. The solvent may tend to carry the agent farther
         into the wall before outward movement occurs.

   1.4 Variations of Idea
         Using a Stanley Steamer® configuration, a chemical can be.
         added to the solvent to decontaminate the agent. As the
         solvent is applied, a vacuum may be applied to remove the
         solvent and the contaminants.

   1.5 Sketch
         See attached.

2.0 Chemical Decomposition Treatment - Not applicable

3.0 Physical Treatment

   3.1 Removal Efficiency, Residue Level
         If the solvent is selected properly it should extract
         most if not all of the contaminants it contacts. The primary
         difficulty is to achieve an inward flux of neat solvent into
         porous building materials followed by (or concurrently) an
         outward flux of solvent contaminated with agents. It is
         unknown whether this may be accomplished within a realistic
         period of time. However, the use of a gaseous (i.e., va-
         porized) solvent may enhance diffusion into and out of
         building materials. HD is very soluble in most organic sol-
         vents. GB and VX are soluble in polar and non-polar sol-
         vents. All have high solubility in alcohols, ethers, ketones
         and halogenated hydrocarbons.

   3.2 Hazardous Wastes
         If neat solvent is used the agent will still be active.
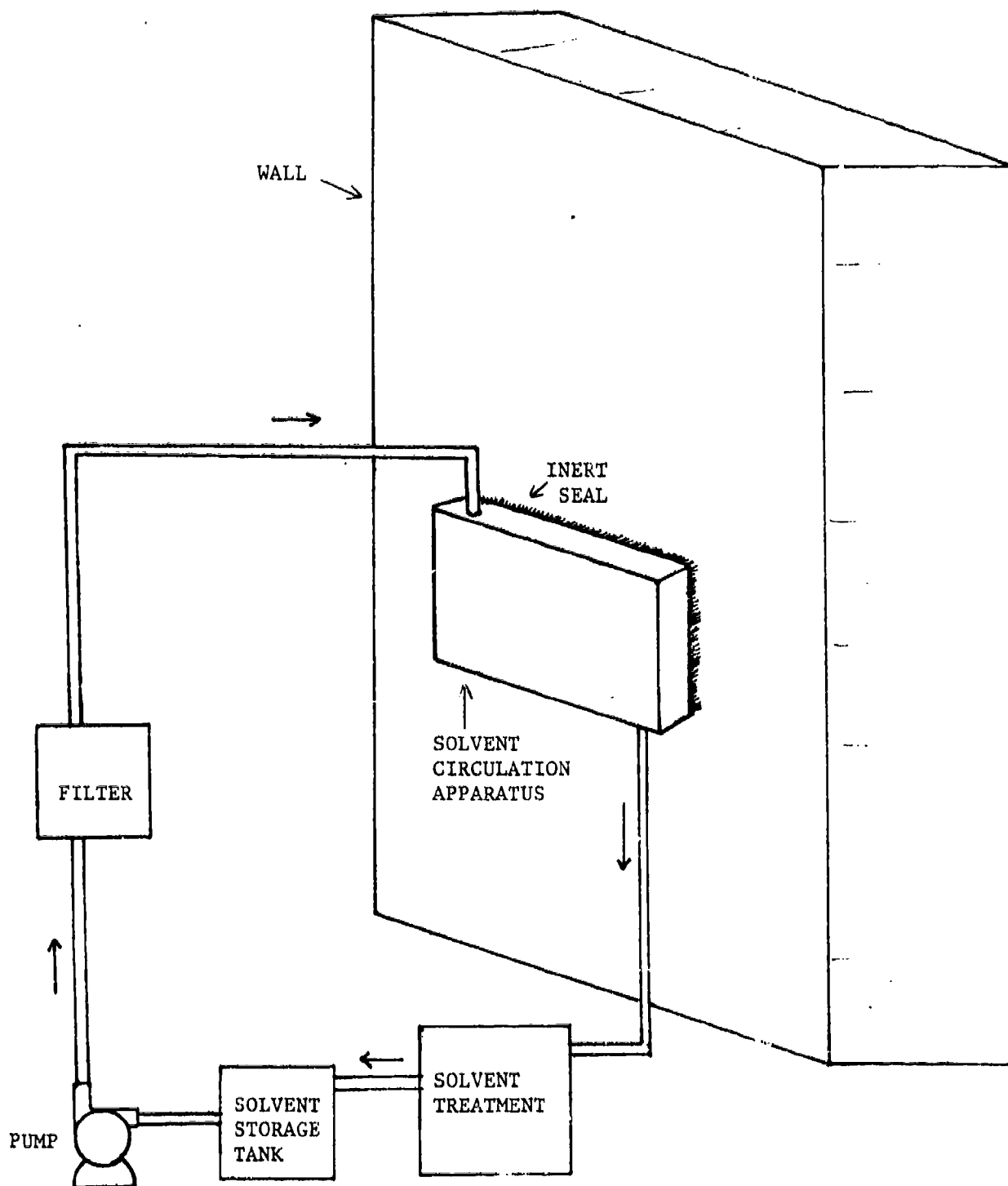
SOLVENT CIRCULATION APPARATUS

The solvent may also be hazardous itself, e.g., flammable or toxic.

3.3 Supplementary Treatment(s)
Probably will require more than one application of solvent.

3.4 Waste Recovery and Disposal
The solvent has to be treated to decompose the agent contaminants. If the solvent is incinerated, pollution standards must be observed. If a chemical treatment is employed, the products may require detoxicification if the solvent is to be reused.

3.5 State-of-the-Art
Solubilities of agents in various solvents are known.

4.0 Applicability

4.1 Agent Applicability
Depending on choice of solvent, method can be applied to any agent.

4.2 Isolated Building Material Applicability
It is applicable to all building materials.

4.2.1 Impact of Substrate on Chemistry
Absorbed agents may be difficult to extract.

4.2.2 Removal or Reaction of Contaminant from Surface
Complete removal of the contaminant from surfaces is anticipated.

4.2.3 Removal or Reaction of Contaminant from Interior
May not remove agent from the interior of building materials. Although solvent penetration into porous materials (e.g. concrete) is expected, reverse diffusion of contaminated solvent may require a great deal of time.

4.2.4 Damage to Material
No damage to building material is expected.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
All obstructions to the apparatus will require removal.

4.3.2 Practical Physical Limitations/Methods to Overcome
It may be extremely difficult to get a tight seal around the solvent circulation apparatus and surface,

especially around uneven areas and in hard to reach
places. Method is only suitable to large open areas
of the building.

4.3.3 Secondary Decontamination Treatment
May need multiple solvent washes to totally remove the
contaminants.

4.3.4 Clean-up Requirements
May need water wash after decontamination to remove
the solvent contained in porous materials. Heating
may also be employed to volatilize residual solvent.

4.3.5 Waste Treatment and Disposal
The contaminated solvent may have to be chemically
treated to decompose the contaminants. If a chemical
method does not remove the contaminant to allow re-
cycle of the solvent, a thermal method (i.e. inciner-
ation) may be employed.

4.4 State-of-the-Art
This technique has not yet been applied to building
decontamination. The method needs development in
application, recovery, collection, and efficiency.

5.0 Engineering

5.1 Process Description

(If necessary)
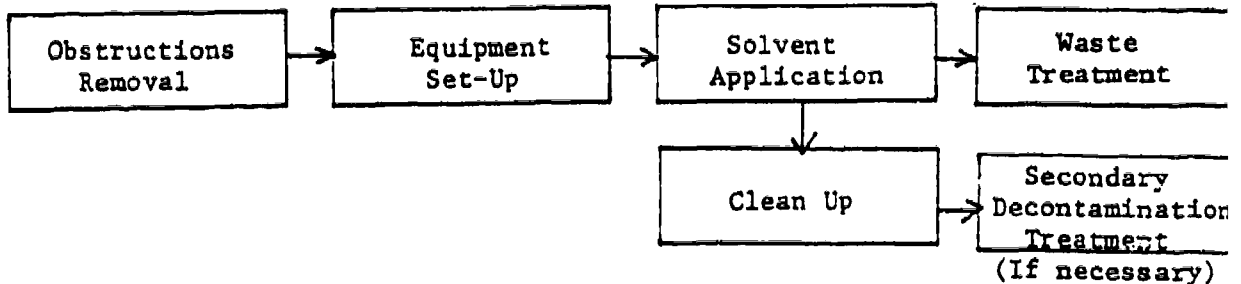
5.1.1 Main Process
The solvent is introduced into a box placed against a
wall. The side of the box facing the wall is open
with all edges sealed. The solvent is allowed to
circulate/penetrate/wet the surface removing the
contaminant. The contaminated solvent is collected at
the bottom of the box, passed through a filter or
packed carbon bed, and recycled.

5.1.2 Variations
The solvent can either be heated or volatilized to
enhance its diffusion into and out of building
materials as well as the solubility of agents.

5.2 Equipment/Support Facilities Needed

    5.2.1 Description
        Solvent pump, circulation box, collection tank, and
        recovery system. For example, filter, neutralizer,
        distillation column, etc. May need a condensor if
        solvent is vaporized during processing.

    5.2.2 Reliability, Availability and Maintainability
        The RAM is expected to be low because of the
        complexity of the equipment.

5.3 Decontamination Time

    5.3.1 Set-up
        Probably extensive but dependent on obstructions which
        require removal, size and configuration of equipment
        used, and number of applications required.

    5.3.2 Application Time

        5.3.2.1 Personnel
            Probably low to moderate - extensive involve-
            ment in set-up and tear-down but only mon-
            itors required during decontamination.

        5.3.2.2 Decontamination
            Dependent on diffusion and number of ap-
            plication required - expected to be long
            (hours to days).

        5.3.2.3 Verification
            Knowledge gap.

    5.3.3 Tear-Down Time

        5.3.3.1 Equipment Removal
            Dependent on size and configuration of equip-
            ment.

        5.3.3.2 Clean-up
            Either a water wash or heating to volatilize
            the residual solvent may be required.

5.4 Safety Requirements

    5.4.1 Process Hazards
        Explosion or fire hazards from inflammable solvents.

    5.4.2 Personnel Hazards
        Toxicity of solvent. If heating is used, agents may

be volatilized.

5.4.3 Protective Methods
If volatile/flammable solvent used, "explosion proof equipment" and concentration monitors will be required. Personnel must wear protective clothing (level A or B) and possibly respirators because of solvent laden with agent.

6.0 Economics

6.1 Building Damage - Repair Costs
No damage to buildings is anticipated.

6.2 Developmental Costs
High development cost to design, construct and test apparatus as well as selection of solvent and designation of optimum operating parameters.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Expected to be low but will require some electricity and possibly steam.

6.3.2 Equipment Cost
Moderate to high equipment cost depending on complexity of recovery/recycle system.

6.3.3 Material Cost
Moderately high material cost (solvent and decon solution) depending on recovery system.

6.3.4 Manpower Cost
System needs operating personnel to move the equip- during decontamination as well as for set-up and tear-down.

7.0 Future Work Required

7.1 Knowledge Gaps
Specification and design of equipment and process parameters, and solvent selection.

7.2 Resolution
Experimental work.

SUPERCRITICAL FLUIDS

1.0 General Description

 1.1 Summary of Idea
  This method is based on the use of a supercritical fluid
  (fluid that exists when temperature and pressure conditions
  are above the critical temperature and pressure of the
  substance) as a solvent extraction medium.

 1.2 Origination of Idea
  Suggested for consideration as a building decontamination
  method by USATHAMA.

 1.3 Obvious Advantages and Disadvantages
  Advantages - Supercritical fluids have superior penetration
  capabilities compared to liquid solvents. Purification of
  supercritical fluids is easier as compared with liquid
  solvents.

  Disadvantages - It would be difficult to maintain super-
  critical conditions for purposes of building decontamination
  because the critical pressure and/or temperature of most
  substances is much higher than standard conditions. For
  example, CO_2 has a critical pressure of 72.9 atmospheres,
  although the critical temperature is only 31 C. If a super-
  critical fluid were found to exist at standard conditions,
  the extraction capabilities would have to be merited.

 1.4 Variations of Idea
  For purposes of this description, it will be assumed that
  CO_2 is the supercritical fluid of choice, since CO_2 is the
  most commonly employed supercritical solvent.

 1.5 Sketch
  None.

2.0 Chemical Decomposition Treatment - Not applicable.

3.0 Physical Treatment

 3.1 Removal Efficiency, Residue Level
  In general, solvent power increases with density at a given
  temperature and increases with temperature at a given
  density. Supercritical CO_2, under maximum solvent power,
  has solvent properties similar to methylene chloride. Thus,
  removal efficiency is anticipated to be high.

 3.2 Hazardous Wastes
  The spent solvent will contain solubilized contaminants.

3.3 Supplementary Treatment(s)
   None anticipated.

3.4 Waste Recovery and Disposal
   Waste solvent can be readily purified and recycled. Con-
   taminant disposal requirements depend on secondary treatment.

3.5 State-of-the-Art
   The extraction properties of a number of supercritical fluids
   (e.g. CO_2, H_2O, propane) have been investigated in con-
   siderable detail, but little data is available on the sol-
   ubility of agents. In general, the solvent properties of
   supercritical CO_2 are comparable to methylene chloride.

4.0 Applicability

4.1 Agent Applicability
   HD, VX and GB would probably be miscible in supercritical
   CO_2.

4.2 Isolated Building Material Applicability

   4.2.1 Impact of Substrate on Chemistry
      Supercritical extraction may be preferred over other
      extraction methods if the agent is adsorbed on the
      surfaces and pores of building materials.

   4.2.2 Removal or Reaction of Contaminant from Surface
      Removal highly probable.

   4.2.3 Removal or Reaction of Contaminant from Interior
      Removal highly probable because of penetration
      capabilities of supercritical fluids.

   4.2.4 Damage to Material
      Possible damage to most materials from high pressure.

4.3 Practical Applicability to Building
   There is no practical applicability to building due to the
   high pressure requirement. May be suitable to small items
   that can be contained in a pressure vessel. However, pipes
   and tanks may be decontaminated with supercritical fluids
   by in situ forming a pressure vessel out of the pipe or tank
   (dependent on strength of the material).

4.4 State-of-the-Art
   Supercritical CO_2 has found industrial application for ex-
   traction of food products such as oils, fats, hops and
   coffee; and for extraction of hazardous materials such as
   tetrachlorodioxin and PCB's. A supercritical water waste
   treatment system has been developed to treat hazardous
   organic wastes.

5.0 Engineering

Design of engineering process is not practical for building decontamination purposes. (See Section 4.3)

6.0 Economics

The economics cannot be evaluated because the method is not practical for building decontamination.

7.0 Future Work Required

The use of supercritical fluids for entire building decontamination purposes does not merit further consideration. However, supercritical fluids may be used to decontaminate small equipment after removal from the building in a separate system. It may also be possible to decontaminate the inside of vessels and piping in situ.

BF-1 SOLUTION

1.0 General Description

1.1 Summary of Idea
BF-1, a water solution of a pyridinium aldoxime and inert surfactant is a safe, rapid acting reagent for decontaminating VX and GB. It can be applied as a foam or cream.

1.2 Origination of Idea
The German Defense Ministry has supported work on this decontaminant at Battelle-Frankfurt (BF) for some years. This work was discussed with the Novel Processing team by Klaus Rossmann (BF).

1.3 Obvious Advantages and Disadvantages
Advantages. Advantages include rapid action, low toxicity, non-corrosive nature. (Reiner, 1982).

Disadvantages. A Disadvantage is lack of applicability for HD.
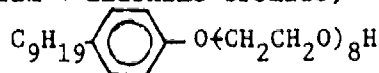
1.4 Variations of Idea
Various application methods could be used including sprays, foams, gels, creams, etc. Inclusion of an additive might make it effective against HD as well as nerve agents. Other oximes might also be effective as cited by Reiner, 1978; Ford, 1974 and Epstein, 1978.

1.5 Sketch (Composition)
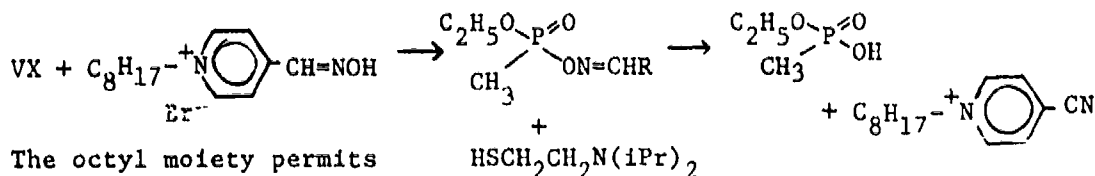5% OPAB (octyl pyridinium 4-aldoxime bromide)
3% Surfactant
92% water

$$C_9H_{19}\text{—}\bigcirc\text{—} O(CH_2CH_2O)_8H$$

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions

$$VX + C_8H_{17}\text{—}{}^+N\bigcirc\text{—}CH=NOH \cdot Br^- \rightarrow \begin{array}{c} C_2H_5O \\ CH_3 \end{array} P{\overset{\nearrow O}{\underset{ON=CHR}{}}} + HSCH_2CH_2N(iPr)_2 \rightarrow \begin{array}{c} C_2H_5O \\ CH_3 \end{array} P{\overset{\nearrow O}{\underset{OH}{}}} + C_8H_{17}\text{—}{}^+N\bigcirc\text{—}CN$$

The octyl moiety permits micelle formation enhancing reaction rates.

2.2 Hazardous Products
Nitrile end product may be toxic.

2.3 Destruction Efficiency, Residue Level
Half life of VX about 2.5 mins. Therefore, very low residue levels may be expected in <1 hour.

2.4 Reaction Rate/Kinetics
   $t_{1/2}$ 2.5 mins. (Rossman communique). Barrass, 1971 cites re-
   action rate constants for other oximes (amidoximes, α-methoxy
   oximes, and pyridine oximes).

2.5 Supplementary Treatment
   None should be needed.

2.6 State-of-the-Art
   Synthesis and evaluation (with VX) has been rather fully
   developed.

3.0 Physical Treatment
   Not applicable.

4.0 Applicability

4.1 Agent Applicability
   Proven effective for VX, should work well (since other oximes
   do) for GB. Ineffective against HD.

4.2 Isolated Building Material Applicability

   4.2.1 Impact of Substrate on Chemistry
      Unless acidic, the substrate should have no effect on
      the chemistry.

   4.2.2 Removal or Reaction of Contaminant from Surface
      Removal should be thorough from surfaces. BF-1
      spreads well and can be held in place by preparation
      of a foam (add carbowax, etc.).

   4.2.3 Removal or Reaction of Contaminant from Interior
      Surface active agent should facilitate penetration
      into cracks, pores and the like. Paint films unlikely
      to be treated well much below the upper surface.

   4.2.4 Damage to Material
      No significant damage is expected.

4.3 Practical Applicability to Building

   4.3.1 Building Preparation
      None should be required except stripping of paint.

   4.3.2 Practical Physical Limitations/Methods to Overcome
      Can be applied to any surface which can be reached
      with a spray/foam - physical limitations appear to be
      negligible. Difficulties encountered will be
      equivalent to those encountered when painting
      the structures.

4.3.3 Secondary Decontamination Treatment
None should be required.

4.3.4 Clean-up Requirements
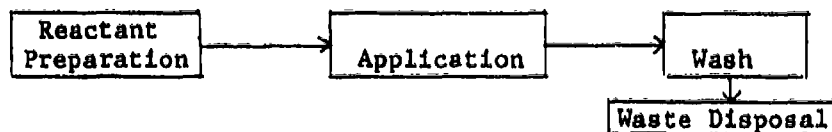Water wash.

4.3.5 Waste Treatment and Disposal
Pretreatment with active carbon should be satisfactory.

4.4 State-of-the-Art
Has not been applied to buildings or building components.

5.0 Engineering

5.1 Process Description

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┌──────────────┐      ┌──────────────┐      ┌──────────┐
│  Reactant    │─────▶│              │─────▶│          │
│ Preparation  │      │ Application  │      │   Wash   │
└──────────────┘      └──────────────┘      └──────────┘
                                                  │
                                                  ▼
                                        ┌──────────────────┐
                                        │  Waste Disposal  │
                                        └──────────────────┘
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5.1.1 Main Process
The reactive liquid is mixed thoroughly and applied to the structure with a spray gun, paint brush, roller, or similar item to thoroughly coat the surface as if it was being painted. The liquid is allowed to soak-in and react decontaminating the agents. After decontamination is completed the solution is removed by washing with an appropriate wash solution.

5.1.2 Variations
The liquid reagent may also be applied in gel or foams. A variety of gelling and foaming agents may be used which are compatible with both aqueous based and organic solvents. A primary advantage of using gels or forms is that they will maintain a long contact time with the building material which will allow continuous diffusion of reactant into the material for decontamination purposes. Polymeric or plastic sheet backings may be applied to the gels and foams to insure inward migration of reactants and minimize outward vapor diffusion into the building. Furthermore, these backed gels or foams may be heated to facilitate reactant migration and enhance decontamination rates.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
An agitating tank for preparing mix.
Painting equipment for application.

5.2.2 Reliability, Availability and Maintainability
The RAM is expected to be high.

5.3 Decontamination Time

5.3.1 Set-Up
Minimal set up time required, just as with spray painting.

5.3.2 Application Time

5.3.2.1 Personnel
Application time would be equivalent to the time required for painting.

5.3.2.2 Decontamination
Should be immediate or very short for VX, knowledge gap for the others.

5.3.2.3 Verification
Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Minimal time is required for removal of application equipment (same as for painting).

5.3.3.2 Clean-up
Minimal clean up required. A fresh solvent water wash may be sufficient.

5.4 Safety Requirements

5.4.1 Process Hazards
None known – nonflammable, low toxicity dilute aqueous solution.

5.4.2 Personnel Hazards
. LD_{50} (sub-cutaneous-rats) at 500 mg/kg.

5.4.3 Protective Methods
Minimal - If sprayed, it may be desirable to use a respirator.

6.0 Economics

6.1 Building Damage - Repair Costs
None expected.

6.2 Developmental Costs
Decontamination efficiency for agents.
Applicability to buildings.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Minimal: electricity for the mixer and the pump.

6.3.2 Equipment Cost
Minimal: brushes and rollers may be obtained from the neighborhood hardware store. Standard spraying equipment is inexpensive ($200-500).

6.3.3 Material Cost
$1.50-2.00/liter for the solution is estimated.

6.3.4 Manpower Cost
Small: same as painting.

7.0 Future Work Required

7.1 Knowledge Gaps
Applicability to buildings.
Destruction efficiency.
Verification.

7.2 Resolution
Experimental work.

DS-2

1.0 General Description

1.1 Summary of Idea
DS-2, an azeotropic mixture of 70% diethylenetriamine, 28% 2-methoxyethanol, and 2% NaOH, is a strongly basic mixture which reacts with and is used for decontaminating HD, GB and VX. (Richardson, 1972; Day, 1974; Fielding, 1964; and Amos, 1977).

1.2 Origination of Idea
Literature references (Yurow, 1981; Davis, 1975).

1.3 Obvious Advantages and Disadvantages
Advantages. This mixture decontaminates GB, VX, and HD rapidly (five minutes).

Disadvantages. Corrosive to epoxy resins, neoprene, wood, and alum. Divinyl sulfide is a toxic by-product of HD.

1.4 Variations of Idea
Chelating agents such as a crown ether may be added to improve the properties of DS2 (Richardson, 1972).

1.5 Sketch

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions

$$HD + DS\text{-}2 \longrightarrow H_2C=\overset{H}{C}-S-\overset{H}{C}=CH_2 \quad \text{some polymerization (Davis, 1975)}$$
Divinyl sulfide (somewhat toxic)

$$GB + DS\text{-}2 \longrightarrow CH_3-\overset{O}{\underset{O}{\overset{\|}{P}}}-ONa + NaF \qquad \text{(Yurow, 1981)}.$$

$$VX + DS\text{-}2 \longrightarrow N-\overset{H_2}{C}-\overset{H_2}{C}-S-S-\overset{H_2}{C}-\overset{H_2}{C}-N + H_3C-\overset{O}{\overset{\|}{P}}-ONa \text{ (Davis, 1975; Yurow, 1981).}$$
$$OCH_2CH_3$$
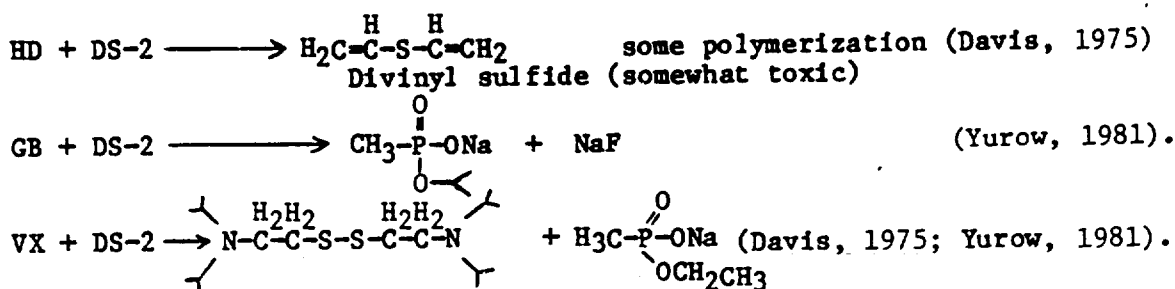
2.2 Hazardous Products
Divinyl sulfide is reported to be toxic. (Yurow, 1981; Davis, 1975).

2.3 Destruction Efficiency, Residue Level
Literature reports 100% destruction of HD within 1 minute with DS-2 (Richardson, 1972) and GB in 5 minutes (Yurow, 1981).

2.4 Reaction Rate/Kinetics
The half lives for HD, GB and VX were found to be 2.3 sec., <30 sec and <7 sec. respectively at room temperatures. (Yurow, 1981).

2.5 Supplementary Treatment
Washing of materials and containment of divinyl sulfide would seem to be a necessary supplementary treatment.

2.6 State-of-the-Art
In work performed with DS-2 at Monsanto, a thorough study was made on the function of the three components in the solution. Some substitute formulations were tested but none were found to be markedly superior to DS-2. (Richardson, 1972).

3.0 Physical Treatment
Not applicable.

4.0 Applicability

4.1 Agent Applicability
Applicable to HD, GB and VX.

4.2 Isolated Building Material Applicability

4.2.1 Impact of Substrate on Chemistry
Substrate should have little to no effect on chemistry.

4.2.2 Removal or Reaction of Contaminant from Surface
Reaction rate of contaminant on surfaces is known to be high and is well documented. (Davis, 1975; Yurow, 1981).

4.2.3 Removal or Reaction of Contaminant from Interior
Knowledge Gap. The physical problem of allowing DS-2 to permeate into the interior of building materials to react with absorbed agent is an important concern requiring experimental evaluation.

4.2.4 Damage to Material
Literature states that DS-2 is "relatively non corrosive". Same reference does suggest that DS-2 is corrosive to epoxy resins, neoprene, and wood. Its use can be expected to remove most paint films. (Yurow, 1981).

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Paint removal may be necessary although DS-2 is expected to strip off paint.

4.3.2 Practical Physical Limitations/Methods to Overcome
Spraying, brushing and rolling DS-2 on intricate areas may be time consuming and cumbersome. Difficulties encountered will be equivalent to those encountered when painting the structures.

4.3.3 Secondary Decontamination Treatment
None required unless thorough contact between the con-
taminated surface and the DS-2 was not achieved.

4.3.4 Clean-up Requirements
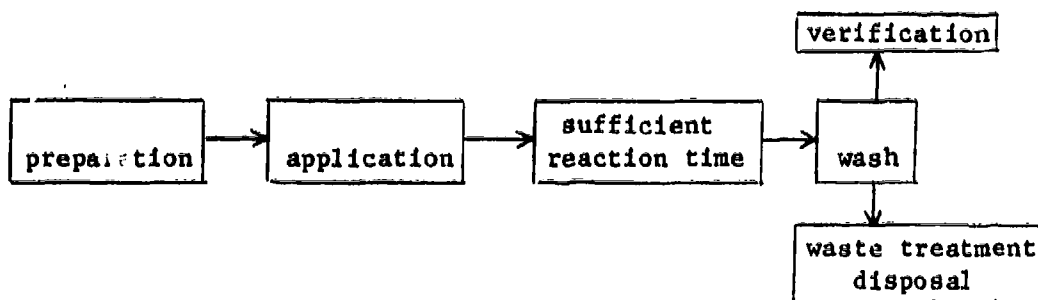Water wash.

4.3.5 Waste Treatment and Disposal
Waste products including divinyl sulfide and sodium
fluoride must be collected and treated, neuteralized
and incinerated.

4.4 State-of-the-Art
Currently used for decontamination of GB, HD and VX.

5.0 Engineering

5.1 Process Description

5.1.1 Main Process
DS-2 is mixed throughly and applied to the structure
with a spray gun, paint brush, roller or similar item
to thoroughly coat the surface as if it was being
painted. The liquid is allowed to soak in and react
decontaminating the agents. After decontamination
is completed the solution is removed by washing with
water.

5.1.2 Variations
DS-2 system may also be applied in gels or foams. A
variety of gelling and foaming agents may be used
which are compatible with both aqueous based and
organic solvents. A primary advantage of using gels
or foams is that they will maintain a long contact
time with the building material which will allow
continous diffusion of reactant into the material for
decontamination purposes. Polymeric or plastic sheet-
ing backings may be applied to the gels and foams to
insure inward migration of reactants and minimize
outward vapor diffusion into the building. Further-
more, these backed gels or foams may be heated to fa-
cilitate reactant migration and decontamination rate.

5.2   Equipment/Support Facilities Needed

   5.2.1   Description
           Tank for preparing mix.   Painting equipment
           for application.

   5.2.2   Reliability, Availability and Maintainability
           The RAM is expected to be high.

5.3   Decontamination Time

   5.3.1   Set-up
           Minimal set up time required, just as with painting.

   5.3.2   Application Time

       5.3.2.1   Personnel
                 Application time would be equivalent to the
                 time required for painting.

       5.3.2.2   Decontamination
                 Should be very good based on half-life data.
                 Will depend on achieving thorough contact
                 between the decontaminating solution and the
                 contaminants.

       5.3.2.3   Verification
                 Knowledge Gap.

   5.3.3   Tear-Down Time

       5.3.3.1   Equipment Removal
                 Minimal time is required for removal of ap-
                 plication equipment (same as for painting).

       5.3.3.2   Clean-up
                 Minimal clean up required.   A fresh water
                 wash may be sufficient.

5.4   Safety Requirements

   5.4.1   Process Hazards
           The liquid is corrosive to certain materials, plastic,
           wood and aluminum.   Appropriate equipment should be
           acquired.   No process hazards associated with the
           application method.

   5.4.2   Personnel Hazards
           Personnel hazards are associated with the application

method because the solution is corrosive and some of the products are somewhat toxic.

5.4.3 Protective Methods
Appropriate clothing, eye protection and probably a respirator are required.

6.0 Economics

6.1 Building Damage - Repair Costs
Small repair costs. None expected in concrete.
Some in wood, aluminum and plastic.

6.2 Developmental Costs
Modest. Evaluation of diffusion/contact of decontaminating solution to contaminants and verification of decontamination required.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Minimal: electricity for the mixer and the pump.

6.3.2 Equipment Cost
Minimal: brushes and rollers may be obtained from the neighborhood hardware store. Standard spraying equipment is inexpensive ($200-500). The price is higher if special materials are required because of the chemical characteristics of the liquid. DS-2 is corrosive.

6.3.3 Material Cost
Reagent:
diethylenetriamine	$6/lb.
methoxyethanol	$4/lb.
NaOH	$4.50/lb.

6.3.4 Manpower Cost
Small: same as painting (painting was assumed to be the base point).

7.0 Future Work Required

7.1 Knowledge Gaps
Diffusivity/contact. Verification.

7.2 Resolution
Experimental work.

CD-1

1.0 General Description

1.1 Summary of Idea

CD-1 (55 vol. percent ethanolamine, 45 vol. percent propylene glycol, and 2.5 weight percent lithium hydroxide, water) reacts with GB and VX forming hydrolysis products. CD-1 also reacts with HD to form the thiomorphylene derivative and vinyl chloroethyl sulfide. Studies have been done using a similar mixture (APD) to decontaminate agents from aluminum, concrete and soil.

1.2 Origination of Idea

Literature (Davis, 1975; Yurow, 1981; Davis, 1978; Day, 1979).

1.3 Obvious Advantages and Disadvantages

Advantages. Destruction of agents is very rapid: VX - 99.2% destruction in 15 minutes; GB - 99.97% destruction after 5 minutes. (Davis, 1975). Destruction rate with HD was reported by Day, 1979 to be $t_{1/2} = 2.7$ minutes.

Disadvantages. Formation of toxic by-product vinyl chloroethyl sulfide and divinyl sulfide has been reported (Davis, 1975).

1.4 Variations of Idea

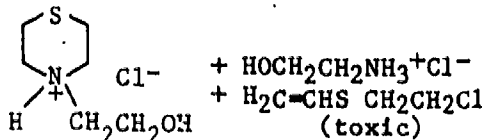Use as a reactive aerosol in building interiors with supplemental heating of structure.
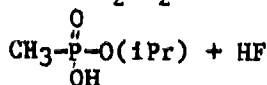
1.5 Sketch

None.

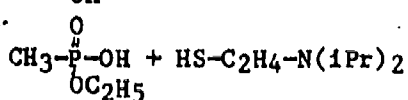## 2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions

HD + CD-1

$$\text{(thiomorpholine structure)}\ Cl^- \quad + HOCH_2CH_2NH_3^+Cl^-$$
$$+ H_2C=CHS\ CH_2CH_2Cl\ (\text{toxic})$$

GB + CD-1

$$CH_3-\overset{O}{\underset{OH}{P}}-O(iPr) + HF$$

VX + CD-1

$$CH_3-\overset{O}{\underset{OC_2H_5}{P}}-OH + HS-C_2H_4-N(iPr)_2$$

2.2 Hazardous Products

Formation of toxic product vinyl chloroethyl sulfide and vinyl sulfide (half life of form 10 minutes at room temp) has been reported (Yurow, 1981).

2.3 Destruction Efficiency, Residue Level

CD-1 destroyed 99.97% of GB present in five minutes. (vapor phase). CD-1 destroyed 99.2% of VX in 15 minutes. Day, 1979 reports the $t_{1/2}$ for VX is 0.34 minutes and for HD is 2.7 minutes.

2.4 Reaction Rate/Kinetics
   VX and HD have a half-life of 3 minutes when treated with
   CD-1 at 25 C. For GB the half-life is reported to be less
   than 2 minutes (Yurow, 1981).

2.5 Supplementary Treatment
   Washing of materials and containment of divinyl sulfide and
   chloroethyl vinyl sulfide would seem to be a necessary
   supplementary treatment.

2.6 State-of-the-Art
   A reference (Brady, 1969) describes the use of an APD aerosol
   in decontaminating GB vapor and reports destruction ef-
   ficiency of APD (similar to CD-1) with VX and HD on aluminum,
   concrete and soil samples. A reference (Yurow, 1981) in-
   dicates that APD is the same as CD-1.

3.0 Physical Treatment
   Not applicable.

4.0 Applicability

4.1 Agent Applicability
   Applicable to all agents of interest.

4.2 Isolated Building Material Applicability

   4.2.1 Impact of Substrate on Chemistry
      No damaging impact anticipated. Alumina and silica
      have been reported to have catalytic effects on
      hydrolysis.

   4.2.2 Removal or Reaction of Contaminant from Surface
      No problems anticipated. Complete removal of surface
      contaminants expected.

   4.2.3 Removal or Reaction of Contaminant from Interior
      Penetration into porous materials not reported.
      Knowledge Gap.

   4.2.4 Damage to Material
      Can be expected to destroy paint films, no damage is
      expected due to spraying, brushing or rolling the
      liquid on the surface.

4.3 Practical Applicability to Building

   4.3.1 Building Preparation
      Paint removal may be necessary although some stripping
      is expected from the application to CD-1.

4.3.2 Practical Physical Limitations/Methods to Overcome
Spraying, brushing or rolling the CD-1 liquid on
intricate areas may be time consuming and cumbersome.
Difficulties encountered will be equivalent to those
encountered when painting the structure.

4.3.3 Secondary Decontamination Treatment
None expected unless contact between the agent and the
reactive liquid is not achieved.

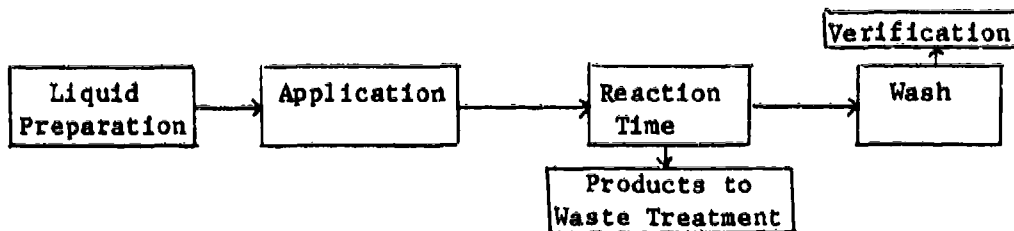4.3.4 Clean-up Requirements
Water wash.

4.3.5 Waste Treatment and Disposal
Waste products must be removed or collected, treated,
neutralized and/or incinerated.

4.4 State-of-the-Art
APD has been used in an aerosol form for the decontamination of
agents on aluminum, concrete, and soil samples (Brady, 1969).

5.0 Engineering

5.1 Process Description

5.1.1 Main Process
The CD-1 liquid is mixed thoroughly and applied to the
structure with a spray gun, paint brush, roller or
similar item to thoroughly coat the surface as if it
was being painted. The liquid is allowed to soak in
and react thereby decontaminating the agents. After
decontamination is completed, the solution is removed
by washing with an appropriate wash solution.

5.1.2 Variations
Liquid reagents may also be applied in gels or foams.
A variety of gelling and foaming agents may be used
which are compatible with both aqueous based and
organic solvents. A primary advantage of using gels
or foams is that they will maintain a long contact
time with the building material which will allow
continuous diffusion of reactants and minimize outward
vapor diffusion into the building. Furthermore, these

backed gels or foams may be heated to facilitate re-
actant migration and increase decontamination rates.

5.2   Equipment/Support Facilities Needed

   5.2.1   Description
           Agitated tank for preparing mix painting equipment for
           application.

   5.2.2   Reliability, Availability and Maintainability
           The RAM is expected to be high.

5.3   Decontamination Time

   5.3.1   Set-up
           Minimal set up time required, not as with painting.

   5.3.2   Application Time

        5.3.2.1   Personnel
                  Application time would be equivalent to the
                  time required for painting.

        5.3.2.2   Decontamination
                  Should be fast and complete if contact
                  between the liquid CD-1 and the agent is
                  achieved.

        5.3.2.3   Verification
                  Knowledge Gap.

   5.3.3   Tear-Down Time

        5.3.3.1   Equipment Removal
                  Minimal time is required for removal of
                  application equipment (same as for painting).

        5.3.3.2   Clean-up
                  Minimal clean up required. A fresh water
                  wash may be sufficient.

5.4   Safety Requirements

   5.4.1   Process Hazards
           None expected.

   5.4.2   Personnel Hazards
           Reaction products are toxic.

   5.4.3   Protective Methods
           Appropriate clothing required.

6.0 Economics

6.1 Building Damage - Repair Costs
None expected.

6.2 Developmental Costs
Modest. Verification on decontamination efficiency for contaminants inside building materials required.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Minimal - electricity for the mixer and the pump.

6.3.2 Equipment Cost
Minimal - brushes and rollers may be obtained from the neighborhood hardware store. Standard spraying equipment is inexpensive ($200-500). The price is higher if special material is required because of the chemical characteristics of the liquids. Some reactants and products may be corrosive.

6.3.3 Material Cost
Modest - depending on the amount required.
MEA $5/lb
LiOH $10/lb

6.3.4 Manpower Cost
Minimal - same as painting. (Painting was assumed to be the base point.)

7.0 Future Work Required

7.1 Knowledge Gaps
Verification of suitability of interior decontamination. Confirmation of published data.

7.2 Resolution
Experimental work.

ALL PURPOSE DECONTAMINANT (APD)

1.0 General Description

1.1 Summary of Idea
APD (54% MEA, 44% isopropanolamine, 2.5% LiOH H_2O) is known to react with GB, VX and HD. Studies have been done using APD for the decontamination of agents from aluminum, concrete and soil.

1.2 Origination of Idea
Brady, 1969; Davis, 1978; Yurow, 1981; Stanford, 1981.

1.3 Obvious Advantages and Disadvantages
Advantages. Applicable in the vapor/aerosol phases. Contains ethanolamine which readily reacts with agents and is a good decontaminate for HD. (Brankowitz, 1978).

Disadvantages. Formation of toxic by-product vinyl chloroethyl sulfide has been reported. (Yurow, 1981).

1.4 Variations of Idea
Use as a reactive aerosol in building interiors with supplemental structure heating. (Brady, 1969).

1.5 Sketch

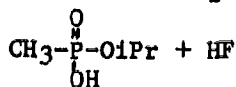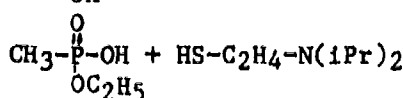2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions
HD + APD (MEA)
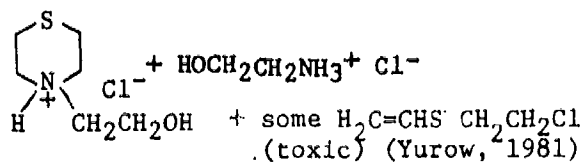
$$+ HOCH_2CH_2NH_3^+ Cl^-$$

+ some $H_2C=CHS$ CH_2CH_2Cl
(toxic) (Yurow, 1981)

GB + APD
$$CH_3-\overset{O}{\underset{OH}{P}}-OiPr + HF$$

VX + APD
$$CH_3-\overset{O}{\underset{OC_2H_5}{P}}-OH + HS-C_2H_4-N(iPr)_2$$

2.2 Hazardous Products
Formation of toxic product vinyl chloroethyl sulfide (half life of form 10 minutes at room temp) has been reported. There is some question whether or not this was formed with APD or CD-1. (Yurow, 1981).

2.3 Destruction Efficiency, Residue Level
APD destroyed 99.8% of GB present in six minutes. (vapor phase) APD destroyed 97% of the applied VX on glass in 1.5 hrs. Experiments on concrete were inconclusive because only 50% of the VX was recovered on a control experiment (Brady, 1969).

2.4 Reaction Rate/Kinetics
VX and HD have a half-life of 3 minutes in water treated with APD at 25 C. For GB the half-life is reported to be less than 2 minutes (Yurow, 1981).

2.5 Supplementary Treatment
Washing of materials and containment of divinyl sulfide would seem to be a necessary supplementary treatment.

2.6 State-of-the-Art
A reference (Brady, 1969) describes the use of an APD aerosol in decontaminating GB vapor and reports destruction efficiency of APD with VX and HD on aluminum, concrete and soil samples. A reference (Yurow, 1981) indicates that APD is the same as CD-1.

3.0 Physical Treatment
Not applicable.

4.0 Applicability

4.1 Agent Applicability
Applicable to all agents of interest.

4.2 Isolated Building Material Applicability

4.2.1 Impact of Substrate on Chemistry
No damaging impact anticipated. Alumina and silica have been reported to have catalytic effects on hydrolysis.

4.2.2 Removal or Reaction of Contaminant from Surface
No problems anticipated. Complete destruction of surface contaminants expected.

4.2.3 Removal or Reaction of Contaminant from Interior
Penetration into porous materials not reported. Knowledge Gap.

4.2.4 Damage to Material
Can be expected to destroy paint films. No damage is expected due to spraying, brushing or rolling the liquid on the surface.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Paint removal may be necessary although some stripping is expected from the application of APD.

4.3.2 Practical Physical Limitations/Methods to Overcome
Spraying, brushing or rolling the APD liquid on

intricate areas may be time consuming and cumbersome.
Difficulties encountered will be equivalent to those
encountered when painting the structure.

4.3.3 Secondary Decontamination Treatment
None expected unless contact between the agent and the
reactive liquid is not achieved.

4.3.4 Clean-up Requirements
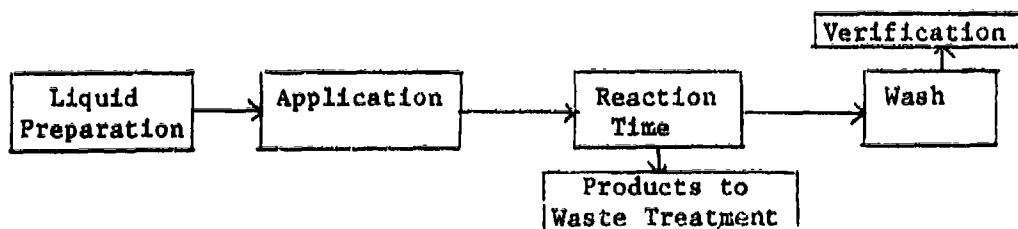Water wash.

4.3.5 Waste Treatment and Disposal
Waste products must be removed or collected, treated,
neutralized and/or incinerated.

4.4 State-of-the-Art
APD has been used in an aerosol form for the decontamination
of agents on aluminum, concrete, and soil samples (Brady, 1969).

5.0 Engineering

5.1 Process Description

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┌──────────────┐   ┌──────────────┐   ┌──────────────┐   ┌──────────────┐
│   Liquid     │→  │ Application  │→  │  Reaction    │→  │    Wash      │
│ Preparation  │   │              │   │    Time      │   │              │
└──────────────┘   └──────────────┘   └──────────────┘   └──────────────┘
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Verification

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          ┌──────────────────┐
          │   Products to    │
          │ Waste Treatment  │
          └──────────────────┘
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5.1.1 Main Process
The APD liquid is mixed thoroughly and applied to the
structure with a spray gun, paint brush, roller or
similar item to thoroughly coat the surface as if it
was being painted. The liquid is allowed to soak in
and react decontaminating the agents. After decon-
tamination is completed the solution is removed by
washing with an appropriate wash solution.

5.1.2 Variations
Liquid reagents may also be applied in gels or foams.
A variety of gelling and foaming agents may be used
which are compatible with both aqueous based and
organic solvents. A primary advantage of using gels
or foams is that they will maintain a long contact
time with the building material which will allow
continuous diffusion of reactants and minimize outward
vapor diffusion into the building. Furthermore, these
backed gels or foams may be heated to facilitate re-
actant migration and increase decontamination rates.

5.2 Equipment/Support Facilities Needed

    5.2.1 Description
        Agitated tank for preparing mix painting equipment for application.

    5.2.2 Reliability, Availability and Maintainability
        The RAM is expected to be high.

5.3 Decontamination Time

    5.3.1 Set-up
        Minimal set up time required, not as with painting.

    5.3.2 Application Time

        5.3.2.1 Personnel
            Application time would be equivalent to the time required for painting.

        5.3.2.2 Decontamination
            Should be fast and complete if contact between the liquid APD and the agent is achieved.

        5.3.2.3 Verification
            Knowledge Gap.

    5.3.3 Tear-Down Time

        5.3.3.1 Equipment Removal
            Minimal time is required for removal of application equipment same as for painting.

        5.3.3.2 Clean-up
            Minimal clean up required a fresh water wash may be sufficient.

5.4 Safety Requirements

    5.4.1 Process Hazards
        None expected.

    5.4.2 Personnel Hazards
        Reaction products are toxic.

    5.4.3 Protective Methods
        Appropriate clothing required.

6.0 Economics

6.1 Building Damage - Repair Costs
None expected.

6.2 Developmental Costs
Modest. Verification needed on decontamination efficiency within building materials.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Minimal - electricity for the mixer and the pump.

6.3.2 Equipment Cost
Minimal - brushes and rollers may be obtained from the neighborhood hardware store. Standard spraying equipment is inexpensive ($200-500). The price is higher if special material is required because of the chemical characteristics of the liquids. Some reactants and products may be corrosive.

6.3.3 Material Cost
Modest - dependent on the amount required.
MEA $5/lb
LiOH $10/lb

6.3.4 Manpower Cost
Minimal - same as painting.

7.0 Future Work Required

7.1 Knowledge Gaps
Verification of suitability of interior decontamination.
Confirmation of published data.

7.2 Resolution
Experimental work.

MONOETHANOLAMINE (MEA)

1.0 General Description

1.1 Summary of Idea
MEA is known to react with chemical agents (HD) and could be applied neat to surfaces with some penetration expected.

1.2 Origination of Idea
Literature references (Brankowitz, 1978; Brady, 1969; Rosenberg, 1977; Mirabella).

1.3 Obvious Advantages and Disadvantages
Advantages: MEA, in the absence of much water, is a good solvent for HD and is not expected to produce divinyl thio-ether or chloroethyl vinyl thioether as do APD and DS-2. For demilitarization of HD, MEA was chosen over NaOH and HTH (Brankowitz, 1978).

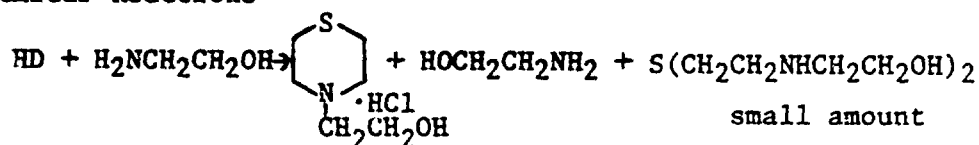Disadvantages: Demilitarization of GB or VX not documented (nor expected).

1.4 Variations of Idea
MEA in combination with decontaminant for GB and VX seems to be promising. MEA combined with 4-(N,N dimethylamino)-pyridine has been employed for destruction of GB. (Cowsar, 1978).
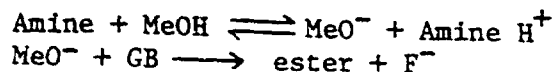
1.5 Sketch — None

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions

$$HD + H_2NCH_2CH_2OH \rightarrow \underset{\substack{N \\ | \\ CH_2CH_2OH}}{\overset{S}{\bigcirc}} \cdot HCl + HOCH_2CH_2NH_2 + S(CH_2CH_2NHCH_2CH_2OH)_2$$

small amount

VX. Knowledge Gap.

GB. Weinberger, 1969 shows the following for a mixture of an amine in methanol:

$$Amine + MeOH \rightleftharpoons MeO^- + Amine\ H^+$$
$$MeO^- + GB \longrightarrow ester + F^-$$

2.2 Hazardous Products
None reported for HD/MEA
Unknown for GB/MEA
Unknown for VX/MEA

2.3 Destruction Efficiency, Residue Level
The reaction of HD with MEA reaction is assumed to proceed to completion.

2.4 Reaction Rate/Kinetics
Half life of HD/MEA 32 minutes at 25 C and 11 minutes at

57 C. (Yurow, 1981).

VX knowledge gap. Epstein, 1970 has shown that primary mono- and diamines increase the hydrolysis rate of GB by the following equatic

$$\frac{-d[GB]}{dt} = k_2 \, [GB][\text{amine active species}] + k_{OH} \, [GB][OH^-]$$

2.5 Supplementary Treatment
   Knowledge Gap (Brankowitz, 1978 - Reports subsequent incineration (at 100 C) of products and scrubbing of the gases with 18% NaOH in water).

2.6 State-of-the-Art
   MEA/HD reaction is well documented (Brankowitz, 1978).
   MEA/GB Knowledge Gap
   MEA/VX Knowledge Gap

3.0 Physical Treatment - Not applicable

4.0 Applicability

   4.1 Agent Applicability
      MEA is known to react with HD
      Relatively strong base may aid hydrolysis of GB and VX

   4.2 Isolated Building Material Applicability

      4.2.1 Impact of Substrate on Chemistry
         Basicity of concrete may aid hydrolysis of GB and VX

      4.2.2 Removal or Reaction of Contaminant from Surface
         HD decontamination is expected to be very efficient.
         GB and VX. Knowledge Gap.

      4.2.3 Removal or Reaction of Contaminant from Interior
         Knowledge Gap.

      4.2.4 Damage to Material
         MEA is not corrosive (Brankowitz, 1978).

   4.3 Practical Applicability to Building

      4.3.1 Building Preparation
         Paint removal may be necessary. Knowledge Gap.

      4.3.2 Practical Physical Limitations/Methods to Overcome
         None anticipated.
         Spraying, brushing and rolling the liquid on intricate areas may be time consuming and cumbersome. Difficulties encountered will be equivalent to those encoutered when painting the structures.

      4.3.3 Secondary Decontamination Treatment
         None required if complete reaction is achieved.

4.3.4 Clean-up Requirements
Wash down.

4.3.5 Waste Treatment and Disposal
Incineration of waste fluids produces Na_2CO_3, NaCl, and Na_2SO_4 Na_2SO_4 as ultimate products.

4.4 State-of-the-Art
Knowledge Gap
Has not been tried on structures.

5.0 Engineering

5.1 Process Description

```
┌──────────────┐     ┌──────────────┐     ┌──────────────┐
│     MEA      │ ──▶ │  Sufficient  │ ──▶ │  Wash Down   │
│ Application  │     │ Reaction Time│     │              │
└──────────────┘     └──────────────┘     └──────────────┘
                                                 │
                                                 ▼
                                    ┌─────────────────────┐
                                    │ Decon Verification  │
                                    └─────────────────────┘
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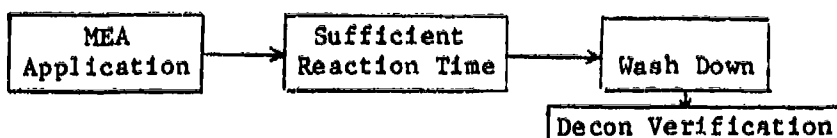
5.1.1 Main Process
The MEA is applied to the surface with spray gun, brush or roll to throughly coat the surface and is allowed to soak in and react. After reaction, the surface is washed off with an appropriate wash solution. Another application performed if required.

5.1.2 Variations
Liquid reagents systems may also be applied in gels or foams. A variety of gelling and foaming agents may be used which are compatible with organic solvents. A primary advantage to using gels or foams is that they will maintain a long contact time with the building material which will allow continuous diffusion of reactants into the material for decontamination purposes. Polymeric or plastic sheeting backings may be applied to the gels and foams to insure inward migration of diffusion into the building. Furthermore, these backed gels or foams may be heated to facilitate reactant migration and the decontamination rates.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
Tank for MEA, painting equipment for application.

5.2.2 Reliability, Availability and Maintainability
Very reliable, readily available, easy to maintain.

5.3 Decontamination Time

5.3.1 Set-up
Minimal set up time required, just as painting.

5.3.2 Application Time

    5.3.2.1 Personnel
        Application time would be equivalent to the
        time required for painting.

    5.3.2.2 Decontamination
        Should be rapid once the MEA comes into
        contact with HD. Rate of reaction with VX
        and GB on surface and with all three agents
        in the interior of building materials is
        unknown.

    5.3.2.3 Verification
        Knowledge Gap.

5.3.3 Tear-Down Time

    5.3.3.1 Equipment Removal
        Minimal time is required for removal of
        application equipment (same as for painting).

    5.3.3.2 Clean-up
        Minimal clean up required. A fresh water
        wash may be sufficient.

5.4 Safety Requirements

    5.4.1 Process Hazards
        None associated with the application method or
        reactive liquid. None expected due to reaction
        products.

    5.4.2 Personnel Hazards
        MEA is strong base.

    5.4.3 Protective Methods
        Eye protection and rubber gloves should be worn.

6.0 Economics

6.1 Building Damage - Repair Costs
    None.

6.2 Developmental Costs
    Appreciable. Need to determine applicability to other
    agents, applicability to structures and destruction
    efficiency for interior decontamination.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Minimal: electricity for the pump.

6.3.2 Equipment Cost
Minimal: brushes and rollers may be obtained from the neighborhood hardware store. Standard spraying equipment is inexpensive ($200-500). The price is higher if special material is required because of the chemical characteristics of the liquid. MEA is corrosive liquid.

6.3.3 Material Cost
Modest. (MEA $20/lb reagent).

6.3.4 Manpower Cost
Small. Similar as painting. Additional expense involved in building washing following treatment and with disposal of waste solutions.

7.0 Future Work Required

7.1 Knowledge Gaps
Applicability to VX and GB, destruction efficiency, and applicability to buildings and structures, especially interior surfaces.

7.2 Resolution
Experimental work.

GAMMA RADIATION/H_2O/ACETONE

1.0 General Description

1.1 Summary of Idea
Gamma radiation can be used to generate reactive free radicals (e.g. hydroxyl radicals) in situ, to decompose agents contained in and on building materials. Gamma radiation may be used in conjuction with a solvent or may be used on neat agents.

1.2 Origination of Idea
Novel Processing Project Team and various references (Jones, 1981; Hart, 1968; Wentsel, 1981).

1.3 Obvious Advantages and Disadvantages
Advantages. Gamma radiation is capable of penetrating all building materials and is therefore potentially useful if agents have penetrated deep (i.e. over a foot) into the building material.

Disadvantages: Reaction products may be toxic and may require subsequent removal. Safety of personnel is a concern when a powerful radiation source is used.

1.4 Variations of Idea
Small concentrations of hydrogen peroxide in water may enhance formation of free radicals. A cosolvent could be used to aid solubility of HD. An x-ray source could replace the gamma ray source. The advantage of x-ray is that it can be turned on and off as needed. However, it does not penetrate as far and may not be as effective in initiating radical formation as gamma rays.
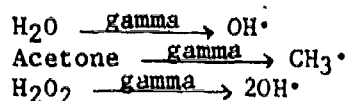
1.5 Sketch
None.

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions
The reaction is thought to proceed by radical or ion attack:

$$H_2O \xrightarrow{\text{gamma}} OH\cdot$$
$$Acetone \xrightarrow{\text{gamma}} CH_3\cdot$$
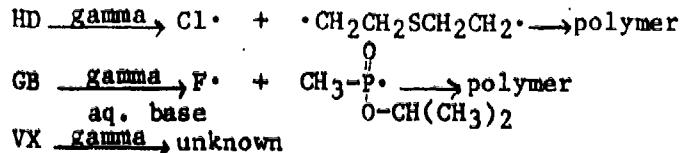$$H_2O_2 \xrightarrow{\text{gamma}} 2OH\cdot$$

Three types of products may be expected from the irradiation of HD, GB and VX:

1. Gases formed by bond cleavage.
2. Intermediate molecular weight products (formed by halogenation, dehydrogenation, dehalogenation, rearrangements and dimerization).
3. High molecular weight products (formed by polymerization

via condensation, cross-linking, and secondary chain
propagation of primary radiolysis products).

Expected products upon direct irradiation:

$$HD \xrightarrow{\text{gamma}} Cl\cdot \; + \; \cdot CH_2CH_2SCH_2CH_2\cdot \longrightarrow polymer$$

$$GB \xrightarrow[\text{aq. base}]{\text{gamma}} F\cdot \; + \; CH_3\overset{\overset{O}{\parallel}}{\underset{O-CH(CH_3)_2}{P}}\cdot \longrightarrow polymer$$

$$VX \xrightarrow{\text{gamma}} unknown$$

2.2 Hazardous Products

The chemistry and products formed from gamma radiation will
need to be studied.

2.3 Destruction Efficiency, Residue Level

Destruction efficiency is expected to be high as long as the
environment of destruction contains H_2O (as a source of
$OH\cdot$).

2.4 Reaction Rate/Kinetics

Unknown.

2.5 Supplementary Treatment

This is dependent on the amount and types of hazardous
products produced, if any.

2.6 State-of-the-Art

Gamma radiation studies are currently being conducted on
chemical warfare agents.

3.0 Physical Treatment

Not applicable.

4.0 Applicability

4.1 Agent Applicability

HD, GB, VX

4.2 Isolated Building Material Applicability

4.2.1 Impact of Substrate on Chemistry

The interaction of certain substrates (e.g. concrete)
with free radicals under gamma radiation exposure may
interfere with agent decomposition.

4.2.2 Removal or Reaction of Contaminant from Surface

Gamma radiation may be an "overkill concept" for
surface decontamination.

4.2.3 Removal or Reaction of Contaminant from Interior
Gamma radiation seems to be very well suited to treating the interior of building materials.

4.2.4 Damage to Material
Gamma radiation is known to soften plexiglass, insulation and other plastics. Free radicals may cause corrosion of metals and may react with cement.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Installation of radiation shields to minimize worker exposure will probably be required. Paint removal and prior decontamination would probably be required to facilitate diffusion of solvent into matrix.

4.3.2 Practical Physical Limitations/Methods to Overcome
None anticipated.

4.3.3 Secondary Decontamination Treatment
A secondary decontamination treatment would be required if the reaction products are toxic and remain in the building material.

4.3.4 Clean-up Requirements
A water rinse may be necessary if a cosolvent is employed.
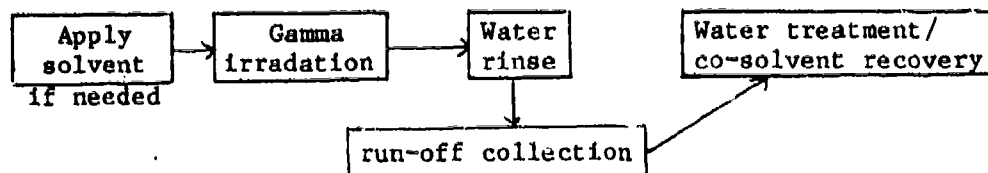
4.3.5 Waste Treatment and Disposal
Depends on the secondary decontamination treatment requirement.

4.4 State-of-the-Art
Gamma radiation studies are currently being conducted on the decontamination of CW agents at Battelle.

5.0 Engineering

5.1 Process Description

5.1.1 Main Process
A water-based solvent, containing possibly significant concentrations of acetone or hydrogen peroxide and possibly other cosolvents to aid in agent solubility,

is sprayed onto a contaminated building surface and allowed to permeate. Gamma radiation is directed onto the wet surface, until decomposition of agents is complete. A water rinse may be necessary, if a co-solvent is utilized.

5.1.2 Variations

The run-off water (from initial spray or post-rinse) may contain residual agent compounds, and could be exposed to the gamma radiation as a means of treatment.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

Pump, spray system, gamma radiation source, radiation shields, and possibly a distillation column for co-solvent recovery.

5.2.2 Reliability, Availability and Maintainability

High RAM for process equipment.

5.3 Decontamination Time

5.3.1 Set-up

Moderate - set up of gamma radiation source and radiation shields would be rather involved.

5.3.2 Application Time

5.3.2.1 Personnel

Low - application of water solution to building surfaces would be rapid.

5.3.2.2 Decontamination

Depends on amount of radiation exposure required.

5.3.2.3 Verification

Knowledge Gap

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal

The gamma radiation source can not be turned off, and will have to be properly shielded for removal and transport. With due pre-caution, this should not require much time.

5.3.3.2 Clean-up

Minimal requirements.

5.4 Safety Requirements

    5.4.1 Process Hazards
        Over heating of wet substrates from gamma radiation
        may occur.

    5.4.2 Personnel Hazards
        Radiation exposure.

    5.4.3 Protective Methods
        Radiation shields, remote operation.

6.0 Economics

6.1 Building Damage - Repair Costs
    Low, assuming metal corrosion and cement degradation are
    minimized.

6.2 Developmental Costs
    Studies to determine the extent of agent decomposition with
    and without a cosolvent. Development of optimum solvent for
    initial saturation. Identification of reaction products.
    Demonstration of effectiveness on a variety of contaminated
    building materials. Dose level requirements.

6.3 Treatment Costs

    6.3.1 Utilities and Fuel Cost
        Minimal.

    6.3.2 Equipment Cost
        High-cost of gamma source, radiation shields.

    6.3.3 Material Cost
        Cosolvent cost may be significant, but solvent recovery
        would greatly reduce the net cost. Gamma source (i.e.,
        Cobalt 60) is relatively expensive.
    6.3.4 Manpower Cost
        Low to moderate: solvent application, set-up of
        radiation dose.

7.0 Future Work Required

7.1 Knowledge Gaps
    Interference of cosolvent with agent reaction;
    reaction products, reaction rates, reaction efficiency
    (i.e. general effectiveness); interference of substrate
    with agents reaction; necessity of a secondary decontami-
    nation treatment.

7.2 Resolution
    Experimental testing.

NITRIC ACID

1.0 General Description

1.1 Summary of Idea
Concentrated nitric acid is reported to be effective in oxidizing HD to the sulfoxide. It also should promote the hydrolysis of GB and VX.

1.2 Origination of Idea
Reported for HD in the literature (Mankowich, 1970).

1.3 Obvious Advantages and Disadvantages
Advantage. The production of relatively safe product from HD and applicability to nerve agents as well.

Disadvantages. Highly corrosive nature of the reagent which limits its applicability, increases hazards to personnel and causes production of hazardous HF when applied to GB. May not react with VX (Domjan, 1975).
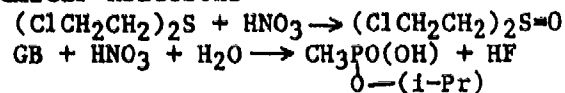
1.4 Variations of Idea
None.

1.5 Sketch
None.

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions
$(ClCH_2CH_2)_2S + HNO_3 \longrightarrow (ClCH_2CH_2)_2S{=}O$
$GB + HNO_3 + H_2O \longrightarrow CH_3PO(OH) + HF$
$\qquad\qquad\qquad\qquad\quad O{-}(i{-}Pr)$

$VX + HNO_3 + H_2O \longrightarrow CH_3PO(OH) + HSCH_2CH_2{-}\overset{H}{\underset{+}{N}}{-}(i{-}Pr)_2 \; NO_3^-$
$\qquad\qquad\qquad\qquad\qquad\quad O{-}Et$
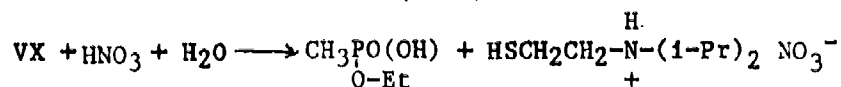
2.2 Hazardous Products
HF is formed in the GB reaction. The sulfoxide from HD may not be entirely inoccuous.

2.3 Destruction Efficiency, Residue Level
Complete decomposition anticipated.

2.4 Reaction Rate/Kinetics
Knowledge Gap.

2.5 Supplementary Treatment
Requires neutralization and disposal; incineration.

2.6 State-of-the-Art
Has been used primarily to decontaminate laboratory glassware contaminated with HD.

3.0 Physical Treatment
   Not applicable.

4.0 Applicability

   4.1 Agent Applicability
       HD, GB, and possibly, VX.

   4.2 Isolated Building Material Applicability

       4.2.1 Impact of Substrate on Chemistry
             None anticipated.

       4.2.2 Removal or Reaction of Contaminant from Surface
             Should be effective.

       4.2.3 Removal or Reaction of Contaminant from Interior
             Unknown - penetration not expected to be especially
             fast.

       4.2.4 Damage to Material
             Probably extensive for metal (except stainless steel)
             paint and, possibly, concrete.

   4.3 Practical Applicability to Building

       4.3.1 Building Preparation
             None required.

       4.3.2 Practical Physical Limitations/Methods to Overcome
             Spraying, brushing and rolling the liquid on hard to
             reach areas may be time consuming and cumbersome.
             Difficulties encountered will be equivalent to those
             encountered when painting the structures.

       4.3.3 Secondary Decontamination Treatment
             A secondary application may be necessary if contact
             between the surface and the liquid is not completely
             achieved. Otherwise none expected.

       4.3.4 Clean-up Requirements
             Water wash required, neutralization may be necessary.

       4.3.5 Waste Treatment and Disposal
             Waste must be neutralized, may require concentration
             and/or incineration.

   4.4 State-of-the-Art
       Nitric acid has been used for the decontamination of labora-
       tory glassware. However it has not been tried on buildings
       and structures.

5.0 Engineering

5.1 Process Description

Nitric acid solution (aqueous or aqueous/organic) is mixed thoroughly and applied to the surface with a spray gun, brush or roll. The nitric acid is allowed to react and decompose the agents producing relatively non-hazardous compounds. After the reaction is completed, the solution is washed off.

5.1.1 Main Process

Nitric acid solution may also be applied in the forms of a gel or foam. A variety of gelling and foaming agents may be used which are compatible with both aqueous or organic solvents. Gels and foams will maintain a longer contact time with the structure for decontamination purposes. Polymeric sheeting backings may be applied to the gels and foams to minimize solvent losses to the environment. The backing may be heated to enhance reactant migration through the structure and to enhance reaction rates.

5.1.2 Variations

None.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

Agitated tank for preparing mix painting equipment for application.

5.2.2 Reliability, Availability and Maintainability

The RAM is expected to be moderate.

5.3 Decontamination Time

5.3.1 Set-up

Minimal set up required, just as with painting.

5.3.2 Application Time

5.3.2.1 Personnel

Application time would be equivalent to the time required for painting.

5.3.2.2 Decontamination

Knowledge Gap. Decontamination time may be short once contact has occurred.

5.3.2.3 Verification

Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Minimal time is required for removal of application equipment (same as for painting).

5.3.3.2 Clean-up
Minimal clean-up required - neutralization and water wash. (May be done by washing with slightly basic aqueous solution.)

5.4 Safety Requirements

5.4.1 Process Hazards
Highly corrosive to metals.

5.4.2 Personnel Hazards
Highly corrosive to tissue.

5.4.3 Protective Methods
Aluminum or stainless steel equipment required for handling of nitric acid. Protective clothing and eye protection required.

6.0 Economics

6.1 Building Damage - Repair Costs
Extensive damage to metals other than aluminum and stainless steel.

6.2 Developmental Costs
Relatively small. The method should be tried on buildings and structures since it is currently used for glassware decontamination.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Minimal - electricity for the mixer and the pump.

6.3.2 Equipment Cost
Minimal - brushes and rollers may be obtained from the neighborhood hardware store. Standard spraying equipment is inexpensive ($200-400). Corrosion resistant equipment is required.

6.3.3 Material Cost
Modest - nitric acid is commodity material. Available at low price.

6.3.4 Manpower Cost
Small - same as painting.

7.0 Future Work Required

    7.1 Knowledge Gaps
          Permeability into the structure.
          Destruction efficiency.

    7.2 Resolution
          Experimental work.

AMMONIA

1.0 General Description

1.1 Summary of Idea
Solutions of ammonia in aqueous or aqueous/organic solvents promote the hydrolysis of nerve agents and HD. Ammonia also reacts directly with the latter.

1.2 Origination of Idea
The use of ammonia (solution or gas) has been proposed in several decontamination systems. References citing the use of ammonia include Corwin, 1968; Franke, 1968; Anonymous, 1967).

1.3 Obvious Advantages and Disadvantages
Advantages. Ammonium hydroxide is not as corrosive as many other bases and is therefore easier to handle, store and apply. Alkylation of NH_3 by HD should limit formation of divinyl sulfide. Nucleophilic reagents (e.g. NH_3) rapidly forms non-toxic products with VX (Domjan, 1975).

Disadvantages. NH_3 requires personnel protection and in sufficient concentration (which could be avoided) is explosive in air.
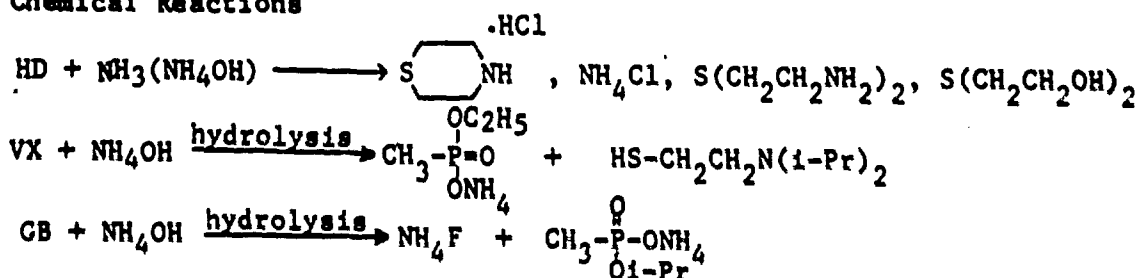
1.4 Variations of Idea
Addition of organic co-solvents and detergents should promote the reactions and aid in penetration. Ammonium bicarbonate may be used as the source of ammonium ions (Domjan, 1975).

1.5 Sketch
None.

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions

$$HD + NH_3(NH_4OH) \longrightarrow S\!\!\bigcirc\!\!\overset{.HCl}{NH} \; , \; NH_4Cl, \; S(CH_2CH_2NH_2)_2, \; S(CH_2CH_2OH)_2$$

$$VX + NH_4OH \xrightarrow{hydrolysis} CH_3-\overset{\overset{\displaystyle OC_2H_5}{|}}{\underset{\underset{\displaystyle ONH_4}{|}}{P}}=O \; + \; HS-CH_2CH_2N(i\text{-}Pr)_2$$

$$GB + NH_4OH \xrightarrow{hydrolysis} NH_4F \; + \; CH_3-\overset{\overset{\displaystyle O}{\|}}{\underset{\underset{\displaystyle Oi\text{-}Pr}{|}}{P}}-ONH_4$$

2.2 Hazardous Products
Products should not be hazardous.

2.3 Destruction Efficiency, Residue Level
Reaction is expected to proceed to completion with all agents.

2.4 Reaction Rate/Kinetics
Knowledge Gap.

2.5 Supplementary Treatment
Concentration and incineration.

2.6 State-of-the-Art
Ammonia (and amines) have been applied to the destruction of agents with satisfactory results.

3.0 Physical Treatment
Not applicable.

4.0 Applicability

4.1 Agent Applicability
Applicable to HD, GB, VX.

4.2 Isolated Building Material Applicability

4.2.1 Impact of Substrate on Chemistry
Nature of the surface should have not effect on the reactions.

4.2.2 Removal or Reaction of Contaminant from Surface
Reaction and subsequent removal of agents as soluble decomposition products should be possible.

4.2.3 Removal or Reaction of Contaminant from Interior
Knowledge gap. Rapid penetration of surfaces by NH_3 seems more likely than by other, larger basic reagents.

4.2.4 Damage to Material
Minimal. Perhaps some effect on paint depending on time of exposure and temperature.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Paint removal may be necessary depending on the time of exposure and temperature of treatment. Low temperature would require paint removal.

4.3.2 Practical Physical Limitations/Methods to Overcome
Spraying, brushing, and rolling the liquid on hard to reach areas may be time consuming and cumbersome. Difficulties encountered will be equivalent to those encountered when painting the structure.

4.3.3 Secondary Decontamination Treatment
No secondary treatment should be necessary unless contact between the agent and the liquid was not achieved. Then another application would be required.

4.3.4 Clean-up Requirements
Water wash-off.

4.3.5 Waste Treatment and Disposal
Concentration and Incineration.

4.4 State-of-the-Art
Ammonia hs been applied to the destruction of agents with satisfactory results. It has not been tried on buildings or structures.

5.0 Engineering

5.1 Process Description
The ammonia solution/aqueous or aqueous/organic) is mixed thoroughly and applied to the surface with a spray gun, brush or roll. The ammonia is allowed to react with the agent. After reaction is completed the structure is washed off.

5.1.1 Main Process

5.1.2 Variations
Liquid ammonia may also be applied in gels or foams. A variety of gelling and foaming agents may be used which are compatible with both aqueous or organic solvents. Gels and foams will maintain a longer contact time with the structure for decontamination purposes. Polymeric sheeting backings may be applied to the gels and foams to minimize solvent losses to the environment. The backing may be heated to enhance reactant migration towards the structure and faster reaction rates.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
Agitated tank for preparing mix.
Painting equipment for application.

5.2.2 Reliability, Availability and Maintainability
The RAM is expected to be high.

5.3 Decontamination Time

5.3.1 Set-up
Minimal set up required, just as with painting.

5.3.2 Application Time

5.3.2.1 Personnel
Application time would be equivalent to the time required for painting.

5.3.2.2 Decontamination
Knowledge Gap. Decontamination time should
be short once contact has occurred.

5.3.2.3 Verification
Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Minimal time is required for removal of ap-
plication equipment (same as for painting).

5.3.3.2 Clean-up
Minimal clean up required. A fresh water
wash may be sufficient.

5.4 Safety Requirements

5.4.1 Process Hazards
Ammonia has a lower explosive limit (LEL) in air.
However, the ammonia concentration can be control-
led and should not present a major process hazard.

5.4.2 Personnel Hazards
Ammonia is an irritant to the eyes and mucous mem-
branes but its commonly used for household chores. It
does not present a major personnel hazard.

5.4.3 Protective Methods
Concentration monitors should be available to insure
ammonia concentration is maintained below or above
explosion limits. Eye protection will be required
as well as breathing apparatus.

6.0 Economics

6.1 Building Damage - Repair Costs
None expected.

6.2 Developmental Costs
Modest. The method should be evaluated with buildings
and structures.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Minimal electricity for the mixer and the pump.

6.3.2 Equipment Cost

Minimal – brushes and rollers may be obtained from the neighborhood hardware store. Standard spraying equipment is inexpensive ($200-500). No special equipment is required.

6.3.3 Material Cost
Relatively small. Ammonia is a commodity material. readily available at low price.

6.3.4. Manpower Cost
Small – same as painting.

7.0 Future Work Required

7.1 Knowledge Gaps
Permeability into the structure decontamination. Time/reaction kinetics.

7.2 Resolution
Experimental work.

DANC

1.0 General Description

1.1 Summary of Idea
DANC (1 part N-chloroamide dissolved in 15 parts acetylene tetrachloride) is a relatively effective decontaminant for HD and VX and could be applied to surfaces of structures with some penetration expected.

1.2 Origination of Idea
Literature agent (Jones, 1981; Yurow, 1981; Mankowich, 1970; Stanford, 1981; Anonymous, 1967).

1.3 Obvious Advantages and Disadvantages
Advantages. DANC is less corrosive than bleaches to most metals. It is also known to be faster acting and has better solubility characteristics for agents than bleaches such as STB.

Disadvantages. Ineffective against GB. Solvent is highly toxic. HCl forms when DANC is brough into contact with moisture (Anonymous, 1967).

1.4 Variations of Idea
Improved formulations of DANC have exhibited lower toxicity characteristics, better corrosiveness properties, and greater effectiveness on wet surfaces than standard DANC (Mankowich, 1970). Alternate solvent system would be desirable such as those cited in Cowsar, 1978; Braude, 1970 and DeMarco, 1967).

1.5 Sketch - None

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions
DANC reacts with H_2O to generate hypochlorous acid (HOCl).

$$DANC + H_2O \longrightarrow HOCl + HD \longrightarrow SO_4^{-2} + Cl^- + CO_2 + H^+ + H_2O$$

$$DANC + H_2O \longrightarrow HOCl + VX \longrightarrow CH_3 - \overset{\overset{O}{\|}}{\underset{OC_2H_5}{P}} - O^- + HN(iPr)_2$$
$$+ SO_4^{-2} + CO_3^{-2} + Cl^- + H_2O$$
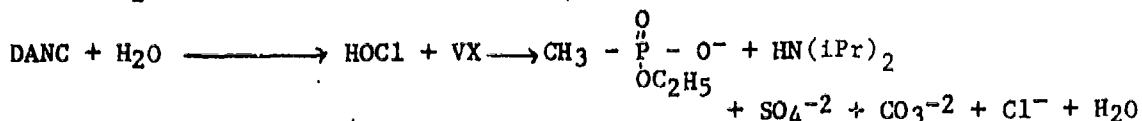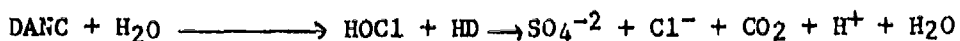
2.2 Hazardous Products
HD and VX decomposed to relatively non-toxic products.

2.3 Destruction Efficiency, Residue Level
Complete decontamination of HD and VX in 30 minutes is anticipated.

2.4 Reaction Rate/Kinetics
HD and VX completely decontaminated within 30 minutes.

2.5 Supplementary Treatment
None anticipated.

2.6 State-of-the-Art
   Chemistry is well known.

3.0 Physical Treatment
   Not applicable.

4.0 Applicability

   4.1 Agent Applicability
   Applicable decontaminant for HD and VX.
   Not applicable for GB.

   4.2 Isolated Building Material Applicability

      4.2.1 Impact of Substrate on Chemistry
      No effect anticipated.

      4.2.2 Removal or Reaction of Contaminant from Surface
      Should react and decontaminate within 30 minutes.

      4.2.3 Removal or Reaction of Contaminant from Interior
      Knowledge Gap - If the DANC actually contacts absorb-
      ed HD or VX decontamination should proceed.

      4.2.4 Damage to Material
      DANC slightly corrosive to metals.

   4.3 Practical Applicability to Building

      4.3.1 Building Preparation
      Paint removal may be necessary although some stripping
      may be expected from corrosive characteristics of
      DANC solutions.

      4.3.2 Practical Physical Limitations/Methods to Overcome
      Spraying, brushing or rolling the DANC solution on
      intricate areas may be time consuming and cumbersome.
      Difficulties would be comparable to that of painting.

      4.3.3 Secondary Decontamination Treatment
      None expected unless contact between the agent and
      the reactive solution is not achieved.
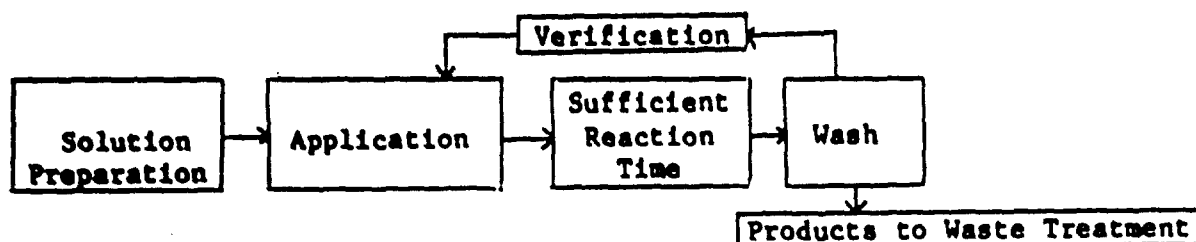
      4.3.4 Clean-up Requirements
      Water wash.

      4.3.5 Waste Treatment and Disposal
      Waste products and water wash must be collected,
      treated and/or incinerated.

   4.4 State-of-the-Art
   DANC was used in the past as a standard decontaminating
   reagent.

5.0 Engineering

5.1 Process Description

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                    ┌──────────────┐
         ┌─────────▶│ Verification │◀─────────┐
         │          └──────────────┘          │
         │                  │                  │
┌──────────────┐   ┌─────────────┐   ┌──────────┐   ┌────────┐
│   Solution   │──▶│ Application │──▶│ Sufficient│──▶│  Wash  │
│ Preparation  │   │             │   │  Reaction │   │        │
└──────────────┘   └─────────────┘   │    Time   │   └────────┘
                                      └──────────┘        │
                                                          ▼
                                     ┌─────────────────────────────┐
                                     │ Products to Waste Treatment │
                                     └─────────────────────────────┘
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5.1.1 Main Process
The DANC solutions are prepared and applied to the structure with a spray gun, paint brush, roller or similar item for thorough surface coating. The liquid is given sufficient time to soak in and react with HD and VX. After decontamination is complete (by verification) the solution is removed by washing with an appropriate wash solution.

5.1.2 Variations
Liquid reagents may also be applied in gels or foams. A variety of gelling and foaming agents may be used. A primary advantage of using gels or foams is that they will maintain a long contact time with the building material which will allow continuous diffusion of reactants and minimize outward vapor diffusion into the building. Furthermore, polymeric backed gels or foams may be heated to facilitiate reactant migration and decontamination rates.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
Agitating tank for solution preparation. Painting equipment for application.

5.2.2 Reliability, Availability and Maintainability
The RAM is expected to be high.

5.3 Decontamination Time

5.3.1 Set-up
Minimal set up time required, just as with painting.

5.3.2 Application Time

5.3.2.1 Personnel
Application time would be equivalent to the time required for painting.

5.3.2.2 Decontamination
Should be relatively fast and complete if contact of sufficient hypochlorite is achieved with VX and HD.

5.3.2.3 Verification
Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Minimal time is required for removal of application equipment.

5.3.3.2 Clean-up
Minimal clean up required. Water wash should be sufficient.

5.4 Safety Requirements

5.4.1 Process Hazards
Corrosive characteristics of DANC solutions may affect application equipment.

5.4.2 Personnel Hazards
Acetylene tetrachloride is an extremely toxic solvent in DANC solution.

5.4.3 Protective Methods
Appropriate protective clothing for applying DANC solutions.

6.0 Economics

6.1 Building Damage - Repair Costs
DANC solutions will probably damage metal surfaces if long application times are required. However, DANC solutions exhibit less corrosiveness properties than do hypochlorite solutions.

6.2 Developmental Costs
Minimal developmental costs are anticipated.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Minimal electricity costs.

6.3.2 Equipment Cost
Minimal: Standard spraying equipment is inexpensive

($200-500). Price may be higher because of special equipment needed to apply corrosive solutions.

6.3.3 Material Cost
Minimal.

6.3.4 Manpower Cost
Minimal and comparable to painting.

7.0 Future Work Required

7.1 Knowledge Gaps
Verification of ability of this method to decontaminate subsurface regions of building materials.

7.2 Resolution
Experimental work.

HYPOCHLORITE SOLUTIONS

1.0 General Description

    1.1 Summary of Idea
        Hypochlorite solutions of STB, HTH, $Ca(OCO)_2$, NaOCl, etc,
        have been recommended for the decontamination of buildings,
        grounds and other large surface areas.

    1.2 Origination of Idea
        Literature (Lewis, 1981; Avenin, 1970; Davis, 1978).

    1.3 Obvious Advantages and Disadvantages
        Advantages Reactive toward HD and VX.

        Disadvantages: Bleaches are reported to be very corrosive.
        May not be applicable to GB. However, Day, 1974 states
        that STB is effective on GF.

    1.4 Variations of Idea
        Variations of hypochlorite solutions exist including HTH,
        STB, etc. The chemistry of these systems are basically identical.

    1.5 Sketch - None.

2.0 Chemical Decomposition Treatment

    2.1 Chemical Reactions

$$HD + OCl^- \rightarrow SO_4^{-2} + Cl^- + CO_2 + H^+ + H_2O \begin{cases} \text{If insufficient } OCl^- \\ \text{Sulfoxide of mustard (rel. toxic)} \\ \text{Sulfone of mustard} \end{cases}$$

$$VX + OCl^- \rightarrow CH_3 - \overset{O}{\underset{OC_2H_5}{P}} - O^- + HN(iPropyl)_2 + SO_4^{-2} + CO_3^{-2} + Cl^- + H_2O$$
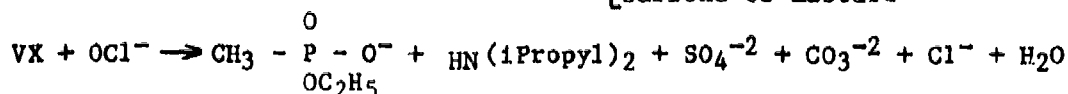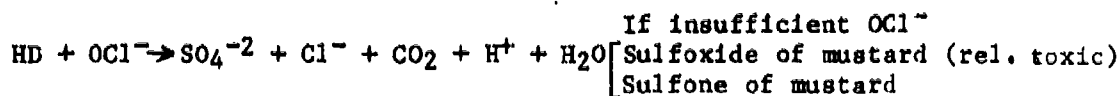
        Highly toxic products form if pH drops below 11.

    2.2 Hazardous Products
        For HD - sulfoxide of mustard is relatively toxic.
        For VX - highly toxic products form if pH drops below 11.

    2.3 Destruction Efficiency, Residue Level
        Destruction efficiency for HD was not reported but above
        reaction assumed with sufficient OCl^- present. Destruction
        efficiency studies for VX are somewhat inconsistent. (Yurow,
        1981).

    2.4 Reaction Rate/Kinetics
        Reaction rates for HD were not reported.
        Reaction with VX is rapid at pH=10 ($t_{1/2}$ = 1.5 minutes)

    2.5 Supplementary Treatment
        Knowledge Gap - wash down walls with H_2O may be suf-
        ficient.

2.6 State-of-the-Art
Much work has been performed with hypochlorite solutions and their ability to decontaminate HD and VX. (Summaries see Yurow, 1981; Stanford, 1981; Mankowich, 1970).

3.0 Physical Treatment
Not applicable.

4.0 Applicability

4.1 Agent Applicability
Only applicable for HD and VX.

4.2 Isolated Building Material Applicability

4.2.1 Impact of Substrate on Chemistry
No effect anticipated.

4.2.2 Removal or Reaction of Contaminant from Surface
Reaction of contaminant on surface is very feasible as long as [OCl$^-$] is sufficient.

4.2.3 Removal or Reaction of Contaminant from Interior
Reaction of contaminant from interior seems feasible only if agent is in direct contact with OCl$^-$.

4.2.4 Damage to Material
Hypochlorite solutions are corrosive.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Paint removal may be necessary although some stripping may be expected from corrosive characteristics of hypochlorite solutions.

4.3.2 Practical Physical Limitations/Methods to Overcome
Spraying, brushing or rolling the hypochlorite solution on intricate areas may be time consuming and cumbersome. Difficulties would be comparable to that of painting.

4.3.3 Secondary Decontamination Treatment
None expected unless contact between the agent and the reactive solution is not achieved.

4.3.4 Clean-up Requirements
Water wash.

4.3.5 Waste Treatment and Disposal
Waste products and water wash must be collected, treated and/or incinerated.

4.4 State-of-the-Art

Hypochlorite have been recommended for large scale decontamination of buildings. (Yurow, 1981)

5.0 Engineering

5.1 Process Description

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                   ┌─────────→│ Verification │←─────────┐
                   │          └──────────────┘          │
 ┌─────────────┐   │   ┌─────────────┐  ┌───────────┐  │  ┌──────┐
 │   Solution  │   │   │             │  │ Sufficient│  │  │      │
 │ Preparation │──→│──→│ Application │─→│  Reaction │─→│─→│ Wash │
 │             │       │             │  │    Time   │     │      │
 └─────────────┘       └─────────────┘  └───────────┘     └──────┘
                                              │
                                              └──→┌──────────────────────────┐
                                                  │ Products to Waste Treatment│
                                                  └──────────────────────────┘
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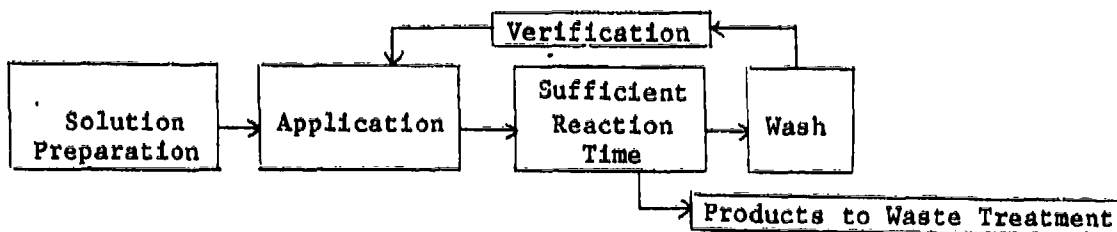
5.1.1 Main Process

The hypochlorite solutions are prepared and applied to the structure with a spray gun, paint brush, roller or similar item for thorough surface coating. The liquid is given sufficient time to soak in and react with HD and VX. After decontamination is complete (by verification) the solution is removed by washing with an appropriate wash solution.

5.1.2 Variations

Liquid reagents may also be applied in gels or foams. A variety of gelling and foaming agents may be used which are compatible with aqueous systems. A primary advantage of using gels or foams is that they will maintain a long contact time with the building material which will allow continuous diffusion of reactants and minimize outward vapor diffusion into the building. Furthermore, polymer-backed gels or foams may be heated to facilitiate reactant migration and decontamination rates.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

Agitating tank for solution preparation. Painting equipment for application.

5.2.2 Reliability, Availability and Maintainability

Because of the corrosivity of the solution the RAM is expected to be moderate.

5.3 Decontamination Time

5.3.1 Set-up

Minimal set up time required, just as with painting.

5.3.2 Application Time

5.3.2.1 Personnel
Application time would be equivalent to the time required for painting.

5.3.2.2 Decontamination
Should be relatively fast and complete if contact of sufficient hypochlorite is achieved with VX and HD.

5.3.2.3 Verification
Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Minimal time is required for removal of application equipment.

5.3.3.2 Clean-up
Minimal clean up required. Water wash should be sufficient.

5.4 Safety Requirements

5.4.1 Process Hazards
Corrosive characteristics of hypochlorite solutions will probably damage application and other process equipment.

5.4.2 Personnel Hazards
Corrosive characteristics of hypochlorite solutions.

5.4.3 Protective Methods
Appropriate protective clothing for applying hypochlorite solutions.

6.0 Economics

6.1 Building Damage - Repair Costs
Hypochlorite solutions will probably damage metal surfaces if long application times are required.

6.2 Developmental Costs
Minimal developmental costs are anticipated.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Minimal electricity costs.

6.3.2 Equipment Cost

Minimal: Standard spraying equipment is inexpensive ($200-500). Price may be higher because of special equipment needed to apply corrosive solutions.

6.3.3 Material Cost

$Ca(OCl)_2$(HTH) is relatively inexpensive in comparison to labor costs.

6.3.4 Manpower Cost

Minimal and comparable to painting.

7.0 Future Work Required

7.1 Knowledge Gaps

Verification of ability of this method to decontaminate subsurface regions of building materials.

7.2 Resolution

Experimental work.

AMMONIA AND STEAM TREATMENT

1.0 General Description

1.1 Summary of Idea
Vapor phase hydrolysis of CW agents (GB, HD, VX) using
ammonia followed by steam. Treat building interiors and
contents by introducing NH_3 gas followed by steam treatment
with containment if needed.

1.2 Origination of Idea
Noted and suggested in (Franke, 1968; Domjan, 1975; Albizo, 1982)

1.3 Obvious Advantages and Disadvantages
Advantage - Gas treatment facilitates penetration of porous
materials and access to otherwise inaccessable structural
configurations.

Disadvantages - Potential difficulty in containing NH_3 and
hazards associated with NH_3. Possible condensation of
water on surfaces, limiting gas penetration. Corrosivity to
cement is unknown.

1.4 Variations of Idea
Heat (hot air) to acheive faster reaction rates high and
prevent steam from condensing.
Use other volatile amines (e.g. dimethyl amine).
Use elevated pressure to aid penetration.
Use super heated steam.

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions

$$ClCH_2CH_2SCH_2CH_2Cl + 4NH_3 \longrightarrow H_2NCH_2CH_2SCH_2CH_2NH_2 + 2NH_4Cl$$
(Mustard)

$$CH_3-\overset{O}{\underset{OC_2H_5}{P}}-SCH_2CH_2N(iPr)_2 + steam \xrightarrow{NH_3} CH_3-\overset{O}{\underset{OC_2H_5}{P}}-OH + HSCH_2CH_2N(iPr)_2$$
(VX)

$$CH_3-\overset{O}{\underset{F}{P}}-OCH(CH_3)_2 + steam \xrightarrow{NH_3} CH_3-\overset{O}{\underset{OH}{P}}-OCH(CH_3)_2 + NH_4F$$
(GB)
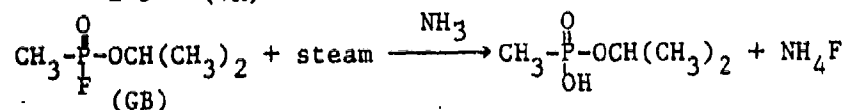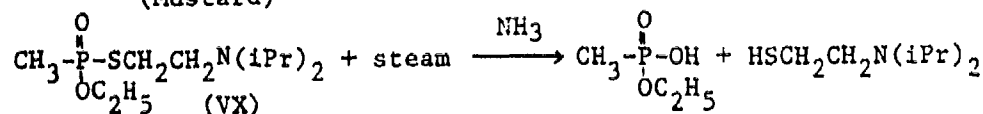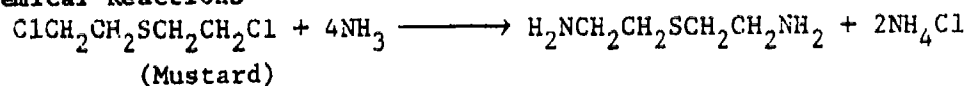
2.2 Hazardous Products - KNOWLEDGE GAP
If GB hydrolysis products becomes neutral or acid, GB may be
regenerate (Epstein, 1975).

2.3 Destruction Efficiency - KNOWLEDGE GAP
Detection limits undefined.

2.4 Reaction rate/kinetics
GB has a half life of 5 minutes (pH = 9.0) at ambient

temperature. (Medema, 1975).
Literature suggests (Medema, 1975) hydrolysis of mustard
occurs in 4-5 minutes, but this is not taking
solubility problems into consideration - KNOWLEDGE GAP.
VX has a half life of 1100 minutes (pH = 9.5) at ambient
temperature. (Jones, 1981)

2.5 Supplementary Treatment
Subsequent wash down with H_2O (under base conditions to
prevent formation of GB).
A significant amount of ammonia may remain in building
materials? KNOWLEDGE GAP.

2.6 State-of-the-Art
Significant literature on hydrolysis and amine alkylation.
is available.

3.0 Physical Treatment - Not applicable

4.0 Applicability

4.1 Agent Applicability
VX, GB, HD

4.2 Isolated Building Material Applicability

4.2.1 Impact of Substrate on Chemistry
Catalytic effect - concrete block (partially composed of
Al_2O_3) may prove to enhance hydrolysis (Medema, 1975).

4.2.2 Removal or Reaction of Contaminant from Surface
Surface reaction highly probable.

4.2.3 Removal or Reaction of Contaminant from Interior
Interior reaction - KNOWLEDGE GAP.

4.2.4 Damage to Material
Corrosivity to cement? KNOWLEDGE GAP.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Paint removal may be necessary. Barrier installation
(bubble or pressure system) may be desirable to keep
gas entrapped.

4.3.2 Practical Physical Limiations
None anticipated. A gaseous decontamination method
should be very flexible.

4.3.3 Secondary Decontamination Treatment
None anticipated.

4.3.4 Clean-up Requirements
Wash down with H_2O.

4.4 State-of-the-Art
Reaction chemistry is well known and documented.
Applications to structures and building materials must be
studied - KNOWLEDGE GAP.

5.0 Engineering

5.1 Process Description

5.1.1 Main Process

5.1.1.1 Paint Removal and Installation of Barriers
KNOWLEDGE GAP.
5.1.1.2 Treatment with NH_3 followed by treatment with
steam.
5.1.1.3 Wash down with water.
5.1.1.4 Dispose of ammonia and waste water solution.

5.1.2 Variations
For Steps 5.1.1.2 and 5.1.1.3, heat may aid kinetics
(e.g., hot air).

5.2 Equipment/Support Facilities Needed

5.2.1 Description
Equipment for efficient removal of paint - KNOWLEDGE
GAP, barrier system (bubble or other system)
(KNOWLEDGE GAP), gas cylinders and ductwork, NH_3
scrubber with pump.

5.2.2 Reliability, Availability and Maintainability
Fairly high considering simplicity of system.

5.3 Decontamination Time

5.3.1 Set-up
Barrier set-up and paint removal may be required.

5.3.2 Application Time

5.3.2.1 Personnel - Regulate NH_3, periodic
inspections.

5.3.2.2 Decontamination - this time would be passive
(no direct involvement of personnel needed).

5.3.2.3 Verification - KNOWLEDGE GAP.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Tear down barrier

5.3.3.2 Clean-up
Wash down walls with water and collect.

5.4 Safety Requirements

5.4.1 Process Hazards
Fire and explosive hazards of ammonia gas.

5.4.2 Personnel Hazards
Protection from NH_3 gas - respiratory gear.
Handling of dilute solutions of ammonia.

5.4.3 Protective Methods
Use respiratory gear when working with NH_3 gas.
Use explosion proof motor on pump and non-sparking
tools.

6.0 Economics

6.1 Building Damage - Repair Costs
None anticipated - potential problem of ammonia leaching out
over a number of months or years needs to be evaluated -
KNOWLEDGE GAP.

6.2 Developmental Costs
Testing of ammonia and steam on contaminated building
materials.
Development of an efficient barrier system.

6.3 Treatment Costs
Minimal considering the cost of ammonia and steam.

6.3.1 Utilities and Fuel Cost
Costs to generate steam.
Costs to heat building if found desirable.

6.3.2 Equipment Cost
Barrier costs.
Scrubber system.
Gas regulators and ductwork.

6.3.3 Material Cost

NH_3 and water.

6.3.4 Manpower Cost
Barrier set-up, wash down and water disposal.

7.0 Future Work Required

7.1 Knowledge Gaps
Corrosivity to cement, product evaluation, destruction efficiency in material matrix, need for paint removal specification of barrier system and explosivity of NH_3/steam mixtures.

7.2 Resolution
Experimental testing.

CHLORINE

1.0 General Description

1.1 Summary of Idea
Chlorine gas released into a contaminated room should react with HD to produce less toxic products. It may not be less effective for decontamination of nerve agents.

1.2 Origination of Idea
Literature reference (Albizo, 1982; Lindsten, 1978; Popoff, 1967).

1.3 Obvious Advantages and Disadvantages
Advantages. Chlorine is a gas which will be accessible to intricate areas.

Disadvantage. Chlorine is toxic. Some HD reaction products may also be toxic. Direct chlorination of bulk VX will start a fire (Benson, 1974). If puddles of agent are present, chlorine may cause formation of an impermeable crust on the surface leaving the agent underneath undecomposed (Prostak, 1956).

1.4 Variations of Idea
Its use could be combined with heating to vaporize agents from interior surfaces; the reaction of HD and Cl_2, both in the vapor phase, is documented (Eldridge, 1927). In presence of water, hypochlorite will be produced which can oxidize with HD, VX, and GB. Chlorination can be expedited by addition of a chlorinated solvent (e.g. dichloroethane) (Domjan, 1975).

1.5 Sketch - not applicable.

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions
Reactions with HD appear to be well established. VX and GB reactions are speculative. See pages III-224 and 225.

2.2 Hazardous Products
Various HD intermediate reaction products are vesicants, therefore less than complete reaction is not suitable. In the presence of water, tetrachlorodiethyl sulfoxide (vesicant) may be an end product.

2.3 Destruction Efficiency, Residue Level
Reported to leave little HD unreacted. With GB, probably ineffective. Benson, 1974 reported that complete decomposition of VX was achieved.
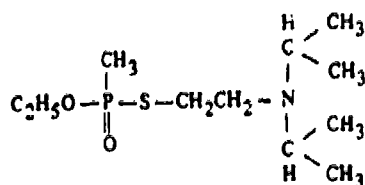
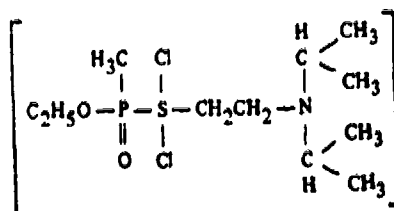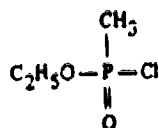2.4 Reaction Rate/Kinetics
Reaction with HD vapor is rapid and complete.

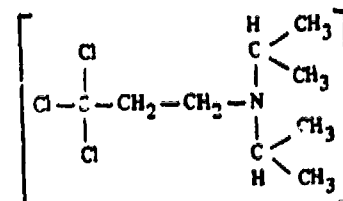2.5 Supplementary Treatment
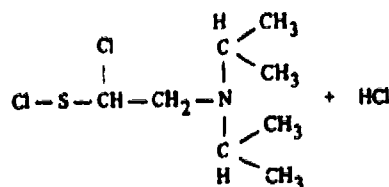Ventilation and water wash down required.

UNCLASSIFIED

VX

Cl$_2$

Ethylmethylphosphonochloridate

+

2-[N,N-diisopropylamino]-ethane sulfenyl trichloride

Cl$_2$

Cl—S—CH—CH$_2$—N + HCl

1-Chloro-2-[N,N-diisopropylamino]-ethane sulfenyl chloride
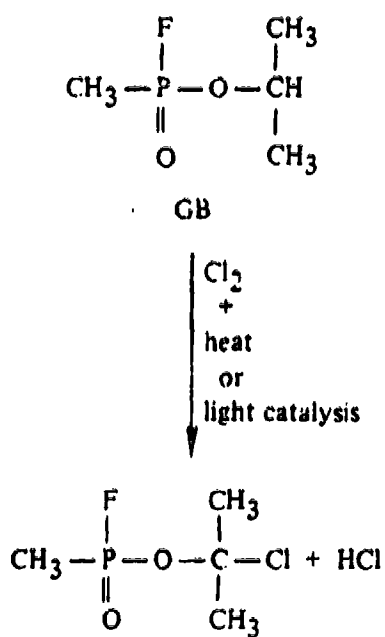
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Figure A-2. (U) The Chlorination of VX with Cl$_2$

(Taken from "New Oxidants and Mechanisms of Oxidation," L. C. Popoff and R. Helitzer, June 1967)
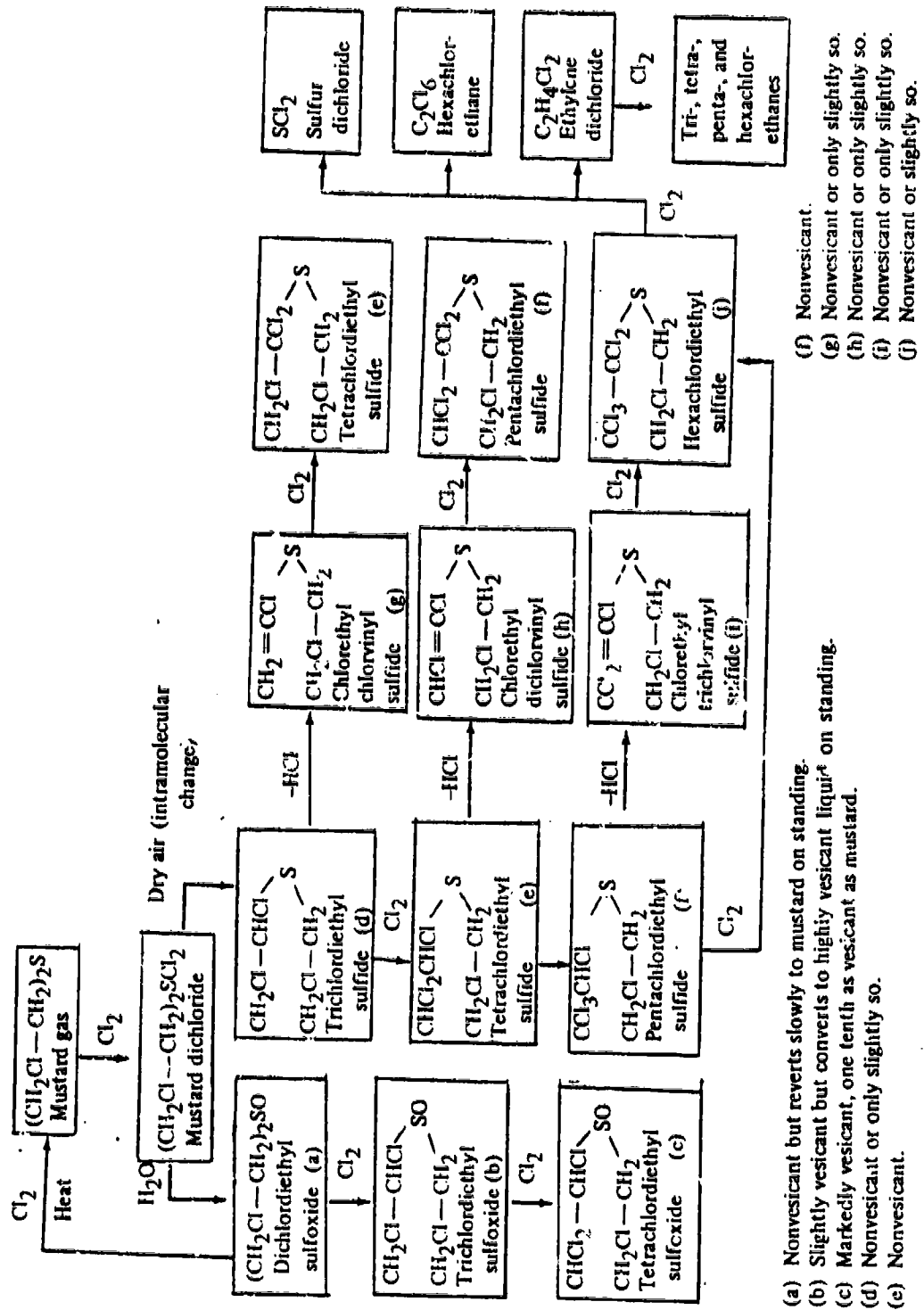
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2-[2-Chloropropyl]-methylphosphonofluoridate

UNCLASSIFIED

Figure A-3. (U) The Chlorination of GB with Cl_2 (Expected Reaction)

UNCLASSIFIED

Figure A-1. (U) The Chlorination of Mustard Gas with Cl_2

(a) Nonvesicant but reverts slowly to mustard on standing.
(b) Slightly vesicant but converts to highly vesicant liquid on standing.
(c) Markedly vesicant, one tenth as vesicant as mustard.
(d) Nonvesicant or only slightly so.
(e) Nonvesicant.
(f) Nonvesicant.
(g) Nonvesicant or only slightly so.
(h) Nonvesicant or only slightly so.
(i) Nonvesicant or only slightly so.
(j) Nonvesicant or slightly so.

UNCLASSIFIED

2.6 State-of-the-Art
Chlorine has been evaluated against HD especially on textiles and surfaces.

3.0 Physical Treatment
Not applicable.

4.0 Applicability
4.1 Agent Applicability
HD reacts rapidly.

4.2 Isolated Building Material Applicability

4.2.1 Impact of Substrate on Chemistry
Substrate should not modify reactions.

4.2.2 Removal or Reaction of Contaminant from Surface
Ventilation will remove unreacted chlorine and HD reaction products. Washing is probably desirable.

4.2.3 Removal or Reaction of Contaminant from Interior
Penetration of porous materials likely to be good for a non-condensible and agent-soluble gas.

4.2.4 Damage to Material
Corrosion of metals, especially in the presence of moisture can be expected. However, with short exposure times and chlorine removal through ventilation and/or aqueous alkali washing, this effect should not be very pronounced.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Paint removal may be necessary. Sealing off and providing an outlet for gas stream also needed.

4.3.2 Practical Physical Limitations/Methods to Overcome
None expected.

4.3.3 Secondary Decontamination Treatment
None expected for HD if carried out in vapor phase. A reapplication may be necessary with VX. Other treatment may be needed for GB.

4.3.4 Clean-up Requirements
Wash with appropriate solvent such as slightly basic solution may be necessary.
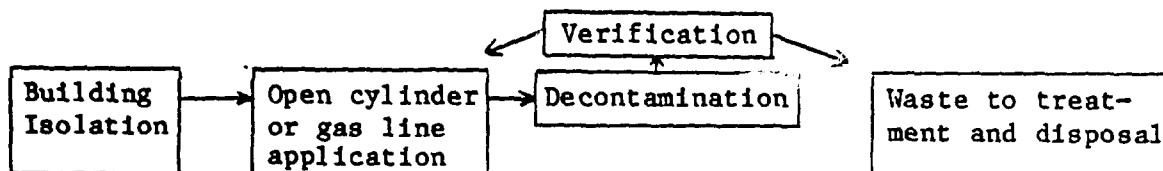
4.3.5 Waste Treatment and Disposal
Reaction products must be treated and disposed of. May incinerate neutralized or chemically treated waste.

4.4 State-of-the-Art
        Has been tested on textiles and surfaces. Cl_2 has also been
        used to decontaminate the internal atmosphere and surfaces
        of buildings exposed to HD (Eldridge, 1927).

5.0 Engineering

5.1 Process Description

```
                              ┌──────────────┐
                  ┌──────────▶│ Verification │◀──────────┐
                  │           └──────────────┘           │
                  │                  ▲                    │
┌───────────┐    ┌─────────────┐    │    ┌────────────────┐    ┌─────────────────┐
│ Building  │───▶│ Open cylinder│──▶│    │ Decontamination│    │ Waste to treat- │
│ Isolation │    │ or gas line │         └────────────────┘    │ ment and disposal│
│           │    │ application │                               │                 │
└───────────┘    └─────────────┘                               └─────────────────┘
```

5.1.1 Main Process
        The building or structure is completely sealed off
        with an outlet for the gaseous product and reactants.
        The Cl_2 gas line or cylinder is opened and the gas
        allowed to migrate throughout the structure. Un-
        reacted gas and gaseous products are collected for
        treatment and disposal. The surface is washed with an
        appropriate wash solution. Another application may be
        necessary.

5.1.2 Variations
        None.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
        Fan to circulate gases in the building; exhaust
        blower; and waste treatment equipment.

5.2.2 Reliability, Availability and Maintainability
        RAM for application/decontamination equipment is high.

5.3 Decontamination Time

5.3.1 Set-up
        Little time needed to set up the cylinders with Cl_2
        gas or the duct work pan or tank. Depends on the size
        and sealing capabilities of the building.

5.3.2 Application Time

5.3.2.1 Personnel
          Little personnel required for equipment set
          up and tear down as well as routine
          maintenance/monitoring. Not a labor
          intensive operation.

5.3.2.2 Decontamination
          Should be complete for HD if contact is
          achieved.

5.3.2.3 Verification
Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Little time needed to remove the cylinders,
duct work, fans and seals.

5.3.3.2 Clean-up
Wash down with appropriate (slightly basic)
solution may be necessary.

5.4 Safety Requirements

5.4.1 Process Hazards
Cl_2 gas is corrosive in a moist environment.

5.4.2 Personnel Hazards
Some products are vesicants. Cl_2 gas is corrosive
and a powerful irritant. Since workers will not be in
the building during decontamination, the degree of
personnel hazard is expected to be minimal.

5.4.3 Protective Methods
Appropriate clothing, eye protection and breathing
apparatus should be worn upon entering the building
following decontamination.

6.0 Economics

6.1 Building Damage – Repair Costs
Minimal damage. Metals may need refinishing.

6.2 Developmental Costs
Some developmental costs are expected to study destruction
efficiency for VX and GB, and waste treatment and disposal
verification.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Minimal. Electricity for fan and blower is required.

6.3.2 Equipment Cost
Relatively inexpensive off-the-shelf equipment can be
used.

6.3.4   Material Cost
May be large, depending on the amount of Cl_2 required. Cl_2 gas costs \$81/150 lb cylinder (99.5% pure).

6.3.4   Manpower Cost
Low. Remote operation only requires routine maintenance.

7.0   Future Work Required

7.1   Knowledge Gaps
Destruction efficiency for GB, VX. Waste treatment and disposal verification.

7.2   Resolution
Experimental work.

STEAM HYDROLYSIS - EXTERNAL STEAM GENERATOR

1.0 General Description

1.1 Summary of Idea

Steaming involves the use of steam combined with an appropriate surfactant to hydrolyze agent contaminants from building materials. In this method the entire building would be flooded with steam from an external steam generator. Condensate would be collected in a sump for treatment.

1.2 Origination of Idea
Novel Processing project team.

1.3 Obvious Advantages and Disadvantages

Advantages. This approach has minimal manpower requirements while providing a simple mechanism to clean an entire building at once. Depending on the depth of the contaminant penetration, physical extraction of agents by steaming may aid in decontamination.

Disadvantages. Only known to be effective for surface decontamination. High temperature steam may cause agents to volatilize. (Davis, 1950).
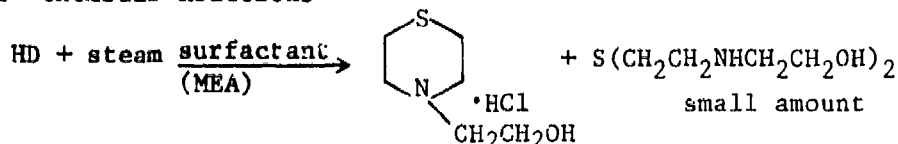
1.4 Variations of Idea
1) Superheated steam, 2) Various types of surfactant could be used, 3) organic solvent/steam mixtures could enhance reaction rate by solubilization of agents, 4) reactant included with steam (e.g., APD or MEA).
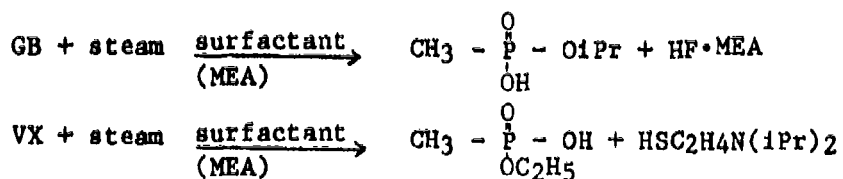
1.5 Sketch
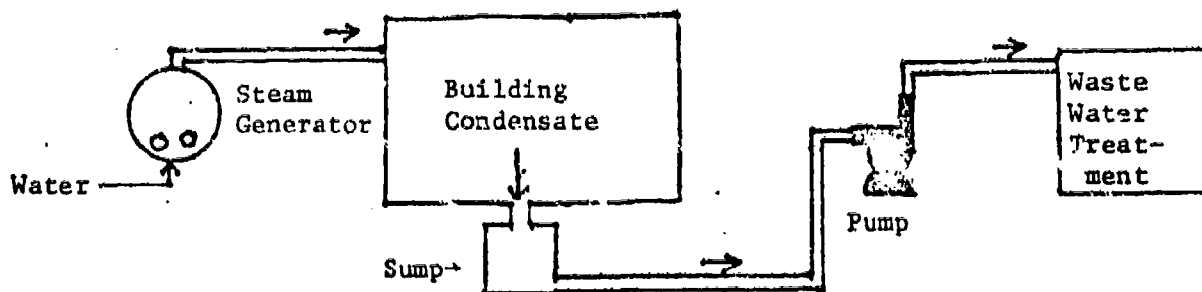
2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions

HD + steam $\xrightarrow{\text{surfactant (MEA)}}$

+ $S(CH_2CH_2NHCH_2CH_2OH)_2$ small amount

$$\text{GB + steam} \xrightarrow[\text{(MEA)}]{\text{surfactant}} \underset{\underset{\text{OH}}{|}}{\overset{\overset{\text{O}}{\|}}{\text{CH}_3 - \text{P}}} - \text{OiPr} + \text{HF} \cdot \text{MEA}$$

$$\text{VX + steam} \xrightarrow[\text{(MEA)}]{\text{surfactant}} \underset{\underset{\text{OC}_2\text{H}_5}{|}}{\overset{\overset{\text{O}}{\|}}{\text{CH}_3 - \text{P}}} - \text{OH} + \text{HSC}_2\text{H}_4\text{N(iPr)}_2$$

2.2 Hazardous Products

Steam hydrolysis should be kept alkaline to insure that GB would not reform. GB has been reported to reform at neutral to acid pH's. (Epstein, 1975).

2.3 Destruction Efficiency, Residue Level

It is believed that the destruction efficiency would be dependent on the surfactant system used. GB and VX should hydrolyze well where HD would be more dependent on the surfactant.

2.4 Reaction Rate/Kinetics

A fast reaction rate (minutes) is anticipated because of enhanced hydrolysis kinetics using an elevated temperature ($100C$) medium. (Davis, 1950).

2.5 Supplementary Treatment

Since the agent has been hydrolyzed or reacted to give non-toxic products, it is anticipated that supplementary treatments will not be required.

2.6 State-of-the-Art

Cante, 1981 addresses many surfactants which may be added to steam with the most versatile and promising surfactant being:

H_2O, 67.5%; Veegum-T, 11.2%; Tergitol 15-5-9, 1%; $\text{BuOC}_2\text{H}_4\text{OH}$, 15%; Carboxymethyl cellulose 0.2%; and Bactericide 0.1%.

Davis, 1950 reported that 100 C steam (no additives) was effective in decontaminating samples exposed to HD in 5-10 minutes with only minute quantities of HD detected in the effluent vapor stream. Steam has been used to decontaminate ton containers of H (Mankowich, 1970).

3.0 Physical Treatment

Not applicable.

4.0 Applicability

4.1 Agent Applicability

Applicable to all agents.

4.2 Isolated Building Material Applicability

Applicable to all building materials.

4.2.1 Impact of Substrate on Chemistry

Alumina in cement may catalyze the decomposition reaction. (Medema, 1975).

4.2.2 Removal or Reaction of Contaminant from Surface
   Complete decomposition of agents from surfaces is
   anticipated.

4.2.3 Removal or Reaction of Contaminant from Interior
   Theoretically, steam could be used to hydrolyze agents
   from interior but a long period of time may be re-
   quired. Paint may act as a barrier.

4.2.4 Damage to Material
   Minor.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
   Set-up ductwork from sump to exterior holding tanks.
   Paint removal may be required unless a water/solvent
   (e.g. acetone) system is employed. Seal off and/or
   insulate doors, windows, etc.

4.3.2 Practical Physical Limitations/Methods to Overcome
   Hydrolysis of agents that have penetrated into the
   building material may be difficult to accomplish
   especially if surface is painted. Paint removal may
   be required.

4.3.3 Secondary Decontamination Treatment
   Other methods may need to be employed to decompose
   agents that have penetrated the surface through cracks
   or pores.

4.3.4 Clean-up Requirements
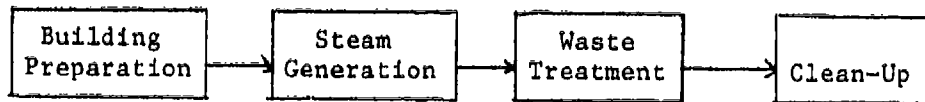   All condensate will have to be collected in sumps.

4.3.5 Waste Treatment and Disposal
   The condensate may contain unreacted agents which will
   have to be treated.

4.4 State-of-the-Art
   Manual steam cleaning is currently used by explosive handling
   and manufacturing facilities to remove explosives from walls,
   floors and equipment. Neither manual steaming or an external
   steam source has been used to treat an entire building at one
   time for agent decontamination.

5.0 Engineering

5.1 Process Description

```
┌──────────────┐     ┌──────────────┐     ┌──────────────┐     ┌──────────────┐
│  Building    │     │   Steam      │     │   Waste      │     │              │
│ Preparation  │────▶│ Generation   │────▶│ Treatment    │────▶│  Clean-Up    │
└──────────────┘     └──────────────┘     └──────────────┘     └──────────────┘
```

5.1.1 Main Process
        Steam is generated using oil, gas, or electric fired
        steam generator located external to building. The
        building is filled with steam. Condensate is collect-
        ed in sumps. The condensate is then removed from
        sumps and treated to destroy any residual agents.

5.1.2 Variations
        An acetone/water steam mixture could be used to
        enhance the agent solubility. The steam could be
        superheated. A wetting agent could be added to the
        steam or applied prior to steaming.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
        Steam generator, pump and collection tanks, waste
        treatment system.

5.2.2 Reliability, Availability and Maintainability
        Very high - due to simplicity.

5.3 Decontamination Time

5.3.1 Set-up
        Minimal - collection systems may have to be designed
        if floor sumps are non-existent while existing sumps
        will need to be checked for leaks. A pumping system
        may be set up to continuously remove condensate from
        sumps.

5.3.2 Application Time

        5.3.2.1 Personnel
                 Minimal - seal off the building, check
                 condensate collection system, monitor steam
                 generation.

        5.3.2.2 Decontamination
                 Dependent on the effectiveness of steam in
                 agent decomposition. Expected to be hours or
                 days.

        5.3.2.3 Verification
                 Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Minimal.

5.3.3.2 Clean-up
A water rinse of the building interior may be desired. Condensate will need to be rinsed from sumps and collection systems.

5.4 Safety Requirements

5.4.1 Process Hazards
None anticipated.

5.4.2 Personnel Hazards
Minimal since personnel will remain outside the building while steaming is being conducted.

5.4.3 Protective Methods
Protective clothes and boots should be worn if personnel enter building.

6.0 Economics

6.1 Building Damage - Repair Costs
Minimal.

6.2 Developmental Costs
Minimal - determine effectiveness of steam on agent hydrolysis and engineering study on applications of steam.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Low - steam generation is relatively inexpensive if (for example) kerosene fired boilers are employed. Steam may also be available from on-site boilers.

6.3.2 Equipment Cost
Low - Steam generator and hoses. Pump and waste water holding tank. Waste water treatment system.

6.3.3 Material Cost
Additives such as surfactants or organic solvents (optional).

6.3.4 Manpower Cost
Low - passive cleaning technique involves only routine maintenance.

7.0 Future Work Required

7.1 Knowledge Gaps

Removal or reaction efficiency of contaminant from interior of porous building materials must be determined. Determination of the proper technique for treatment of condensate. Paint removal necessity. Selection of additives, surfactants, and/or co-solvents.

7.2 Resolution

Experimental testing.

STEAM CLEANING - MANUAL

1.0 General Description

1.1 Summary of Idea
Steaming involves the use of steam with an appropriate
surfactant to chemically decompose by hydrolysis agent
contaminanted building materials. The steam would be
applied to the building through other hand-held wands or
automated systems and the condensate would be collected in a
sump for treatment.

1.2 Origination of Idea
Novel Processing project team.

1.3 Obvious Advantages and Disadvantages
Advantages. Steam cleaning is a relatively inexpensive and
simple mechanism used throughout industry. By using a sur-
factant, the steam would preferentially wet the surface and
pores of building materials. Hydrolysis of residual agents
by steam may be rapid.

Disadvantages. High temperature steam may cause agents to
volatilize more rapidly than the hydrolysis reaction (Davis,
1950). Labor intensive operation if manual approach, costly
process if automated.

1.4 Variations of Idea
Steam could be superheated. An organic solvent/steam mixture
could be used to take advantage of the agent solubility in
organic solvents. Steam-jet action could be employed
see attachment. (Manufacturer's Brochures) A reactive
liquid (e.g. - APD or MEA) may be added to enhance the
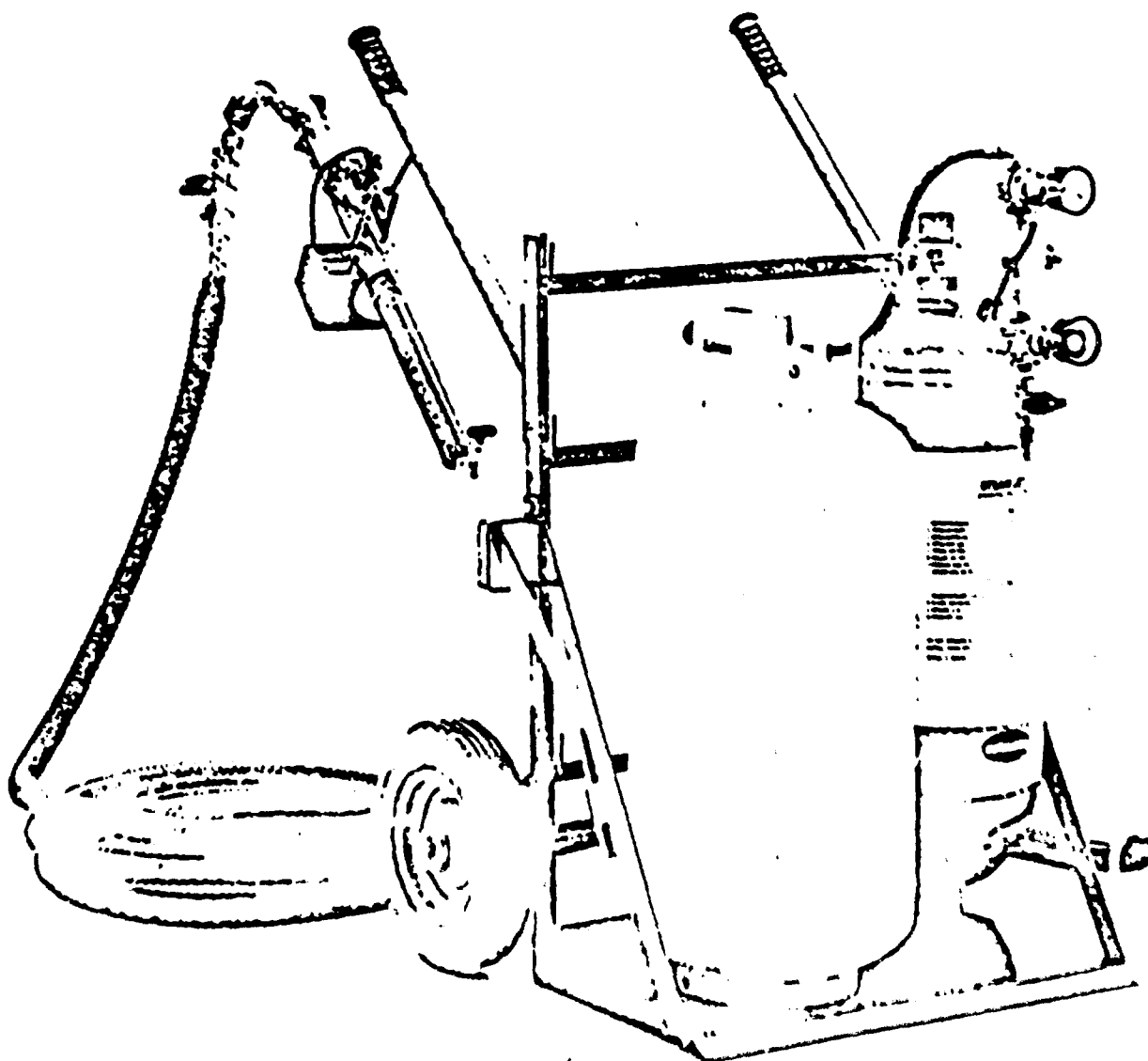decomposition kinetics.

1.5 Sketch
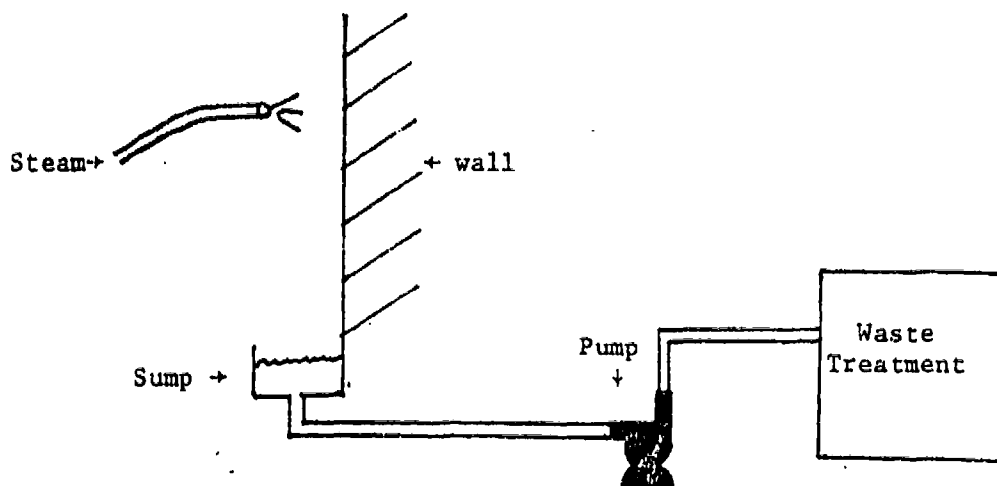
STEAM JET™ SPECIFICATIONS

Weight w/o gas bottle	122 lbs.
Height overall	40 in.
Width overall	30 in.
Depth overall	30 in.
Gas consumption	2 to 4 lbs./hr.
Air consumption	8 to 14 cfm
Detergent tank limit	9 hrs.
Water consumption	30 to 120 gals./hr.
Air pressure requirements	35 to 60 psi
Shipping weight	126 lbs.

HOW IT WORKS

Steam Jet is a revolutionary machine that handles just about any steam-cleaning application more simply, reliably, and efficiently than conventional systems. Simple change of nozzles lets you select light, medium, or heavy levels of cleaning.

Compressed air is mixed with LP gas in a manifold and the mixture is fed into the combustion chamber of the gun. Battery-powered, solid-state ignition is activated by a pushbutton located on the gun. Compressed air also pressurizes the detergent tank, assuring detergent dispensing at any elevation. Water flows under its own pressure and is injected at the downstream end of the combustion chamber.

Steam Jet, Orlando FL (Ref. EG 12)
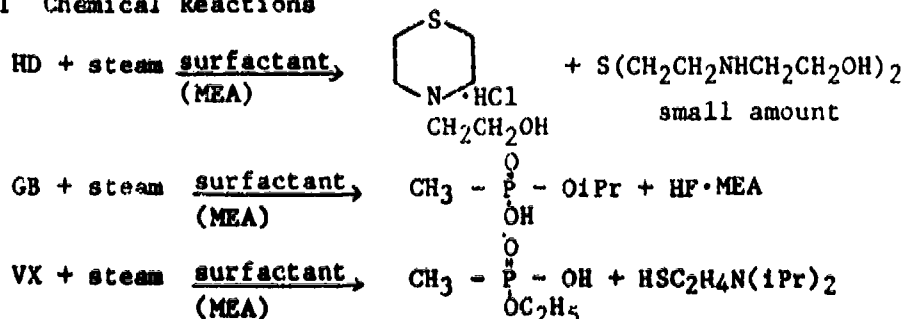
2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions

HD + steam $\xrightarrow{\underline{\text{surfactant}}}$ (MEA)

$$\begin{array}{c} \text{S} \\ \overbrace{} \\ \underset{\text{CH}_2\text{CH}_2\text{OH}}{\text{N} \cdot \text{HCl}} \end{array} + \text{S}(\text{CH}_2\text{CH}_2\text{NHCH}_2\text{CH}_2\text{OH})_2$$

small amount

GB + steam $\xrightarrow{\underline{\text{surfactant}}}$ (MEA) $\quad CH_3 - \overset{O}{\underset{OH}{\overset{\|}{P}}} - OiPr + HF \cdot MEA$

VX + steam $\xrightarrow{\underline{\text{surfactant}}}$ (MEA) $\quad CH_3 - \overset{O}{\underset{OC_2H_5}{\overset{\|}{P}}} - OH + HSC_2H_4N(iPr)_2$

2.2 Hazardous Products

Steam hydrolysis should be kept alkaline to insure that GB would not reform and to avoid the presence of free HF (toxic). GB has been reported to reform at neutral to acid pH's.

2.3 Destruction Efficiency, Residue Level

Knowledge Gap - It is believed that the destruction efficiency would be dependent on the surfactant system used. GB and VX should hydrolyze well where HD would be more dependent on the surfactant.

2.4 Reaction Rate/Kinetics

A fast reaction rate (minutes) is anticipated because of enhanced hydrolysis kinetics using an elevated temperature ($\sim$100C) medium.

2.5 Supplementary Treatment

Since the agent has been hydrolyzed or reacted to give non-toxic products, it is anticipated that supplementary treatments will not be required.

2.6 State-of-the-Art

Cante, 1981 addresses many surfactants which may be added to steam with the moot versatile and promising surfactant being:

H_2O 67.5%; Veegum T, 11.2%; Tergitol 15-5-9, 1%; $BuOC_2H_4OH$, 15%; Carboxymethyl cellulose 0.2%; and Bactericide 0.1%

3.0 Physical Treatment

Not applicable.

4.0 Applicability

4.1 Agent Applicability

Applicable to all agents.

4.2 Isolated Building Material Applicability
Applicable to all building materials.

4.2.1 Impact of Substrate on Chemistry
Alumina in cement may catalyze the decomposition reaction.

4.2.2 Removal or Reaction of Contaminant from Surface
Complete decomposition of agents from surfaces is anticipated.

4.2.3 Removal or Reaction of Contaminant from Interior
Probably poor since agents have limited solubilities in water. Theoretically, steam could be used to hydrolyze agents from interior but a long period of time may be required for penetration. Paint may act as a barrier.

4.2.4 Damage to Material
Minor.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Minimal set-up of piping from sump to exterior holding tanks. Paint removal may be required unless a water/solvent system is employed.

4.3.2 Practical Physical Limitations/Methods to Overcome
Decomposition of agents that have penetrated into the layer may not be possible by manual steaming.

4.3.3 Secondary Decontamination Treatment
Other methods may need to be employed to decompose agents that have penetrated the surface through cracks or pores.

4.3.4 Clean-up Requirements
All condensate will be collected in sumps.

4.3.5 Waste Treatment and Disposal
The condensate may contain unreacted agents which will have to be treated further.

4.4 State-of-the-Art
Manual steam cleaning is currently used by explosive handling and manufacturing facilities to remove explosives from walls, floors and equipment, although it has not been used on buildings contaminated with agents. Homestead Industries, Inc. Manufacturer's Brochures is one of the many manufactures of portable steam cleaning equipment (see attachment).

JENNY SUPER 200-C

Jenny Super 200-C two-way cleaning has a penetrating 72 gph vapor spray to melt and emulsify grease and oil on contact. Its powerful 140 gph, 600 psi pressure wash spray lifts and floats away caked dirt and grime like a "hydraulic chisel." And no matter what the output, the pump speed remains the same—a slow 300 rpm. A full-cover is optional.

Certified

```
PUMP OUTPUT—Steam Cleaner .......... 72 gph
PUMP OUTPUT—Pressure Washer ...... 140 gph
WASH PRESSURE..................... 600 psi
PUMP TYPE ..................... duplex piston
PUMP SPEED ....................... 300 rpm
CHECK VALVES...... ... non-corrosive disc type
SOLUTION TANK..................... 6 gallons
FUEL TANK......................... 6 gallons
BURNER JET SIZE .................... 2¼ gph
CLEANING HOSE ................... ¼" ID x 25'
CLEANING GUN............ insulated ⅜" x 40"
DIMENSIONS .............. 50"L x 27"W x 33"H
WEIGHTS ........... 252 lbs. net, 302 lbs. crated
```
(Complete specifications on Form No 02-70-2)

JENNY 760-C

Jenny Series 760-C Combination Steam Cleaner/Pressure Washer has the same efficiency—same dependability—as the 760 Steam Cleaner, but with an added 180 gph 600 psi wash spray. Because of its size and versatility Jenny 760-C can be used in industrial maintenance shops, car dealer reconditioning and de-waxing departments, fleets, implement repair shops, garages, food and meat processing plants. Gasoline engine driven model shown
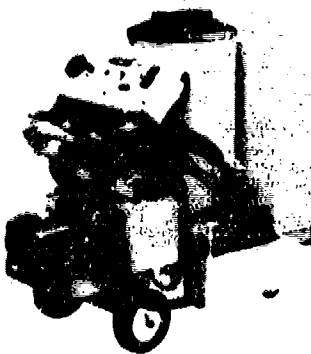
Certified

```
PUMP OUTPUT—Steam Cleaner ........ 100 gph
PUMP OUTPUT—Pressure Washer ...... 180 gph
WASH PRESSURE..................... 600 psi
PUMP TYPE ..................... duplex piston
PUMP SPEED ....................... 260 rpm
CHECK VALVES......... non-corrosive disc type
SOLUTION TANK .................. 12 gallons
FUEL TANK....................... 12 gallons
BURNER JET SIZE ................... 2¼ gph
CLEANING HOSE.................. ½" ID x 25"
CLEANING GUN ...... swivel, insulated, ⅜" x 46"
DIMENSIONS .............. 47"L x 27"W x 41"H
WEIGHTS ........... 395 lbs. net, 445 lbs. crated
```
(Complete specifications on Form 02-70-5)

JENNY 1000-C

The Jenny 1000-C combination Steam Cleaner/Pressure Washer is efficiency and versatility in a compact design For those cleaning jobs which require a high impact vapor spray to melt and emulsify grease and grime it's 325° F 350 psi cleaning spray is up to handling the job. Should pressure washing be needed to wash away dirt and oil the 1000-C's 240 gph at 1200 psi pressure wash action is powerful enough to perform those tasks in record time

```
PUMP OUTPUT (Steam Cleaner) ...... 130 gph ¼
                              350 psi, up to 325° F
PUMP OUTPUT (Pressure Washer)....... 240 gph
WASH PRESSURE AND TEMPERATURE 1200 psi,
                              up to 200° F
PUMP TYPE...................... triplex piston
PUMP SPEED ........................ 1025
CHECK VALVES......... non-corrosive disc type
SOLUTION TANK ................. 12 gallons
FUEL TANK....................... 12 gallons
BURNER JET SIZE ...................... 2.5
CLEANING GUN ................... ⅜ x 60'
DIMENSIONS............... 47"L x 27"W x 41"H
WEIGHT ........... 395 lbs. net, 445 lbs. crated
```

JENNY 1600-C

Jenny Series 1600-C Combination Steam Cleaner/Pressure Washer takes up where Jenny 1560 leaves off. In addition to its 150 plus gph high-impact vapor, it also produces a powerful 300 gph pressure spray for washing or rinsing Thick, heavy dirt and grease on trucks, trailers, construction equipment and machinery are no match for Jenny Series 1600-C
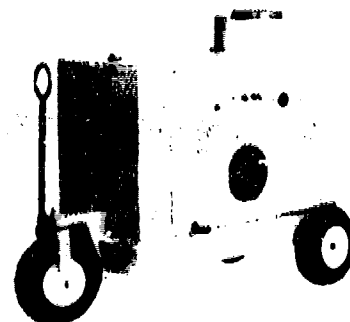
```
PUMP OUTPUT—Steam Cleaner ........ 150 gph
PUMP OUTPUT—Pressure Washer ...... 300 gph
WASH PRESSURE..................... 250 psi
PUMP TYPE ..................... duplex piston
PUMP SPEED ....................... 300 rpm
CHECK VALVES......... non-corrosive disc type
SOLUTION TANK .................. 20 gallons
FUEL TANK....................... 20 gallons
BURNER JET SIZE .................... 4 gph
CLEANING HOSE.................. ½" ID x 25'
CLEANING GUN ...... swivel, insulated, ⅜" x 46"
DIMENSIONS .............. 90"L x 41"W x 65"H
WEIGHTS ......... 815 lbs. net, 990 lbs. crated
```
(Complete specifications on Form No 02-70-21)

Specifications subject to change without notice.

5.0 Engineering

5.1 Process Description

| Building Preparation | → | Steaming | → | Waste Treatment | → | Clean-Up |

5.1.1 Main Process

Steam is generated using oil, gas, or electric fired steam generators. The steam is applied to the walls through either a hand held wand or automated system. The condensate is collected in sumps. The condensate is then removed and treated to destroy any residual agents.

5.1.2 Variations

Steam could be generated in the form of a water/solvent mixture to enhance solubility. A wetting agent could be mixed with the steam. The steam could be superheated. Steam-jet systems could be used for higher fuel efficiency.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

Steam generators, spray systems, collection sumps, waste treatment system.

5.2.2 Reliability, Availability and Maintainability

Quite high - commercial scale steam cleaners are available from many manufacturers (Manufacturer's Brochures).

5.3 Decontamination Time

5.3.1 Set-up

Minimal - collection systems may have to be designed if floor sumps are inadequate. Existing sumps will need to be checked for leaks. A pumping system may be set up to continuously remove condensate.

5.3.2 Application Time

5.3.2.1 Personnel

Probably extensive - dependent on the size and complexity of building. Automated steam wands may reduce personnel time for decontamination of large buildings.

5.3.2.2 Decontamination
Time dependent on the technique used for condensate treatment and effectiveness of steam in accomplishing agent hydrolysis.

5.3.2.3 Verification
Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Minimal.

5.3.3.2 Clean-up
A water rinse of the building interior may be desired. Condensate will need to be rinsed from sumps and collection systems.

5.4 Safety Requirements

5.4.1 Process Hazards
None anticipated.

5.4.2 Personnel Hazards
Steam burns; acetone/steam mixtures are slightly toxic; agent volatilization.

5.4.3 Protective Methods
Breathing apparatus will be required to protect against any volatilized agent. Protective clothing including boots is recommended.

6.0 Economics

6.1 Building Damage - Repair Costs
Minimal.

6.2 Developmental Costs
Minimal - Steam generators/cleaners and other support equipment is commercially available and technology exists for the treatment of agent contaminated water.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Low - steam generation is relatively inexpensive.

6.3.2 Equipment Cost
Steam cleaners $2000-5000 (Manufacturer's Brochures). Pump and waste water holding tank. Waste water treatment system.

6.3.3 Material Cost
Additives such as surfactants or acetone (optional).

6.3.4 Manpower Cost
Probably high — steam must be applied to all surfaces and may be more than one application may be necessary. Water rinse required. Automated steam wands may reduce manpower cost but increase equipment costs.

7.0 Future Work Required

7.1 Knowledge Gaps
Removal or reaction efficiency of contaminant from interior of porous building materials must be determined. The proper technique for treatment of condensate will need to be selected. Paint removal necessity. Selection of additives, surfactants, and/or co-solvents.

7.2 Resolution
Experimental testing.

PERCHLORYL FLUORIDE

1.0 General Description

1.1 Summary of Idea
ClO_3F is a good oxidizing agent capable of permeating materials and inaccesible spaces to oxidize agents.

1.2 Origination of Idea
(Popoff, 1967; Albizo, 1982).

1.3 Obvious Advantages and Disadvantages
Advantages: Active against HD in vapor phase or in very thin films.

Disadvantages: Can present an explosion hazard if contacted with reducing agents (i.e. alcohol). Forms a film (of products) on HD, limiting penetration. Forms salts with VX which can be regenerated to the active agent on neutralization.

1.4 Variations of Idea
None

1.5 Sketch
None

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions
$HD + ClO_3F \longrightarrow (ClCH_2CH_2)_2S=O$
$VX + ClO_3F \longrightarrow$ fragmentary products
$GB + ClO_3F \longrightarrow$ unknown
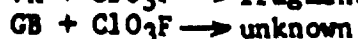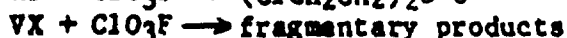
2.2 Hazardous Products
Unknown except that bis(2-chloroethyl) sulfoxide is not entirely inoccuous and may revert to HD. Some of VX forms a salt from which VX may be regenerated. Other toxic products are possible.

2.3 Destruction Efficiency, Residue Level
Knowledge gap.

2.4 Reaction Rate/Kinetics
9.5-11.5% VX remains after 30 minutes on cloth.
31% VX remains on glass after undefined exposure time.

2.5 Supplementary Treatment
Difficult to define since both efficiancy of destruction and nature of reaction products are not reported in detail.

2.6 State-of-the-Art
Some evaluation has been conducted but the results are inconclusive.

3.0 Physical Treatment
    Not applicable

4.0 Applicability
    4.1 Agent Applicability
        Possible application to HD; applicability to nerve agents is
        in doubt.

    4.2 Isolated Building Material Applicability

        4.2.1 Impact of Substrate on Chemistry
              None expected.

        4.2.2 Removal or Reaction of Contaminant from Surface
              Surface removal of HD should be complete if used in
              the vapor phase or in a very thin film. Incomplete if
              a film of product is formed between the reagent and
              the agent. No reaction with nerve agents.

        4.2.3 Removal or Reaction of Contaminant from Interior
              Some reaction with HD from interior is expected since
              ClO_3F can penetrate some materials.

        4.2.4 Damage to Material
              ClO_3F is a strong oxidating agent. Corrosive under
              moist conditions. No damage to materials is expected
              unless metals are moist or there are reducing agents
              present (not expected).

    4.3 Practical Applicability to Building

        4.3.1 Building Preparation
              Sealing off and providing an outlet for gas stream.
              Paint removal may be necessary.

        4.3.2 Practical Physical Limitations/Methods to Overcome
              None expected.

        4.3.3 Secondary Decontamination Treatment
              None required if reaction is carried in the vapor
              phase. Reapplication if a film of material produced
              interferes with the contact between HD and ClO_3F.

        4.3.4 Clean-up Requirements
              Wash with appropriate solvent to remove film of
              products deposited on the surface.

        4.3.5 Waste Treatment and Disposal
              Knowledge gap. Reaction products are unknown but

waste must be treated and disposed of probably
via incineration.

4.4 State-of-the-Art
Experimental work is inconclusive. Has not been evaluated
with contaminated structures.

5.0 Engineering

5.1 Process Description

5.1.1 Main Process
The building or structure is completely sealed off
with an outlet for the gaseous products and reactants.
The ClO₃F cylinder is opened and allowed to
migrate throughout the structure. Unreacted gas and
gaseous products are collected for treatment and
disposal. Solid film is removed from the surface with
appropriate wash solution. This waste is also treated
and disposed of. Another application is carried out
if necessary.

5.1.2 Variations
None

5.2 Equipment/Support Facilities Needed

5.2.1 Description
Fan to circulate gases in the building exhaust blower,
waste treatment equipment.

5.2.2 Reliability, Availability and Maintainability
RAM for application/decontamination equipment is high.
Knowledge gap for waste treatment equipment.

5.3 Decontamination Time

5.3.1 Set-up
Modest — set up the cylinders with ClO₃F. Will
depend on size and sealing capabilities of the
building.

5.3.2 Application Time

5.3.2.1 Personnel
Small — little personnel required for

equipment set-up and tear down as well as
routine maintenance/monitoring. Not a labor
intensive operation.

5.3.2.2 Decontamination
Could be complete if contact is achieved.

5.3.2.3 Verification
Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Small - to remove cyclinders and fan. Remove
seals.

5.3.3.2 Clean-up
Wash down with appropriate solutions may be
necessary.

5.4 Safety Requirements

5.4.1 Process Hazards
ClO_3F may explode if brought in contact with
reducing agents, e.g. alcohols.

5.4.2 Personnel Hazards
ClO_3F may be absorbed through the skin and is
poisonous but since workers will not be in the
building during decontamination the degree of
personnel hazards is reduced. Unknown products are
potential hazards.

5.4.3 Protective Methods
None required. Appropriate cloth, eye protection and
breathing mask should be worn in the building
immediately after application.

6.0 Economics

6.1 Building Damage - Repair Costs
Small (unless explosion occurs.)

6.2 Developmental Costs
Evaluation of substantial destruction efficiency, reaction
product/waste treatment and disposal, verification,
applicability to buildings/diffusivity, applicability to
nerve agents required.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost

Small - electricity for fan and blower. Unknown for waste treatment.

6.3.2 Equipment Cost
Small - relatively inexpensive off-the-shelf equipment can be used.

6.3.3 Material Cost
Depends on amount required. May be large.

6.3.4 Manpower Cost
Low - remote operation only requires routine maintenance.

7.0 Future Work Required

7.1 Knowledge Gaps
Destruction efficiency, reaction products, waste treatment and disposal, verification, applicability to buildings/ diffusivity, applicability to nerve agents.

7.2 Resolution
Experimental work.

HYDROLYSIS WITH A COPPER LIGAND

1.0 General Description

    1.1 Summary of Idea
        Apply an aqueous solution of tetramethylethylenediamine-
        Cu(II) to a contaminated surface to rapidly hydrolyze
        GB.

    1.2 Origination of Idea
        Literature references (Courtney, 1957; Wagner-Jauregg, 1955);
        Gustafson, 1962; Morgan, 1968).

    1.3 Obvious Advantages and Disadvantages
        Advantages. Fast hydrolysis of GB.

        Disadvantages. Not demonstrated for VX, HD.

    1.4 Variations of Idea
        Other metals: $UO_2(VI)$, $ZrO(IV)$, $Th(IV)$, or $MoO_2(VI)$.
        Other ligands: amino acids, peptides, phenols, 5-sulfo-8-
        hydroxyquinoline.

    1.5 Sketch
        Not applicable.

2.0 Chemical Decomposition Treatment

    2.1 Chemical Reactions

$$CH_3-\underset{\underset{\text{O-iPr}}{|}}{\overset{\overset{O}{\|}}{P}}-F \quad + \quad H_2O \longrightarrow CH_3-\underset{\underset{\text{O-iPr}}{|}}{\overset{\overset{O}{\|}}{P}}-OH \quad + \quad HF$$
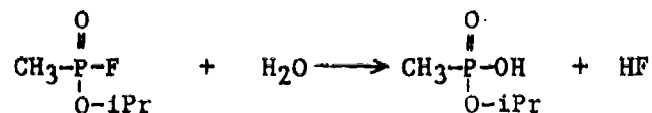
    2.2 Hazardous Products
        HF is strong acid.

    2.3 Destruction Efficiency, Residue Level
        Knowledge Gap.

    2.4 Reaction Rate/Kinetics
        Cu(II): TMEN : GB (5:5:1)
        $t_{1/2} = 0.5$ min $k_1 = 1.4$

    2.5 Supplementary Treatment
        None.

    2.6 State-of-the-Art
        Chemistry known.

3.0 Physical Treatment
    Not applicable.

4.0 Applicability

4.1 Agent Applicability
     GB; may be applicable to other agents.

4.2 Isolated Building Material Applicability

     4.2.1 Impact of Substrate on Chemistry
          None anticipated.

     4.2.2 Removal or Reaction of Contaminant from Surface
          Good removal from surface.

     4.2.3 Removal or Reaction of Contaminant from Interior
          Knowledge gap.

     4.2.4 Damage to Material
          None anticipated.

4.3 Practical Applicability to Building

     4.3.1 Building Preparation
          Strip paint.

     4.3.2 Practical Physical Limitations/Methods to Overcome
          None anticipated.

     4.3.3 Secondary Decontamination Treatment
          None anticipated.

     4.3.4 Clean-up Requirements
          Wash walls with water to remove reagents and products.

     4.3.5 Waste Treatment and Disposal
          Knowledge gap. The acid (HF) requires neutralization
          before disposal.

4.4 State-of-the-Art
     Not used on buildings.

5.0 Engineering

5.1 Process Description

     5.1.1 Main Process
          The reactive liquid a solution of tetramethyl-
          thylenediamine-Cu II is mixed thoroughly and applied
          to the structure with a spray gun, paint brush,
          roller, or similar item to thoroughly coat the
          surface. The liquid is allowed to soak in and react
          with the agent. After decontamination is completed

the solution is removed by washing with water or an organic solvent.

5.1.2 Variations

Liquid reagents systems may also be applied in gels or foams. A variety of gelling and foaming agents may be used which are compatible with both aqueous based and organic solvents. A primary advantage of using gels or foams is that they permit a longer contact time which will allow continuous diffusion of reactant into the material for decontamination. Polymeric or plastic sheeting backings may be applied to the gels and foams to insure inward migration of reactants and minimize outward vapor diffusion into the building. Furthermore, these backed gels or foams may be heated to facilitate reactant migration and increase decontamination rates.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

An agitation tank for preparing mix.
Painting equipment for application.

5.2.2 Reliability, Availability and Maintainability

The RAM is expected to be high.

5.3 Decontamination Time

5.3.1 Set-up

Minimal set up time required, just as with painting.

5.3.2 Application Time

5.3.2.1 Personnel

Application time would be equivalent to the time required for painting.

5.3.2.2 Decontamination

Should be immediate.

5.3.2.3 Verification

Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal

Minimal time is required for removal of application equipment.

5.3.3.2 Clean-up

Minimal clean up required. A fresh solvent wash may be sufficient.

5.4 Safety Requirements

    5.4.1 Process Hazards
        Knowledge gap. No hazard associated with the
        application method.

    5.4.2 Personnel Hazards
        Hydrofluoric acid is highly irritating and poisonous
        and may not be painful or visible for hours.

    5.4.3 Protective Methods
        Appropriate clothing, eye and breathing protection may
        be required.

6.0 Economics

6.1 Building Damage – Repair Costs
    None anticipated.

6.2 Developmental Costs
    Minimal. Destruction efficiency data and interior
    decontamination waste generation and disposal need to be
    developed.

6.3 Treatment Costs

    6.3.1 Utilities and Fuel Cost
        Minimal: electricity for the mixer and the pump.

    6.3.2 Equipment Cost
        Minimal: brushes and rollers may be obtained from the
        neighborhood hardware store. Standard spraying
        equipment is inexpensive ($200-500).

    6.3.3 Material Cost
        May be high depending on the amount of chelate
        required and its cost. ($20/1b laboratory reagent).

    6.3.4 Manpower Cost
        Small: same as painting.

7.0 Future Work Required

7.1 Knowledge Gaps
    Application to buildings.
    Application to other agents.
    Destruction efficiency.
    Interior decontamination.
    Waste generation and disposal.

7.2 Resolution
    Experimental work.

HYDROLYSIS WITH A VANADIUM CATALYST

1.0 General Description

    1.1 Summary of Idea
        Wet surfaces are washed with a solution of $VO^{+2}-AlF_3$ to rapidly hydrolyze VX.

    1.2 Origination of Idea
        Literature reference (O'Connell, 1968).

    1.3 Obvious Advantages and Disadvantages
        Speeds up hydrolysis of VX. Probably applicable to GB as well.
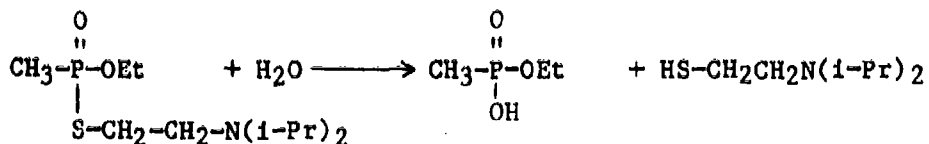
    1.4 Variations of Idea
        None.

    1.5 Sketch
        Not applicable.

2.0 Chemical Decomposition Treatment

    2.1 Chemical Reactions

$$CH_3-\overset{\overset{O}{\|}}{\underset{\underset{S-CH_2-CH_2-N(i-Pr)_2}{|}}{P}}-OEt \quad + H_2O \longrightarrow CH_3-\overset{\overset{O}{\|}}{\underset{\underset{OH}{|}}{P}}-OEt \quad + HS-CH_2CH_2N(i-Pr)_2$$

    2.2 Hazardous Products
        Knowledge Gap.

    2.3 Destruction Efficiency, Residue Level
        Knowledge Gap. Expected to be complete where contact is achieved.

    2.4 Reaction Rate/Kinetics
        $t_{1/2}$ = 41 mins for first 3 hours; $t_{1/2}$ = 121 mins after 3 hrs.

    2.5 Supplementary Treatment
        May need reapplication if the surface is not completely wetted with the reagent.

    2.6 State-of-the-Art
        Known chemistry.

4.0 Applicability

    4.1 Agent Applicability
        VX, and possibly GB.

4.2 Isolated Building Material Applicability

    4.2.1 Impact of Substrate on Chemistry
        None expected.

    4.2.2 Removal or Reaction of Contaminant from Surface
        Good surface removal.

    4.2.3 Removal or Reaction of Contaminant from Interior
        Knowledge Gap.

    4.2.4 Damage to Material
        None anticipated.

4.3 Practical Applicability to Building

    4.3.1 Building Preparation
        Strip paint.
        Wet walls with H_2O

    4.3.2 Practical Physical Limitations/Methods to Overcome
        None anticipated.

    4.3.3 Secondary Decontamination Treatment
        None.

    4.3.4 Clean-up Requirements
        Wash walls with water to remove reactants and
        products.

    4.3.5 Waste Treatment and Disposal
        Knowledge gap. Derivatives may require special
        disposal.

4.4 State-of-the-Art
    Never used on buildings.

5.0 Engineering

5.1 Process Description

    5.1.1 Main Process
        The reactive liquid is mixed thoroughly and applied to
        the wet structure with a spray gun, paint brush,
        roller, or similar item to thoroughly coat the surface
        as if it was being painted. The liquid is allowed to
        soakin and react with the agent. After decontamina-
        tion is completed the solution is removed by washing
        with water.

5.1.2. Variations

Liquid reagents systems may also be applied in gels or foams. A variety of gelling and foaming agents may be used which are compatible with both aqueous based and organic solvents. a primary advantage of using gels or foams is that they will maintain a long contact time with the building material which will allow continuous diffusion of reactant into the material for decontamination. Polymeric or plastic sheeting backings may be applied to the gels and foams to insure inward migration of reactants and minimize outward vapor diffusion into the building. Furthermore, these backed gels or foams may be heated to facilitate reactant migration and increase decontamination rates.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

An agitation tank for preparing mix,
Painting equipment for application.

5.2.2 Reliability, Availability and Maintainability

The RAM is expected to be high.

5.3 Decontamination Time

5.3.1 Set-up

Minimal set up time required, just as with painting.

5.3.2 Application Time

5.3.2.1 Personnel

Application time would be equivalent to the time required for painting.

5.3.2.2 Decontamination

Expected to be fairly short.

5.3.2.3 Verification

Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal

Minimal time is required for removal of application equipment.

5.3.3.2 Clean-up

Minimal clean up required. A solvent wash may be sufficient.

5.4 Safety Requirements

  5.4.1 Process Hazards
        None expected. Knowledge Gap.

  5.4.2 Personnel Hazards
        None expected. Knowledge Gap.

  5.4.3 Protective Methods
        None required. Knowledge Gap.

6.0 Economics

  6.1 Building Damage - Repair Costs
      None expected.

  6.2 Developmental Costs
      Substantial. Decomposition products and destruction
      efficiency data, waste treatment and disposal requirements
      need to be developed.

  6.3 Treatment Costs

    6.3.1 Utilities and Fuel Cost
          Minimal. Electricity for the mixer and the pump.

    6.3.2 Equipment Cost
          Minimal. Brushes and rollers may be obtained from the
          neighborhood hardware store. Standard spraying
          equipment is inexpensive ($200-500).

    6.3.3 Material Cost
          May be large depending on the amount required and its
          availability.

    6.3.4 Manpower Cost
          Minimal.

7.0 Future Work Required

  7.1 Knowledge Gaps
      Decomposition products, destruction efficiency,
      applicability to agents, and waste treatment and disposal.

  7.2 Resolution
      Experimental work.

ANTHRANILIC ACID-SILVER COMPLEXATION

1.0 General Description

    1.1 Summary of Idea
        Contaminated surfaces are sprayed with anthranilic acid and silver nitrate to decompose HD.

    1.2 Origination of Idea
        Literature reference (Megson, 1969).

    1.3 Obvious Advantages and Disadvantages
        Advantage. Effective on HD.

        Disadvantages. Large excess of expensive reagent is used. The method is reported to apply to HD only.

    1.4 Variations of Idea
        None.

    1.5 Sketch
        None.

2.0 Chemical Decomposition Treatment

    2.1 Chemical Reactions
        Knowledge Gap.

    2.2 Hazardous Products
        Knowledge Gap.

    2.3 Destruction Efficiency, Residue Level
        60 µg of HD was completely inactivated by 4000 µg of reagent (Megson, 1969).

    2.4 Reaction Rate/Kinetics
        Knowledge Gap.

    2.5 Supplementary Treatment
        None implied.

    2.6 State-of-the-Art
        Successfully applied to cellulosic fabric used for protective clothing.

3.0 Physical Treatment
    Not applicable.

4.0 Applicability

    4.1 Agent Applicability
        HD.

4.2 Isolated Building Material Applicability

    4.2.1 Impact of Substrate on Chemistry
        None expected.

    4.2.2 Removal or Reaction of Contaminant from Surface
        Knowledge Gap. Should be complete once contact is achieved.

    4.2.3 Removal or Reaction of Contaminant from Interior
        Knowledge Gap.

    4.2.4 Damage to Material
        None expected.

4.3 Practical Applicability to Building

    4.3.1 Building Preparation
        Paint removal may be required.

    4.3.2 Practical Physical Limitations/Methods to Overcome
        None expected.

    4.3.3 Secondary Decontamination Treatment
        None expected.

    4.3.4 Clean-up Requirements
        Wash walls with water to remove reagent and products.

    4.3.5 Waste Treatment and Disposal
        Knowledge Gap.

4.4 State-of-the-Art
    Has not been applied to buildings.

5.0 Engineering

5.1 Process Description

    5.1.1 Main Process
        Anthranilic acid is applied to the brush, roller or similar item to thoroughly coat the surface. A solution of $Ag\ NO_3$ is then sprayed on and allowed to react with HD. After decontamination is completed the solution is removed by washing with an appropriate wash. The acid and $AgNO_3$ may be mixed and applied simultaneously (Knowledge Gap).

    5.1.2 Variations
        Liquid reagents systems may also be applied in gels or foams. A variety of gelling and foaming agents may be

used which are compatible with both aqueous based and
organic solvents. A primary advantage of using gels
or foams is that they will maintain a long contact
time with the building material which will permit
continuous diffusion of reactant into the material for
decontamination. Polymeric or plastic sheeting
backings may be applied to the gels and foams to
insure inward migration of reactants and minimize
outward vapor diffusion into the building. Further-
more, these backed gels or foams may be heated to
facilitate reactant migration and increase decontam-
nation rates.

5.2 Equipment/Support Facilities Needed

5.2.1 Description
An agitation tank for preparing mix.
Painting equipment for application.

5.2.2 Reliability, Availability and Maintainability
The RAM is expected to be high.

5.3 Decontamination Time

5.3.1 Set-up
Minimal set up time required.

5.3.2 Application Time

5.3.2.1 Personnel
Application time would be equivalent to the
time required for painting, although doubled
if separate application is required.

5.3.2.2 Decontamination
Knowledge Gap – but expected to be complete.

5.3.2.3 Verification
Knowledge Gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal
Minimal time is required for removal of
application equipment.

5.3.3.2 Clean-up
Minimal clean up required. A solvent wash
may be sufficient.

5.4 Safety Requirements

    5.4.1 Process Hazards
        None anticipated.

    5.4.2 Personnel Hazards
        Anthranilic acid is toxic and an anesthetic (LD_{50} = 23 mg/Kg) $AgNO_3$ is irritating.

    5.4.3 Protective Methods
        Should exercise precaution when handling and appropriate clothing should be worn.

6.0 Economics·

6.1 Building Damage ~ Repair Costs
    None expected.

6.2 Developmental Costs
    Destruction efficiency, reaction products and kinetic data need to be developed. Waste treatment must be determined.

6.3 Treatment Costs

    6.3.1 Utilities and Fuel Cost
        Minimal. Electricity for the mixer and the pump.

    6.3.2 Equipment Cost
        Minimal. Brushes and rollers may be obtained from the neighborhood hardware store. Standard spraying equipment is inexpensive ($200-500).

    6.3.3 Material Cost
        Could be large depending on amount required.
        Acid ($10/lb reagent)
        $AgNO_3$ ($500/lb reagent)

    6.3.4 Manpower Cost
        Small.

7.0 Future Work Required

7.1 Knowledge Gaps
    Destruction efficiency and reaction products need to be determined.

7.2 Resolution
    Experimental testing.

ALUMINA IMPREGNATED WITH MAGNESIUM HYDROXIDE

1.0 General Description

   1.1 Summary of Idea
         A gel of alumina impregnated with magnesium hydroxide is
         applied to a wet, contaminated surface to accelerate
         hydrolysis of GB.

   1.2 Origination of Idea
         Literature references (Medema, 1975; Kuiper, 1973; Epstein,
         1967; Epstein, 1958; Epstein, 1968).

   1.3 Obvious Advantages and Disadvantages
         Advantage. Alumina has excellent adsorbent properties.

         Disadvantages. Slurry may not reach interior contaminants.
         Not effective on VX.

   1.4 Variations of Idea
         Use other bases such as chromium oxides to impregnate
         alumina. Use charcoal instead of alumina.

   1.5 Sketch
         Not applicable.

2.0 Chemical Decomposition Treatment

   2.1 Chemical Reactions

$$CH_3-\overset{\overset{O}{\|}}{\underset{O-iPr}{P}}-F \ + \ H_2O \longrightarrow CH_3-\overset{\overset{O}{\|}}{\underset{O-iPr}{P}}-OH \ + \ HF$$
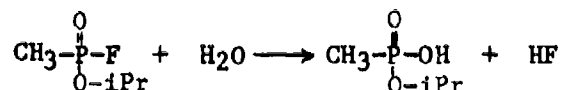
   2.2 Hazardous Products
         Knowledge Gap.

   2.3 Destruction Efficiency, Residue Level
         Limited to sites of adsorbtion.

   2.4 Reaction Rate/Kinetics
         Activation energy = 4 kcal/mole, but large entropy change
         causes a relatively slow reaction rate.

   2.5 Supplementary Treatment
         Remove alumina. Add base to contaminated alumina to ensure
         hydrolysis is complete.

   2.6 State-of-the-Art
         Proposed for protective clothing.

3.0 Physical Treatment
Not applicable.

4.0 Applicability

4.1 Agent Applicability
Applicable to GB.

4.2 Isolated Building Material Applicability

4.2.1 Impact of Substrate on Chemistry
Basic nature of cement may aid hydrolysis.

4.2.2 Removal or Reaction of Contaminant from Surface
Good removal from surface.

4.2.3 Removal or Reaction of Contaminant from Interior
Knowledge Gap.

4.2.4 Damage to Material
None anticipated.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Strip paint.

4.3.2 Practical Physical Limitations/Methods to Overcome
Difficult to apply a "solid" system to inaccessible areas.

4.3.3 Secondary Decontamination Treatment
None, if hydrolysis products are non-toxic. (Knowledge Gap). May require another application or decontamination sequence if contact between the alumina and the agent is not complete.

4.3.4 Clean-up Requirements
Wash walls with H_2O to remove traces of reactants and products (i.e., HF).

4.3.5 Waste Treatment and Disposal
Add acid to water to neutralize base.

4.4 State-of-the-Art
None.

5.0 Engineering

5.1 Process Description

5.5.1 Main Process
Alumina gel containing magnesium hydroxide is mixed

5.0 Engineering

5.1 Process Description

5.5.1 Main Process

Alumina gel containing magnesium hydroxide is mixed thoroughly and applied to the structure with a spray gun, paint brush, roller, or similar item to thoroughly coat the surface. The gel is allowed to soak in and react with GB. After decontamination is completed the solution is removed by washing with an appropriate wash.

5.1.2 Variations

Magnesium hydroxide may also be applied as a dispersion in liquid or foams. A variety of foaming agents may be used which are compatible with both aqueous based and organic solvents. A primary advantage of using suspensions or foams is that they will maintain a long contact time with the building material which will permit continuous diffusion of reactant into the material for decontamination. Polymeric or plastic sheeting backings may be applied to the gels, foams, and suspensions to insure inward migration of reactants and minimize outward vapor diffusion into the building. Furthermore, these backed gels or foams may be heated to facilitate reactant migration and increase decontamination rates.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

An agitation tank for preparing mix.
Painting equipment for application.

5.2.2 Reliability, Availability and Maintainability

The RAM is expected to be high.

5.3 Decontamination Time

5.3.1 Set-up

Minimal set up time required.

5.3.2 Application Time

5.3.2.1 Personnel

Application time would be equivalent to the time required for painting.

5.3.2.2 Decontamination

Knowledge Gap. Decontamination time would

depend on the contact achieved between the agent and the magnetic hydroxide. It may be long considering it is a reaction between a solid and a removed agent.

5.3.2.3 Verification
Knowledge Gap.

5.3.3 Tear-Down Time
Minimal time is required for removal of application equipment.

5.3.3.1 Equipment Removal
Minimal clean up required. A solvent wash may be sufficient.

5.4 Safety Requirements

5.4.1 Process Hazards
No process hazards associated with this concept.

5.4.2 Personnel Hazards
$Mg(OH)_2$ is strong base.

5.4.3 Protective Methods
Appropriate clothing and eye protection should be worn.

6.0 Economics

6.1 Building Damage - Repair Costs
None expected.

6.2 Developmental Costs
Reaction kinetics, degree of contact, and reaction rate need to be developed as well as application methods.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Minimal. Electricity for the mixer and the pump.

6.3.2 Equipment Cost
Minimal. Brushes and rollers may be obtained from the neighborhood hardware store. Standard spraying equipment is inexpensive ($200-500).

6.3.3 Material Cost
$Mg(OH)_2$ is a commodity chemical which can be obtained at a resonable low price.

6.3.4 Manpower Cost
Small.

7.0 Future Work Required

    7.1 Knowledge Gaps
        Degree and rate of reaction, and application method need to
        be developed.

7.2 Resolution
        Experimental work. To determine the rate limitations and its
        applicability to building decon.

COMPLEXATION WITH MOLYBDENUM LIGAND IN ACETONITRILE

1.0 General Description

   1.1 Summary of Idea
   Wash walls with molybdenum ligand, $Mo(O\phi)_3Cl_2$ and
   acetonitrile to complex with mustard. Collect wash, add
   H_2O to dissociate complex. Incinerate mustard, and
   regenerate molybdenum ligand.

   1.2 Origination of Idea
   Literature reference (Morgan, 1968, other molybdenum ligands
   may be used O'Connell, 1968; Cogliano, 1970).

   1.3 Obvious Advantages and Disadvantages
   Removes mustard by chemical/physical means. Doesn't destroy
   mustard in situ.

   1.4 Variations of Idea
   None.

   1.5 Sketch
   Not applicable.

2.0 Chemical Decomposition Treatment

   2.1 Chemical Reactions

$$HD + Mo(O\phi)_3Cl_2 \xrightarrow{\text{dry}} ClCH_2CH_2\text{-}S\text{-}CH_2CH_2Cl$$

$$CS_2 \quad \xleftarrow{H_2O} \quad MoCl_5 + \phi OH$$
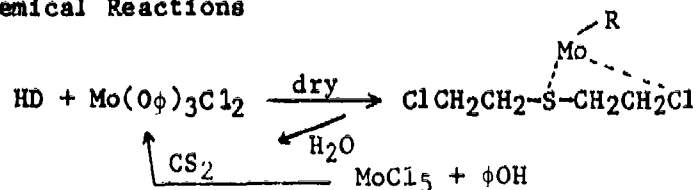
   2.2 Hazardous Products
   Collected product mustard is still toxic. Acetonitrile is
   neither volatile and combustible (flashpoint 12.8 C) and
   toxic. Phenol is also highly toxic and may be present
   unreacted from the organometallic preparation.

   2.3 Destruction Efficiency, Residue Level
   90% complexation. Incineration destroys mustard.

   2.4 Reaction Rate/Kinetics
   Knowledge Gap.

   2.5 Supplementary Treatment
   May need to rewash walls with regenerated $Mo(O\phi)_3Cl_2$.
   Also may need a final water wash.

   2.6 State-of-the-Art
   Chemistry known.

4.0 Applicability

    4.1 Agent Applicability
        Mustard.

    4.2 Isolated Building Material Applicability

        4.2.1 Impact of Substrate on Chemistry
            None anticipated except probable damage paint.

        4.2.2 Removal or Reaction of Contaminant from Surface
            Good removal if air and walls are dry.

        4.2.3 Removal or Reaction of Contaminant from Interior
            Knowledge Gap.

        4.2.4 Damage to Material
            None anticipated.

    4.3 Practical Applicability to Building

        4.3.1 Building Preparation
            The building must be thoroughly dry, otherwise the
            complex would dissociate.

        4.3.2 Practical Physical Limitations/Methods to Overcome
            None expected.

        4.3.3 Secondary Decontamination Treatment
            Add H_2O to dissociate complexes. Separate
            organometallic from mustard.

        4.3.4 Clean-up Requirements
            Wash area with water to remove any reagents or
            products.

        4.3.5 Waste Treatment and Disposal
            Incinerate mustard.

    4.4 State-of-the-Art
        Never used on buildings.

5.0 Engineering

    5.1 Process Description

        5.1.1 Main Process
            The reactive liquid $Mo(O\phi)_3Cl_2$ in acetonitrile is
            mixed thoroughly and applied to the structure with a
            spray gun, paint brush, roller, or similar item to
            thoroughly coat the surface. The liquid is allowed to
            soak in and react, complexing with mustards. After
            reaction is completed, the solution is removed by

washing with solvent. The complex is dissociated by the addition of H_2O and mustard separated for incineration. The surface is finally washed with water.

5.1.2 Variations

Liquid reagents systems may also be applied in gels or foams. A variety of gelling and foaming agents may be used which are compatible with both aqueous based and organic solvents. a primary advantage of using gels or foams is that they will maintain a long contact time with the building material which will permit continuous diffusion of reactant into the material for decontamination. Polymeric or plastic sheeting backings may be applied to the gels and foams to insure inward migration of reactants and minimize outward vapor diffusion into the building. Furthermore, these backed gels or foams may be heated to facilitate reactant migration and faster complexation rates.

5.2 Equipment/Support Facilities Needed

5.2.1 Description

An agitation tank for preparing mix; a collection tank or sump for mustard; a separation system; an organometallic regeneration system. Painting equipment for application. Ventillation system.

5.2.2 Reliability, Availability and Maintainability

Reliable; available; easy to maintain.

5.3 Decontamination Time

5.3.1 Set-up

Moderate.

5.3.2 Application Time

5.3.2.1 Personnel

Application time would be equivalent to the time required for painting.

5.3.2.2 Decontamination

Knowledge gap.

5.3.2.3 Verification

Knowledge gap.

5.3.3 Tear-Down Time

5.3.3.1 Equipment Removal

Moderate.

        5.3.3.2 Clean-up
                Water wash.

5.4 Safety Requirements

    5.4.1 Process Hazards
          Potential for fire (acetonitrile flash point -
          12.8 C).

    5.4.2 Personnel Hazards
          Acetonitrile and phenol are highly poisonous.

    5.4.3 Protective Methods
          Gas masks and appropriate clothing recommended.

6.0 Economics

    6.1 Building Damage - Repair Costs
        None expected.

    6.2 Developmental Costs
        Reaction kinetics need to be determined.
        Effect of reaction on building materials also must be
        addressed.

    6.3 Treatment Costs and Solvent/Organometallic

        6.3.1 Utilities and Fuel Cost

        6.3.2 Equipment Cost

        6.3.3 Material Cost

            Acetonitrile is not too expensive ($2.50/lb reagent)
            grade). $MoCl_5$ costs $65/lb and phenol costs $81/lbs.

        6.3.4 Manpower Cost
            Substantial. Separation and regeneration of
            molybdenum complex may require large effort.

7.0 Future Work Required

    7.1 Knowledge Gaps
        Reaction kinetics need to be determined. Effect of reaction
        on building materials shared also be addressed.

    7.2 Resolution
        Experimental work.

SODIUM HYDROXIDE SOLUTION

1.0 General Description

1.1 Summary of Idea
Sodium hydroxide solutions will react with HD, GB and VX producing relatively non-toxic products. Solutions in water or water/organic solvent mixtures may be applied to surfaces by swabbing or spraying to reach inaccessible areas.

1.2 Origination of Idea
Sodium hydroxide has long been used for purpose of decontamination and demilitarization and is a component of DS-2. References citing the use of sodium hydroxide include Steyermar 1974; Davis, 1978; Plucker, 1969 and Weber, 1973.

1.3 Obvious Advantages and Disadvantages
Advantages include rather complete reaction with HD, VX, GB to produce relatively non-toxic products.

Disadvantages are the slowness of some of the reactions and hazards of handling the solutions (though less hazardous than DS-2, for example).

1.4 Variations of Idea
Use of mixed solvents to enhance agent solubility, e.g., DMSO (Steyermark, 1974). Addition of metal ions as a catalytic aid to reaction with GB and VX. Application of hot solutions to enhance kinetics. Addition of surface active agents to improve penetration and contact of agent with water. Addition of methycellosolve to enhance decontamination (Davis, 1979).

1.5 Sketch
None.

2.0 Chemical Decomposition Treatment

2.1 Chemical Reactions

$$HD + NaOH(H_2O) \longrightarrow (HOCH_2CH_2)_2S + NaCl$$

$$GB + NaOH(H_2O) \longrightarrow CH_3-\overset{\overset{O}{\|}}{\underset{O-\!\!\prec}{P}}-ONa + NaF$$

$$VX + NaOH(H_2O) \longrightarrow CH_3-\overset{\overset{O}{\|}}{\underset{OC_2H_5}{P}}-ONa + HS-CH_2CH_2N(-\!\!\prec)_2$$
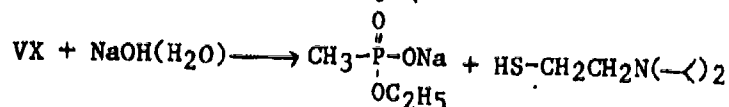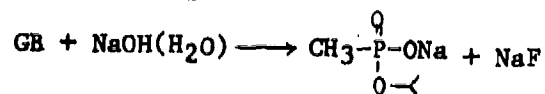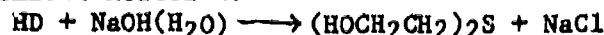
2.2 Hazardous Products
Reaction products all are relatively safe.

2.3 Destruction Efficiency, Residue Level
Agents react completely if adequate time is allowed.

2.4 Reaction Rate/Kinetics
Reaction with VX is reasonably fast because of good water
solubility but HD reaction rate is limited by water sol-
ubility of HD. GB has a half life of about 1 minute at 35 C
in water at pH 10.

2.5 Supplementary Treatment
Disposal of waste solutions including neutralization,
concentration, and incineration.

2.6 State-of-the-Art
Caustic solutions have been demonstrated as effective on a
variety of materials.

3.0 Physical Treatment
Not applicable.

4.0 Applicability

4.1 Agent Applicability
Applicable to HD, VX, GB.

4.2 Isolated Building Material Applicability

4.2.1 Impact of Substrate on Chemistry
Substrate should not influence the reaction signific-
antly.

4.2.2 Removal or Reaction of Contaminant from Surface
Reaction on surfaces and removal by washing (spraying,
swabbing, etc.) should be highly effective.

4.2.3 Removal or Reaction of Contaminant from Interior
Uncertain. Penetration could be enhanced by use of
surfactants.

4.2.4 Damage to Material
Some damage to paint is to be expected especially at
elevated temperatures. No appreciable damage to
metals or concrete anticipated.

4.3 Practical Applicability to Building

4.3.1 Building Preparation
Paint removal may be necessary depending on the
temperature and length of application.

4.3.2 Practical Physical Limitations/Methods to Overcome
Spraying, brushing and rolling the liquid on hard to
reach areas may be time consuming and cumbersome.
Difficulties encountered will be equivalent to those
encountered when painting the structure.

4.3.3 Secondary Decontamination Treatment
None necessary unless subsurface penetration in-complete. Another application would be required in this case.

4.3.4 Clean-up Requirements
Water wash.

4.3.5 Waste Treatment and Disposal
Reaction products and waste are relatively safe. Neutralization, concentration and/or incineration may be needed for disposal.

4.4 State-of-the-Art
Sodium hydroxide solutions are currently used for the decontamination of facilities. It is a component of DS-2.

5.0 Engineering

5.1 Process Description
The sodium hydroxide solution is mixed and applied to the surface with a spray gun, brush or roll. The liquid is allowed to react and decompose HD, GB and VX producing relatively non-toxic products. After reaction the solution is washed off. Another application is performed if decontamination is incomplete.

5.1.1 Main Process
Sodium hydroxide solution may also be applied in gel or foam form. A variety of gelling and foaming agents may be used which are compatible with both aqueous or organic solvents. Gels and foams will maintain a longer contact time with the structure for decontamination purposes. Polymeric sheeting backings may be applied to the gels and foams to minimize solvent losses to the environment. The backing may be heated to enhance reactant migration through the structure and achieve faster reaction rates.

5.1.2 Variations

5.2 Equipment/Support Facilities Needed

5.2.1 Description
Agitated tank for preparing mix and painting equipment for application.

5.2.2 Reliability, Availability and Maintainability
The RAM is anticipated to be high.

5.3 Decontamination Time

5.3.1 Set-up
Minimal set up required (similar to painting).

5.3.2 Application Time

    5.3.2.1 Personnel
Application time would be equivalent to the time required for painting.

    5.3.2.2 Decontamination
Very rapid decontamination of contacted GB (GB's half life = 1 minute at 35 C and pH 10). Less rapid decontamination of VX and HD.

    5.3.2.3 Verification
Knowledge Gap.

5.3.3 Tear-Down Time

    5.3.3.1 Equipment Removal
Minimal time is required for removal of application equipment (same as for painting).

    5.3.3.2 Clean-up
Minimal clean up required. A fresh water wash may be sufficient.

5.4 Safety Requirements

5.4.1 Process Hazards
None.

5.4.2 Personnel Hazards
Sodium hydroxide is an irritant and corrosive to all tissues.

5.4.3 Protective Methods
Appropriate clothing and eye protection should be worn.

6.0 Economics

6.1 Building Damage - Repair Costs
None expected.

6.2 Developmental Costs
None.

6.3 Treatment Costs

6.3.1 Utilities and Fuel Cost
Minimal - electricity for the mixer and the pump.

6.3.2 Equipment Cost
Minimal - brushes and rollers may be obtained from the neighborhood hardware store. Standard spraying equipment is inexpensive ($200-500). Corrosion resistant equipment is required.

6.3.3 Material Cost
Relatively small. Sodium hydroxide is a commodity material, readily available at low price.

6.3.4 Manpower Cost
Small - same as painting.

7.0 Future Work Required

7.1 Knowledge Gaps
Permeability into the structure.

7.2 Resolution
Experimental work.

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APPENDIX IV

ADDITIONAL CHEMICAL CONCEPTS

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ADDITIONAL CHEMICAL CONCEPTS

Because some documents were received after the draft of this report had been submitted for Army review and because we believe that novel concept generation is an ongoing part, additional decontamination concepts will be listed as they are uncovered or generated from ideas. They are to be listed in broad chemical reaction categories and compared to other concepts within that category to determine if they might displace those selected for experimental evaluation. They might be screened experimentally when other chemical concepts in the same category are being evaluated or eliminated based on the chemistry of similar reagents.

The following concepts were uncovered or thought of since the draft copy of this report was completed.

ClO_2

HD reacts with ClO_2 gas to give 2,2-dichlorodiethyl sulfoxide (Popoff 1967). A mixture of 3 percent ClO_2 in nitrogen decomposed 98 percent of the HD on a cloth sample in 60 minutes. However, only 35.5 percent of the HD on an aluminum sample and 22.5 percent of the HD on a glass sample was decomposed in 60 minutes. ClO_2 also effectively decontaminated cloth contaminated with VX under one tenth atmosphere pressure (Popoff, 1967). No reaction is anticipated between ClO_2 and G-agents. Care must be taken when ClO_2 is generated because of the explosive nature of the undiluted gas (Yurow, 1981).

MACROCYCLIC ETHERS

Casselman, 1979 showed that macrocyclic ethers can rapidly de-
compose nerve agents. Cryptand [2,2,2], shown below,
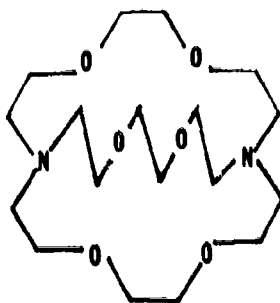
CRYPTAND [2.2.2]

dissolved in an organic solvent (e.g., cyclohexanone) achieved 100 percent
decomposition of HD in 2 minutes, 90 percent of VX in 2 minutes and 46
percent of GF in 5 minutes.

PERBORATE SOLUTION

Sodium perborate and perborate cleaning compounds applied in
excess (2 liters of a 4 percent cleaning solution containing 20 percent
perborate/gram of nerve agent) achieved greater than 99 percent removal of
G agents in 1 to 2 minutes at temperatures at or above 0 C (Kowalska,
1978). 98 percent removal of VX was obtained in 15 minutes at 60 C and in
2 hours at 25 C using the excess perborate solution treatment.

PERCHLORATE SOLUTION

Two rinses with 5 percent calcium perchlorate solution followed
by a sea water rinse effectually decontaminated painted metal, painted
wood and navy canvas surfaces that were contaminated with VX (Hott, 1965).
After 90 minutes no significant concentration of VX was detected on the
surfaces, within the surfaces, or in the vapor above the surfaces as de-
termined by both chemical and bioassay analysis.

NITROGEN TETROXIDE

N_2O_4 rapidly and completely decomposes HD to form 2,2-dichlorodiethyl sulfoxide. Over a period of one hour at one atmosphere pressure, 88 percent of the HD on contaminated cloth swathes was destroyed. HD was quantitatively decontaminated at one atmosphere pressure in 30 minutes from aluminum and glass surfaces (Popoff, 1967). No reaction occurred between N_2O_4 and GF (Popoff, 1967).

Microbial

Several references were identified on the microbial decomposition of nerve agents. Holwerda, 1975 added VX to soil to determine which micro-organisms can decompose VX. Repeated applications of VX were required because VX was quickly decomposed by the moist soil. The results of the tests were inconclusive other than finding species that can survive in the presence of VX. A later study (Huisman, 1979) identified pseudomonas aeruginosa as an organism capable of hydrolyzing VX. No studies could be found relating to the microbial decomposition of HD or GB.

Permanganate Solutions

Potassium permanganate dissolved in acetone was cited as early as 1918 as an oxidant for the destruction of HD on metallic instruments (Yurow, 1981).

Neutral permanganate solution was reported to completely detoxify (measured by enzyme-assay) VX at molar ratios greater than 20 to 1. (Yurow, 1981). The reaction products of the VX reaction were ethyl methylphosphonic acid, N,N-diisopropylformamide, sulfate ion, and gelatinous manganese dioxide, along with unreacted permanganate. These compounds present potential disposal problems.

Propionyl Fluoride

Propionyl fluoride was found to cause rapid hydrolysis of GB (Lapkin, 1955).

DMSO

DMSO was found to rapidly oxidize agents (Hedley, 1970). Laboratory results indicate that solutions containing about 30 to 100 weight percent dimethyl sulfoxide, 0.05-5 moles/1 of a strong base selected from the group consisting of alkali metal hydroxides, alkali metal alkoxides, alkali metal phenoxides, and quaternary ammonium hydroxides, and 0-70 percent of at least one cosolvent selected from a group consisting of water, alcohols glycols, and triols effectively decontaminated VX, GF and mustard gas in several minutes (Steyermark, 1974). In one case DSMO water solution containing NaOH (10 g/liter) was used to successfully treat a laboratory worker whose arm had been exposed to mustard gas.

UV Light

Although Hedley, 1970 reports that neat GB, HD or VX is unaffected by UV light, other studies indicate that decomposition of nerve agents can be accomplished if additives are present. For example, Mill, 1978 has a patent on a method to oxidize GB in aqueous solution by addition of an excess of hydroxyl radicals (e.g. H_2O_2, ozone, nitrous acid, peroxydisulfate, etc.) and subjecting the solution to UV light. The reaction, complete in 1-2 hours, formed H_2PO_4, CO_2 and H_2O.

Another reference (Murai, 1976) showed that an organo-phosphate chemical similar in structure to VX rapidly decomposed in UV light by a photo-oxidation mechanism.

Phenols/Catechols

Phenols/catechols combine with G-agents through hydrogen bonding (Braude, 1970). The fluoride ion is then displaced to form a catecholate (Epstein, 1970) as shown below:

GB +
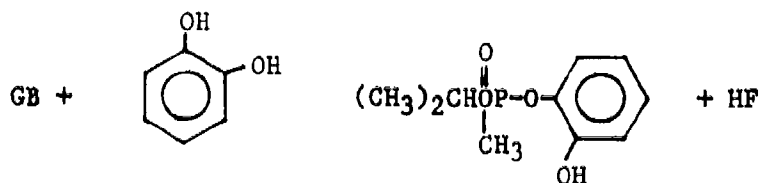
Reaction rates for GB with catechols are substantially less than with GB and hydroxamic acids (Epstein, 1971).

BF₃ Etherate Solution

Boron trifluoride etherate reacts rapidly and reversibly with GF to produce a complex, which subsequently reacts slowly and irreversibly with oxygen (Braude, 1970). Boron trifluoride does not appear to be a viable reagent due to the anticipated low oxygen concentration within building materials and the slow decomposition rate of the intermediate. Furthermore, BF_3 is likely to be highly corrosive since it yields HF upon hydrolysis (Stanford, 1981).

Chlorite Solutions

Solutions of sodium chlorite were found to be less effective than solutions of bleaching powder on H (Mankowich, 1970).

Carbonate/Bicarbonate Solutions

Mankowich, 1970 has reported that sodium carbonate and/or bi-carbonate slightly aided the hydrolysis of HD but were essentially not

that effective. In contrast, Anonymous, 1967 states that a hot or cold solution of sodium bicarbonate is very effective for the decontamination of G-agents. Carbonate and/or carbonate solution are less corrosive than stronger bases (e.g. NaOH).

Enzymes Proteins

An enzyme (squid type DFPase) was identified by Hoskin, 1982 as being able to detoxify GD.

Suspended proteins (e.g. milk) may be used to act as chemical receptors for nerve agents to potentially render the agents non-toxic.

Methionine, a protein constituent from another source decomposed 90 percent of H to form a sulfonium salt (Stein, 1946).

Hydroxamic Acids

Hydroxamic acids have been shown to be inferior to oximes of similar structure in terms of chemical reactivity as reactivators of inhibited acetylcholinesterase (Barrass, 1971). However, Epstein, 1971, showed that hydroxamic acids have a rate constant for the displacement of the fluoride ion from GB an order of magnitude (or more) above that of catechols, keto-oximes, phenols and hydrated aldehydes. In another study, Davis, 1978 recommended the use of a highly water-soluble, buffered hydroxamic acid solution to decompose VX. The hydroxamic acids were noted to have a high reactivity and were non-corrosive.

Sodium Sulfide Solution

Sodium sulfide reacts with H to produce nontoxic products with a strong sulfide odor which may be confused with H. The reaction was too slow and too incomplete at ordinary temperatures to warrant its use in the

field. When compared to standard decontaminants sodium sulfide was listed as less effective than bleaching powder and dichloramine-T (Mankowich, 1970).

Ozone

Ozonated air was shown (Mankowich, 1970) to convert H into sulfoxide. Its use at the time was not thought practical because of the amount of ozone required put the method beyond the capacity of the then-current commercial ozonator. Current commercial ozone generators have the capacity to supply the required amount of ozone; however, the cost may be exorbitant.

SULFUR DICHLORIDE

The possible use of sulfur dichloride in the field and its value for the destruction of H in soil was investigated. Sulfur dichloride was shown to rapidly and completely chlorinate H, although rats died when exposed to the sulfur dichloride treated surfaces, the cause of death was attributed to evolved HCl from the mustard decomposition reaction (Mankowich, 1970).

SUMMARY

Other reported decontamination methods have been summarized by Stanford, 1981. Of the methods listed, a majority have been discussed in the body of this report. As other concepts or studies are uncovered (for example the work of Outterson, 1982), they will be compared with our list of concepts, categorized and compared to those within that category to determine if they might displace any of concepts already selected for laboratory evaluation. We anticipate that this will be an ongoing program within subsequent phases of the current program.

APPENDIX IV

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MEMORANDUM TO Mr. Larry Downing, Defense Technical Information Center, 8725 John J. Kingman Road, Ft Belvoir, VA 22060-6218

SUBJECT: Downgrading from Limited Distribution to Unlimited Distribution

1. The following documents were reviewed, and it was determined by our Technical POC, Mr. Marty Stutz, that the distribution statement should be changed from limited to unlimited distribution.

 a. AD Number: ADB073052: Development of Novel Decontamination Techniques for Chemical Agents (GB, VX, HD) Contaminated Facilities. Phase I. Identification and Evaluation of Novel Decontamination Concepts. Volume 1.
From Distribution Code 03 - US GOVERNMENT ONLY; DOD CONTROLLED to Distribution UNLIMITED, APPROVED FOR PUBLIC RELEASE.

 b. AD Number: ADB073034: Development of Novel Decontamination Techniques for Chemical Agents (GB, VX, HD) Contaminated Facilities. Phase 1. Identification and Evaluation of Novel Decontamination Concepts. Volume 2.
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 c. AD Number: ADB093506: Development of Novel Decontamination Techniques for Chemical Agents (GB, VX, HD) Contaminated Facilities. Phase II. Laboratory Evaluation of Novel Agent Decontamination Concepts.
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 d. AD Number: ADB087418: Development of Novel Decontamination and Inerting Techniques for Explosives Contaminated Facilities. Phase 1. Identification and Evaluation of Novel Decontamination Concepts. Volume 1.
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 e. AD Number: ADB125304: Pilot Plant Testing of Hot Gas Building Decontamination Process.
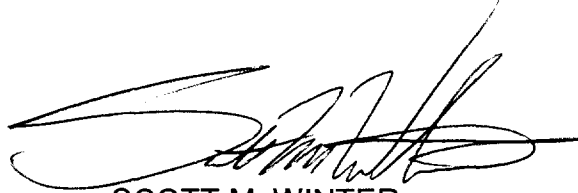From Distribution Code 03 - US GOVERNMENT ONLY to Distribution UNLIMITED APPROVED FOR PUBLIC RELEASE.

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MAJ, CM
Security Officer