History of Pollution Sources and Hazards at Rocky Mountain Arsenal

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Rocky Mountain Arsenal
Information Center
Commerce City, Colorado

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ACKNOWLEDGMENTS

Most of the information in this report was obtained from volumes one (1) through sixteen (16) of the RMA Laboratory Sample Registry and from the History of RMA volumes one (1) through ten (10).

A large number of personal interviews were conducted with long-time RMA employees to help fill information gaps. To all of those people contacted the authors express their appreciation for their help and cooperation. We also express our appreciation to Mr. Gene Kaufman of Shell Chemical Company for his assistance with the history and activities of the RMA Leaseholders.
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VI
1. Historical Observation... "There are adequate waste disposal facilities in the form of natural reservoirs which have been supplemented by diking. These disposal reservoirs lie immediately to the north of the plants area and do not constitute a safety hazard to the streams and potable water supply in the vicinity." (History of Rocky Mountain Arsenal, Vol I, pg 12).
2. Introduction

a. The acquisition of land for the Rocky Mountain Arsenal (RMA) (Figure 1) was initiated with the signing of Memo of Approval 438 on 12 May 1942. Authority to proceed with construction was received in June 1942.

b. The designated mission of RMA was to produce chemical munitions for the Armed Forces. Items produced at RMA were primarily war gases, incendiary chemicals and intermediary products used in the manufacture of the primary products. The chronology of production operations at RMA is shown in table 1. Raw chemical materials used by RMA are listed in Appendix A.

c. Manufacturing at RMA from 1942 to 1951 was accomplished primarily in the south plants area (B, C - Figure 2) while warehouses, shops and the salvage disposal yard were located in area A (Figure 2). The north plants area (D, Figure 2) was built in 1952. Expanded views of these areas are found in Figures 3, 4, 5, and 6.

d. Starting in 1946 a succession of private firms have leased portions of the south plants area. Products manufactured by the leaseholders include herbicides, pesticides and other similarly toxic products as given in the leaseholder section of this report and Appendix B. Appendix C lists the raw chemical materials used by Shell Chemical Co. and Appendix J gives the process materials and solvents plus the process intermediates produced or used.

e. The north plants complex (Figure 6) was constructed in 1951 for the manufacturing of nerve agent (GB) and munitions filling. The north plants area was also used for the demilitarization of GB munitions, bulk GB and phosgene as well as the manufacturing of the lead azide button bombs.

f. A wide variety of chemical munitions and commercial chemical preparations have been manufactured or processed at RMA since 1942. The manufacture of these products involved the use of vast quantities of numerous raw materials (Appendices A and C) and resulted in the production of large volumes
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Figure 4. South plants area, west half. Expanded view.
Figure 5. South plants area, east half. Expanded view.
of both liquid and solid chemical wastes. The nature and disposal of chemical waste products is a matter of increasing concern with the passage of time.

g. Waste from the operations of RMA was disposed of in various ways. Liquid waste was sometimes held in decontamination or settling ponds in specific plants areas prior to entering basin A. Some other liquid waste from the plants areas was carried directly to basin A through the contaminated (industrial) sewer system or by surface drainage ditches. Additional unlined basins B, C, D and E were constructed and used for varying periods of time. The asphalt lined basin F was constructed in 1956 and all liquid waste was subsequently sent to this basin (Figure 7).

h. Solid waste was disposed of in a number of burning and burial pits located in sections 4, 9, 20, 30, 33, and 36 (Figure 6).

i. In 1951-52 the U.S. Department of Interior Fish and Wildlife Service conducted a study of waterfowl mortality in Upper Derby, Lower Derby and Ladora Lakes on RMA. The report of that study is attached as Appendix E.

3. RMA Waste Disposal

   a. Liquid Waste

   (1) With the beginning of RMA in 1942 a natural depression in section 36 was chosen as a liquid waste disposal area which became known as basin A (Figure 7). With a limited amount of diking basin A became a 90 to 100 acre waste pond. A contaminated or industrial waste sewer system carried industrial waste from all parts of the plants area to basin A. Surface drainage from the plants area also entered basin A.

   (2) Basin A was the primary liquid waste disposal area from 1942 until 1952. Occasionally during this period basin A would overflow and some of the fluid would follow surface ditches to basin B and section 33, 34 and 35.

   (3) With the initiation of operations at the north plants complex it became necessary to build basins C, D and E in section 26 (Figure 7). All of these basins were unlined as were basins A and B. These basins functioned from 1952 until 1955 when complaints were received from RMA neighbors about contaminated groundwater. Asphalt lined basin F was constructed
Figure 7. Liquid waste disposal sites.
in 1956 and all liquid from the other basins was pumped into basin F. The industrial sewer system was also modified to empty into basin F. Since 1956 all industrial liquid waste has emptied into basin F.

(4) In 1962 the amount of liquid in basin F became a problem. A 12,000 foot deep disposal well was drilled northeast of basin F to receive this liquid. The well was operated from 1962 to mid 1967 with some 150 million gallons of waste being disposed of in this manner. The amount of waste in basin F remained a problem and a spray evaporation system was installed. The liquid was sprayed approximately 100 feet high and since liquid loss was ± 140 gpm it can be assumed the aerosol droplets were carried some distance downwind.

(5) Since 1979 Shell Chemical Co. has been taking their liquid waste elsewhere. The only waste now entering basin "F" is from the Federal facilities in the south plants area and the Hydrazine plant.

b. Solid Waste -

(1) During the production phases at RMA the primary concern was the manufacture of the end items on schedule. Therefore, solid and slurry waste was often disposed of in the most convenient and expeditious manner, often without regard to its contamination status.

(2) The chronology of the use of solid waste pits is shown in table 2. The first and longest used burial sites were in section 30, east and north of basin A (Figure U). Multiple burial pits were excavated in these areas. Solid and slurry waste as well as contaminated tools, equipment and unwanted agent containers were buried in the pits east of basin A. The pits north of basin A in section 30 were used primarily for destruction and burial of incendiaries and explosives. Some tools and equipment from mustard, lewisite and other operations may also be buried there. Several noncontaminated trash pits were also located in this area. The incendiary components disposed of included "Napalm" thickener M-1, and incendiary mix PT-1 and PT-5 while the other munition items included several types of fuzes and hand grenades.

(3) Waste from the North Plants complex was disposed of in pits in section 30. Some of the solids from the neutralized G3 agent is said to have been dumped in the lime settling basins south of basin A. Section 30 is the site of the present land fill.
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Figure 3. Solid waste disposal sites.
(4) Incendiary M-31 bombs were disposed of in the southwest part of section 20. This area with parts of sections 19, 29, and 30 were also part of an impact range at one time. Incendiary M-31 bombs and HD munitions were also disposed of in the western part of section 32.

(5) Near the center of section 9 there is reported to be disposal pits used for white phosphorus grenades and components. Several disposal pits are reported to have been located in section 4 west of B621 and in the northeast part of the section and extending into the southeast part of section 33. These pits were used primarily for "noncontaminated" trash.

(6) In section 11 a strip of land along the northern edge of the section contains the dredgings from the bottoms of the lakes and contained high amounts of Dieldrin and Endrin.

4. RMA Operations -

a. Mustard, Crude (H)(HS) -

(1) The crude mustard facility was the first to go into operation on 31 Dec 1942 and ended 28 May 1943. The mustard manufacturing complex consisted of 27 separate structures (Figure 9) which were:

Bldgs: 412, 422 Mustard manufacture and filling
414, 424 Scrubbers
415, 425 Caustic makeup tanks
416, 426 Disposal reactors
417, 427 Decontamination pits
429 Salt storage and brine makeup
431 Refrigeration apparatus
433 Ethylene compressor and drying unit
434, 435 Ethylene holding tanks
461 Pumphouse
462, A-B. Ethylene holding tanks
463, A-H Alcohol storage tanks

(2) Crude mustard (H)(HS) was manufactured at RMA by the Levinstein process. The chemical designations for mustard are:

Chemical name: 5,5'-dichlorodiethylsulfide

Empirical formula: \((\text{C}_2\text{H}_4\text{Cl})_2\text{S}\)

Structure:

\[
\begin{array}{c}
\text{C1} - \text{C} - \text{C} - \text{S} - \text{C} - \text{C} - \text{Cl} \\
\text{H} - \text{H} - \text{H} \\
\text{H} - \text{H} - \text{H}
\end{array}
\]
Reaction: \[ S_2Cl_2 + 2 C_2H_4 \rightarrow (C_2H_4Cl)_2 S + S + \text{Heat} \]

Sulfur + Ethylene → Mustard
monochloride

The raw materials used in the production of mustard were:
sulfur monochloride, ethylene, ethyl alcohol, fuel oil,
salt brine, and aluminum oxide. The ethylene and sulfur
monochloride were manufactured at RMA.

(3) Tank car loads of fuel oil and alcohol were unloaded
through the pump house B461 and stored in tanks 462A, B for
fuel oil and in tanks 463A-H for the ethyl alcohol. In the
ethylene plant B433 the ethyl alcohol was vaporized, the
vapor superheated and passed over an aluminum oxide catalyst
to form ethylene. The ethylene was stored in the ethylene
holding tanks B434, 435. Ethylene gas was dried and compressed
in part of 5431 then sent to B412 and 422 for the manufacture
of mustard.

(4) In the production of crude mustard a seed charge of
mustard is put into a reactor. Measured amounts of ethylene
and sulfur monochloride are introduced and an exothermic
reaction ensues. Brine from 3429 was used in cooling the
reaction vessels. As the ethylene content in tail gas increased,
samples of the reaction mixture were titrated to determine
the mustard concentration and purity. Finished batches of
mustard were stored in underground holding tanks until accepted
or rejected. Unabsorbed ethylene went to the caustic scrubbers
in B414, 424. Caustic mixing tanks were located in B415, 425.
Vent gases were neutralized in coke packed scrubbers in B414,
424 which ran counter current to the caustic solution. Un-
acceptable and wild batches of mustard were sent to disposal
reactors in B416, 426 for neutralization then to the decontamination
pits B417, 427 and finally through the contaminated
sewer line to basin A.

(5) The neutralization of mustard did not always go to
completion as high levels of mustard were often found in the
water of basin A near the sewer outlet. Since the specific
gravity of mustard is 1.27 it is very likely that the mustard
permeated the soils and sediment on the basin bottom near the
contaminated sewer outlet.

b. Lewisite

(1) The Lewisite plant went into production in April 1943
and operated for 8 months. Production ended in November 1943.
The plant capacity was 50 tons of M-1/day. The plant consisted
of two duplicate groups of buildings (Figure 10):
3-511, 514 Lewisite reactors
511A, 514A Crude Lewisite storage
515, 516 Lewisite Distillation
512 Filling building
513 Lewisite disposal facility (unhoused) consisting of 4 reactors, two pits near 512
517 change house

Raw materials used in Lewisite production were:

- Acetylene \((C_2H_2)\) Manufactured at RMA
- Arsenic trichloride \((AsCl_3)\) (A.T.)
- Thionyl chloride \((SOCl_2)\) (T.C.)
- Hydrochloric acid \((HCl)\)
- Mercuric chloride \((HgCl_2)\)

Lewisite was produced by reaction of arsenic trichloride with gaseous acetylene in the presence of an aqueous hydrochloric acid solution of mercuric chloride as a catalyst. In this reaction large amounts of the secondary (M-2) and tertiary (M-3) arsines are also produced.

\[
\text{HgCl}_2 + \text{AsCl}_3 + C_2H_2 \xrightarrow{\text{CAT}} \text{ClCH} = \text{CHAsCl}_2 + (\text{ClCH} = \text{CH})_2\text{AsCl} + \text{M-1 M-2}
\]

\[
(C\text{ICH=CH})_3\text{As} \text{M-3}
\]

The chemical names and structures of the three arsines are:

- M-1, B-chlorovinyl dichloroarsine
  \[
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  \text{H}
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  \text{C1} \\
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  \text{Cl}\text{-C=C-As} \\
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  \end{array}
  \]

- M-2, Bis (B-chlorovinyl) chloroarsine
  \[
  \begin{array}{c}
  \text{H} \\
  \text{H}
  \end{array}
  \begin{array}{c}
  \text{Cl-C=C} \\
  \text{As-Cl}
  \end{array}
  \begin{array}{c}
  \text{Cl-C=C} \\
  \text{Cl}
  \end{array}
  \]

- M-3, B-chlorovinyl trichloroarsine
  \[
  \begin{array}{c}
  \text{H} \\
  \text{H}
  \end{array}
  \begin{array}{c}
  \text{Cl-C=C} \\
  \text{As-Cl}
  \end{array}
  \begin{array}{c}
  \text{Cl-C=C} \\
  \text{Cl}
  \end{array}
  \]
Process - The reaction vessels in B511 and B514 were charged with the aqueous acidic solution of the mercuric chloride catalyst, arsenic trichloride and thionyl chloride. Gaseous acetylene was passed through the reaction mixture. Noxious gases and excess, contaminated acetylene were vented to refrigerated condensers then to caustic scrubber towers for decontamination then vented to the atmosphere.

(2) Crude Lewisite from the reaction vessels was piped under air pressure to tanks in the basement of B511 or B514. The catalyst solution was allowed to separate by gravity then was drawn off and stored for reuse. The crude Lewisite was stored in tanks in B511A and B514A. From the storage tanks the crude Lewisite was pumped to the distillation building B515 or B516. Here the Lewisite was put through a degasser, a fractionation column where excess arsenic trichloride was removed, a reboiler, a cooler and was decanted to a distilled Lewisite holding tank. The distilled Lewisite then went to B512 for filling of ton containers and 55 gallon drums.

(3) The M-2 and M-3 arsines which were recovered in the fractionation process were converted to M-1 by refluxing with additional arsenic trichloride. In the production of M-1 the following equilibriums exist between arsenic trichloride and the three arsines:

\[
\begin{align*}
2\text{M-1} & \rightleftharpoons \text{M-2} + \text{AsCl}_3 \\
2\text{M-2} & \rightleftharpoons \text{M-1} + \text{M-3} \\
\text{M-3} + \text{AsCl}_3 & \rightleftharpoons \text{M-1} + \text{M-2}
\end{align*}
\]

(4) Waste disposal - B513 was the disposal facility for the Lewisite complex. The facility consisted of a group of
Process - The reaction vessels in B511 and B514 were charged with the aqueous acetic solution of the mercuric chloride catalyst, arsenic trichloride and thionyl chloride. Gaseous acetylene was passed through the reaction mixture. Noxious gases and excess, contaminated acetylene were vented to refrigerated condensers then to caustic scrubber towers for decontamination then vented to the atmosphere.

(1) Crude Lewisite from the reaction vessels was piped under air pressure to tanks in the basement of B511 or B514. The catalyst solution was allowed to separate by gravity then was drawn off and stored for reuse. The crude Lewisite was stored in tanks in B511A. From the storage tanks the crude Lewisite was pumped to the distillation building B515 or B516. Here the Lewisite was put through a degasser, a fractionation column where excess arsenic trichloride was removed, a reboiler, a cooler and was decanted to a distilled Lewisite holding tank. The distilled Lewisite then went to B512 for filling of ton containers and 55 gallon drums.

(3) The m-2 and M-3 arsines which were recovered in the fractionation process were converted to M-1 by refluxing with additional arsenic trichloride. In the production of trichloride and the three arsines:

(4) Waste disposal - B513 was the disposal facility for the Lewisite complex. The facility consisted of a group of
four disposal reactors, two waste settling basins and auxiliary piping all in the open. The reactors were on concrete foundations with concrete troughs to carry waste to the settling basins. The basins were unlined with earth dikesides and had a capacity of 300,000 gallons each. This disposal facility received waste from the acetylene plant, the thionyl chloride plant and the arsenic trichloride plant in addition to the waste from the Lewisite plant. Wastes from the settling basins were eventually sent to basin A or the burial pits.

(5) Of the 203,000 pounds of mercuric chloride used in the catalyst 163,000 pounds were lost in waste. There were large losses of arsenic trichloride due to formation of arsenic oxides sludge through hydrolysis in the reaction vessels. Acetylene losses of approximately 35% were due to escape of unreacted gas from the reactor vents. Large amounts of Lewisite were lost through leakage of pipes and tanks. Several large spill incidents also occurred in the reactor rooms. The Lewisite spilled on floors was washed down floor drains with water since caustic would cause crude Lewisite to gelatinize and compound the cleanup problem. Lewisite with a specific gravity of 1.88 tended to settle to the bottom of basin A near the contaminated sewer outlet. High levels of Lewisite were found in basin A water at that time.

(6) Solid waste was taken daily to burning and burial pits for disposal.

c. Acetylene

(1) The acetylene plant was designed and constructed as an auxiliary plant of the Lewisite complex. It went into production in April 1943 and operated for eight months until November 1943. The plant had four acetylene generators with a capacity of 10,000 ft³/day each.

b. The plant consisted of six structures (Figure 11):

B-518 Acetylene gas holder
519 " " "
521 Compressor and scrubber
522 Acetylene generator bldg.
522A Sulfuric acid storage tank
525 Scrubber and compressor
Raw materials used in manufacturing of acetylene were:

- Calcium carbide
- Water
- Sulfuric acid

Acetylene (C_2H_2) is produced by reaction of calcium carbide (CaC_2) and water (H_2O).

\[
\text{CaC}_2 + \text{H}_2 \rightarrow \text{C}_2\text{H}_2 + \text{Ca}
\]

The quick lime (CaO) formed, reacts with water to form milk of lime (Ca(OH)_2)

\[
\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2
\]

Calcium carbide was delivered in 100 and 600 pound drums and put in storage. Measured amounts of calcium carbide were put into the acetylene generators, water added and the raw acetylene gas was vented to the gas holding tanks 5510 and 510. Acetylene gas from these tanks was put through a series of three scrubbers, two with sulfuric acid and one with caustic in 8521 and 525. The acetylene was then compressed and stored in cylinders for use in the Lewisite plant.

(2) Lime sludge Ca(OH)_2 from the acetylene generators was discharged to holding pits outside 3522, to the settling basins in the 8513 complex or was sent to the sulfur dioxide (SO_2) disposal plant 8524 for further use. Water containing lime sludge from washdown of equipment was flushed into the contaminated sewer system to basin A. Much of the lime solids were eventually disposed of in burial pits in the eastern part of section 36.

(3) Reaction of acetylene with the sulfuric acid in the scrubber resulted in deposition of polymerization products on the scrubber walls. These were removed and discarded by melting the products and washing them down floor drains to the contaminated sewer system to basin A.

d. Arsenic Trichloride

(1) The arsenic trichloride (AT) plant was designed and constructed as an auxiliary plant of the Lewisite complex. The plant began production in April 1943 and ceased production in November 1943. The plant had a designed capacity of 40 tons of AT/day.
The AT plant consisted of a group of nine structures (Figure 12):

- B523: AT manufacturing, reactors and equipment
- 523A: AT wet storage
- 523B: Auxiliary SM manufacturing
- 523C-G: Arsenic oxide storage silos
- 524: Sulfur dioxide (SO₂) disposal plant

Raw materials used in the AT plant were:

- Arsenic trioxide (ATO)
- Sulfur (S)
- Chlorine (Cl₂) Manufactured at RMA
- Sulfur monochloride (SM) "" ""
- Auxiliary SM (ASM) - SM with varying amounts of AT
- Arsenic oxide

The arsenic trichloride (AT) is produced by reaction of arsenic trioxide (ATO) with sulfur monochloride (SM):

\[
2\text{As}_2\text{O}_3 + 6\text{S}_2\text{Cl}_2 \rightarrow 4\text{AsCl}_3 + 9\text{S} + 3\text{SO}_2
\]

Process - ATO was delivered to RMA in tank cars and transferred to storage silos B523-C, D, E, F, G. In B523 a seed charge of AT was placed in a reactor. Measured amounts of ATO were added to the AT to form a slurry. The slurry was heated and SM was added. The reaction proceeded as indicated in the equation above.

The AT was distilled from the reaction mixture and sent to 3523-A for storage. Additional SM was added to the remainder of the reaction mixture to react with excess ATO and to fluidize the mixture for movement to the auxiliary SM plant B523-B. Excess sulfur recovered from the AT reactors was also sent to 523-B. In 523-B the auxiliary SM and recovered sulfur were rechlorinated to SM and returned to the AT reactors in B523.

For each 40 tons of AT manufactured ten (10) tons of sulfur dioxide (SO₂) was produced. The SO₂ and vent gases from the auxiliary SM plant B523-B, were disposed of at the SO₂ disposal plant, B524. Three absorption towers used "milk of lime" from the acetylene plant or caustic to neutralize the SO₂ and vent gases. Spent lime and sulphite were pumped to the lime slurry basin in the Lewisite disposal area B513 (Figure 10). This sludge was eventually transferred to basin "A."
Figure 12. Arsenic trichloride plant (1), Sulfur monochloride plant (2) - South plants, east.
(7) The arsenic trioxide storage silos were found not to be dust tight. The ATO did leak out to some extent and was distributed by the winds.

e. Sulfur Monochloride and Sulfur Dichloride -

(1) The sulfur monochloride (SM) and sulfur dichloride (SD) were manufactured in a single structure B-411 (Figure 12). The SM was used in the manufacture of mustard and arsenic trichloride. The SD was used in the manufacture of thionyl chloride. The plant operated from April 1943 to November 1943 and was later converted to a white phosphorus storage and handling area.

(2) Raw materials used were:

- Sulfur (S) Bulk
- Chlorine gas (Cl) Manufactured at F&I

Finished products:

- (S.) Sulfur monochloride (S2Cl2)
- (SD) Sulfur dichloride (SCl2)

(3) Process - The bulk sulfur was unloaded from railroad cars and stored on a concrete slab in B-411. Sulfur was loaded into the reactor and chlorine gas passed through under controlled pressure and temperature. One of the 12 reactors was reserved for manufacture of SD only.

(4) Finished SM was stored in tanks B-411-A through B-411-J. These tanks were later enclosed and redesignated B-413. Finished SD was transferred to storage tanks in the thionyl chloride plant.

(5) Fumes from the reaction vessels were vented to caustic spray towers in B-411. Spent caustic was washed into the contaminated sewer system which emptied into basin A. Inert gases were vented to the atmosphere.

f. Thionyl Chloride -

(1) The thionyl chloride (TC) plant was designed and constructed as an auxiliary plant of the Lewisite complex. Production of TC started in April 1943 and ended in November 1943. The plant had a capacity of 3.3 tons/day of TC which was produced for use in the manufacture of Lewisite. The facility consisted of a group of four buildings (Figure 13):
Figure 13. Thionyl chloride plant - South plants, east.
(2) Raw materials used:

Sulfur dichloride (SCl₂) Manufactured at RMA
Chlorine gas (Cl₂) " " " Caustic " " "
Oleum, 65% (4H₂SO₄·9SO₃)
Antimony trichloride (SbCl₃)
Monochlorobenzene For cooling
Aluminum chloride (AlCl₃)

(3) Process - Oleum was delivered in tank cars which had to be warmed in B-475 to facilitate unloading. The oleum was manufactured in B-411 and transferred directly to B-471. The chlorine and caustic were manufactured in the chlorine plant area.

(4) Reactors in B-471 were charged with sulfur dichloride and the antimony trichloride catalyst. Oleum was added slowly as an exothermic reaction takes place. The reactors were cooled with monochlorobenzene at -10°C. The maximum allowable temperature in the reactor was 25°C. When addition of oleum was completed chlorination began. When addition of all components was completed the cooling was stopped and steam heat refluxing began. The reaction is given as:

\[ 4H_2SO_4·9SO_3 + 15SCl_2 + 2Cl_2 \rightarrow 13SOCl_2 + 15SO_2 + 8HCl \]

(5) The completed batches of crude TC were transferred to intermediate holding tanks in B-471. The crude TC was distilled and the first 100 gallons of distillate was considered low grade TC and stored for reworking. The rest of the distilled TC was considered technical grade TC.

(6) Low grade TC was treated with sulfur in the presence of the aluminum chloride catalyst. This resulted in high grade TC. Usable TC was formulated by blending technical TC and high grade in a ratio of 2:1. Accepted batches of TC were loaded into drums in B-473.
(7) Sulfur dioxide (SO₂) and HCl given off during the reaction process were put through caustic scrubbing towers. Spills of TC were considered highly hazardous because of toxic and corrosive effects. Spilled TC and equipment wash and waste water were flushed down the contaminated sewer system to basin A. Spent caustic slurry and solid waste were taken to burning and burial pits in section 36.

g. Chlorine and Caustic -

(1) The chlorine and caustic plant was a separate complex. The plant began operation on 18 March 1943 and continued until 16 August 1945. The fused caustic production began October 1944 and also ceased in August 1945.

(2) The complex consisted of 14 units (Figure 14):

B-241 Administration and laboratory
242 Chlorine cell facility
243 Chlorine liquifaction and purification
244 Chlorine storage tanks
245 Electric substation
247 Raw brine plant (8 tanks)
248 Brine treatment facility (11 tanks)
249 Treated brine storage (10 tanks)
251 Caustic evaporation
252 Crude caustic storage (6 tanks)
253 50% Caustic storage (6 tanks)
254 Caustic fusion and drum assembly
255 Pump house and 2 fuel oil storage tanks
- Salt storage (300' x 150' concrete slab)

(3) Raw materials used:

Salt (NaCl) 97 + % pure
Sodium Bicarbonate (NaHCO₃)
Sodium Carbonate (Na₂CO₃)
Sodium hydroxide
Sulfuric acid 98% (H₂SO₄)
Fuel oil
Water

(4) Process - In unit B-247 salt was mixed with water to make the raw brine. Raw brine was pumped to the brine treatment unit B-248 where it went through a series of treatment tanks where sodium carbonate or sodium bicarbonate were added, transferred to the clarifloculator where sodium hydroxide was added. Calcium precipitated as calcium carbonate (CaCO₃) and magnesium precipitated as magnesium hydroxide (Mg(OH)₂). The purified
Figure 14. Chlorine plant - South plants, west.
brine was passed through sand filters and stored in unit B249. The precipitated sludge was discarded in basin A and burial pits in section 36.

(5) Purified brine from B249 was resaturated with salt and transferred to the electrolytic cell unit B242 where gaseous chlorine and hydrogen plus aqueous sodium hydroxide were produced in the ratio of 2.8 tons hydrogen and 112.5 tons sodium hydroxide to 100 tons chlorine. The wet chlorine gas was pumped from B242 to the chlorine purification and liquifaction unit B243. The gas was put through a cooler using chilled industrial water as a coolant. Then through a series of two ceramic drying towers containing sulfuric acid (98%). The chlorine gas was then compressed at 35 psi and sent to using agency. Chlorine gas which could not be used in 24 hours was liquifed for storage.

(6) The raw caustic went to unit B-252 for storage then to B-251 for removal of sulfate and excess water resulting in purified 50% caustic which was stored in B-253. Part of the 52% caustic was transferred to B254 where fused caustic was produced. The fused caustic was packed in 700 pound drums in B254 for storage or shipment.

(7) Fuel oil for use in the caustic fusion plant was stored in the tanks B-255-A and 3-253-3. Building 3-255 was the pump house for unloading tank cars of fuel oil and for metering fuel oil to the caustic plants area.

(8) Contamination hazards in the area included, sodium chloride from the salt storage and brine spills, caustic, chlorine, sulfuric acid and fuel oil. Salt brine, liquid caustic waste, neutralized sulfuric acid, and equipment wash water were flushed into the contaminated sewer system. Solid waste, consisting primarily of calcium, magnesium and sulfate sludge from the brine plant, was taken to burial pits in east part of section 36.

h. Phosgene (CG) Filling -

(1) The phosgene bomb filling plant operated from January 1944 through December 1944. The complex consisted of two (2) buildings (Figure 15):

B331 Contained most major operational equipment (i.e., filling booths, paint spray booths, CG cylinder unloading, caustic scrub tower, etc.)

B332 Working storage for filled bombs

Chemical materials used:
Figure 15. Phosgene (CG) filling plant - South plants, west.
Phosgene
Naptha
Calcium chloride brine
Paints
Thinners
Oil

(2) Process - Empty 500 and 1000 pound bomb casings were unloaded on the dock at the northeast end of B-331. The casings were placed on conveyers and flushed with oil till no trace of water remained. The casings were emptied, the outside washed with naptha then were painted and stenciled. The painted casings went to the filling hoods, were filled and weighed, sealed, leak tested and accepted or rejected. Accepted bombs went to B332 for a final leak test and shipment.

(3) The phosgene was delivered in ton containers on special railroad cars. One end of each tank was elevated slightly to allow removal of the phosgene from the bottom of the containers under air pressure. The phosgene was put through two coolers in series then to the filling booths. The gas coolers were cooled by calcium chloride brine at 0° to -15°C.

(4) Fumes from the filling booths and the emptying booths for rejected bombs were vented through caustic scrubbing towers. Problems with leaking bombs were quite frequent.

(5) Liquid waste consisting mainly of spent caustic, naptha and paint thinner plus some oils were washed into the contaminated sewer system to basin A. Solid waste consisted of emptied rejected bomb casings, packing materials and spent coke and caustic sludge from the scrubbers and were burned and buried in section 36.

i. Chlorinated Paraffin -

(1) Chlorinated paraffin was used by the Quartermaster Corps for moldproofing and fireproofing of fabrics.

(2) Construction was authorized 15 February 1945 and the retrofitting for paraffin began on 20 January 1945 in 3471 of the former thionyl chloride complex due to an urgent need by the Quartermaster Corp. Production in this facility ended 15 April 1945. Production in the 511 complex began 1 May 1945 and ended 20 June 1945. A total of 960 tons was produced from January through April and 2049 tons additional was produced from 1 May through 20 June.
The buildings used for manufacture of chlorinated paraffin were (Figure 16):

29 Jan to 15 Apr 45;

B-471 Reactor facility
-473 Drum loading

1 May to 20 Jun 45;

B-511 Paraffin chlorination (formerly acetylation of As Cl₃ to Lewisite)
511A Auxiliary chlorinator (formerly Lewisite storage)
533 Fan house - connected to 3 rd floor of B-511
534 Pumphouse, storage tanks and concrete pad

Raw materials were:

Paraffin
Chlorine
Triethanolomine

Waste products:

Paraffin
Chlorine gas
HCl gas
Triethanolomine

Paraffin delivered in tank cars was transferred to the storage tanks, heated to 60°C, passed through filters and put into the chlorinators. Chlorination was carried out at 43°C by bubbling chlorine through the paraffin from the bottom of the reaction vessel. When the specific gravity of the load reached 1.175 the load was transferred to a holding tank at the end of the reactor room. The paraffin was air blown to reduce HCl content to 3.004%. Triethanolomine was then added at 0.1% as a stabilizer. Loads of the product were analyzed and if accepted were loaded into tank cars or storage tanks.

The fan house and B533 stack were for the disposal of HCl gas and unreacted chlorine gas from the chlorinators. The gases were diluted with air and discharged into the atmosphere in nontoxic concentrations.
Figure 16. Chlorinated paraffin plant - South plants, east.
(7) Cooling water from the cooling jackets was returned to Derby Lake. Wash down water was flushed into floor drains into contaminated waste sumps. The liquid went to basin A. The slop from the sumps and traps was loaded into drums and burned and buried in section 36.

j. Mustard Distillation (HD) -

(1) The mustard distillation plant was constructed for the purification of Levenstein mustard to produce a product of high stability, standard analysis and which was more suitable for munitions filling. Operations began in July 1945 and were completed in 1946.

(2) The mustard distillation complex consisted of four (4) renovated buildings of the former Lewisite plant, and seven (7) newly constructed facilities (Figure 17):

B-512  HD filling - Formerly L filling plant
-514  HD Distillation - " " Reactor
-514A Dowtherm boiler unit - Former L Storage
-517  Change house

New Construction:

B-528  HD Residue burner
-529  Caustic makeup building
-536  Crude H storage
-537  Thaw house
-533  H Drum disposal
-538A Compressor house
-539  Electric substation

(3) Chemical materials used:

Crude mustard, H, HS
Caustic
Sulfuric acid
Nitric acid
Dowtherm - (mixture of diphenyl and dephenyl oxide used as a heat transfer medium)
Tret-O-Lite - Demulsifying agent
Chloride of lime (bleaching powder) CaOCl2

(4) Process - Crude Levenstein mustard (H) was received in the "Thaw House" B-537 in 65 gallon drums or ton containers. The mustard was warmed in the shipping containers and transferred to receiving tanks under vacuum. The "empty" containers, which
Figure 17. Mustard distillation plant - South plants, east.
still contained 60-100 pounds of residue which could not be removed under vacuum, were transferred by overhead monorail to the Drum Disposal Plant B-538. The container ends were cut out and containers put into furnaces to pyrolyze any residue. Cooled, burned containers were crushed and sold as scrap.

(5) Crude mustard was pumped from the receiver tanks in B-537 to holding tanks in B-536 where the mustard was sampled and analyzed prior to processing. Batches of mustard were then transferred to working storage tanks in B-514. The demulsifying agent "Tret-O-Lite" was added during the transfer.

(6) Treatment crude mustard was pumped to holding tanks on the third floor B-514 then to wash reactors where the mustard was washed with measured quantities of water. The two phase system was allowed to separate, mustard formed the lower phase. The washed mustard was pumped to washed mustard holding tanks. The contaminated water which contained soluble iron and sulfur compounds, mustard and other toxic and undesirable impurities was discharged to a decontamination pit outside the southeast corner of B-514.

(7) Washed crude mustard was discharged at high velocity with a dry air jet into mustard drying tanks. Dry, washed mustard was heated and pumped to vacuum stills on the second floor of B-514. The stills were heated with hot Dowtherm from B-514-A. Purified distillate was passed through heat exchangers to cool, to storage tanks, analyzed then transferred to B-512 for filling of ton containers.

(8) During distillation non-condensable gases passed from the stills to stripping condensers to a hot well decontamination pit from where the liquids went through a hard lead sewer pipe to basin A. Distillation residue from the stills was transferred to B-513 and burned in the furnace. Compressed air from B-538-A was used to aid combustion. Combustion gases contain sulfur dichloride, hydrogen chloride, carbon monoxide and carbon dioxide. Caustic for decontamination and scrubbing was made up in B-522.

k. M-47 Incendiary Bomb Filling -

(1) The M-47 100 pound incendiary bomb filling plant was designed and built exclusively for the manufacturing of jellied gasoline and the filling of M-47, 100 pound incendiary bombs. Construction was started January 1943. The plant was activated 25 March 1943 for training of the working crew. The first bombs were filled 29 April 1943 and continued, with a few stoppages, until 15 August 1944. In 1944 the plant operated at three times its designed capacity until October 1944.
Figure 18. Incendiary bomb plant - South plants, east.
(2) The facilities in this complex were (Figure 13):

- 741 Refrigeration and mixing
- 742 Empty bomb warehouse
- 743 Finished bomb warehouse
- 744 Bomb Filling
- 745 Bomb painting and stenciling
- 746 Bomb assembly
- 747 Shipment packing
- 748 Change house, laboratory
- 749 Change house, laboratory
- 744 Pumphouse for unloading gasoline and benzol
- 745A 100,000 gal tank - gasoline
- 745B 100,000 gal tank - gasoline
- 745C 200,000 gal tank - M65X
- 747 Cafeteria
- 748 Paint, lacquer and thinner storage

(3) Chemical materials used:

Gasoline - a specially prepared type
Benzol - to adjust aniline point of gasoline
Napalm - a powdered thickening agent also known as thickener M-1
Paint
Lacquer
Thinners

The term "Napalm" is often misused to mean the jellied gasoline. This is not correct as "Napalm" is the name of the powdered thickening agent only.

(4) Process - Building 741 contained three 1000 gallon mixing vats on the ground floor, south. Gasoline and benzol were piped into these vats from the storage tanks 2-745 A, B, or C. Napalm (M-1) was delivered to 741 in fiberboard drums. A proper amount of "Napalm" thickener was put into the vat and the contents mixed. Upon reaching a proper consistency samples of the gel were analyzed in 743. Accepted batches were piped from the mixing vats in 741 to the bomb filling lines in 742. All equipment coming into contact with the gel was washed with gasoline which was saved and reused.

(5) Rejected lots of "Napalm" thickener, gel, rejected gel filled bombs and remainders of laboratory samples were taken to the burning and burial pits in the eastern half of section 36. Waste wash water from the plant plus liquid waste from the paint lines was flushed into the industrial sewer system which emptied into basin A.
1. **M-74 Incendiary Bomb Plant**

(1) The purpose of this plant was to fill the M-74, 10 lb incendiary bombs, arm them and assemble them into 500 lb cluster bombs, E-43.

(2) This plant operated from 26 March 1945 until 15 August 1945 with short shutdowns because of material shortages. The facilities in this complex were (Figure 19):

| B-328  | PTI mixing and filling
| -329   | Gasoline unloading pumphouse
| -333   | IM Polymer storage and processing
| -338   | Intermediate fuze storage magazine
| -339   | Intermediate powder and primacord magazine
| -341   | Supply, HQ, Locker room, offices
| -342   | Storage; M-74 casings, E-43 parts
| -343   | Final assembly and preclustering, inspect, paint, install fuzes, and tail cup
| -344   | Final clustering operation
| -345A  | Drop test (three concrete vaults)
| -345   | Accepted bomb final assembly of tail fins, release wires, pack for shipment
| -346   | Intermediate storage of accepted clusters

(3) Definitions: (From History of RMA)

- **Gel** - Thickened mixture of gasoline and IM

- **GOOP** - Magnesium dust paste. A mixture of impure magnesium dust protected from rapid oxidation by an oil-asphalt mixture: an ingredient in the PTI filling mixture

- **GOOP Bomb** - Bomb, Incendiary, 10 lb., M-74, PTI filled

- **IM** - Isobutylmethacrylate polymer. A thickening agent for gasoline. Thickened gasoline is one component of PTI mixture. \([(\text{CH}_2-C(\text{CH}_3)\text{COCH}_2\text{CH}(\text{CH}_3)_2)]\)

- **POE** - Petroleum oil extract. A viscous phenol extract of petroleum, an ingredient of PTI mixture
Figure 19. H-74 Incendiary bomb plant - South plants, west.
PTI - Pyrotechnic incendiary

PTI Mix - Final mixture for filling GOOP bombs.
Contains GOOP, POE and IM thickened gasoline

WP - White phosphorus

(4) Chemical materials used:

Benzol - to adjust aniline point of gasoline
Gasoline
GOOP
Isobutylmethacrylate polymer
Magnesium, coarse and dust
Petroleum oil extract
Sodium nitrite

(5) Procedure - Gasoline was stored in two 12,000 gallon underground tanks. The IM polymer was stored and processed in B-333. This sometimes required heating the IM before it could be ground and powdered. Most other ingredients were received on a daily basis.

(6) Chemical components were analyzed by the laboratory B-313. Experimental batches of PTI mix were tested and formulation instructions were issued to the plant mixing unit.

(7) GOOP was received in drums which were put through a heating tunnel then sent to the second floor of B-328 and emptied into mixing tanks. Dried, ground sodium nitrite, and coarse magnesium metal were added. Gasoline and POE were blended in and the IM polymer added. Each batch was tested and accepted or rejected. Accepted batches were piped to the first floor where the M-74 bombs were assembled. Each bomb contained a white phosphorus cup, was filled with PTI mix and was sealed. The M-74 bomblets were fused, assembled into clusters, drop tested and finished for shipping.

(8) The PTI mixing equipment was washed with gasoline. The waste gasoline, floor sweepings, rejected PTI batches, rejected M-74 bomblets, and any other plant waste was taken to the burning and burial pits in the eastern part of the section 36 and burned. Waste water was flushed through the industrial sewer to basin A.

m. White Phosphorus Cup Filling -

(1) This plant was used in 1944 and 1945 and was activated again in 1952, 53, 58, 59 and 1960. The plant consisted of eight buildings (Figure 20).
(2) Chemical materials used:

- Alcohol
- Copper Sulfate
- Sodium silicate
- White phosphorus
- Sealing compound

(3) Process - Catalin or bakelite cups were dipped in a 40% solution of sodium silicate in B-541. In B-522 the cups were filled with W.P., tipped to remove excess W.P., washed, capped and sealed with a sealing compound. Excess sealing compound was washed off with alcohol. The filling process occurred with the W.P. under water hot enough (68°C) to keep the W.P. liquid. As the W.P. filled cups came from the water they were immersed in a solution of copper sulfate. The copper sulfate reacts with surface W.P. to form a seal. Any excess W.P. on the outside of the cups is removed with copper sulfate. After being capped and sealed the cups were cured for six hours at 32°C to harden the sealant. The cups were then leak tested at 63°C (to melt the W.P.), cooled, excess sealant sanded off and were sent to the 1-74 filling plant.

(4) 'Phossy Water' containing phosphates, copper sulfate and other impurities was stored in tanks in B-522A until released through the industrial sewer to basin A. Solid wastes and rejected items were taken to section 36 and burned and buried.

(5) In the later time periods (1952, '53, '55, '59, '60) other items such as bomb burster tube igniters and W.P. filled hand grenades were manufactured. Some of the wastes from these periods went to basin F and burial pits in section 4.
NOTE

For many of the following listed projects neither the dates of occurrence nor the precise areas of occurrence have been verified. Therefore, the process descriptions will be abbreviated.
o. Mustard (H, HS, HT) Demilitarization -

(1) The demilitarization of munitions filled with mustard (H, HS, HT) was accomplished in B-537, 533, 532, 540 (Figure 21).

(2) Chemical materials involved:

- Mustard (H, HS) - Crude mustard with various impurities
- Mustard (HT) - Crude mustard with various impurities plus Bis 2-chloroethylmercapto (ethyl) ether
- Sulfuric acid - used for decontamination
- Nitric acid - used for decontamination
- Sodium hydroxide - used to neutralize acid
- Toluene

(3) Process - Many types of both thick wall and thin wall munitions were demilitarized. Burster tubes or explosive components were removed. The munitions bodies were then cut, sheared or perforated to allow the agent to drain. Mustard (H and HS) which could be salvaged was put in ton containers and sent to the toxic storage yard.

(4) Unrecoverable H, HS and all HT was pyrolyzed in the furnaces. Most of the heavy wall scrap and some ton containers also were decontaminated in the furnaces. Thin wall scrap was decontaminated in a mixture of sulfuric and nitric acids and neutralized with sodium hydroxide. The metal was sold as scrap.

(5) Liquid waste was primarily wash water containing sulfuric and nitric acids, sodium hydroxide, mustard and by-products. This was flushed into the industrial sewer system to basin A or F. Solid waste included drums of decontamination residues, furnace ash, and steel and lumber scrap. These were taken to pits in section 36.

p. Mustard Munitions Filling -

(1) Filling of munitions with distilled mustard (HD) occurred at two locations. B-538 (Figure 21) and B-742 (Figure 22). In B-538 115 15 lb. bombs, 1-70 were filled. In B-742 4.2 inch mortar shells and artillery shells (105 and 155 millimeter) were filled with HD. The HD was delivered in ton containers and piped directly to the filling machines. The munitions were filled, sealed, outside surfaces cleaned, dried and painted.
Figure 21. M-70 bomb, Mustard filling and demilitarization plant - South plants, east.
(2) Chemical materials used:

- Distilled mustard
- Calcium hypochlorite \((\text{Ca} \text{Cl}_2)\)
- Sodium hypochlorite \((\text{NaClO})\)

(3) The sodium hypochlorite and calcium hypochlorite were used for decontamination of munitions, equipment and working areas where mustard contamination might be found. Liquid waste including mustard and decontamination products was washed into the industrial sewer system for disposal into basin A or basin F. Solid waste was burned and buried in section 36. It is possible that soil in the areas and porous surfaces may still remain contaminated.

q. Nerve Agent (GB) -

(1) Nerve agent (GB) was manufactured at RMA in the north plants area (Figure 6) from 1953 through 1953. Demil operations occurred in 1972, 73, and 76.

(2) Chemical materials used:

- Dichloro - (Methyl phosphonic dichloride)
  Manufactured by Shell Chem. Co.
- Hydrofluoric acid
- Isopropyl alcohol
- Tributylamine - stabilizer
- Sodium hydroxide - decontamination

(3) Chemical data:

Dichloro - \[\begin{array}{c}
\text{CH}_3-\text{P-Cl} \\
\text{O-Cl}
\end{array}\]

Name: Methyl phosphonic dichloride

GB - \[\begin{array}{c}
\text{CH}_3-\text{P - F} \\
\text{O - CH}=(\text{CH}_3)_2
\end{array}\]

Name: Isopropylmethanefluorophosphonate
Synonyms: Fluoroisopropoxy methyl phosphine, Isopropylmethylphosphonofluoridate
(2) Chemical materials used:

Distilled mustard
Calcium hypochlorite (Ca(ClO)₂)
Sodium hypochlorite (NaClO)

(3) The sodium hypochlorite and calcium hypochlorite were used for decontamination of munitions, equipment and working areas where mustard contamination might be found. Liquid waste including mustard and decontamination products was washed into the industrial sewer system for disposal into basin A or basin F. Solid waste was burned and buried in section 36. It is possible that soil in the areas and porous surfaces may still remain contaminated.

q. Nerve Agent (GB) -

(1) Nerve agent (GB) was manufactured at RMA in the north plants area (Figure 6) from 1953 through 1958. Demil operations occurred in 1972, 73, and 76.

(2) Chemical materials used:

Dichloro - (Methyl phosphonic dichloride)
Manufactured by Shell Chem. Co.
Hydrofluoric acid
Isopropyl alcohol
Tributylamine - stabilizer
Sodium hydroxide - decontamination

(1) Chemical data:

Dichloro -

Name: Methyl phosphonic dichloride
GB -

Name: Isopropyl methané fluorophosphonate
Synonyms: Fluoroisopropoxy methyl phosphine,
Isopropylmethyl phosphonofluoridate
Figure 22. Mustard shell filling plants (A). Wheat rust facility (E) - South plants, east.
The dichlor precursor was manufactured in the south plants area by Shell Chemical Company and shipped to the north plants complex. In the north plants complex the fluorine and isopropyl radicals were attached to the dichlor replacing chlorine thereby resulting in the finished product. The GB was loaded into ton containers and a variety of munitions.

Acceptable batches of GB contained no more than 3% DIMP (diisopropylmethylphosphonate) and traces of IMP (isopropylmethylphosphonate). Batches which were rejected were neutralized with sodium hydroxide and dumped into the lime pits south of basin A. Waste water from the plants area was flushed into the industrial sewer to basin A until 1956 when basin F was put into use.

Demilitarization of GB in ton containers and munitions occurred in 1972, 73 and 1975, 76. The agent was drained from the containers or munitions and neutralized with sodium hydroxide. The liquid with 4% excess sodium hydroxide was flushed through the industrial sewer system to basin F. Solid residues were neutralized and taken to the lime basins in basin A. Scrap metal was decontaminated and sold as scrap.

Phosgene (CG) and (CK) Demilitarization -

The demil of CG filled 500 and 1000 lb. bombs occurred in B-1601 of the north plants area (Figure 6). Demil of the (CK) filled M-76 and M-78 bombs was done in B-533 (Figure 21).

Chemicals used:

- Carbonyl chloride - (CG) phosgene
- Cyanogen chloride - (CK) - a chemically unstable compound (C3Cl) which can polymerize to form (C3=Cl3) a cyclic compound which can easily explode.

In S-1601 the burster tubes were removed and the CG transferred to ton containers for storage in the toxic storage yard. In S-533 burster tubes were removed, the bombs were connected by hose to a manifolds and placed in a hot water bath. The agent (CK) volatilized and went directly into the furnace where it was pyrolyzed. Bombs containing CK crystals were detonated in disposal pits in the north part of section 36. Bomb casings which were salvageable were steam cleaned and returned to the Ordinance Department for further use.
(4) Waste water containing CG and CK residues and degradation products was flushed into the industrial sewer system. Solid wastes from B-1601 were disposed of in pits in section 30. Solid wastes from B-538 were disposed of in the north part of section 36.

s. Laundry and Clothing Treatment

(1) Building 314 (Figure 23) functioned as a laundry for the decontamination and cleaning of clothing items used in toxic agent areas. It also served as a plant for the reimpregnation of such clothing prior to reuse.

(2) Chemical materials involved:

- Sodium hypochlorite
- Soaps
- Phosphate detergents
- CC2 - Octachlorocarbanilide
- CC3 - Octachlorocarbanilide + Zinc oxide
- Chlorinated paraffin
- Trichloroethylene

(3) The clothing arriving at the laundry were decontaminated in aqueous solutions of sodium hypochlorite then washed with soaps and detergents. The clothing was dried and reimpregnated by treating with trichloroethylene solutions of chlorinated paraffin and CC2 and CC3.

(4) The wastes generated in B-514 were decontamination and wash water, also spent and rejected solutions of impregnate. The waste water was released into a surface ditch along the east side of B-314 which emptied into basin A. Impregnate solutions were flushed into the industrial sewer system.

t. Laboratory

(1) This laboratory B-313 (Figure 23) acted as primary analytical and testing facility for RMA. All chemical raw materials and finished products used, produced or stored at RMA were analyzed or tested to determine specification compliance. Process control laboratories were supported and chemical items from other defense installations were also tested.
Figure 23. Laboratory B-313 and Laundry B-314 - South plants, east.
(2) Chemical material involved are listed in Volumes 1 to 15 of the laboratory samples registry.

(3) Chemical wastes included all of the raw materials and products tested at the laboratory and their residues. The toxic agents were returned to their respective sources for decontamination and disposal. Liquid waste from analysis of toxic agents was decontaminated, stored in bottles and emptied into basin A. Toxic solid waste was neutralized, collected in metal drums and buried in toxic waste pits in section 36. Inflammable wastes and remnants of incendiary samples were taken in metal containers to the burning pits in section 36. The remnants of all samples other than toxic agents were held 30 days then discarded in the burning pits.

(4) Waste water from the laboratory sinks drained into the open ditch east of B-313 which drained into basin A. This practice stopped when the new industrial sewer system was installed.

(5) An estimated 232 tons of samples were disposed of through the laboratory.

u. **Unsymmetrical Dimethylhydrazine (UDMH)**

(1) The UDMH plant (Figure 24) consisted of 3 structures:

- 3755 change house
- 756 mixing plant
- 757 storage tanks

(2) The plant started operation in 1961 and remains in operation in 1970. The components hydrazine and dimethylhydrazine are blended to form unsymmetrical dimethylhydrazine. Samples are analyzed to determine specifications compliance. Unused sample is returned to the plant for disposal. UDMH is decomposed in a solution of calcium hypochlorite (Ca\((\text{ClO}_2)\)). Decomposition of UDMH results in large amounts of sediment. The solid sludge was disposed of in pits in section 36. Waste water containing some sediment and the hypochlorite solution were flushed into the industrial sewer which emptied into basin F.

v. **Boiler Plant**

(1) Corrosion and scale formation are problems associated with boilers in hard water areas. Sodium carbonate was introduced into boiler water to convert calcium sulfate and magnesium sulfate to their respective carbonates and soluble sodium sulfate.

(2) The sulfates were flushed into the industrial sewer with the boiler water. The solid sediments would also be removed with the water during boiler blowdown.
Figure 24. Hydrazine plant - South plants, east.
w. Maintenance and Shop Areas -

(1) Post Maintenance Division -

(a) The maintenance facilities were located in several buildings in the south plants area (Figure 25). The buildings of known use were:

- B-543 Maintenance shops
- B-543B Offices, lockers, shops
- B-544 Maintenance shops
- B-545 Paint shop
- B-548 Pumphouse
- B-549 Cooling tower
- B-551 Water tower
- Equipment yard

(b) Chemical materials used in this area includes petroleum products, paints, thinner and solvents.

(2) Heavy Industrial Equipment Renovation (HIER) -

(a) This facility was located in B-751 (Figure 25) and was involved in the cleaning, renovation and preparation for storage of heavy machinery from all other shops. Chemical materials used included, Organochlorine degrease solvents, paint strippers (see Celite, Turco, etc.), rust removers, paints, thinners, solvents, rust inhibitors, gear oil, lubricating oil, grease, and other petroleum products.

(3) Field Equipment Renovation (FER) -

(a) This shop was located in B-624 (Figure 3). Small field equipment such as 4.2 inch mortars, flame throwers and other items in this category were renovated and prepared for storage in this facility.

(b) Chemical materials used were the same as those used in the HIER shops.

(4) Ordnance Shops -

(a) The shops were located in B-633 area west of "C" Street (Figure 2) and were responsible for repair and maintenance of vehicles.

(b) Wastes included crankcase drain oil, grease, solvents, gasoline spills.
(5) Salvage Property Division -

(a) Government property to be sold as salvage was sent to B-621 and was stored in one of the warehouses or open fenced yards behind B-621 (Figure 3). Chemical waste included containers of deteriorated paints, lacquer, thinner, commercial solvents and industrial chemicals which could not be sold.

(b) The waste water from all of these shop areas containing some solvents and other chemicals was flushed into the industrial sewer system and emptied into basin A or basin F. Burnable solid and liquid waste was burned in pits in section 36. Other solid waste was buried in section 36 or section 4.

x. Railroad Right of Way -

Spills occurred along the railroad at unloading positions on sidings. When faulty exit valves on tank cars leaked, contamination could occur anywhere along the right of way (Figure 26). This contamination could include any chemicals shipped in tank cars.

y. Wheat Rust (TX) -

(1) This project was to develop a viable wheat rust strain from among those common to the U.S. The project ran from 1964 until 1966. Large plots of wheat were planted for production of TX in sections 23, 24, 25 and 26 (Figure 27). The stockpiled TX was destroyed in 1972 and the ash incorporated into the soil in southeast section 19. Some solid waste from the active years was buried in a pit in the eastern central part of section 24.

(2) B-741 (Figure 22) was used as a laboratory and processing center during the TX project. Freon was used in the processing of TX. Liquid waste from B-741 went through the industrial sewer to basin F. Solid waste was burned and buried in section 24.

z. Toxic Storage Yard (TSY) -

(1) The toxic agent storage area (Figure 27) has served as a repository for toxic agents manufactured at RMA or manufactured elsewhere and shipped to RMA for storage. Most agents were stored in ton containers although some were stored in 55 gallon drums or loaded into munition items. The TSY was still in operation at time of writing.
Figure 20. AMRA Railroad network.
2. Agents which have been stored at the TSY include:
(a) Lewisite M-1 (L), B-chlorovinyl dichloroarsine
\[
\begin{array}{c}
H & H & Cl \\
\mid & \mid & \mid \\
C & = & C - As \\
\mid & \mid & \mid \\
Cl & & Cl
\end{array}
\]
(b) Mustard (H, HS, HD), BB' dichlorodiethylsulfide
\[
\begin{array}{c}
H & H & H & H \\
\mid & \mid & \mid & \mid \\
Cl & - & C - C - S - C - C - Cl \\
\mid & \mid & \mid & \mid \\
H & H & H & H
\end{array}
\]
(c) Phosgene (CG) Carbonyl Chloride
\[
\begin{array}{c}
O \\
\| \\
Cl - C - Cl
\end{array}
\]
(d) Nerve agent (GB) Isopropylmethanefluorophosphonate
\[
\begin{array}{c}
0 \\
\| \\
CH_3 - P - F \\
\| \\
O - CH - CH_3
\end{array}
\]
(e) Nerve agent (VX)
\[
\begin{array}{c}
S - (2-Diisopropylaminoethyl)-O-ethylmethylphosphonothiatric \\
\end{array}
\]
\[
\begin{array}{c}
\text{CH}_3 \\
\| \\
\text{C}_2\text{H}_5 \quad S - \text{C}_2\text{H}_4:N(CH_3)_2CH
\end{array}
\]
3. Other chemical materials stored or used in the TSY are those used for decontamination of agents and include:

Calcium hypochlorite powder and solutions for decontamination of mustard
(2) Agents which have been stored at the TSY include:
(a) Lewisite M-1 (L), B-chlorovinylchloroarsine
(b) Mustard (H, HS, HD), BB' dichlorodiethylsulfide
(c) Phosgene (CG) Carbonyl Chloride
(d) Nerve agent (GB) Isopropylmethanefluorophosphonate
(e) Nerve agent (VX) S-(2-Diisopropylaminoethyl)-0-ethylmethylphosphonothioate
(3) Other chemical materials stored or used in the TSY are those used for decontamination of agents and include:
Calcium hypochlorite powder and solutions for decontamination of mustard 6C
Figure 27. Wheat rust (TX) areas (A), Toxic storage yard (B), Former agent storage yard (C).
Sodium hydroxide solid and solutions - used in solution for decontamination of Phosgene (CG) and Nerve agents (GB, VX).

(4) Containers and ground spills are decontaminated with the appropriate chemical and flushed with water. Since decontamination products are seldom cleaned up, the entire area can be considered suspect of high contamination. Solid waste from the TSY was formerly disposed of in pits in section 36.

(5) The former agent storage area (Figure 27) is located south of the TSY. Agents stored there included mustard and phosgene. Several mustard spills occurred in this area. The chemicals used for cleanup and decontamination would be the same as those used in the TSY.

aa. Waste From Outside RMA -

During 1947-48 many carloads of medical supplies were returned from overseas. Medical, dental and surgical supplies including drugs, chemicals, medicines, bandages and other items were found to be contaminated. RMA entered into an agreement with the Medical Corps to destroy and dispose of this property. The medical supplies were brought to RMA in dump trucks and was dumped into dump pits, burned and buried. It is thought these supplies are buried in the southern part of section 36 but this has not been verified.

5. RMA Leaseholders -

a. Julius Hyman Co. was the first leaseholder on RMA. This company began operations on RMA in 1946 and continued until 1952. The J. Hyman Co. manufactured pesticides such as Aldrin, Dieldrin and Chlordane in the south plants area east of "D" Street. A research laboratory was maintained in B-313.

b. The Chemical Division of the Colorado Fuel and Iron Co. was a leaseholder on the RMA from 1950 to 1953. They also maintained a research laboratory in B-313. Buildings occupied by CF & I included parts of the old mustard plant (Figure 14) chlorine plant, and several nearby facilities. Products manufactured by CF & I included: chlorobenzene, DDT, Napthaline, chlorine and fuzed caustic.
c. The Shell Chemical Co. (SCC) came on RMA in 1952 and remains at present. Their operations encompass most of the buildings in the south plants area. During 1952-53 SCC manufactured Dichloro MC for the U.S. Government. The Dichloro was manufactured in the old mustard area (Figure 3) and transported by tank cars to the north plants area. Other products manufactured on the leasehold are listed in appendix B. For raw materials used see appendix C. Appendix D lists Process Materials and Solvents, also known Process Intermediates.

d. Waste disposal by the leaseholder was similar to that of RMA. Liquid waste went through the industrial sewer line to basin A or F. The solid or slurry waste went to open burial pits.
APPENDIX

A

Raw Chemical Materials Used
in RMA Operations
Raw chemical materials used in RNA operations

1. Acetic Acid
2. Alcohol, Ethyl
3. Alcohol, Isopropyl
4. Alcohol, Methyl
5. Arsenic Oxide
6. Arsenic Trichloride
7. Arsenic Trioxide
8. Benzol
9. Calcium Carbide
10. Calcium Chloride
11. Calcium Hypochlorite
12. Chlorine
13. Copper sulfate
14. Dichloro MC (Methylphosphonicdichloride)
15. N,N' - Diisopropylcarbodiimide
16. Ethylene Glycol
17. Freon 113
18. Fuel Oil #6
19. Gasoline, Grades 4 & 5
20. Gasoline, Unleaded

21. Hydrazine
22. Hydrazine, Dimethyl
23. Hydrofluoric acid

25. Impregnite, CC-2
26. Impregnite, CC-3
27. Isobutylmethacrylate Polymer

28. Lead, Azide
29. Lime, Chlorinated
30. Lime, Type C

31. Magnesium metal (coarse)
32. Magnesium metal (dust)
33. Magnesium metal (powder)
34. Mercuric chloride
35. Mercury
36. Methylphosphonic difluoride
37. Monochlorobenzene
38. Mustard (H, HS, HN)

39. Nitric Acid
40. Nitric Acid/Sulfuric Acid (Mixed)
41. Paraffin
42. Paraffin, Chlorinated
43. Petroleum Oil Extract #2
44. Phosgene (CC) - (Carbonyl Chloride)
45. Phosgene (CK) - Cyanogen Chloride)
46. Phosphorus, Red
47. Phosphorus, White
48. Phosphorus Trichloride
49. Rosin, wood
50. Sodium Bicarbonate
51. Sodium Chloride
52. Sodium Hydroxide (solid)
53. Sodium Hydroxide (Solution)
54. Sodium Hypochlorite
55. Sodium Nitrate
56. Sulfur Monochloride
57. Sulfuric Acid
58. Sulfuric Acid (fuming)
59. Thickener M-1 (Napalm)
60. Toluene
61. Tributylamine
63. Trichloroethylene

64. Zinc Oxide
<table>
<thead>
<tr>
<th>TRADE NAME</th>
<th>CHEMICAL NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>AKTON* Insecticide</td>
<td>Phosphorothic acid, O-[2,5-dichlorophenyl) vinyl 0,0-diethyl ester</td>
</tr>
<tr>
<td>Aldrin</td>
<td>Hexachlorohexahydro-endo,exo-dimethanonaphthalene (principal constituent, known as HEXIN)</td>
</tr>
<tr>
<td>AZODRIN* Insecticide</td>
<td>Dimethyl phosphate of 3-hydroxy-N-methyl-cis-crotonamide</td>
</tr>
<tr>
<td>BIDRIN* Insecticide</td>
<td>3-(dimethoxyphosphinyloxy)-N,N-dimethyl-cis-crotonamide</td>
</tr>
<tr>
<td>BLADEX* Herbicide</td>
<td>2-(4-chloro-6-ethylamino-s-triazin-2-yamino)-2-methylpropionitrile</td>
</tr>
<tr>
<td>CIODRIN* Insecticide</td>
<td>Alpha-methylbenzyl 3-(dimethoxyphosphinyloxy)-ciscrotonate</td>
</tr>
<tr>
<td>DIBROM</td>
<td>1,2-dibromo-2,2-dichloroethyl dimethylphosphate</td>
</tr>
<tr>
<td>Dieldrin</td>
<td>Hexachloro-p-xyloxytetrahydro-endo,exo-dimethanonaphthalene (principal constituent, known as HECD)</td>
</tr>
<tr>
<td>Endrin</td>
<td>Hexachloro-p-xyloxytetrahydro-endo,exo-dimethanonaphthalene</td>
</tr>
<tr>
<td>Ethyl parathion</td>
<td>0,0-diethyl 0-1-nitrophenyl thiophosphate</td>
</tr>
<tr>
<td>GARDENA* Insecticide</td>
<td>2-chloro-1-[4-(1,3,5-trichlorophenyl) vinyl dimethyl phosphate (RT 136, SD 6447)</td>
</tr>
<tr>
<td>LANDRIN* Insecticide</td>
<td>Mixture of the 3,4,5 and the 2,3,5 trimethylphenyl methylcarbamate isomers, which are present in approximately a 1:1 ratio respectively</td>
</tr>
<tr>
<td>Methyl parathion</td>
<td>0,0-diethyl 0-1-nitrophenyl thiophosphate</td>
</tr>
<tr>
<td>NEUGCIN* Soil Fumigant</td>
<td>1,2-dibromo-1-chloropropane</td>
</tr>
<tr>
<td>NUDRIN* Insecticide</td>
<td>S-methyl-N-[N-methylcarbamoyl]oxy-thiacetimidate</td>
</tr>
<tr>
<td>PHOSDRIN* Insecticide</td>
<td>Dimethyl phosphate of methyl 3-hydroxy-cis-crotonate</td>
</tr>
<tr>
<td>PLANAVEN* Herbicide</td>
<td>4-(methylsulfonyl)-2,6-dinitro-N,N-dipropylamino</td>
</tr>
<tr>
<td>PYDRIN* Insecticide</td>
<td>Cyano(3-phenoxyphenyl)methyl 4-chloro-alpha-(1-methyl ethyl)benzeneacetate</td>
</tr>
<tr>
<td>Shell Antifreeze (59-14-6)</td>
<td>-</td>
</tr>
<tr>
<td>Shell Atrazine Herbicide</td>
<td>2-chloro-4-ethylamino-6-isopropylamino-s-triazine</td>
</tr>
<tr>
<td>SUPONA* Insecticide</td>
<td>2-chloro-1-(2,4-dichlorophenyl)vinyl diethyl phosphate</td>
</tr>
<tr>
<td>VAPONA* Insecticide</td>
<td>2,2 dichlorovinyl dimethyl phosphate</td>
</tr>
</tbody>
</table>

*Registered Trademark U. S. Patent Office
### APPENDIX B

#### DENVER PLANT OPERATIONS

<table>
<thead>
<tr>
<th>Insecticide/Herbicide</th>
<th>Period Produced</th>
</tr>
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<tbody>
<tr>
<td>Aldrin</td>
<td>1955-1975</td>
</tr>
<tr>
<td>Dieldrin</td>
<td>1955-1973</td>
</tr>
<tr>
<td>Methyl parathion</td>
<td>1957-1967</td>
</tr>
<tr>
<td>Ethyl parathion</td>
<td>1964-1966</td>
</tr>
<tr>
<td>PHOSDRIN Insecticide</td>
<td>1956-1970</td>
</tr>
<tr>
<td>BIDRIN Insecticide</td>
<td>1963-1975</td>
</tr>
<tr>
<td>CIODRIN Insecticide</td>
<td>1962-1973</td>
</tr>
<tr>
<td>VAPONA Insecticide/DDVP</td>
<td>1960-1975</td>
</tr>
<tr>
<td>NEMAGON Soil Fumigant</td>
<td>1955-1975</td>
</tr>
<tr>
<td>DIBROM</td>
<td>1962-1970</td>
</tr>
<tr>
<td>SUPONA Insecticide</td>
<td>1963-1967</td>
</tr>
<tr>
<td>PLANAVIN Herbicide</td>
<td>1966-1975</td>
</tr>
<tr>
<td>GARDONA Insecticide</td>
<td>1966-1968</td>
</tr>
<tr>
<td>AKTON Insecticide</td>
<td>1967</td>
</tr>
<tr>
<td>LANDRIN Insecticide</td>
<td>1969</td>
</tr>
<tr>
<td>BLADEX Herbicide</td>
<td>1970-1971</td>
</tr>
<tr>
<td>NUDRIN Insecticide</td>
<td>1973-1975</td>
</tr>
</tbody>
</table>
Dicyclopentadiene
Hexachlorocyclopentadiene
Hydrogen peroxide
Vinyl chloride
O₂O-dimethyl phosphorochloridothionate
O₂O-diethyl phosphorochloridothionate
p-nitro sodium phenolate
Methylacetoacetate
Trimethyl phosphate
Diketene
Dimethylamine
Alpha-methylbenzyl alcohol
Methylaniline
Chloral
Allyl chloride
Bromine
2,2,2',4'-tetrachlorocacetophenone
Triethyl phosphate
p-chlorobenzensethiol
Methyl chloride
Nitric acid
Di-n-propylamine
1,2,4-trichlorobenzene
Dichloroacetyl chloride
p-dichlorobenzene
Chloroacetyl chloride
Sodium methylate
Isophorone
Acetone cyanohydrin
SMA 1440 E
IGEPAL CA-897
Bentonite ZRM 20
Maraspese 3-22
Kelzan

Ammonia
Cyanuric chloride
Ethylamine
Acetiloxime
Methyl mercaptan
Methyl isocyanate
Formaldehyde
SHELLFLEX 210 Oil
Sodium nitrite
meta-dinitrobenzene
Sponto 232
Sponto 234
HAN (heavy aromatic azepha)
Ethylene glycol
Dipotassium acid phosphate
Sodium mepaptobenzothiazole
Borax
Sodium nitrate
Sodium meta-silicate
Sodium orthophosphate
Pluronic L-61
Aerosol OT-100%
Dye, Alizarin cyanine green
Uranine C
Benzaldehyde
Bromine chloride
Phenol
Hydrazine cyanide
2[para-chlorophenyl]-3-methylbutric
Anilin
Triton X-100
Shell sodium sulfonates
Sodium nitrite
Emulphogene BC-720

*Registered Trademark U. S. Patent Office
APPENDIX B

PROCESS MATERIALS AND SOLVENTS

Acetic acid
Acetone
Aluminum chloride
Ammonia
Benzene
Calcium carbide
Carbon tetrachloride
Chlorine
Chloroform
Copper sulfate
1,2-dichloroethane
Ethylene glycol monoethyl ether
Hexane
Mineral spirits

Isopropyl alcohol
Methyl isobutyl ketone
Methylene chloride
Shell cyclo-
f-9
Sodium hydride
Sulfur dioxide
Sulfuric acid
Sulfuryl chloride
Thionyl chloride
Toluene
Triethylamine
Urea
Xylene

PROCESS INTERMEDIATES

Cyclopentadiene
Acetylene
Bicycloheptadiene
2,2',5'-trichloroacetophenone
N-methylacetoacetamide
N-methyl-2-chloroacetamide
N,N-dimethylacetamide
2-chloro-N,N-dimethylacetamide
2-methylbenzyl acetate
carboxylic acid
meta-bromobenzaldehyde
meta-phenoxysalicylic acid
1-chlorocetaldehyde
1-methylcetaldehydine
Methyl acetate
Methyl-2-chloroacetate
p-chlorophenyl methyl sulfide
p-chlorophenyl methyl sulfoxide
p-chloro-3,5-dinitrophenyl methyl sulfoxide

Alpha-amino-iso-butyronitrile
2(1'-cyano-1'-methyl-ethylamino)4-
6-dichloro-s-triazine
2,2',4',5',pentachloroacetophenone
2-chloroisophorone
3,4,5-trimethyl aniside
2,3,5-trimethyl phenol
1,2,3,4,5,7,7-heptachlorobicyclo-
(2.2.1)-2-heptane
1,2,3,4,7,7-hexachlorobicyclo-
(2.2.1)-2,3-heptadiene
1,2,3,4,10,10-hexachloro-1,4,5,6,7,8-
hexahydro-1,4,5,6-endo,endo-
dimethanonaphthalene (isoccin)
Col. Kellogg
Commanding Officer
Rocky Mountain Arsenal
Derby, Colorado

Dear Col. Kellogg:

I am transmitting herewith a copy of a report prepared by Mr. George W. Sciple of this Laboratory with respect to his findings in connection with waterfowl mortality at the Arsenal lakes. Whereas, we do not have the chemical facilities to perform all the analysis necessary in determining the identity of modern insecticides, it would appear quite evident from the work done by Mr. Sciple that toxic material of some kind has been present in these bodies of water.

Very truly yours,

/s/E. R. Kalmbach

E. R. Kalmbach
Director

Attachment

cc: Director, Fish & Wildlife Service
    Dept. of Game Management
    Food & Drug Administration, Denver
    Mr. Dale Prentice, Rocky Mountain Arsenal
    Dr. Charles Davis, Bureau of Animal Industry
    Mr. Gurney Crawford, State Game Department
    Mr. George Sciple
The program of investigation by the Wildlife Research Laboratory of duck mortality on lakes at the Rocky Mountain Arsenal was carried out in four phases. These were:

1. A field epidemiological survey.
2. Field toxicity experiments.
3. Chemical, gross pathological, and histopathological studies.1/
4. Feeding and skin absorption tests.

The purpose of the first phase was to assess the mortality and to determine from field evidence the most likely source of the malady. The findings here guided operations in the other phases.

The purpose of the second phase was to determine whether healthy penned ducks could be intoxicated and killed by exposure on the waters of the Arsenal lakes.

Gross pathological and histopathological studies were undertaken to determine what lesions occurred, if any, in the dead birds, and whether pathognomonic lesions might be present.

Feeding and skin absorption tests were undertaken when strong indications of the source of the difficulty were found.

1. Field Epidemiological Survey

The field survey initially revealed many dead and dying birds on the water and along the shorelines of Upper Derby, Lower Derby, and Ladora Lakes. Many more carcasses were found far out in the surrounding grasslands and fields. Sick birds were seen to go into convulsions and fall while in flight. The many undisturbed carcasses found in the fields surrounding the lakes appeared from their distribution pattern to have come to their final resting places in this manner. A very rough estimate of total losses on the Arsenal lakes and on areas peripheral to them (during the period of investigation) was in the neighborhood of 1,200 ducks. In addition, several species of birds other than ducks were found dead on the shores of the lake. Carcasses of six species of mammals were reported in similar locations.

1/ The latter carried out by Dr. Charles L. Davis, Pathological Laboratory, U.S. Bureau of Animal Industry, Denver, Colorado
A characteristic syndrome was observed in the sickened free birds. The individual duck would sit quietly on the bank when approached closely by the observer. Its only movements would be an unusual repetitive "feeding" tremor of the mandibles and a coarse tremor of the head and neck. Depending upon the severity of the symptoms, the bird would either allow itself to be picked up without a struggle or would suddenly become alert as the observer came within a few feet of it. In the first situation, the duck seemed unable to coordinate muscular activity and could not escape. In the second situation, the bird apparently had a greatly reduced sensorium and was unable to respond except to the strongest stimuli. These latter birds, once they became alerted, would fly up strongly as the observer approached within 4 - 5 feet of them. They would rise sharply, but as an altitude of perhaps 50-75 feet was gained, the ducks would go into violent convulsions and fall back into the water. The convulsions were of a mixed sort with some clonic features, but also with a constant final opisthotonic component. Several birds were observed which were less heavily affected. They rose from the water and got into flight fairly well when flushed. After flight was underway, however, they were unable to maintain direction, level flight, equilibrium, or to judge distance. Several instances occurred where birds flew at full speed into the sides of buildings or into the ground, or folded their wings and "landed" while still 25 or 30 feet above the surface of the water.

These bizarre findings indicated strongly the action of an agent or agents affecting the central nervous system of the birds.

It was found that resident individuals (banding data) were the hardest hit by the mortality. While migrant species were also found to be susceptible to the agent or agents, they were found not to sicken immediately after their arrival in the area, but only after a time lag of about two weeks or slightly more. A similar time-lag was observed in experimental birds, as will be described later.

In every one of more than 30 daily periods of observation, resident species were found to be present on Upper Derby, Middle Derby, and Ladora Lakes. Only twice were birds seen on the toxic lake north of the plant area. On both of these occasions, the birds were found to be migrant species and not the resident birds.

Degree of mortality on the three industrial lakes appeared to be closely correlated with the population of birds resident on the lakes for a considerable period. Although "waves" of heavy mortality appeared to occur, it is believed that these were in reality reflections of heavy population use of the lakes through an extended time period precedent to the high mortality. In addition, as a fairly steady day-to-day mortality went on carcasses piled up to the point where they were noticed by the casual observer, who then tended to conclude that all the dead seen were representative of a single heavy mortality episode. The preponderance of field evidence was contrary to this point of view. Mortality actually seemed to be proportional to degree and intensity of population usage of the area, one an initial time-lag of two to three weeks had passed.
2. Field Toxicity Experiments

Field toxicity experiments were carried out by penning wild mallard drakes in various types of locations on all three of the industrial lakes. The experimental birds were obtained from a distant area free of any possible arsenal influence. This area was the Two Buttes Reservoir near Springfield, Colorado. (The full day to day record of the experiments is on file at the Laboratory. Because of its length an abbreviated summary will follow.)

A total of 12 mallards was used. Two of these were wing clipped, held on a small pool at the Federal Center, and were used as controls. Their diet was identical with that offered the experimental birds at the Arsenal. Both these birds remained well throughout the period of the experiment. They finally escaped after a storm wrecked a barrier enclosing them.

The experimental birds were at first exposed in one large cage on Upper Derby Lake for a one week adjustment and initial exposure period. All 10 birds were then moved to smaller cages, and were placed two to a cage in 5 locations on the three lakes. Two birds in one cage escaped due to the tampering with the cage by uninformed laborers. They were ruled out of the experiment. All of the 8 experimental birds died and both controls remained healthy.

The conditions preceding the deaths of these birds are of interest. Some of the caged birds died soon after the "lag period" mentioned above, while the others did not. It was at first thought that the locations were the differential factor. This view had to be modified, however, when it was found that the differential factor was surface exposure and exposure to the oily foam on the water surface. Ducks did not die when the base-boards of the cage projected above the water and closed off the cage from the general lake water surface. When water-surface and foam exposure were constantly present, the birds died without exception. Birds were taken from non-surface exposed cages where they had lived for extended periods and placed in cages offering surface and foam exposure. These birds then died after passage of the lag period. This evidence links toxicity directly to surface and foam exposure.

3. Chemical, Gross Pathological and Histopathological Studies

Sixteen necropsies were performed on ducks dying on the lakes. The following were the findings in the 12 carried out by the author. With exception of brain, intestine, and lungs no pathology was noted grossly. A rather constant finding of unknown significance was a heart with ventricle in systole, auricles in diastole. The auricles were massively engorged with blood. Liver appeared normal, grossly, in all cases and no evidence of phosphorus poisoning could be detected. Gizzards were all normal and no evidence of arsenical substances was found.

1/ Dr. Charles L. Davis, Pathological Laboratory, U.S. Bureau of Animal Industry, did three of these and Mr. Casimir Kuzniar, Rocky Mountain Arsenal, did one.
traces of lead shot could be detected. (One test for lead by the acetate method was negative also.) The intestine in several cases showed marked vascular congestion. In several cases the intestinal lumen, though clear of food material, was filled with an opaque, viscous, custard-yellow mucoid material. The lungs in 7 cases where markedly edematous, congested, and filled with a thin, blood-tinted effusion. The thin bloody fluid was also found in some quantity within the coelomic cavity in these cases. The brain showed considerable vascular congestion and pinkish coloration throughout. The meninges likewise showed vascular engorgement. A strong "chemical" odor, similar to that smelled on the lakes, was noted in the flesh and in the plumage of the birds.

Dr. Davis reports, in the histopathological examination, that no apparent histological changes were observed in the visceral organs. The appearance of possible tissue alterations in the brain has necessitated further examination of the material in hand. This examination has not yet been completed.

Gutzeit tests for the occurrence of arsenic were run on the organs of six birds. All were negative for the presence of arsenic.

Duck fat from birds dying on the lakes was supplied to Dr. Y.P. Sun, of Julius Hyman & Company, for bioassay and spectrophotometric analysis. His results were incorporated in a report to the Division Engineer dated 14 May, 1952.

Benzene extracts were carried out on several crude foam deposits found on Upper Derby Lake. One of these products was supplied to Dr. Sun for analysis.

Duck fat similar to that given Dr. Sun was turned over to Mr. Macdonald of Food and Drug Administration for bioassay and analysis.

4. Laboratory Experiments

Since a detailed account of the protocols of these experiments would be too voluminous for incorporation in this report, a condensation will be made.

The experiments involved feeding and skin absorption tests in mice and ducks. The material tested was an oily liquid, lighter than water, and with a viscosity and color roughly comparable to that of molasses. The odor was very strong and similar to that noted in the plant area of the Arsenal. This material was obtained by a simple benzene extraction of foam collected on the inlet stream (effluent from the plant) of Upper Derby Lake.

Practical obstacles hindered this work considerably and precluded the running of any but acute toxicity tests. Chief among these practical obstacles were limited time and the non-availability of wild male mallard ducks. In addition, the spring filling of the Arsenal lakes flooded out

* One of these was run by Mr. Casimir Kuznair of the Rocky Mountain Arsenal. Five were run by Messrs. Crabtree and Robison of the Wildlife Research Laboratory.
scum board and collection area. A single sample was available for tests on ducks. Three samples had previously been available for tests on mice.

Twenty-three to twenty-eight gram white mice were stomach tubed with as little as 0.05 cc. of the brown oily extract. Convulsions and death occurred in some of these animals within a minimum of an hour and fifteen minutes. This amount was uniformly fatal to all mice so dosed. Controls having "Mazola" corn oil in like amount remained unaffected.

Crystals were obtained from the brown oily extract. These were cleaned with benzene, air dried, ground to dust in a mortar, and the finely divided resulting material suspended in corn oil. Varying doses of this suspension stomach tubed into mice resulted in no deaths. The only observable symptom was a slight reflex hypersensitivity to sudden aural stimuli. The brown oil from which the crystals were isolated was then re-tested in mice and was found to retain its toxicity.

In a test of skin absorption, mice had an area of bare skin exposed by shaving the hair on the back above the pectoral girdle. Three drops of the brown oil were applied to this area. All mice so treated died within 24 to 25 hours. Terminal convulsions were observed in one case. Controls treated similarly with 3 drops of a bland corn oil ("Mazola") remained well.

Only 6 ducks and a single sample of foam extract were available for testing. An attempt was made to stomach tube the brown oil, undiluted, into a male mallard. It was found that the material was not retained. Vomiting occurred. It was found necessary to mix the brown oil with corn oil in order to avoid loss of the material through vomiting. This mixture was stomach tubed for three successive days. Neither death nor marked debility occurred. Some rather slight repetitive tremors of mandibles, head and neck, and wings were found to occur.

Control dosed only with corn oil appeared normal during the course of the experiment.

A bird was prepared for a skin absorption test by removing the plumage from an area on the back between the wings. Bare skin was exposed. The brown oil (0.2 cc.) was skin-applied at approximate 2 hour intervals. Neither death nor debility resulted. Some slight tremors of mandibles, head and neck, and wings were observed.

A control handled in a similar manner with corn oil applied to the skin surface appeared normal.

The only conclusion which can be drawn from the above is that, in the amounts administered, this sample of air-dried benzene extract of foam was not acutely toxic to male mallard ducks.

The need for more extensive studies is evident. Chronic toxicity studies should be run.
Conclusions

On the basis of the information gathered, it seems indicated that the avian mortality occurring on Upper Derby, Lower Derby, and Ladora Lakes is related etiologically to a surface-borne agent, or agents, toxic to the central nervous system. Though not yet proven, it is believed probable that this surface agent is contained in an oily scum which entered the lakes through a process-water drain from the plant area. The drain comprised one of the two sources of the "plant effluent" channel. This channel drains directly into Upper Derby Lake.

28 May 1952