Intelligence Report on Japanese Chemical Warfare

Volume II

THE CHEMICAL WARFARE RESEARCH AND DEVELOPMENT WORK OF THE JAPANESE

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ABSTRACT

This report describes the chemical warfare research and development organizations in Japan and the work carried out by them.

In Japan there was no real connection between the Army and the Navy organizations, and their work was carried out independently of each other with very little liaison between the groups. Neither had a Chemical Warfare Service as such, but the research and development work on chemical warfare subjects was confined, in general, to organizations working only on CW subjects. In the Army the Sixth Military Laboratory having a total of 715 personnel did the principal chemical warfare work. The Eighth Laboratory did work on flame throwers, and the Third Air Technical Laboratory worked on chemical warfare subjects of interest to the Air Forces. In the Navy only the Chemical Study Department of the Sagami Naval Arsenal worked on chemical warfare subjects. This laboratory employed 300 people. The work carried out by the Army Organization was in general much superior to that of the Navy group.

The status of the work done on chemical warfare subjects is summarized below:

a. Both the Army and Navy had gas masks which gave good protection against gases such as phosgene and mustard. They realized that their mask did not protect against HCN very satisfactorily and were concentrating on this work. Apparently they were unaware of the desirability of improving the protection against CK.

b. After the development of the model 100 portable flame thrower and the latest model mechanized one in 1944, work was stopped on these weapons by the Army because they believed that their shortage of fuel would limit the usefulness of this weapon. The Navy, however continued work and developed a light weight portable flame thrower which was never produced.

c. Both the Army and the Navy had impervious clothing, but neither had developed satisfactory permeable protective clothing. Their work consisted of trying to use Chloramine-T as the impregnating material. Shortly before the war's end the CW Laboratory in Manchuria initiated the development of carbon-impregnated clothing which they considered very promising.

d. Practically all the research and development work on smoke was completed several years before the end of the war and is of little interest. The latest information obtained was used in the design of munitions which were standardized.

e. The work on the development of detector kits resulted in the standardization of several kits prior to the end of the war.

f. No unusual methods or agents for decontamination were developed. The Japanese report, however, that the methyl ester of anthranilic acid is an effective decontaminant for mustard on the skin. The system of gas proofing buildings and fortifications was not improved over the standard methods.

g. Both the Army and Navy had carried out extensive work on the search for new agents. Except for the limited production of a "non-freezable" mustard only the common agents mustard, lewisite, phosgene, hydrogen cyanide, chloracetophenone, and diphenylcyanarsine were produced. Work on CK and HN-3 was carried out, but they were not adopted. No evidence that work was done on agents of the trilon group exists. Except in the case of HCN no instability of the agents was encountered during storage. The Japanese used approximately two percent of copper net or powder, $AsCl_3$, or SO_2 with the HCN and reported that the material was then stable for at least three years.

Shell and bombs were coated on the inside with a Bakelite type resin. This was believed to prevent corrosion, but in the case of HCN it was not considered helpful to the stability of the material.

The toxicity of the standard agents had been studied using rabbits, guinea pigs, pigeons, etc., but the information concerning the dosages required for man were very doubtful. Particularly in the case of the effects of mustard vapor the data were inadequate.

h. The raw materials usually used in the production of the common toxic agents and the ordinary materials of construction were very scarce in Japan; consequently, the pilot plant work was directed to developing methods of producing the agents out of materials more readily obtainable and is of little interest or value.

i. A considerable number of field tests were carried out by the Japanese in studying the effectiveness and behavior of toxic agents when used in the field. Much of this work was done before they initiated the war with the United States and at that time they probably had better information on this subject. Work during the war has not proceeded apace that of the Allies, however.

j. The Japanese did very little work on the development of incendiary munitions.

k. No unusual weapons of great interest were developed.

l. Some work on the treatment of gas casualties had been carried out, but no improvements in the common methods of treatment used before the war were standardized.

I. INTRODUCTION

This report describes the research and development work done by the Japanese on chemical warfare subjects. The results of their work and the conclusions reached by the Japanese are also included. For the sake of completeness no effort is made to eliminate from the report known information. No comparison of the chemical warfare work of the Japanese with that of the United States is made. Neither is there included a discussion of the state of chemical warfare knowledge since it is believed that experts in various subjects will be more competent to evaluate this from the report than can this group. In general more history of the development work and related information has been included than is necessary in a strictly technical report. This material has been recorded so that the overall development picture can be more easily visualized.

Shortly after the Japanese agreed to surrender, orders were issued by the Imperial General Headquarters to destroy all records and reports of Japanese research and development work. Even though these orders were countermanded within several days, a very thorough job of destruction was apparently done for few documents of importance concerning chemical warfare work have been located at this time. The report is, therefore, based on verbal information obtained from Japanese officers, officials, and professors connected with chemical warfare work and on reports prepared by the Japanese for submission to this office. Great effort has been made to verify the information obtained and to uncover additional information which the Japanese may not desire to disclose. The success of these efforts is difficult to determine.

Reference is made to the report on Japanese Chemical Warfare "Report on Scientific Intelligence Survey in Japan", Volume IV, 1 November 1945 issued by the Scientific and Technical Advisory Section, AFPAC. For the sake of completeness and unity certain information from that report has been included in this one. At other places only a reference is made to the report for data and detailed information.

II. RESEARCH AND DEVELOPMENT ORGANIZATIONS

Even though there was no clearly defined Chemical Warfare Service in the Japanese Armed Forces, research and development work on chemical warfare subjects was confined to organizations which were set up for this purpose. In general, the same subjects considered to be chemical warfare subjects by the U.S. Army were studied by these organizations.

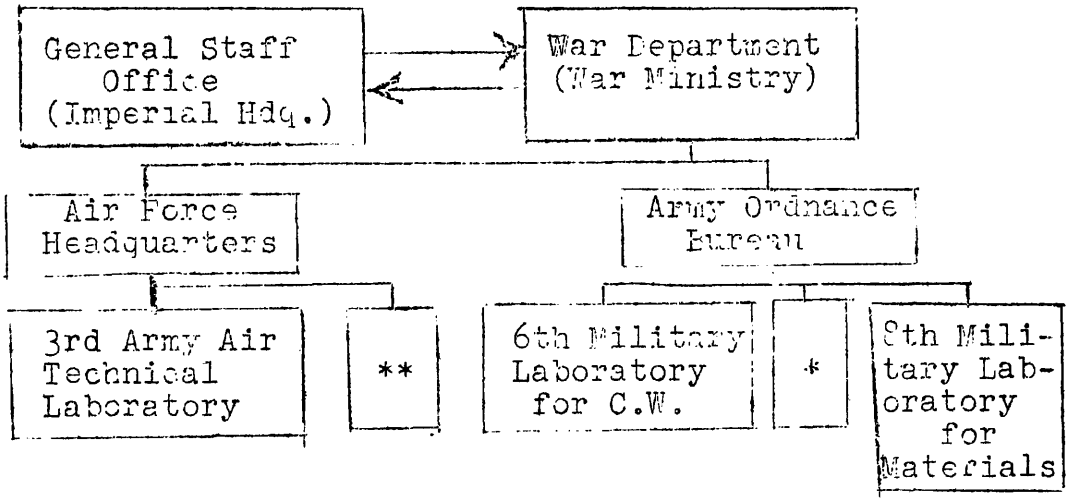
The Army and Navy were independent of each other and, as a consequence of this fact, separate chemical warfare research and development organizations doing parallel work existed with little, if any, liaison between them. The Air Forces, while not independent of the Army, carried out development work on munitions of interest to the Air Forces.

In view of the sharp division between the Army and Navy, this report will be similarly divided.

A. Army CW Research Organizations

1. Table of Organization

The table of organization of the Japanese Army, showing only those groups connected with research and development work on chemical warfare subjects, is given below. The organization shown is the one which was in existence on 1 August 1945.



* There is a total of 10 Military Laboratories, but only the 6th and 8th did work pertaining to CW.

** There is a total of 8 Air Technical Laboratories but only the 3rd did work pertaining to CW.

2. Sixth Military Laboratory (6th Army Technical Research Institute)

This laboratory from a chemical warfare viewpoint is the most important one in Japan; consequently, it will be discussed in detail. It is located at 100 Nincho 4 chome, Yodobashi-Ku, Tokyo.

a. History

In August 1919 the Army established a science research station - one part at Kaishikawa and the other at Itabishi. This station was divided into two sections, the first working on physical armaments and the second working on explosives and chemical warfare. In 1922 the station was moved to its present location. The Second Section was divided in April 1925 into the second and third sections with all research on chemical warfare subjects being done by the Third Section. At this time research on the following subjects was started.

(1) Chemical Warfare agents
(2) Hygiene and treatment of gas casualties
(3) Offensive weapons
(4) Protection from gas

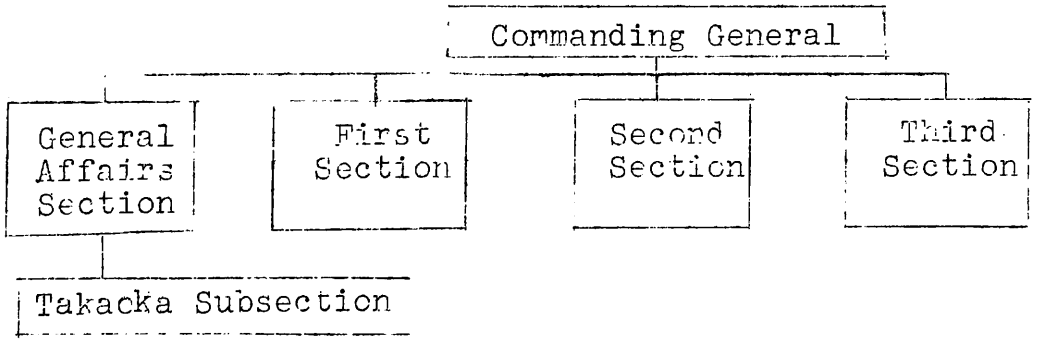
In August 1932 responsibility for research on explosives was removed from this station and the Third Section became the second department. This department was annexed to the Army Technical Bureau in June 1941 and the name was changed to the Sixth Laboratory of the Army Technical Bureau. In October 1942 the 6th Laboratory was placed under the Army Ordnance Bureau. Part of the laboratory was burned in an incendiary raid in 1945 and the personnel of this part were evacuated to Takaoka, Toyama Ken, but they were unable to begin work again before the end of the war. It was planned that the substation set up here would be the chief one of a number set up to replace the Sixth Lab. which was considered to be too vulnerable to bombings. The plan proceeded no further, for on 5 September 1945, the Sixth Army Laboratory ceased to function because of the war's end.

b. Functions

The function of this laboratory, as defined by the Army Ordnance Bureau (Army Ordnance Administration Headquarters), to which the laboratory was responsible, was to carry out research on chemical weapons, to test the weapons developed, to study chemical agents, and to do medical and veterinary research related to chemical warfare. This includes research on defensive measures for gas warfare and research on the prevention and treatment of gas casualties. The functions of particular sections will be given in detail below.

c. Table of Organization

The table of organization of the laboratory is as follows:



Since this laboratory is the most important CW research establishment in Japan, the key personnel of each section will be listed along with their duties.

(1) Major General Kinsei Akiyama - Commanding General

(2) General Affairs Section - This section handled all the administrative matters of the laboratory.

Col. Shinji Ichino, chief
Col. Hashimoto, in charge of Takaoka substation
Major Kanaya, in charge of property
Major Sakurai, in charge of photograph and electric equipment
Major Nagao, in charge of military weapons and materials
Major Sanagami, in charge of meteorology and mathematical calculations
Captain Higashiura, in charge of personnel
Captain Shirohata, in charge of transportation
Captain Noomi, in charge of finance

The following personnel were in the process of being transferred from this laboratory to the manufacture of explosives. Their specialties are listed opposite their names.

Col. Sayeki - Protection from gas
Lt. Col. Imaoka - former head of the section of the attack arms and studied smoke candles and other weapons
Major Iwata - testing of gas in the field
Major Hotta - gas analysis
Major Satao - gas weapons to attack the tank
Major Tanaka - flame projector and the flame tank
Major Saeki - Gas analysis
Major Onishi - Rocket gas shell
Major Takakubo - Rocket gas shell
Capt. Mutoo - Gas analysis
Capt. Itoo - Rocket gas shell
Lt. Mitsuishi - Gas weapon to attack the tank
Lt. Inone - Rocket Gas shell
Lt. Umezawa - Rocket gas shell

The Takaoka substation was set up to carry out work on chemical materials to be used in weapons and equipment designed by the Sixth Laboratory.

(3) First Section

This section was responsible for the search for new chemical warfare agents and for information on the manufacture of chemical agents.

Group 1 The study of poison gas (Including the development of new gases)
Chief Engineer Hayashi
Col. Nakagima
Capt. Yosuda
Lt. Yeno
Lt. Akita

Group 2 The study of the synthesis of arseneous acid
Lt. Mastui
Lt. Kinoshita
Lt. Morimoto

Group 3 The study of a practical method of manufacture of mustard using ethylene oxide from acetylene
Major Takada
Major Endo
1st Lt. Sasamori

Group 4 The study of separating arseneous acid from coal gas
Major Saseki
Major Okura
Capt. Murezo
Lt. Seto

Group 5 The study of use of chlorine obtained as a by-product in the manufacture of magnesium
Engr. Yokoyama

(4) Second Section

This section was responsible for work on gas detection and gas protection.

Group 1 The study of detecting apparatus
Major Kosaki
Capt. Koyedi
Capt. Kawai
Engr. Higashi

Group 2 The study of protection from gases
Capt. Kondo
Lt. Ibaragi
Lt. Kitahara
Engr. Mizutani

(5) Third Section

This section was responsible for studies concerning the medical treatment of gas casualties and for toxicity studies.

Group 1 The study of emergency treatment of casualties of mustard and prussic acid.
Lt. Col. Okamura, chief

Group 2 The study of the poisonous character of nitric Yperite and arsine applying to animals.
Surgical Capt. Uchida
Surgical Lt. Naka
Surgical Lt. Morishiri
Surgical Lt. Nakagawa

Group 3 The study of protection to military horses and dogs
Veterinary Major Niemi
Veterinary Capt. Oyama
Veterinary Capt. Saito

d. Personnel

(1) At the end of the war the following personnel were employed at the laboratory:

Distribution According to Work	Senior Officials	Junior Officials	Employees	Total
Military	64	19		83
Civilian	9	40	583	632
Total	73	59	583	715

Included in the employees were 212 women. Of the 715 workers 200 were assigned to the Takaoka substation. In 1943 only 500 people were employed at the laboratory, but the drafting for the armed forces of trained and experienced personnel resulted in a decrease in the efficiency of operation and necessitated the hiring of more workers.

(2) During the past fifteen or twenty years the laboratory followed the policy of hiring scientific personnel immediately after they finished school. These men remained civilians and were assigned to specific fields in which they became specialists. Not until hostilities broke out between Japan and the United States did these men become officers in the Army.

(3) Little use was made of civilian scientists by the laboratory. Apparently the Army did not take civilians completely into their confidence. Certain professors, however, were given specific problems on which to work. These are listed below.

Hokkaido Imperial University
Prof. Jiro Horiuchi - Synthesis of arsenic acid
Prof. Zenichi Shibata - Study of the extraction of arsenic acid from iron manufacturing plants
Nagoya High Technical School
Prof. Yoshiaki Mastunaga - Study of smokes
Osaka Imperial University
Prof. Tashizo Chitani - Synthesis of arsenic acid
Tohoku Imperial University
Prof. Rienzaburo Hara - Synthesis of arsenic acid
Tokyo Imperial University
Prof. Taneoburo Samejima - Study of smoke
Prof. Morizo Ishitato - Study of the mechanism of poisoning

(e) The budget for the laboratory for each year since 1940 is given below.

Year	Budget Yen*
1940	1,500,000
1941	1,600,000
1942	1,800,000
1943	2,100,000
1944	2,300,000
1945	2,900,000

For the fiscal year 1945 the budget was broken down as follows:

Yen 1,500,000	Salaries (civilian employees)
300,000	General affairs section
450,000	First Section
350,000	Takaoka substation
100,000	Second Section
200,000	Third Section

(f) Attached is a ground layout of the laboratory.

*Value of Yen was pegged at 23 7/16 cents.

3. Chichihara, Manchuria, Laboratory

Little accurate information concerning this laboratory is available since it has not been accessible to United States Intelligence Teams. Interrogation of personnel who were stationed at or who had visited this laboratory indicates that approximately 300 people were employed there before the end of the war. The laboratory was apparently set up to do chemical warfare research and development work for the Kwantung Army. It is believed that the laboratory worked mainly on the development of defensive materials such as masks and protective clothing, but some work was carried out to determine the behavior of chemical agents in the field. It is further reported that approximately six months before the end of the war this laboratory was converted from a study of CW problems to work on explosives. The information available concerning the work carried out at this station will be found in Section III of this report.

4. Eighth Military Laboratory
Koganei-Machi, Kitatama-gun, Tokyo

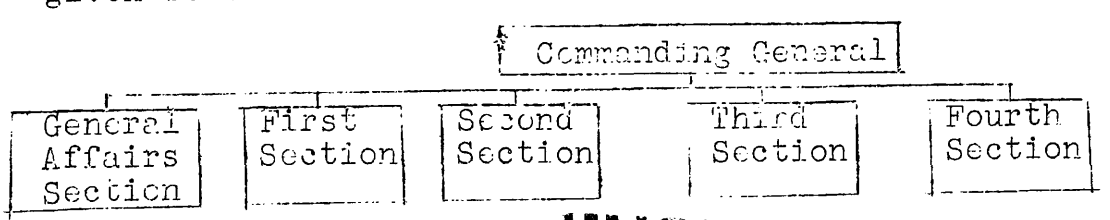
a. History

Prior to June 1941 this laboratory was a part of the Army Scientific Research Institute which was subordinate to the Army Technical Headquarters. At this time the Institute was absorbed by the Army Technical Headquarters and certain sections of the Institute were made into independent and seperate laboratories such as No 6, No 7, No 8, and No 9. In 1942 further administrative changes were made and this laboratory came under the administrative control of the Army Ordnance Administrative Headquarters. In November 1943 the Laboratory moved from its cramped location at Okubo to its present one at Koganei. In September 1945 the Laboratory ceased to function.

b. Functions

This laboratory was responsible for investigating, planning, testing of, and researches on fundamental materials for munitions, researches on chemical industrial materials, and investigation of basic facts concerning specifications and preservation of munition materials. Although these functions are not directly connected with chemical warfare, certain subjects of a chemical warfare nature fall within this laboratory's responsibilities and were investigated by it. These subjects were (1) flame thrower fuel, (2) activated charcoal, (3) area smoke screen, and (4) incendiary bomb material.

c. The table of organization of the laboratory is given below.



(1) The General Affairs Section was responsible for planning, personnel, finance, and miscellaneous affairs.

(2) The First Section was responsible for carrying out basic researches in metallic materials.

(3) The Second Section was responsible for carrying out basic researches in non-metallic materials

(4) The Third Section was responsible for carrying out basic researches in materials for chemical industry.

(5) The Fourth Section was responsible for carrying out basic researches in agricultural resources.

d. Personnel

(1) Following is the list of personnel employed by the laboratory.

Officers	1942	1943	1944	1945	August 1945
General			1	1	1
Maj. to Col.	7	20	5	8	9
Lt. to Capt.			36	43	42
Non-coms			10	12	11
Civilians					
Experts	2	3	1	1	1
Engineers	11	16	19	23	28
Male workers	30	50	103	157	135
Female "	15	35	78	144	129
Clerks	28	43	85	81	78
Total	93	167	338	470	434

(2) This laboratory used civilian scientists to some extent. The Army assigned and financed the program. Only work on the activation of carbon is of CW interest.

e. Budget

The budget for the laboratory for each year since 1941 is given below.

Year	Budget - Yen
1941	400,000
1942	1,250,000
1943	2,500,000
1944	2,900,000
1945	2,617,880

Only a portion of this was used for CW work. The exact amount could not be determined.

f. A ground layout of the laboratory is attached.

5. Third Air Technical Laboratory
Tachikawa Air Base, Tokyo Prefecture

a. History

In 1931 the Air Force Laboratory became responsible for chemical warfare research in the Japanese Air Forces, and work was begun on both offensive and devensive matters.

In 1942 the Air Force Laboratory was divided into eight separate organizations, known as Army Air Technical Laboratories. The only one of these having a chemical section was the Third Army Air Technical Laboratory at Tachikawa Air Base.

The decision was made in 1943 by the Japanese Air Force GHQ to reduce chemical warfare research to the minimum, and since that time the work of the chemical section was mostly on smoke and incendiary bombs.

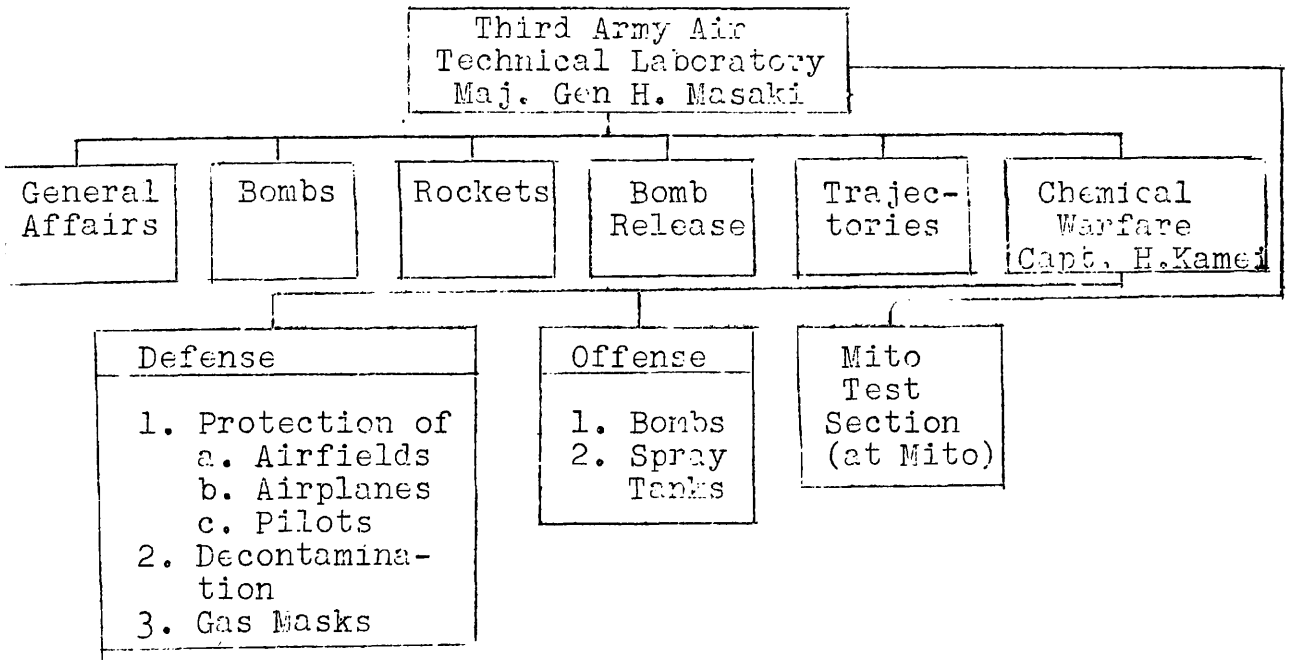
The Third Air Force Technical Laboratory was completely destroyed by an air raid in April 1945. The organization moved elsewhere, but by that time the chemical section was no longer operating.

b. Functions

The Laboratory was responsible for the development of air chemical munitions, and in the period from 1938 to 1943 research was done on toxic gas bombs, smoke bombs, incendiary bombs, toxic gas spray tanks, and smoke spray tanks.

Defense against chemical attack was also studied by the laboratory, and between 1935 and 1943 projects were carried out on gas detection devices, decontamination methods for airfields and airplanes, protective covers for airplanes, and protective suits and masks for air crews.

c. Table of Organization



d. Personnel

The total personnel of the Third Army Air Technical Laboratory was 300, of whom 30 were scientists. The Chemical Warfare Section had two officers and seventeen men.

e. Budget

The average annual budget for the period during the war was 1,000,000 Yen, of which 30,000 Yen were allocated for the Chemical Warfare Section.

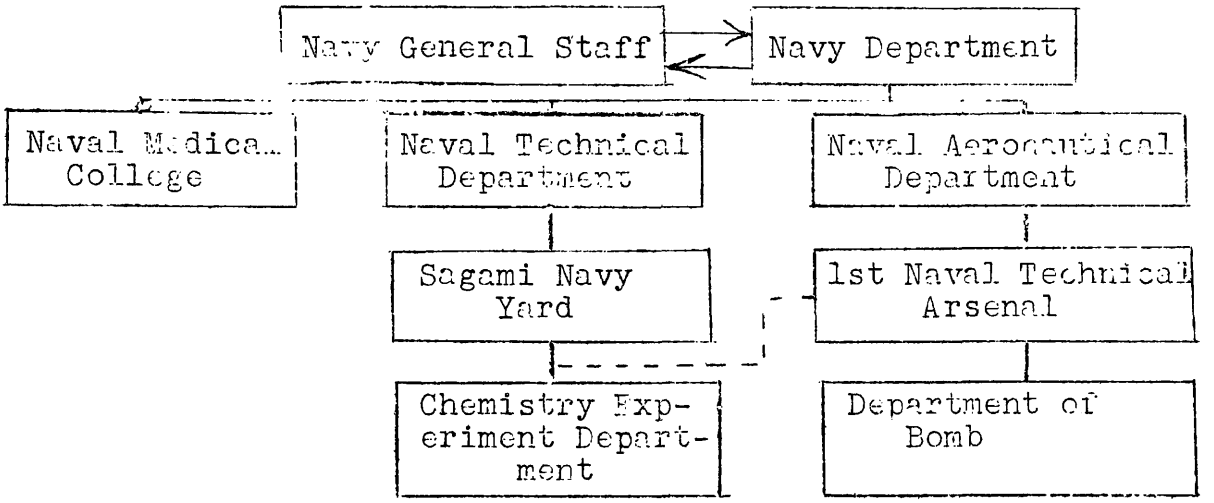
f. Ground Layout

The Laboratory was housed in seven buildings, of which one was assigned to the Chemical Warfare Section. No drawing is shown, as the whole laboratory was destroyed by air raids.

B. Navy CW Research Organizations

1. Table of Organization

The table of organization of the Japanese Navy showing only the groups connected with research and development work on chemical warfare subjects is given below. The organization shown is the one which was in existance 1 August 1945.



2. Sagami Navy Arsenal Chemistry Experiment Department

This organization is the only one set up for research on chemical warfare subjects in the Japanese Navy. Work for the naval air force was done by this installation whenever the 1st Naval Technical Arsenal requested it. One exception was made to this procedure; chemical bombs were designed by the Department of Bombs. The Sagami research installation was located next to the Naval powder factory at Hiratsuka, Kanagawa Ken, Honshu.

a. History

In 1923, the first naval laboratory of chemical munitions was established as a section of the Naval Technical Institute at Tsukiji, Tokyo. In 1925, it changed its attachment to the Scientific Research Department and, in 1931, moved within the bounds of the Naval Powder Factory at Hiratsuka where it was located at the end of the war. After the Manchurian affair in 1932 the personnel and the research work were gradually increased and in 1934 the organization became independent and known as the Naval Chemical Experiment (Study) Department. In the early years of the laboratory, the characteristics of agents and, shortly thereafter, the manufacture of agents were studied. After the outbreak of the war, the development of the laboratory was accelerated because of the necessity of increasing the production of chemical warfare materials. By 1943, it had greatly expanded and became the Sagami Navy Yard (or Arsenal). The experimental work continued under the Chemical Experimental Department, a branch of Sagami Arsenal. Two of the twelve buildings were burned in an incendiary raid

in 1945. After the war the laboratory ceased operation.

b. Functions

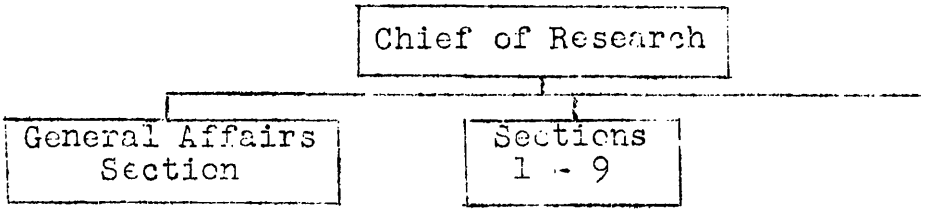
The functions of this installation were to do research and development work on the following subjects:

Gas protective equipment
Smoke weapons
Manufacture of toxic gases
Gas shells and bombs
Incendiaries
New gases
Medical treatment for gas casualties
*Explosives and ammunition for marine troops
*Balloons
*Rubber weapons

*These subjects did not pertain to CW but were assigned to the laboratory

c. Table of Organization

The table of organization of the laboratory is given below:



Section 1: Analysis and Standardizing
Engineer K. Chuja, Chief
Sub Lt. K. Hirose
Sub Lt. K. Osawa

Section 2: Fundamental Research
Lt. Comdr. K. Yoshida, Chief
Sub Lt. H. Hamada
Eng. R. Eto
H. Tamura

Section 3: Gas, Smoke and Incendiaries
Lt. Comdr. H. Kuwabara, Chief
Sub Lt. W. Asai
Eng. M. Doshi
Ensign K. Suga
Ensign T. Saito

Section 4: Synthesis of agents
1st Lt. J. Yoshida, Chief
1st Lt. H. Ishii

Section 5: Explosives and munitions (not chemical warfare)
1st Lt. K. Ohashi, Chief
1st Lt. T. Wakeo
1st Lt. G. Nooma
Sub. Lt. M. Kamiya
Sub Lt. Owaki

Section 6: Defensive Weapons
Lt. Comdr. T. Ishihara, Chief
1st Lt. H. Kamata
Ensign T. Yoshino

Section 7: Medical Research for misc. chem. products(not gas)
Comdr. I. Tanimura, Chief
Lt. Comdr. M. Shinonaga
Section 8: Medical Research for Gas
Lt. Comdr. T. Takafuji
1st Lt. T. Iwamoto
1st Lt. A. Nakamoto
Section 9: Technical work for production of agents
Lt. Comdr. T. Arima
Eng. M. Mitsuishi
Sub Lt. S. Fujishima

d. Personnel

At the end of the war there were 300 people employed in the laboratory. Thirty of these (24 naval and 6 civilian engineers) were scientists. The laboratory had certain professors or experts to whom they assigned specific problems. A list of these people and the subjects on which they worked follows.

Professor or Expert	Location	Problem
N. Somiya	Tokyo University	a. Analysis and separation of micro-quantities of water in oily liquid. b. Analysis of white phosphorus in red phosphorus
N. Kameyama	Tokyo University	Calcium hydride and H_2 generating agents
T. Mogi	Tokyo University	Application of fluorescence and phosphorescence to CW
J. Sameshima	Tokyo University	Filtering of Smoke
H. Endo	Tohoku University	Hydrochloric acid proof alloys
H. Tominaga	Tohoku University	Oxidizing agent for CO and oxygen generating agents
K. Nozu	Kyoto University	Detection of Gas
M. Kotake	Osaka University	Synthesis of HCN and styrene
Y. Tanaka	Dinihon Rubber Research Institute, Tokyo	Rubber materials
T. Shono	Osaka City Industry Research Institution	Adhering Agents
N. Sakuma	Yokohama Gomu Co.	Polymolecular Compounds
B. Kusano	Yasui Kagaku Co.	Ethyl zinc and polyvinyalcohol

e. Budget
The estimated budget is given below.

Year	Amount in Yen
1940	600,000
1941	700,000
1942	900,000
1943	900,000
1944	1,000,000
1945	1,300,000

f. Ground Layout
The ground layout of the laboratory is attached.

III. RESULTS OF THE RESEARCH AND DEVELOPMENT WORK

The results of the work are discussed under the individual subject headings.

A. Gas Masks

1. Japanese Army Work

The Japanese Army first carried out work on the gas mask at the Military Medical School, but no results of any value were obtained. In 1922 the gas mask was considered as ordnance material and studies were carried out at the Military Scientific Institute (former organization of the Sixth Military Laboratory), standardization was done by the Army Technical Headquarters, and procurement and supply by the Army Ordnance Headquarters. In 1927 the type 87 gas mask was adopted as standard. Administrative changes resulted in 1930 from the classification of the gas mask as clothing rather then ordnance material and the Army Clothing Headquarters took over procurement and supply of the masks. Following this change the type 91 mask was developed in 1931, type 95 in 1935, and type 99 in 1939. With the beginning of war with the United States the shortage of materials, especially rubber and cotton cloth, increased and work was carried out to develop a direct type gas mask without hose. In 1944 the Army Clothing Headquarters was made responsible for all work concerning gas masks.

Prior to 1937 the Air Forces showed little interest in gas masks, but at that time they requested a small size gas mask which the pilot can put on with one hand. The development of such a mask was undertaken by the Army Scientific Institute. The nearly completed design was turned over to the Third Military Laboratory of the Japanese Air Forces, who completed it.

a. Development of the Canister

(1) Fundamental studies of filtration

The Japanese Army did little fundamental research on filtration mechanism. They state that all their information came from reference books.

(2) Studies of Absorbents

The absorbents for the canister of the type 87 gas mask contained Dutch charcoal "Norite" with soda lime impregnated with a solution of $NaMnO_4$ as the auxiliary absorbent. In the type 91 canister charcoal made from hardwood and activated by steam was used. The same auxiliary absorbent was used in the type 87 canister. The canister of the type 95 mask contained active carbon made from a mixture of powdered charcoal and coal tar which was carbonized and then activated by steam. As the auxiliary absorbent, soda lime (without permanganate) was used. The same type of charcoal was used in the type 99 mask and a type hopcalite for the catalytic oxidation of hydrocyanic acid was used as an auxiliary agent. Proportions of each agent were as follows.

Active Charcoal	70% by volume
Hopcalite (Brown grain or Katsurya)	30% by volume

Composition of the Hopcalite was:

Manganese Dioxide	49% by volume
Copper Oxide	21% by volume
Calcium Hydroxide	20% by volume
Sodium Hydroxide	5% by volume
Magnesia cement (binding material)	5% by volume

Research on the activation of charcoal has been carried out by the Fighth Military Laboratory. Three processes have been developed and are described below.

(a) Steam activation process

Charcoal powder, preferably from coconuts or hardwood, and coal powder, both of mesh 140 - 200, are mixed in the ratio of three to one. This is then mixed with coal tar in the proportion of 10 to 6, and the mixture is agitated with steam at 100°C. for 3 hours. After this time the material is made into pellets 2 - 2.3 mm in diameter and 2.5 mm in length and dried at 120 to 130°C. The dried material is then carbonized in two steps. The first step is for 3 hours at 350° - 400° C. and the second step is of 4 hours duration at a temperature of 750° - 800°C. The resulting material is then activated in an inclined revolving furnace by superheated steam at a temperature of 850° - 900°C. for 24 hours. Careful control of this step is necessary in order to prevent softening of the charcoal. The charcoal used by the Army after 1941 was manufactured by this general process.

(b) Zinc Chloride Process

Ten parts of sawdust (140 to 200 mesh) are mixed with 6 parts of $ZnCl_2$ and enough water to make a paste. This material is then made into pellets, dried, and carbonized at a temperature of 650° to 700°C. for one hour. The pellets are then washed with HCl to remove the zinc, water washed, and dried. The advantages claimed for this process are: no high temperature furnace is required, no high quality coal is required, no special technical skill is required. The man in charge of this work said that no analysis of the final product was made and that the zinc content was unknown. This process was never adopted for the manufacture of absorbents.

(c) Special Activating Process

Material A, consisting of sawdust and zinc chloride in the ratio of 10 to 6, is mixed with material B, consisting of 100 parts of sawdust and two to four parts of a 20% solution of $Cu(NH_3)_4(OH)_2$ or $Cu(NH_3)_4(SO_4)$. The ratio of material A to material B varies between 3 to 1 and 4 to 1, depending on the kind of gases to be absorbed. The manufacturing process is the same as process (b) previously described. This process was devised after it had been learned that the addition of 2.5% of oxidized heavy metals

such as Cu, Ni, Co, Fe, etc. to the carbon increased the HCN absorbing capacity of the charcoal. Pilot plant work was initiated, but an incendiary raid destroyed the plant before data were obtained. The composition of the final product is not known, because analyses were not made. The solution used to mix with the sawdust in material B was made by mixing $CuSO_4$ and NH_4OH solution. The final composition contained 66.3 g/l. of NH_3 and 5.6 g/l. of copper.

Charcoals were tested in the laboratory by filling a 2 cm. tube with the charcoal to a height of 10 cm. Air containing 0.5% toxic gas was passed through at a rate of 500cc/cm²/minute at a temperature of 20°C., and the time required for the test solution or paper to change color was determined.

The comparative absorbing capacity of the active charcoals are as follows:

	Time in Minutes		
	Chloropicrin	Phosgene	Hydrocyanic Acid
Steam Activation process	100 - 115	30 - 33	15
Zinc Chloride process	120	25	12
Special activating process	100 - 110	45 - 50	45

(3) Filter Material

In the first type masks such as the type 87 a filter cap made out of wool was used. In the latter types the filter was lantern shaped and made of Egyptian cotton, paper, pulp, and asbestos impregnated with Congo Red dye. This impregnation improved the filtering properties, but the Japanese didn't know why.

(4) Dosages required to penetrate canisters.

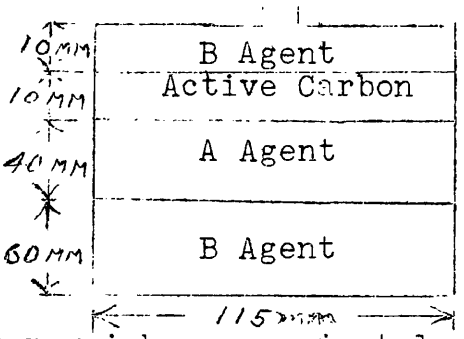
Air dried by calcium chloride and by sulfuric acid is mixed with water vapor and toxic agent in such quantities as to have a relative humidity of 50% at 20°C. and to have the desired concentration. The mixed gases are passed through the canister and through a test paper which changes color when the toxic agent penetrates the canister. The time required to penetrate the canister is determined. The following results are listed:

Gas	Flow Rate l/m	Conc. vol.%	Time (Minutes for breakpoint to be reached) to penetrate Type 99 Canister (min.)
Chloropicrin	30	0.5	20 - 25
Phosgene	30	0.5	18 - 23
HCN	30	0.2	12 - 16

Information is not available on other canisters, but the Japanese who furnished the information believed that type 87, 91, and 95 gave only 0.1 the HCN protection but gave greater protection for gases such as phosgene or chloropicrin than the type 99.

(5) Protection against Carbon Monoxide

Only one canister for the absorption of CO was developed. A diagram of this canister is given below.



This canister weighs approximately 1 Kg and has no type number. Composition of A and B agents are as follows:

A Agent	Manganese dioxide	70% (by volume)
	Copper Oxide	30% " "

Material is approximately 2 to 3 mm in diameter

B Agent	Calcium Chloride	60%
	Silica Gel	40%

This canister is said to protect for 480 minutes against a concentration of CO of 20,000 mg/m^3 at a flow rate of 30 l/m, temperature 20°C., and relative humidity 50%.

(6) Protection against HCN

Even though the Japanese knew that their canister gave very poor protection against HCN, they did and were doing little work on the problem. They adopted the use of 30% brown grain (See above) with 70% charcoal to increase the HCN absorbing capacity. The Eighth Lab which worked on charcoal did a certain amount of work on the addition of metals to the charcoal to increase the absorbing capacity for HCN, but the results of the work were never used. They finally planned to use charcoal similar to that found in the latest captured American mask (type unknown) although there are no indications that they knew how to make it, knew what was in it, or had the materials to use.

b. Face Pieces

(1) Design of Facepieces

(a) For different shaped faces:
The Japanese Army had masks of only one shape because the shape of Japanese faces does not vary much.

(b) To allow wearing of glasses:
No change is made in the design of the facepiece to allow for the wearing of glasses, but the glasses are modified. The arms of the ordinary glasses are taken off and a piece of rubber tape is fastened to the glasses and is worn around the head.

(c) To improve speech transmission
Little work was carried out on this subject. A mica plate was attached to the expiratory valve, but this resulted in practically no improvement in the speech transmission properties of the mask.

(d) To enable use of binoculars
On some of their masks an attachment was made to enable the use of binoculars.

(e) For special functions of jobs

1. For use in tanks, the canister is smaller than the one with the type 99 mask.
2. For the injured, facepieces are designed to cover the head and to be fastened and made airtight at the neck.
3. For battle at the "sea side" the Japanese had developed a hose attachment about two feet in length which contained the valve in the end of the hose. The top of the hose was tied to the upper part of the head of the wearer.
4. For protecting "shooter in fortress" from high concentrations of gas a long connecting tube is attached to the bottom of an ordinary canister and placed outside the fortification.

(2) Materials used in Facepiece
Rubber pressed on cotton cloth was used in the manufacture of the facepiece.

(3) Penetration of facepiece and hose by mustard gas
Two to three hours are required for liquid mustard to penetrate the rubber. Vapor (200 mg/m3) is said not to penetrate the rubber.

c. Carriers
Carriers were made out of cotton cloth soaked in aluminum acetate for water proofing.

d. Data on latest gas mask
See Table I.

e. Comparison of Japanese mask with masks of other Nation
The following table gives the information obtained from the Japanese on this subject: Table II.

		Purpose	Construction	Total Wearing Weight	
93 type Mark 2		Service Gas Mask	face piece, main canister, sub canister, carrier, anti-dimmer, training plug	(g) 3420	(g) 1850
93 type	Mark 3	for land battle in general	face piece, main canister, water tight plug, carrier, anti-dimmer.	1430	1430
	Mark 4	for ship in general	face piece, main canister, sub canister, carrier, anti-dimmer.	3020	2040
97 type	Mark 3	diaphragm	same as 93 type M3		
	Mark 4	gas mask	the same as 93 type M4		
5 Type		for land battle in general	face piece, canister, carrier	1200	1200
direct system		for land battle in general	face piece, canister, carrier (no hose)	800	800
3 type			mouth piece, canister, carrier.	1806	400

Character of Canister

		Weight(g)	Breathing Resistance	Smoke Filtering Efficiency	Weight of Absorbant	for Cl_2 (Min.)	for Cl_2NO (Min.)	For CO (Min.)	For field concentration (Hours)
93 type Mark 2		main canister 980 sub canister 530	main (mm) 14 - 16 sub. 3 - 5	(%) 99.85	Main 320g. active carbon : soda lime - 8:2 Sub Hopcalite 300 g.	70-80	90-110	30-40	100
93 Type	Mark 3	main canister 660	main 13-15	99.85	Main 250g. active carbon : soda lime - 8:2 Sub Hopcalite 160-180g. drying agent 80 g.	40 - 50	60-70	Sub 90-120	80
	Mark 4	sub canister 630	Sub 5 - 7						
97 type	Mark 3								
	Mark 4								
5 Type		660	13-15	99.85	active carbon : soda lime - 8:2 250 g.	40-45	50-55	--	60
direct system				99.0	active carbon : soda lime - 8:2 150 g.	15-20	20-25	--	25
3 type		270	18-20	about 80		30		--	--

Kind of Test (NAME OF NATION / KIND / NAME OF MANUFACTURING COMPANY)		Japan			America	England	Soviet Russia		China	Germany
		95 type	99 type	98 type Special No. 1	unknown	unknown	unknown A	unknown B	unknown	unknown
		Nippon Kako Co. Fujikura Kogyo Co.		Nippon Kako Co.	Mine Safty Co.	C.B.Gorman Co.			made in Holland	Auer Co.
Ability of smoke filtration (%)		99.80	99.98	99.98	98.80	99.90	99.92	98.0	87.5	99.90
Ability of Gas Absorption (Time in Minutes)	$CoCl_2$ (conc. 0.5%)	30	24	148	60	30	65	120	11	20
	CCl_3IO_2 (conc. 0.5%)	50	28	29.6	30	40	65	120	12.5	15
	HCN (conc. 0.2%)	4	15	216	100	—	65	—	0	6
	CO (conc. 0.2%)	0	0	420 (360 above)	—	—	—	—	—	—
Resistance for flowing air (mm water/30 l./ min.		12.5	10.5	25	15.5	12.5	18.5	24.	20	15

f. Information on use and serviceability in the field of the gas mask.

(1) Wearability of the mask

Tests carried out by personnel of the Army Chemical Warfare School at Narashino indicated that under hot weather conditions one hour in action was about the maximum length of time that the mask could be worn. The Sixth Laboratory thought that the maximum wearing time was increased by 2 or 3 times if the temperature was decreased to ordinary or to winter temperatures.

(2) Replacement of masks and canisters

It was first intended, in case of the use of gas, to replace the canisters depending on the number of times they had been used. On account of the difficulties encountered in producing enough canisters work was carried out on refreshing them. The refreshing apparatus consisted of an oven in which the canisters were placed. Then hot air at 120° was passed in. This procedure had not been used at the end of the war.

g. Gas Mask work at Chichiharu, Manchuria

The Chemical Warfare station at Chichiharu, Manchuria did some work on gas masks. From interrogations of personnel who were there but are now in Japan it was learned that their most important development in this field was an emergency mask. It consisted of cotton cloth instead of rubber. Nine pieces of cloth soaked in an impregnating solution were put together and made to fit over the nose and mouth. Two solutions were used for impregnating the cloth. The first was a solution of hexamethylene-tetramine, sodium carbonate and nickel sulfate or zinc acetate. The second and better solution had a composition as follows:

Active carbon powder	50 grams
Zinc oxide	50 - 100 "
Lime	100 "
Water	1 liter

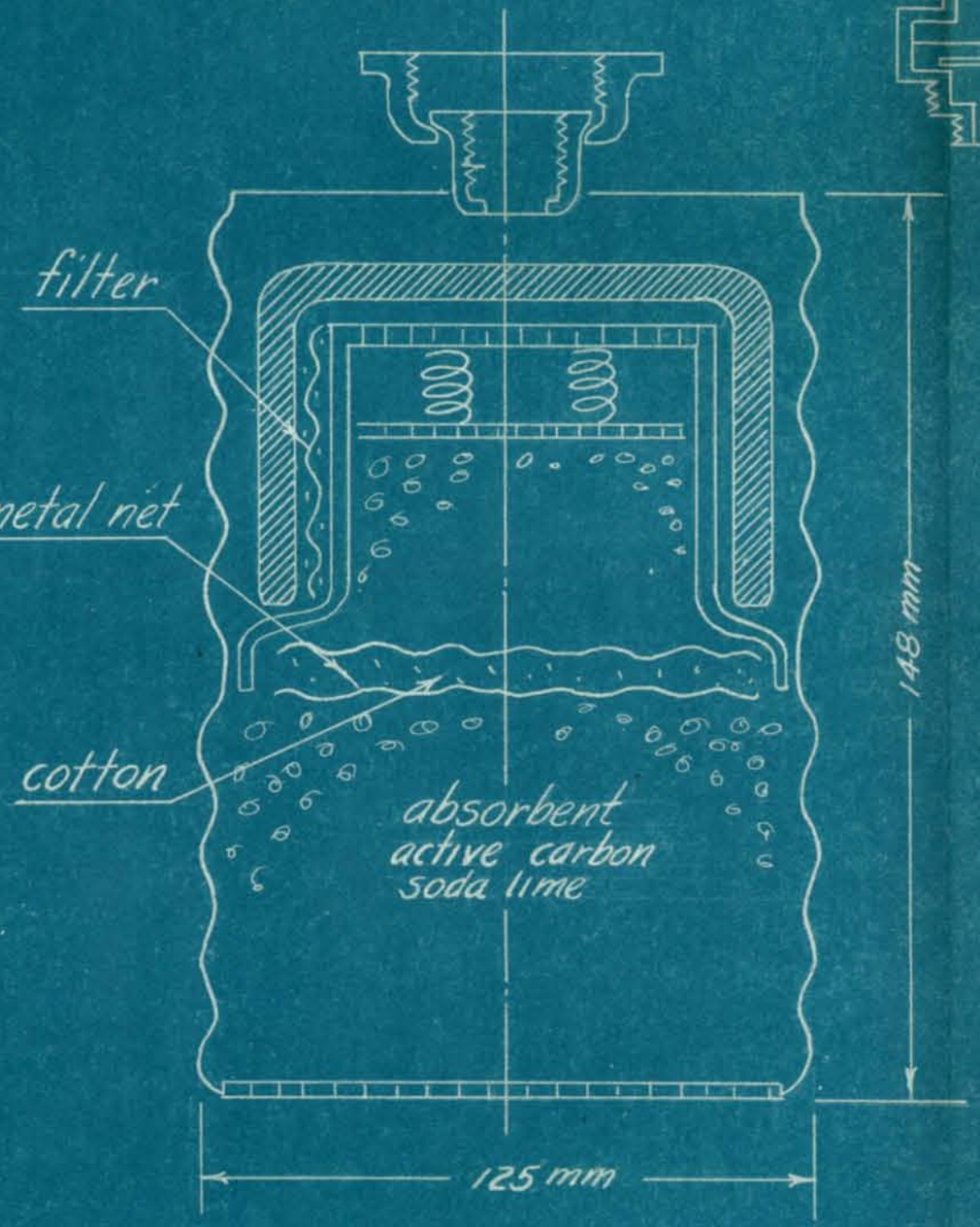
It was planned that air tight goggles would be worn with this mask.

h. Research in progress at the end of the war.

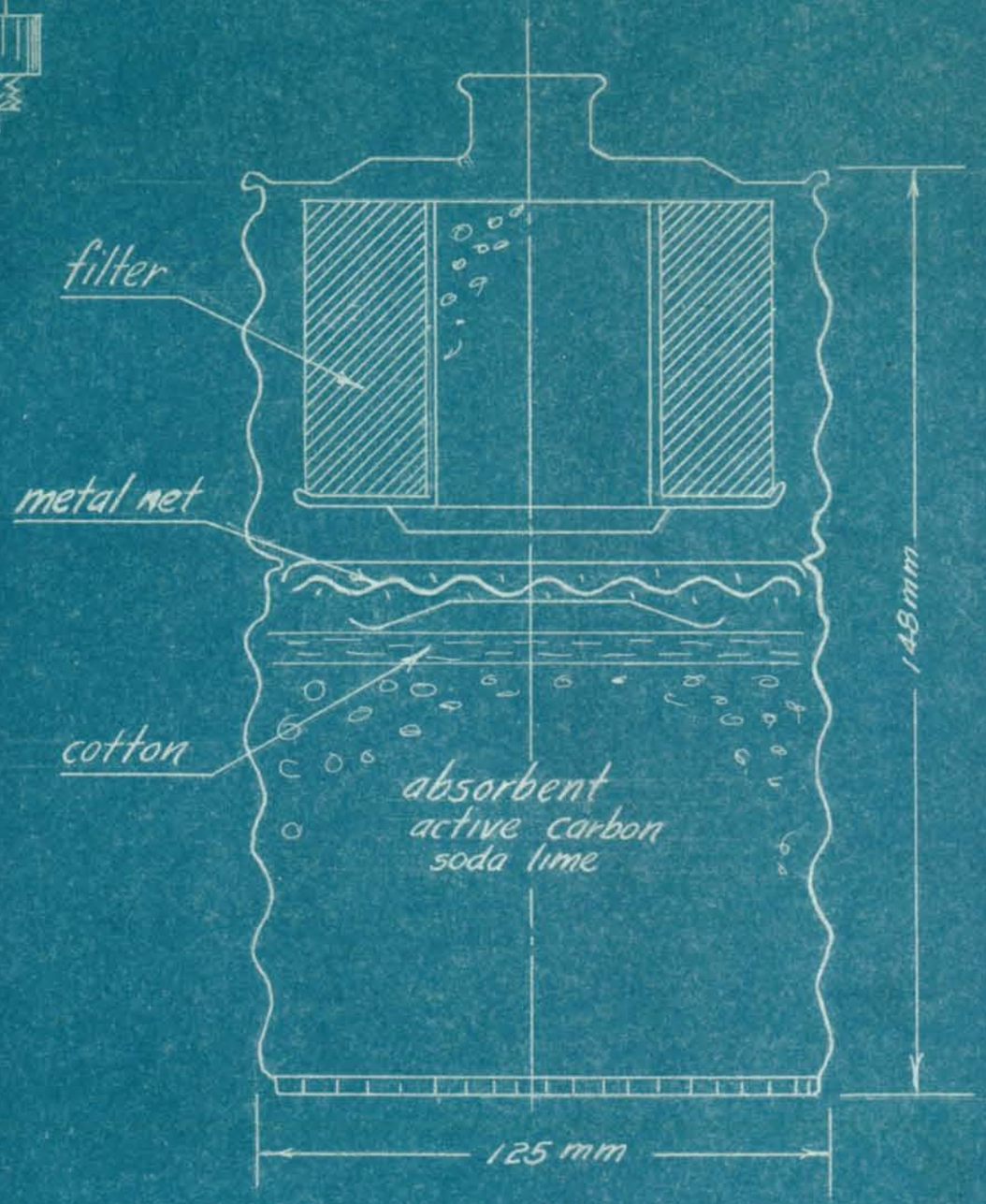
The Japanese realized that their canisters were inferior to the American masks in adsorbing power for HCN. They consequently considered that their main research problem was to increase the HCN protection of their canisters.

DEVELOPMENT OF CANISTER

TYPE 87

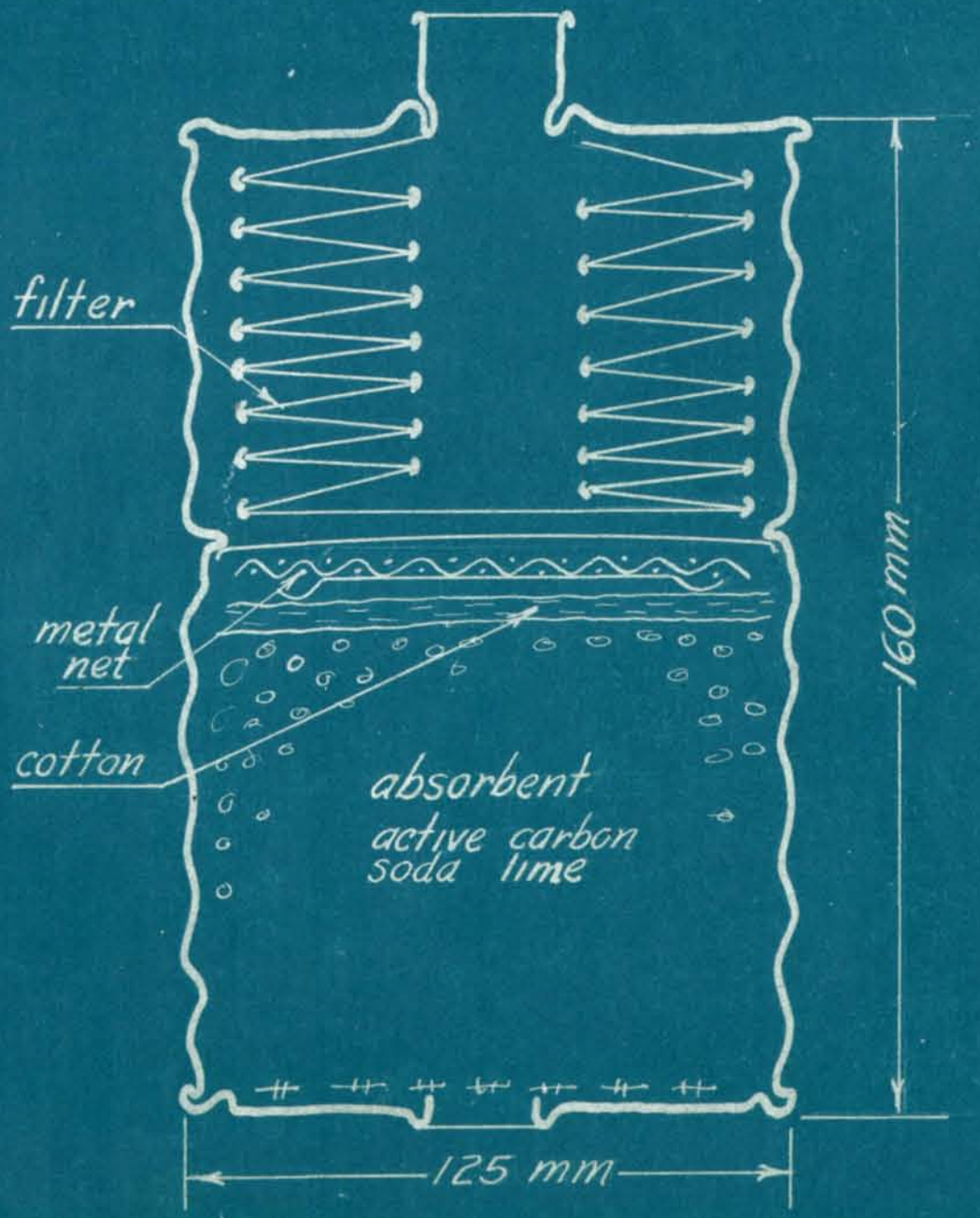


TYPE 91

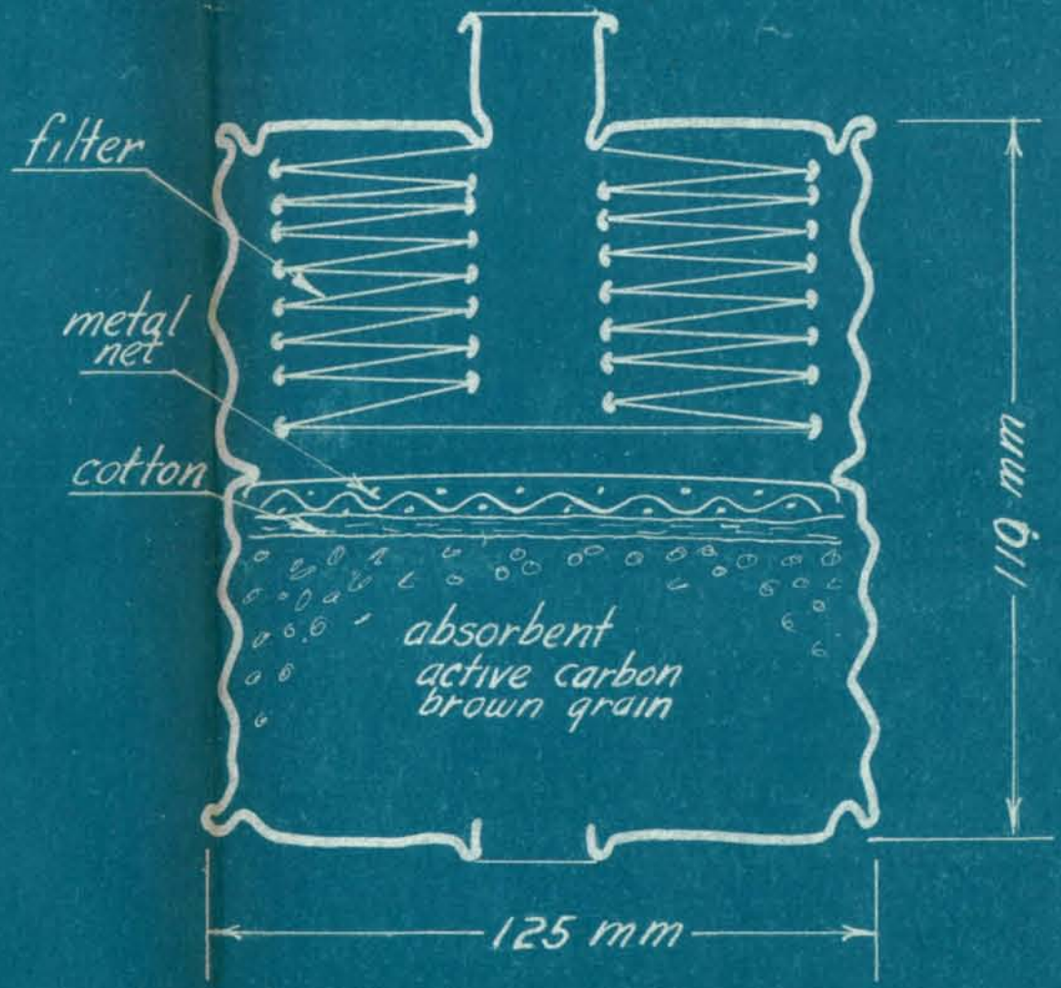


DEVELOPMENT OF CANISTER

TYPE 95



TYPE 99



2. Japanese Navy Work

In the Navy the research and manufacture of gas masks were commenced in 1926 by the chemical warfare section of the Naval Technical Institute, Tsukiji, Tokyo. Changes in design were made as the work continued until the following masks were developed:

Year	Kind of Mask	Remarks
1927	2 type, M1	
1933	93 type, M1	
1936	93 type, M2	
1937	97 type	
1938	98 type	For optical work, not manufactured
1938	Oxygen gas mask	
1940	Oxygen mask, modified I	
1941	93 type, M3(no sub canister)	
1942	93 type, M4(sub canister)	
1943	3 type	Not manufactured
1945	5 type Oxygen gas mask	" "
1945	Direct type	" "
1945	5 type	" "

a. Development of the Canister

(1) Fundamental studies of filtration

The Japanese Navy apparently did no fundamental studies on filtration mechanism even though that was a function of the laboratory's 2nd Section.

(2) Studies of absorbents and filters

The chief absorbent filled into the canister consists of coconut shell activated carbon and granulated soda lime. After some research it was decided to use the following proportions:

2 type and 93 type gas mask	Carbon 7 parts Soda Lime 3 parts
93 type M2 gas mask and all thereafter	Carbon 8 parts Soda Lime 2 parts

The composition of the soda-lime is as follows:

Slaked lime - - - - -	67% by weight
Cement - - - - -	21%
Kieselguhr - - - - -	9%
Caustic Soda - - - -	3%

The coconut shell active carbon was produced by steam activation. At the end of the war coconut shell had become so scarce as to necessitate research on the use of wood charcoal impregnated with zinc chloride. This type carbon never was used in the field, however.

The materials used in the filters of the masks are listed below:

Year	Kind of mask	Material	Filtering Efficiency
1927 1933	2 type 93 type M1	Felt silk-cotton* filled into the canister	85% 94%
1936	93 type M2 and all those thereafter except AS model.	silk-cotton and fiber of moxa mixed in proportion of 2:1 and made up as filter paper with lantern shape.	99.8%
1945	Direct type	Silk-cotton and moxa fiber mixed in the proportion of 3:2 and made up as filter paper with lantern shape.	99%

*"Silk-cotton" is Kapok fiber.

The research workers seem to be convinced that their silk-cotton moxa filter material was the best in existence.

(3) Dosages required to penetrate canisters

Canisters were tested by passing a 0.5% concentration of gas at a continuous rate of 30 liters per minute through them and measuring the time required to reach the break point. This point was determined by the change in color of an indicator solution or paper through which the gas was passed after going through the canister. The temperature of the gas entering the canister was 20°C. except in the case of the testing of CO when the temperature was regulated to 15°C. The reason for this was apparently to make the CO canister look better than it would have if tested at the higher temperature. The following results were obtained:

Time (minutes) required for break point to be reached

Gas	Type Canister Used			
	93 type M2	93 type M2	present system canister coconut coal No. 1	present system canister coconut coal #2
Chlorine	>70	>40	25	20
Chloropicrin	90 - 110	60 - 70	30	25
Phosgene	30 - 35	20 - 25	-	-
HCN	11 - 13	7 - 8	3 - 5	approx. 15

(4) Protection against CO

For protection against CO an auxiliary canister filled with Hopcalite is connected to the main canister. The Hopcalite has a composition of 70% active manganese dioxide and 30% copper oxide. The 93 type M1 sub canister

containing 300 grams of hopcalite was first developed. Due to insufficient effectiveness it was improved to the 93 type M4 sub canister. This was more satisfactory. The complete assembly included a three way valve to bypass the sub canister when no CO was present. Besides the hopcalite a drying agent was present. This agent was composed of 60% silica gel and 40% calcium chloride. At 20°C. it could absorb 90% of its weight of moisture.
Data on these sub canisters follow.

	93 type M2	93 type M4
Weight, grams	530	630
Air resistance, mm of H_2O	3 - 5	5 - 7
Oxidizing capacity, min	30 - 40	90 - 120
Weight of hopcalite, g.	300	160 - 180 g. and 80 g. drying agent

(5) Protection against HCN

For protection against HCN a special hopcalite was worked on, but it was never satisfactory enough to be used in service canisters. Even though it was realized by the research people that their canisters gave very poor protection against HCN, troops were taught that the sub canister protected them. At the same time work was being carried out to develop a satisfactory absorbent for HCN. At the end of the war the coconut coal No. 2 had been developed. It was made by dipping ordinary active carbon into a 30 - 40 percent solution of $CuSO_4$ containing 0.5 percent gelatin, then dipping the active carbon into a 10 - 20% solution of Na_2CO_3 also containing 0.5% solution of gelatin, and then drying the material. This charcoal gave 3 to 5 times as much protection against HCN as the No. 1 type coconut coal.

b. Facepieces

(1) Design of Facepieces

(a) For different shaped faces

The Navy 2 type gas mask was made with three facepiece sizes. Eighty percent were medium size and 10% were large and 10% small. This division of sizes was determined after the examination of 500 sailors' faces.

(b) To allow wearing of glasses

No special gas masks for wearers of glasses were worked on. A small amount of work developing glasses with thin rims and handles to be worn inside the mask was carried out.

(c) To improve speech transmission

The Navy always has considered speech transmission important and placed the exhaling valve at the front of the mouth to improve this quality in its first mask(2 type). In the 97 type mask the exhaling valve was made larger for the same reason. The need for

a mask having especially good speech transmission properties for commanding officers resulted in the development of the 97 type mask. This mask has a thin rubber diaphragm about 80 mm in diameter placed at the front of the mouth. It was believed that this 97 type mask was 90% efficient and the 93 type 70% efficient in comparison with voice transmission without mask.

(d) To enable the use of binoculars
The 98 type gas mask with a round, small eyepiece had been developed for users of binoculars. It was not manufactured because it was uncomfortable to wear, it allowed no adjustment for distance between the centers of the eyes, and it lacked antidimness.

(e) The oxygen mask
The Navy developed two oxygen masks. Data on these two are given below.

Oxygen Gas Mask

Model 1 5 type

		Component	Front part	Latter Part
Oxygen Generating Agent	Sodium Peroxide 90% $KMnO_4$ and NaOH 10% about 800 g. of agent in the granulated state is filled into the canister.	$KMnO_4$	80.0%	67.77%
		Iron Powder	13.0%	9.21%
		Ferric Oxide		4.98%
		MnO_2	3.0%	0.78%
		Na_2CO_3		13.55%
		Asbestos	4.0%	3.82%
		Weight	185 g.	
Oxygen produced	80 liters		150	
Effective life	60 - 90 min.		approx. 30 min	
Wearing weight	4.3 Kg.		5.0 Kg.	

(f) 3 type gas mask
This mask is used for working with broken batteries in submarines and protects chiefly against chlorine gas. It consists of a canister, mouthpiece, and carrier.

Canister Characteristics

Weight	270 grams
Breathing resistance (30 l/m)	15 - 20 mm water
Absorbing capacity for Cl_2 (0.5% per 10 l/m)	30 minutes

(g) Hose mask
The facepiece is the same as the 93 mask and is equipped with 4 to 6 lengths of hose each 5 meters in length. Breathing resistance is 3 mm water per 5 meters of hose.

(2) Materials used in face pieces.

Naval gas masks are made from rubber, reinforced with knitted goods. The thickness of the rubber is as follows:

Type	Thickness mm.	
	Facepiece	Hose
2 type	2.5 - 3.0	-
93 type 2	2.0 - 2.3	2.0
5 type	1.6	1.5

With the idea of increasing the durability of the facepiece against heat and oil, work was carried out on increasing the carbon black content of the rubber with favorable results; however, the information was not used. Near the end of the war the loss of the Japanese sources of rubber necessitated research on materials such as pulp and silk cotton to replace rubber in the mask.

(3) Penetration of hoses and facepieces by mustard

More than two hours is required for liquid mustard to penetrate the rubber. No work was done on the penetration of the rubber by mustard vapor.

c. Carriers

At first cotton was used in the construction of the carrier. During the war, however, silk canvas partially replaced the No. 10 cotton canvas. Emulsions have been tried for waterproofing but recently this has been abandoned.

d. Data on Latest Gas Masks

See Table II attached.

e. Comparison with Captured American Masks

Since no records remain, exact information on this subject is not available; however, the following conclusions had been reached concerning the comparison of their 93 type M2 mask with American masks (of unknown model).

(1) The smoke filtering efficiency of their mask is 99.85%. Consequently, it was considered superior to other masks.

(2) The main canister of the 93 type mask had superior absorbing capacity for all gases except hydrocyanic acid. Capacity for hydrocyanic acid was inferior to American gas masks and work on No. 2 active carbon was being carried out to improve this.

(3) Since the 93 type mask was designed to have a large visual scope, it has a better field of vision than others.

(4) The materials used in the Navy gas masks were considered to be worse in general than the American materials, particularly in respect to the aging of rubber.

(5) The construction of the canister and facepiece of the Japanese mask didn't allow mass production as readily as did the American mask.

f. Distribution of Masks

All battle troops and front line auxiliary troops were to be issued masks, but only 60 percent of the troops in the rear and auxiliary troops were to have gas masks available. Near the end of the war there were only approximately 60% enough masks to equip the troops as above.

g. Information on use and servicability in the field of the gas mask.

(1) Wearability of the mask

Under moderate working conditions it was believed that the mask could be worn for about four hours but only one hour under severe working conditions, such as continuous gun loading. It was believed that the decrease in efficiency due to the wearing of the mask was approximately 10% except for the users of optical instruments where the decrease was unknown but much greater. The above are impressions obtained during observations of the wearing of masks. No field tests were carried out.

(2) Life of the Mask

The deterioration of the material in the facepiece due to mechanical wear was very great. For example, the facepiece was useless in about one or two years when the mask was worn in engine rooms. Research was carried out to increase the durability against heat and oil by using rubber containing carbon black.

For gases easily hydrolyzed such as phosgene or chlorine, the absorptive capacity of the standard canister was believed to increase with increase in moisture content. Hopcalite is reported to lose its ability to oxidize carbon monoxide if over three percent water has been absorbed. In subcanister No. 4 this defect was avoided by using a drying agent. If this subcanister absorbs organic vapor such as gasoline, the canister is ruined by overheating. They say that this was experienced often during accidents on airplane carriers. No solution had been reached by the end of the war.

h. Research in progress at end of the war.

At the end of the war all work on the gas mask was directed toward the development of masks which could be readily mass produced and which used very small amounts of rubber and metal.

B. Flame Thrower

1. Army Work

World War I convinced the Japanese that the flame thrower would be a very effective weapon; consequently, its development was begun in 1918 and was considered to be one of the Army's most important projects. Two types were worked on in the beginning - a large one to be placed in trenches and a small one to be carried by one soldier. By 1926 a portable flame thrower had been designed and issued to an engineer corps. Defects in the units designed in 1926 were discovered, and the M93 flame thrower was built to replace the earlier model in 1933. This model was used in the China-Japanese incident. During the period 1933 to 1940 it became apparent that the large flame thrower for trenches would be of no value, and research on it was stopped. In 1940 the M93 model was redesigned again, and the resulting M100 type was distributed to the infantry and engineer corps to be used in the Southern and China area during this war.

Experiments on the mechanized flame thrower were carried out during 1930 to 1934, and a regiment with catapillared vehicles provided with this unit as its main weapon was formed in Manchuria. In 1937, the M96 flame thrower, an improved model of the first one, was designed and tested on two M97 medium weight tanks. The mechanized flame thrower is reported to have been used very little in the Chino-Japanese conflict or in the war with the United States. Information available indicates that no research program for flame thrower development was carried out after 1943.

The Third Military Laboratory, under the Army Ordnance Administration Headquarters, was responsible for the work on flame throwers. Some work, however, was done by the Eighth Military Laboratory on the thickening of fuels and methods of ignition of the fuel. The Engineer branch of the Army was responsible for the testing of the flame thrower units.

a. Fundamental and Engineering Studies

(1) Nozzle Design

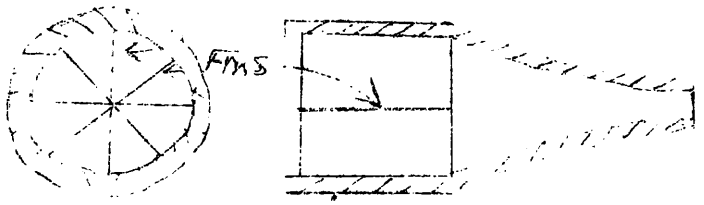
The Japanese studied the fundamentals of nozzle design using models. Water to which a colored solution had been added in such a way that streamlines could be seen was passed through a nozzle and the resulting streamlines photographed. These photographs were studied to determine friction loss in the nozzle.

The ratio of pipe diameter to nozzle diameter was studied and the desired ratio was found to be greater than 20 to 7, but for practical reasons the

*See "Report on the Researches Made With a View to Increase the Range of Flame Fuel". This Japanese report was not completely translated before being forwarded to the Washington Document Center.

20 to 7 ratio was used with the 7 mm. nozzle. The method of changing from pipe diameter to nozzle diameter was studied. Changes in range no greater than ten percent resulted when radical changes in nozzle design were made. In view of this finding no further work was done on this feature.

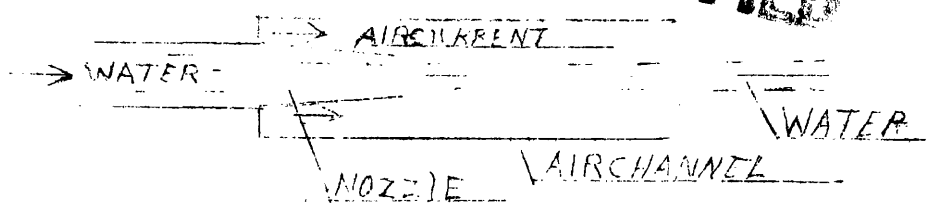
It was believed by the Japanese that the formation of spray after the liquid had left the nozzle was the primary factor influencing the range of the flame fuel. The spray tendency of the fuel becomes greater as the velocity at the nozzle is increased; consequently, optimum value of pressure for maximum fuel range existed. Several methods to decrease the spray tendency were tried. The first one consisted of placing a set of fins (4 to 8) inside the nozzle close to the back of the nozzle in order to decrease the turbulence.



No increase in range using the device could be established. In the second method a needle shaped resistance body of streamlined form having vanes was inserted near the back of the nozzle. As an improvement to this a cylinder of diameter one third the main pipe was used to replace the needle shaped body. (The length and exact location can be determined by consulting the report referred to above.) In the case of the M1C0 flame thrower the range could be increased three to four meters at the 25 meter range. In all this work water was used as the test liquid. When their standard flame thrower fuel was used, they reported that the increase in range was not so apparent and that the reason for this was unknown. It was believed that the formation of spray was due in large part to the difference in velocity between the outer part of the fuel column and the central part of it; consequently, it was desired to flatten the velocity distribution curve in the nozzle as much as possible. The insertion of the objects in the pipe was believed to accomplish this in part.

Another method was tried to decrease the spraying tendency of the ejected fuel. An air current was set up around the fuel to reduce the relative velocity of the fuel and the surrounding air and thus decrease the disturbance of air and fuel at their boundry. Two devices were tried. The first consisted of a tube with diameter 10 times that of the nozzle fastened over the outside of the nozzle. Air streamlined by means of fins was passed through this tube.

A diagramatic sketch is shown below:



In the case of an air channel 50 cm. long the range was increased by five meters if very high velocity air is used. It was soon decided that the device was not practical and the research was stopped. In the second method a number of small orifices through which air is forced are located around the fuel nozzle. The results of tests were not promising. (See "Report on the Researches Made with the View to Increase the Range of Flame Fuel")

The main amount of work on nozzle design was done between 1941 and 1943. Since that time no systematic studies on this subject have been undertaken.

(2) Fuel

After a number of experiments it was decided that for a definite nozzle diameter an appreciable increase in range could not be expected by improving the nozzle design or by increasing the pressure above a certain value. In view of this it was decided that the only practical way to increase the range of the flame thrower was to increase the viscosity and the specific gravity of the flame fuel. The effect of these two factors was consequently studied.

A viscous fuel was made as follows: Crude rubber was cut into small strips and added to gasoline (10% by weight). This mixture is allowed to stand for ten days (in the summer) after which time a paste or jelly-like substance has been formed. The material is diluted to the desired viscosity by adding more gasoline and light oil. The viscosity of the mixture was measured with a Stormer viscosimeter taking the viscosity of water as 1.

From tests made with this thickened fuel it was concluded that at any nozzle diameter there exists an optimum viscosity and the larger the diameter the larger the optimum viscosity. With an increase in nozzle diameter and fuel viscosity the optimum pressure increases also. The values for viscosity and pressure for optimum range are given below.

Nozzle Diameter mm.	Relative Viscosity (Water = 1, Temp. unknown)	Pressure kg/cm^2	Range m.
5 - 7	3.5	25	25 - 35
8 - 10	7	30 - 35	40 - 50
12 - 14	9	40	60 - 70
16 - 20	12	50	80 - 90

Besides rubber it was found that a polymerized soy bean oil could be used to increase the viscosity. Its use was not investigated thoroughly due to the greater need for it as a food product. With increase in range with the increase in viscosity established, work was done on increasing the specific gravity of the flame fuel. At the same time the problem was confused by attempting to give the fuel other characteristics such as the high temperature combustibility of metallic materials and inorganic agents, and high adhesive properties so that the fuel will stick persistantly to the object which it contacts in addition to its increase in specific gravity.

To obtain all these characteristics a fuel containing the following type components was finally decided upon:

(a) Inflammable oil
gasoline
(b) Thickener
Rubber
(c) Agent to give high temperature combustibility
Al, Mg, or Magnalium
(d) Stabilizing solution
Nitro cellulose solution

The specific composition of one of the fuels is as follows in order of mixing:

Magnesium	12 grams
Nitro cellulose solution	5 cc.
Gasoline	5 cc.
Rubber solution(5% rubber in gasoline)	10 cc.
Sulfur	1 gram
NH_4ClO_4	10 grams
Gasoline	5 cc.

Other problems of course resulted when this fuel was used. First the pipe loss was increased which resulted in an increase in the discharge time. To correct this the pressure had to be increased. However the greatest problem, apparently, was the prevention of separation of the solid materials in the mixture. The first step to solve this problem was to use metallic particles ground fairly fine (50% of 80 - 150 mesh and 50% of 150 mesh and above). The next and most important step was the use of a nitro cellulose solution. When this was mixed with the gasoline and rubber solution, the nitro cellulose forms hair like fibers and surrounds the metallic particles, holding them in the mixture. This use effectively solved the settling problem.

The next problem was to make the mixture stable. The Mg and sulfur in the solution tended to cause the formation of H_2S gas. The use of Al to replace Mg prevented the formation of the H_2S, but its substitution was not desirable for several reasons; consequently, magnalium (80 to 90% Mg) was tried. The formation of H_2S gas was decreased but not stopped so they resorted to coating the particles with nitrocellulose by mixing the zinc with nitrocellulose solution and evaporating the solvent. This was the final, although not altogether satisfactory, solution.

The beneficial effect of increasing the specific gravity was considered evident when the fuel of specific gravity 1.00 to 1.05 gave a range 30 percent to 50 percent greater than that of fuel with specific gravity of 0.85 to 0.90.

Additional studies were carried out on increasing the specific gravity to 1.25 by the addition of a thermit mixture to the solution, but no actual firing tests were made.

The use of the high specific gravity material as flame thrower fuel never advanced beyond the experimental stage.

(3) Methods of Ignition

(a) Cartridge type

No work on this type ignition was done after the development of the cartridge which was used in the field. Since information on this subject is already available, no discussion of it will be given here.

(b) Electrical

In order to develop an ignition system capable of consistently igniting long range fuel of high viscosity, electrical ignition methods were studied. Although this method was never used for the portable flame thrower ignition, the final solution is shown below.

Auxiliary nozzle diameter	2 mm.
Source of electrical ignition	batteries
Spark	High tension spark by induction coil
Electrode	Wedge type, two poles (Gap 2 mm.
Discharging voltage	About 5000 V.
Interrupter	Small automobile type No. of interruption 60 - 100 times/sec. Driving motor 1/6 H.P. 1000 - 1500 R.P.M.
Priming matter	Gasoline

On opening main cock of injection pipe, at the time of fuel injection, switch is closed and high tension sparks take places at electrode. And on opening auxiliary cock, priming matter is injected and ignited. By auxiliary nozzle alone, flame reaches 7 - 8m. long.

(4) Causes of death by flame

No systematic research work was done on this subject. From clinical experience it was decided that the causes of death by flame and by burn are identical. In case of high degree flame burn it is reported that most of the patients die of shock within 48 hours. Among the remainder of the patients, many die of symptoms of blood intoxication within one week after the burn. It is believed that the high degree burn of respiratory organs by inspiring flame is the main reason of death.

No special devices were advocated for protection against flame. All that was taught was to prevent the flame from contacting the body by any means available.

b. Design and specifications for the latest model flame thrower.

(1) Portable Flame Thrower, M100

This flame thrower is the latest model developed by the Army. Since samples of it have been taken, only a brief description of it will be given.

The M100 was designed to be used in surprise attacks on fortifications. It consists of the ejector, oil tank, compressed air cylinder, and miscellaneous accessories. The igniter has ten ignition charges, and the throwing and ignition of the fuel can be done by pulling one handle.

Data on the flame thrower:

Range of the flame	25 m,(nozzle diameter 7 mm.) 20 m.(nozzle diameter 5 mm.)
Width of flame	about 3 m.
Nozzle diameter	5 mm. and 7 mm.
Throwing time	10 sec. (nozzle diameter 7 mm.) 15 sec. (nozzle diameter 5 mm.)
Flame thrower fuel	gasoline 50% light oil 50%
Fuel quantity	about 11 liters
Quantity of compressed air	about 4 liters
Throwing method	by compressed air (20 to 25 A.P.)
Ignition method	percussion type
Length of the ejector	60 cm.
Equipped weight	about 23 Kg.
Gross weight	about 51 Kg.

(2) Mounted Flame Thrower

Samples of the mechanized flame thrower have been taken; consequently, only a brief description of the latest models will be given.

The flame thrower mounted on the M97 type tank was built to be used to attack movable targets. It consists of the ejector fuel pump, and fuel tank. The pump is a turbine type driven by the tank's engine.

(a) Data on this flame thrower

Range of flame	43 m.
Width of flame	about 5 m.
Diameter of nozzle	12 mm.
Throwing time	100 seconds
Flame thrower fuel	light oil (same as the tank running fuel)
Quantity of fuel	about 750 liters
Throwing method	by turbine pump
Throwing pressure	18 - 20 A.P.
Ignition method	Semi-electrical type
Length of ejector	about 1 meter

c. Lines of Future Development

In view of the great shortage of fuel the Japanese Army had stopped development work on this flamethrower over a year before the end of the war.

2. Navy Work

Before 1937 the Japanese Navy bought the Army type flame thrower for their use. They considered this weapon to have the following disadvantages:

The total weight was too great for one man to carry.
It used either compressed nitrogen or compressed air which are both difficult to furnish in the field.
It could only be carried on the back or shoulders.

After it became necessary for the Navy to do most of its fighting on land and with instructions to develop weapons to attack the tank, work was started at the beginning of 1945 to develop a flame thrower with the following characteristics:

The total weight should be near 10 Kg.
Compressed air or nitrogen should not be used.
The method of carrying the weapon should be simple.

It had been planned to produce about 4000 by the end of 1945, but with the war's end none were manufactured. The only model which was constructed was reportedly dismantled and destroyed before the entry of United States forces after the end of the war.

a. Fundamental Studies

Some work was done on the design of the nozzle, but no improvement over the Army nozzle could be made so a similar one was adopted.

The flame fuel is heavy oil mixed with gasoline. The proportions vary according to the temperature at which the weapon is to be used, but the optimum viscosity is not known. The relation between viscosity and pressure was determined but the data were destroyed. Besides the oil-gasoline fuel, carbon disulfide thickened with crude rubber was also used and gave longer range, but the supply was not considered practicable.

b. Design of the flamethrower.

A sketch of the flame thrower is attached as figure I.

The pressure bottle is made of 1.6 mm. steel plate and is of welded construction. It was tested at 50 kg/cm^2 but the maximum pressure generated in the bottle is 20 - 25 kg/cm^2. The generating system which is separated from the fuel by means of lead packing which is broken when pressure is generated.

At first methyl formate and sulfur trioxide were used to generate the pressure. When the shortage of methyl formate became apparent, it was planned to use water and calcium hydride which was more readily available in Japan. No trouble was encountered with hydrogen explosion. The calcium hydride is put in the pressure room, and when pressure is desired, water is released by puncturing its container.

The nozzle has a lead sheet cover held in place by means of a stopper. When the weapon is fired, the stopper is thrown out by means of a spring and the lead cover is blown off allowing the fuel to be thrown out.

To ignite the fuel a friction primer is used. A pull match ignites the combustible rubber mix containing magnesium metal and this in turn ignites the flame fuel. Two friction primers are used to insure ignition.

The performance data were:

Range	about 30 meters for heavy oil
	about 50 meters for CS_2 with rubber
Quantity of fuel	5 liters
Fuel ejection time	7 seconds
Total weight	10 kg. heavy oil
	12 kg. CS_2

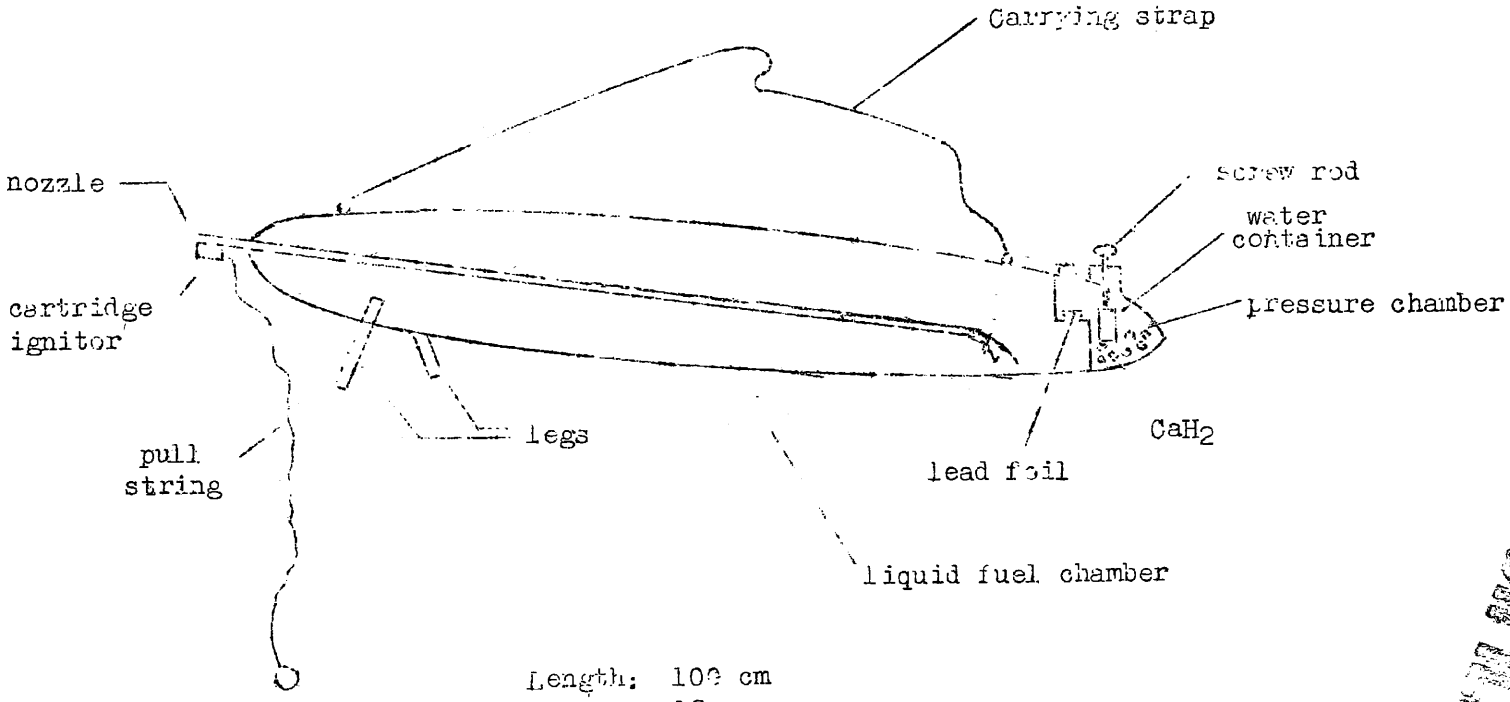


Figure I -- Sketch of Japanese Navy Flame Thrower.

3. Summary

The flame thrower development work which the Japanese have been carrying out since 1918 resulted in three types of flame throwers: (1) The Army portable flame thrower M100, which had a cartridge ignition system and used compressed air to expel the fuel, (2) The Army mechanized flame thrower which had an electrical ignition system and used a turbine pump to expel the fuel, and (3) The Navy flame thrower which used a calcium hydride-water generator to develop the pressure to expel the fuel. Work on this development was stopped by the Army over a year before the war ended, but the Navy carried on work until the surrender.

C. Protective Clothing

1. Army Work

For a long time the Army had worked on the development of clothing to be worn for protection against vesicant agents. This work was carried out by the Second Section of the Sixth Military Laboratory. The description of the work will be broken up into two parts: impermeable clothing, and permeable clothing.

a. Impermeable Clothing

The work on impermeable clothing resulted in the development of the following:

(1) Type 96, light, which was made out of rubber, silk cloth, and cellophane. The suit consisted of trousers, gloves, overshoes, and a breast cover. It weighed approximately 1,200 grams. The mustard penetrating time was about 24 hours (30°C.).

(2) Type 96, heavy, which consisted of the type 96, light, with a gas protective coat with hood and a wrapping cloth. The total weight of the suit was approximately 2000 grams. This clothing was very uncomfortable and in the tropics it could be worn no longer than 20 minutes.

(3) There was an impermeable suit developed for the Air Force. It was made of pure rubber and was constructed so that arms, legs, etc. could be removed by the pilot in flight when the need for protection had passed. This was developed so that the pilot would not be subjected to the discomfort of wearing the suit any longer than necessary.

Samples of these materials have been obtained and will be forwarded to the United States for examination.

b. Permeable Clothing

Realizing that the impermeable clothing which they had developed was inadequate, the Army tried to develop a permeable clothing.

(1) Chloramine T Clothing

The Army did some work on using chloramine T to impregnate clothing. Their final suit consisted of a khaki cotton undershirt waterproofed with Al soap and paraffin. This was worn to protect the skin from the chloramine T in the gauze shirt which was worn over the undershirt. This gauze shirt consisted of three layers soaked in a chloramine T water solution immediately prior to its use. Along with this was worn the type 96, light impermeable protective clothing and a khaki cotton coat with hood, waterproofed to spread the drops and increase the rate of vaporization of the material. The total weight of this suit was approximately 2000 grams. It was believed that this suit might be worn for three hours and protect against a Ct of 2000 mg min/m^3 of mustard vapor if the suit remained damp.

(2) Carbon Impregnated Clothing

The laboratory at Chichiharu in Manchuria did some work on the carbon impregnation of silk clothing. General Akiyama who was stationed at that laboratory and has returned stated that about 80 grams of activated charcoal were placed inside of two layers of silk material (for one suit) and that this was heated to 70 - 80°C. at which temperature the fibers soften and the charcoal adheres to them. Field tests were carried out in which personnel clothed in suits made of this material stayed in an area contaminated with mustard for an unknown time. These suits protected the personnel and were considered very promising. Orders were to be placed in Manchuria to produce some of these suits, but the war ended before that was done. The work described above was carried out in June 1945 and was still in progress so General Akiyama does not believe that the work was officially reported.

2. Navy Work

The work on protective clothing for the Navy was carried out by the Chemical Study Department of the Sagami Naval Arsenal.

a. Impermeable Clothing

The model 98 protective suit was the latest model developed by the Navy. It consisted of coat, trousers, and gloves made of gas-proof cloth coated with rubber, boots and a carrier. The penetrating time for vesicants was given as 60 to 80 minutes. The suit weighed approximately 4.5 Kg. Samples of this suit have been obtained so no more detailed description will be made in this report.

b. Permeable Clothing

At Cavite a document marked secret describing the permeable protective clothing of the United States was captured when the Japanese occupied the Philippines. The nature of the impregnating material was not mentioned but the Japanese assumed that it was chloramine T and went to work on the development of a similar clothing.

They determined that a mixture of 16% chloramine T, 81% bentonite and 3% sea water soap used to form a 2 - 3% chloramine T water solution was the best impregnating solution. Underwear made of absorbent material is dipped in this solution prior to use. A coat is worn over the underwear in order to decrease the rate of evaporation of the water. In trials these suits were more comfortable than the rubber protective suits. When tested for the effectiveness in preventing vesicant vapors penetrating the clothing (rabbits covered with the material), little advantage seemed to result.

D. Smoke

The chief agencies engaged in research on the use of smoke for war munitions were the Sixth Military Laboratory for the Japanese Army and the Laboratory of Sagami Arsenal for the Japanese Navy. In general, this research consisted of the development of a specific munition. However, two projects dealing with fundamental research on aerosols, particle size, and mask clogging were pursued over a period of five years under the direction of the Sixth Military Laboratory by Major Sakagami and by Professor Sameshima of Tokyo University. Certain other laboratories did a limited amount of work with non-irritant smoke munitions. Experiments pertaining to the tactical use of smoke were performed at the Narashino School and will be reported elsewhere (Report on "Training in Chemical Warfare, Offensive and Devensive", Office of the Chief Chemical Officer, AFPAC.) This work will be described in the following section, which deals with the research topics investigated by the above agencies.

In brief, it may be said that of the various agents and munitions investigated only the following presented interesting features: self-projecting smoke candles; the compounding of DC with celluloid whose combustion vaporized the agent; smoke from the reaction of metallic sodium with bodies of water onto which it was projected; the compounding of Thiokol and HC; pressure for oleum-chlorsulfonic acid smoke generator obtained by reaction of methyl formate with the SO_3.

1. Japanese Naval Research Laboratory, Sagami Arsenal (Capt. S. Tsuruo)

a. Development of Type 91 Smoke Generator

A smoke generator utilizing oleum-chlorsulfonic acid was originally developed as Type 88, (1928). This was modified to Type 91 (1931) which was adopted for production. The generator consists of four units mounted in the stern of the ship, each with a storage tank, smoke tank, and nozzle. Compressed air reduced from 150 kg/cm^2 pressure to less than 10 kg/cm^2 pressure forces oleum-chlorsulfonic acid from the storage tank to the smoke tank as required and from the smoke tank through the nozzle. This nozzle is of the rotating disc type utilized commonly for domestic oil burners. Agent is fed through a central tube and impinges on the disc where it is turbulently mixed with compressed air flowing through the annular space around the agent tube. This compressed air is from the same source as that used to eject the liquid from the tank. Each smoke tank contains four such nozzles. Operation is controlled from a central control panel located in the fantail. Moving this panel to the bridge was unsucessful The total weight of the generator was 2000 kg. and its capacity was 1000 kg. of oleum-chlorsulfonic acid of the following composition: SO_3 - 57%; $ClHSO_3$ - 43%; H_2SO_4 - trace.

Experiments indicated that approximately 15 grams of this agent were required per meter length of effective smoke screen. Consumption of agent and operating capacity thus varied with the velocity of the vessel.

b. Smoke Bombs

Around 1930 the laboratory experimented with a WP smoke bomb. It was found that this smoke mushroomed up leaving almost no effective smoke screen at sea level. When metallic sodium was added, the screen was considered effective in experimental runs, but the fleet officers did not like to carry smoke bombs and no naval smoke bomb was ever standardized.

c. Smoke Candles

In 1935 research was undertaken on smoke candles and pots for use chiefly by naval landing forces. The following types were developed:

Type	Weight	Operating Time	Use	Production
Special small type	100 gm.	5 minutes	Training	Less than 1000/year
Small type	400 gm.	50 seconds	Training	"
1 kg. type	1,000 gm.	1½ minutes	Training Land Battle	30,000 per year
10 kg. type	10,000 gm.	5 minutes	"	Less than 200/year
30 kg. type	30,000 gm.	5 minutes	"	5,000

All of these munitions except the special small type candle used Berger Mixture of the following composition: CCl_4 - 50%; Powdered Zn - 25%; ZnO - 20%; Kieselguhr - 5%. A small fraction of the production used C_2Cl_6 in place of CCl_4 mixed with the other constituents in the same proportions. The special small type candle consisted simply of HC packed in a zinc-plated cylinder which accounts for its long burning time. The metal wall of the container melted down with the mixture as it burned.

At the close of the war the laboratory experimented with self-projecting smoke candles to be used in anti-tank defense. 100,000 candles similar to the Army Type 99 using HC were ordered for August 1945. Meanwhile the laboratory experimented with the use of chlornapthalene to replace scarce HC and also worked on the use of "special rubber" smoke candles to save steel (cf. project). This work was considered successful, but the war ended before the development had been completed. Zinc was also scarce in Japan and at an earlier date the laboratory experimented with the use of iron sand. (The beaches of Japan contain considerable quantities of iron ore.) This work was abandoned when it was found that the presence of moisture caused spontaneous ignition.

d. Sea Smoke Shell

In 1937 the laboratory worked on a shell which could be used to provide a smoke screen for destroyers preparing to attack the enemy with torpedoes. Requirements were for a large amount of smoke with a relatively short range. The final design was for a shell with a long body, maximum cavity and minimum wall thickness to safely withstand a reduced charge. The smoke agent was small pieces of metallic sodium pressed into a cylindrical shape. This was held in a plate steel container built in four segments soldered together. The cylinder was held in the shell by means of a base plate attached to the casing by a shear pin. At the head of the cylinder was a steel pressure plate backed by a charge of Black powder. A time fuse in the nose of the shell ignited the black powder resulting in the release of the sodium metal over the surface of the ocean. The shell was fired from standard 12.7 cm or 14 cm guns located in the bow of the destroyer. Shells contained 5 kg and 8 kg of sodium respectively. Total weight of the shells was the same as HE shell, 23 kg and 38 kg. Range was about 2000 m. Only several thousands of these shells were produced.

e. Ground Smoke Shell

In 1939 a shell was developed which could be fired from naval vessels to the shore to protect landing forces. These shells contained standard HC mix with the addition of NH_4ClO_4 and coal tar. The agent was pressed into a steel tube which was contained in the shell. A black powder charge in the nose of the shell fired by a nose fuze ejected and ignited the smoke cylinder which burned for about ten minutes. The tubes were designed for use in standard nose-fuze shells of the following bores: 15 cm, 14 cm, 12.7 cm, and 12 cm. Only several hundreds of these shells were produced.

f. Development of 40 Kg. Smoke Generator(Smoke Box)

In 1942 the laboratory was called upon to develop a floating smoke producer to be used to screen slow-moving vessels. Research led to the adoption of a 40 kg smoke generator containing 25 kg. of oleum-chlorsulfonic acid, referred to by Navy personnel as a"smoke box". The generator consists of a steel tank with a nozzle similar to that used in the Type 91 smoke generator eccentrically mounted. Directly under the centrally-located cover is a can containing 200 cc. of methyl formate. In the center of this can is a blasting cap which may be exploded by striking a pin in the cover. This ruptures the methyl formate can and permits its reaction with SO_3 to generate CO. This gas develops a pressure in the tank sufficient to eject smoke agent for about 5 minutes. The pressure in the can never rises above 10 kg/cm^2. At the end of the war this weapon was used chiefly to provide smoke screens for air-raid protection of important factories. The pressure can was ruptured by a nail struck with a hammer.

g. Hand Smoke Bottle

In 1943 the laboratory developed a smoke grenade to be used to limit enemy tank maneuverability by temporarily blinding the crew. A spherical glass flask 8 cm in diameter and containing 200 cc of liquid smoke agent was adopted. Originally the agent used was FM, but at the end of the war oleum-chlorsulfonic acid was used. With that agent, glass wool was added to increase the length of generation to about 30 seconds.

h. Special Rubber Mortar Shell

A smoke barrage shell for the 80 mm. trench mortar was developed and produced in 1944 - 1945. The smoke agent used was "special rubber" compounded of the following composition: Thiokol - 9.3%; Crude rubber - 5%; Stearic Acid - 0.2%; Sulfur - 0.5% KNO_3 - 8%; Zn - 27%; C_2Cl_6 - 50%. 200 grams of this material were contained in the shell with 200 grams of explosive. The shell was timed to explode at a height of 1000 meters 13 seconds after firing, the steel tube containing the smoke agent being expelled at that time. The tube is suspended by parachute and generated smoke during its descent. The explosive was provided to damage any planes which fouled the parachute lines.

i. Smoke Agents

The agent in most general use by the Japanese Navy was oleum-chlorsulfonic acid. This was mixed in various proportions according to the following table:

Smoke Agent	$\%SO_3$	$\%ClHSO_3$	$\%H_2SO_4$	Remarks
A	57	43	Trace	For general use
B	57	33	10	For airplane spray
C	38	0	62	For cold weather operations
D	>25	0	<75	Produced in large quantity but not considered effective

Type A was most widely used and was the mixture for Type 91 smoke generator, 40 kg smoke generator, hand smoke bottle. Type B was an improvement developed for spray tanks. In general, Capt. Tsuruo felt that the agents actually filled in the munitions discussed above were the best of the possible agents studied for the specific application involved. He felt that HC was a better mix than Berger Mixture for smoke candles because the smoke produced over a longer period of time and the filling operation was non-toxic. However, C_2Cl_6 was difficult to obtain. The substitution of chlornapthalene for C_2Cl_6, already mentioned, did not provide as effective a smoke.

j. Irritant Smokes

In 1941 some experiments were undertaken on the use of 30 kg floating candles filled with DC. It was found that this smoke rose too fast for effective use and DC was not adopted for smoke purposes. A certain amount of DC was produced at Sagami Arsenal and filled into shells and bombs, but the agent was used only for its toxic effect. No experiments with other irritant smokes were revealed.

2. First Naval Air Technical Arsenal

a. Spray Tanks

Research on the use of spray tanks was undertaken by the First Naval Air Technical Arsenal at Yokosuka. This research is fully described in "Report on Japanese Navy Chemical Smoke Tanks", Advance Echelon, Far East Air Forces, 4 December 1945. Copies of this report are available from Air Documents Division, T-2, Wright Field, Dayton, Ohio. The research covered the period from 1933 to 1940 and culminated with the adoption of the Type 99 tank, which was produced in very limited quantities. The research appears to have been carried out under the assumption that smoke must be discharged from the tank at the same velocity as that of the plane. It was felt that this resulted in the formation of a screen rather than a cloud. In view of the speeds necessary for present operations, no satisfactory tank was developed by the Japanese Navy, since their best tank could only be used at speeds up to 140 knots.

3. Sixth Military Laboratory (Lt. Col. Yoneichiro Imaoka, Director of Smoke Researches)

With the exception of the theoretical work of Major Sakagama and Professor Samejima (described at the end of this section) the work pertaining to smoke undertaken by the Sixth Military Laboratory centered on the development of specific munitions. These munitions are described elsewhere ("Captured Japanese Materiel Technical Reports", filed at the Office of the Chief, Chemical Warfare Service, Washington, D.C.) and are treated but briefly below.

a. Smoke Candles

Over a period of years from 1924 to 1930 Major Nobuharu Imata developed the various standard smoke candles in use by the Japanese Army. A small Berger Mixture candle was adopted in 1928 as Type 88. This was later slightly modified, and in 1934, Type 94A and Type 94B small, large, and floating candles (pots) were adopted. The "A" and "B" refer to the type filler used, "A" being Berger Mixture and "B" HC. Berger Mixture was preferred by this laboratory as the smoke was found to be denser and to be emitted over a shorter period of time. Berger Mixture was thus used in all these munitions. It was found, however, that the CCl_4 tended to evaporate from the floating type, so that HC was used in production after 1940. Since the standard small candles were considered too expensive for training purposes, a "substitute" candle of lighter construction

containing less agent was developed in 1933.

b. Smoke Generator for Landing Craft

Engineer Chokitsu Onodera worked on a $TiCl_4$ smoke generator which was to be mounted in landing craft and used to provide a screen for landing operations. Bottles of compressed air supplied the pressure necessary to expel the fluid from Venturi-type nozzles. Experiments were undertaken over a period of years from 1938 - 1933. The generator was never adopted as it was found that ordinary smoke pots mounted in the boats proved more practicable.

c. Smoke Generator for Tanks

Parallel to the above experiments on a smoke generator for boats, Col. Takao Maejima conducted experiments from 1930 - 1932 on the use of a similar device to be mounted in tanks. This was also superseded by the use of smoke pots, which were deemed more economical. The equipment was later used as a mechanized flame thrower. Chlorsulfonic acid and FM were the only agents investigated.

d. Persistent Smoke Shell

A smoke shell for the 90 mm. light trench mortar was developed by Col. Nobuharu Ichino in the period from 1934 to 1937. This shell was to provide a more persistent smoke than the ordinary WP shell developed by the First Military Laboratory. The shell was given the trial production number Mark I and produced in small quantity by the Second Tokyo Military Arsenal. It contained six small HC smoke candles, but was not considered to supply a sufficient quantity of smoke and so never adopted.

e. Substitute for Zinc

Zinc was a critically short material in Japan and the laboratory sought to find a substitute metal for the production of smoke candles. Major Nobuharu Iwata studied this problem during the years 1935 - 1940. Various materials were studied, including iron, aluminum, and magnesium. It was finally decided that TiO_2 possessed the best potentialities, but the production of this material was never in sufficient quantity to warrant its use in munitions manufacture. The ultimate source of titanium for this application was to be from steel refineries using beach sand as ore. (Beaches in Japan contain a large quantity of iron and other minerals.) No material other than zinc was used in actual production.

f. Hand Smoke Bottle

In 1940 Lt. Col. Imaoka developed a small glass smoke grenade. This was modified by the Third Military Laboratory, and further work on the grenade for use with HCN was conducted by Major Akio Sato of the Sixth Military Laboratory. In its final form, the filled grenade was known as the "chibi" ("small") grenade and consisted of a flat-bottomed, spherical, glass flask 10 cm in diameter with a short neck covered with a steel cap and rubber

gasket. It was to be used as an anti-tank grenade to "blind" the driver and gunners, and was to be thrown from a distance of five meters or less.

g. Aquatic Smoke Shell

In 1940 - 1941 Major Iwata experimented with a shell to lay a smoke screen over bodies of water. WP and HC shells were found unsuitable for this purpose and the experiments investigated the use of metallic sodium which was to produce smoke by reaction with the water. It was found that the speed of smoke generation could not be controlled and that explosions were likely. For these reasons the munition was never standardized.

h. Anti-tank Smoke Shell

A shell weighing about 4000 grams containing 1000 grams of FM was developed by Major Sato and Lt. Mitsiushi on a project started in September 1944 and lacking a few months before completion at the close of the war. The shell was developed to be fired from an 8 cm recoil-less gun at a range of 200 meters. The shell contained no charge, the agent being released by the rupture of a cast iron head upon impact. The recoilless feature involved the use of a sand-bag which was expelled to the rear a distance of about 100 meters.

i. Smoke Compositions

Compositions of the various smoke agents used in the munitions discussed above are as follows:

Smoke A (Berger Mixture)	
Zn	25%
ZnO	20%
CCl_4	50%
Diatomaceous earth	5%
Smoke B (HC)	
Zn	28%
ZnO	22%
C_2Cl_6	50%
for use in floating smoke pots	
Zn	28%
ZnO	20%
C_2Cl_6	47%
$NaNO_3$	5%
Substitute smoke	
TiO_2	30%
CCl_4	55%
$KClO_4$	10%
Diatomaceous earth	5%

Liquid smoke	
$TiCl_4$	50%
$SnCl_4$	50%
Aquatic smoke	
Na	90%
Mg powder	10%

j. Irritant Smoke Munitions

In 1932 - 1933 Lt. Col. Imaoka experimented with irritant smoke mixtures and the design of an irritant smoke candle. In 1933 a candle containing DC mixed with granules of pumice was standardized as Type 934 later slightly modified to Type 97. Heat for the generation of the smoke was obtained by the combustion of charcoal mixed with NH_4NO_3. From 1935 - 1938 work was done with an agent composed of DC mixed with small particles of celluloid. The celluloid acted as binder and to produce heat for smoke generation. The mix was used in Type 99 small and medium candles and Type 98 and Mark I large smoke pots. (Mark I was the same as Type 98 except that it included a 2 mm steel plate at the bottom for stabilization when floated on water.) The manufacture of the Type 97 candle was complicated and expensive, but it was found that the celluloid mix was not sufficiently stable for long storage. It was produced only on a trial basis. In 1939 and 1940 Col. Ichino developed a self-projecting irritant smoke candle of slightly different composition. This was standardized as Type 99 and Type 100. For training purposes a substitute irritant smoke candle was developed in 1932 - 1933 by Engineer Onodera and standardized as Type 93. This candle was filled with C^{IV} and flour.

k. Irritant Smoke Agents

In 1934 - 1935 Lt. Col. Imaoka experimented with diphenylchlorarsine, diphenylbromarsine, and DM. He decided that DC was superior to these, and so ceased work on other irritant smoke agents. At first DC was considered a very effective agent since it penetrated the Japanese gas mask. However, around 1935 the mask was modified by the incorporation of asbestos fibers in the filter. Col. Imaoka claimed that the mask then protected against DC and the agent was only considered tactically for use against unmasked troops. The compositions of the various mixes used in munitions are as follows:

Pumice Type (used in Type 93A and Type 97 medium candles)

DC	40%
Powdered pumice	60%
Heating (combustion) compound	
NH_4NO_3	90%
Charcoal	10%

Celluloid Type (used in Type 99, small, medium, and large; Mark I large)

DC	47%
Powdered celluloid	50%
MgO	3%

Celluloid Type (used in self-projecting, Mark I)

DC	35%
Powdered celluloid	62%
MgO	3%

1. Fundamental Research Conducted by Professor Jitsusaburo Sameshima

From 1936 to 1941 Professor Sameshima, of the Tokyo Imperial University, performed some experiments pretaining to the mechanism of filtering smoke particles with a fibrous membrane. These experiments were performed in conjunction with the Sixth Military Laboratory. A description of Professor Sameshima's experiments and conclusions is given below.

(1) Permeability of Solid and Liquid Smoke Particles

An apparatus consisting of a smoke chamber, filtering chamber, and Cottrell precipitator was used to study the filtration of smoke through filter paper. Smoke particles of ammonium chloride were formed by heating of crystals or by the action of dry HCl on NH_3. At a temperature of 15°C. and at 50% humidity these particles were found to be solid. Liquid particles were obtained by bubbling the smoke through water to produce droplets of an aqueous solution of NH_4Cl which were introduced into the smoke chamber containing an atmosphere saturated with water vapor. The smoke particles caught on the filter paper, and those passing through to the Cottrell tube (which was found to precipitate the particles completely) were analyzed separately. The samples were dissolved in a standard quantity of water to which a given quantity of Nessler's solution was added. Turbidity was measured with a Pulfrich colorimeter. Particle size was determined by observing settling velocity with an ultramicroscope and using the Stokes-Cunningham equation. The experiments showed that the filter paper permitted the passage of roughly twenty times more liquid material than solid. The mean particle diameter was about 1×10^{-4} cm, the filter paper had a mean of 1.48×10^{-3} cm and interstice thickness of 0.0180 cm. The average filtering rate was 67.7 cc/min. X cm^2 and the amount filtered was 1 liter.

From these experiments Professor Sakeshima drew the following conclusions: (1) Sieve action was not significant since the mean diameter of interstitial

capillaries was found to be about seven times greater than the mean particle diameter, (2) differences in hydrodynamic action (the collision of solid and liquid particles with filtering fibers) were insignificant, (3) differences in Brownian movement of the two kinds of particles were also insignificant. From this, the theory was developed that solid particles built up in the interstitial spaces, tending to block them while liquid particles merely wet the fibers and do not decrease free space. The theory was substantiated by further experiments which showed that the resistance of the filter paper increased with the filtration of solid particles of ammonium chloride, metallic oxides, and stearic acid while there was no appreciable increase for liquid smokes of phosphoric acid, ammonium chloride, or oleic acid. The permeability of the filter paper for liquid particles was found to vary with the ability of the liquid to wet the paper.

(2) Efficiency of Filtration of Liquid Particles with Varying Filter Thickness

Professor Sameshima used the same apparatus as above to test the efficiency of different thickness of paper in filtering liquid particles of ammonium chloride, phosphoric acid, and oleic acid. Thickness was varied by using numbers of sheets of filter paper from zero to five. It was concluded that for smokes of homogeneous particle size the following relation holds: $c_n = c_o e^{-kn}$ where c_n denotes the amount of smoke material and k is a constant.

(3) Effect of Particle Size on Filtration

According to Professor Sameshima's theory, the filtration of smoke particles depends on the collision of these particles with the fibers of the filter. The number of collisions should depend on the kinetic energy of the particle and Brownian movement. The former should govern filtration of large particles, and the latter that of small particles. To test this theory, particle size of smoke before and after filtration was measured. The amplitude of vibration of charged particles in an alternating electric field was observed by a micrometer-ultramicroscope. (The charged particles were obtained by heating stearic acid in an electric furnace.) The mean radius was then calculated using the following equations:

$$Ee = 6\pi rv\left(1 + \frac{Al}{r}\right)^{-1}$$

and $$Tv = 2a$$

where E is the field density (600 - 700 volts/cm^2), e the particle charge (considered to be one electron on the basis of other unpublished experiments), r is the radius of the particle, v its velocity, T the period (0.8 sec) and a the amplitude of vibration, and the quantity in parentheses is Cunningham's correction factor

where A is a constant, l the mean free path, and where the value of Al was taken as 9×10^{-6}. a was taken as the mean of fifty readings observed over an interval of 2 - 3 minutes.

From the results, it was concluded that the percentage of particles with a radius greater than 2×10^{-5} decreases by filtration. No conclusions could be drawn about smaller particles.

(4) Filtration of Charged Particles

Stearic acid particles (obtained from sublimation by heating) were charged by one of three methods: point discharge, ultraviolet rays, or passing through coal gas flame. The percentages of positive, negative, and neutral particles was determined by observing the drift of particles toward electrodes by means of an ultramicroscope. The percentages of these particles was then observed after the smoke had been passed through a special cellulose-fiber filter, both plain and dyed with malachite green. It was thought that the use of this basic dye might affect the filtration. No significant change in percentages was obtained.

m. Researches Conducted by Major Sakagami

During the period 1936 to 1941, Major Sakagami of the Sixth Military Laboratory conducted various experiments on the clogging of masks, the stabilization of aerosols, and the measurement of particle size. This research is described below.

(1) Clogging of Filters

Using a simple apparatus consisting of a glass filtration chamber (volume ca. 1 meter, filter 10 cm diameter) the resistance of the filter to the filtration of about 200 smoke compounds was studied. Resistance was measured by a U-tube manometer and plotted vs. time, a constant quantity of raw smoke material (2 gm) being used to generate the smoke in all instances. Flow rate was regulated to correspond to a rate of 30 liters/min through the Japanese Type 95 canister. It was found that the behavior of smoke composed of solid particles differed markedly from that of liquid particles. For solids, resistance increased rapidly at first but then more slowly, approaching a rather low final resistance asymptotically. On the other hand, resistance for liquid particles increased very gradually at first and very rapidly after a period of time. If resistance is plotted vs. time, curves are obtained resembling parabolas whose axis is the time axis for solid smokes and the resistance axis for liquid smokes. The materials were compared on the basis of the length of time required to establish a resistance corresponding to 1000 mm H_2O in the manometer. The best material studied was a mixture of 0.75 gm solid NH_4Cl with 1.25 gm lanolin with which

a resistance of 1000 mm was obtained in 1 minutes.

Experiments were run in a gas chamber with human subjects wearing Japanese Type 95 masks in a concentration of about 1000 mg/m^3 of a smoke consisting of 90% pine-resin and 10% NH_4Cl. In 35 - 40 minutes the resistance was such that the subjects could no longer breathe through the masks. The results were not reproducible, being affected by numerous variables including temperature, humidity, and impurities in smoke mix. It was concluded that the project was not practicable, and the research was discontinued.

(2) Particle Size and True Density of Smoke Particles

Smoke particle size is usually measured by observing settling velocity with an ultramicroscope. This, however, involves the use of Stoke's law (or one of its modifications) which contains the density of the particle as a variable. In order to measure the density of the particle, Major Sakagami used an alternating electric field oriented in the vertical direction. If the charge on the particle is ne, where e is the electron unit and n the number of these units, the following equations hold:

$$6\pi r V_f \eta = 4/3\,\pi r^3 \rho g + neE$$

$$6\pi r V_a \eta = 4/3\,\pi r^3 \rho g - neE$$

$$6\pi r (V_f - V_a) \eta = 2neE$$

where V_f and V_a are the falling and ascending velocities of the particle in the field, r the radius of the particle, η the viscosity of air, g the gravitational constant, E the density of the field, and ρ the density of the particle. The number of the charges on the particle was changed by bombarding the particle with X-rays and the path of the particle was photographed. Since the charge on the particle must change by an integral number of electron charges, n, the greatest common divisor of the ratios $(V_f - V_a)_1 : (V_f - V_a)_2 : (V_f - V_a)_3 : \ldots$ corresponds to a value of $V_f - V_a$ for $n = 1$.

For the experiments, particles of diphenylcyanarsine, diphenylchlorarsine, and diphenylbromarsine were used. The model value of the size distribution was a radius of $5 - 6 \times 10^{-5}$ cm and the range was from 5×10^{-6} to 1.2×10^{-4}. The normal (bulk) density was encountered in the largest number of cases, but in an appreciable number values of 1/3 and 1/5 the normal density were met.

(3) Stabilization of Smoke

Smoke particles have a tendency to coagulate which increases the falling velocity of the particle. Coagulation was measured for various smokes by measuring concentration with time, using a light source and photoelectric cell. Coagulation of particles of napthaline,

phthalic acid, and soot produced by combustion of benzene was readily observable. It was found that if solid paraffin was mixed with napthaline or phthalic acid their smokes became very stable. This was not effective for soot. No stabilizers could be found for diphenylcyanarsine or diphenylchlorarsine.

(4) Mechanism of Smoke Filtration

Major Sakagami developed a complicated theory for the mechanism of smoke filtration. The assumptions are: (1) since the size of the smoke particle is small compared to the free space of the filter, sieve action is insignificant, (2) the particles describe simple harmonic motion about a streamline (an approximation to provide for Brownina motion). If the amplitude and wavelength of the vibration are known, the probability of the collision of a particle with a fiber may be calculated. The probabilities of all stream lines are averaged to obtain the effective breadth of texture necessary to filter the particles. The theory indicates that filters manufactured from thin textures are more effective than those made from thick textures. The theory was tested by filtering smoke particles with glass wool filters with fiber diameters of 1 - 10 microns. It was considered that the results substantiated the theory.

4. Eighth Military Laboratory (Major Teiji Takada)

From January to April 1944, Major Takada and colleagues of the Eighth Military Laboratory conducted studies on the use of various "substitute" smoke agents and on methods of generating chlorsulphonic acid smoke without pressure. The results of these experiments are summarized below from translations of the printed laboratory reports of the Eighth Military Laboratory.

a. Experiments with Smokes from Grasses, Leaves, and Straw.

Experiments were conducted with the incomplete combustion (carbonization) of fresh and dried leaves, grasses, and straw. Techniques were developed for area screening from smoldering fires of these materials. It was found that about 7 - 8 times as much by weight of these materials were required for effective screening than the Japanese standard Berger Mixture. Investigation of resources of these materials was made. It was calculated that 30 tons of this material would be required to provide a smoke screen four by one kilometers for a duration of one hour. In view of this, plants were recommended as a possible substitute smoke agent.

b. Studies of Smoke Screens from Anthracene and Coal Tar

Smoke composed of black carbon particles from the incomplete combustion of pools of anthracene and coal tar in small pits was studied. It was found that about 4 - 5 times the weight of these materials was necessary to provide a screen of the same dimensions as the Type 94A large smoke pot (Berger Mixture). However, smoke was generated from the substitute agents

for about one hour. The smoke was also found to be more stable (settled less rapidly) than standard agents. These substitute smoke agents were proposed for area screening of military targets against air attack.

c. Measurement of Screening Ability of Various Smoke Agents

Measurements were made comparing the effectiveness of various smoke agents. These were reported as the length of a smoke screen that could be produced which would have a cross-section of one square kilometer and last one hour, using as a basis air observation of screens from Type 94A large smoke pot (Berger Mixture). Results are tabulated below.

Agent	Length of Standard Screen Km.	Color of Smoke	Quantity of Agent Required Metric Tons	Method of Generation
White Phosphorus	940*	White	1.380	Combustion or Explosion
Fuming H_2SO_4	650*	White	2.000	Heating or Explosion
$SnCl_4$	380*	White	3.400	Explosion
C_2Cl_6	290*	White	4.500	Explosion
Berger Mixture	260*	White	4.800	Combustion
$ClHSO_3$	330	White	3.950	Heating
95% H_2SO_4	230	White	Not Given	Not Given
Anthracene	140	Black	9.300	Combustion
Pitch	100	Black	13.000	Combustion
Crude Rubber	100	Black	13.000	Combustion
Wood Tar	95	Black	13.700	Combustion
Napthaline	88	Black	14.700	Combustion
Coal Tar	85	Black	15.300	Combustion
Kerosine or Light Oil	84	Black	15.500	Combustion
Heavy Oil	80	Black	16.300	Combustion
Cresol	75	Black	17.300	Combustion
Gasoline	50	Black	26.000	Combustion
Twigs of Japanese Cypress	40	White	32.500	Smoldering
Hay and Straw	30	White	42.000	Smoldering

* Figures obtained from other experiments.

d. Experiments on the Generation of Chlorsulphonic Acid Smoke without the use of Pressure

Smoke from chlorsulphonic acid was generated by heat, either from (1) direct heat from combustion of various materials, or (2) chemical heat of combustion. The best formula for the latter was found to be chlorsulphonic acid, white phosphorus, and water in the ratio 1:0.1:0.06. Field tests were made, and it was found that the best screening effect was obtained by direct heating of chlorsulphonic acid by combustion of napthaline or anthracene. This produced an effective screen length of 500 meters, and it was calculated that by this method 3 metric tons of chlorsulphonic acid were required to effectively screen 1 square kilometer. The smoke was grey in color and was composed of a mixture of particles from $HClSO_3$ and the heating material.

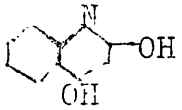
E. Detector Kits

In view of the fact that samples of the detector kits developed by the Japanese have been obtained only a brief description will be included in this report. No research has been done since the development of the standard kits.

1. Army Kits

The following table includes the information on the Japanese Army detector kit:

Names of Parts	Use, sensitivity, change of color	Constitution and reagents
#1 Detecting Tube	Used to get off mask for gases having no odour. $CoCl_2$ 30 mg/m^3 w. → y.	Glass tube. Test Paper ($(CH_3)_2N\langle\rangle CHO$ ($(C_2H_5)_2NH$ (alcohol Sealed tube 5% $HgCl_2$ in alc. sol.
#4	H_3As 50 mg/m^3 w. → y. - b.	Glass tube SiO_2 gel 2g. 5% $HgCl_2$ in alc. sol.
#3	HCN 50 mg/m^3 y.b. → d.bl.	Glass tube O-Tolidin) CuAc$_2$) Alc. Sol. Sealed tube CH_3OH) C_2H_5OH) 0.15 cc.

Names of Parts	Use, sensitivity, change of color	Constitution and reagents
#2	CCl_3NO_2 50 mg/m^3 w. ⟶ v.	Glass tube Silica gel 2 g.  0.5 g. Sealed tube $(CH_3)_2N$-⟨◯⟩ 0.01 g. Toluol 0.1 cc.
#5	$CoCl_2$ 50 mg/m^3 y. ⟶ bl.v. - g.	Glass tube SiO_2 gel 2 g. $(CH_3)_2N$ CHO 0.02 g. Sealed tube $(CH_3)_2N$ 0.001 g. Toluol
#6	Lewisite y. ⟶ r.	Glass tube SiO_2 gel. 2 g. Cu_2Cl_2 NH_2OH^2 < 0.1 g. Sealed tube NaCH 15% aq. sol. 0.15cc
#7	N - yperite y. ⟶ r.	Glass tube SiO_2 gel 2 g. Sealed tube NH_4BiJ_4 aq. sol. 0.15cc.
Detecting Paper	Yperite, Lewisite, etc. (persistent gas) Red spot on yellowish green surface of detecting paper.	(Dithizon 1 - 2 g. (ZnO 30 g. (Yellow pigment 30 g. (Talc 30 g. (gelatin water
Note	1. y: yellow, b: brown, bl: blue, r: red, v: violet, g: green 2. alc. sol. alcoholic solution aq. sol. aqueous solution	

A rubber aspirator is also included in the kit. This kit was designed for two purposes: (1) to identify toxic gases and (2) to determine the time when the mask may be removed.

Instructions for the use of the kit are as follows:

Operation:

a. To determine the time the mask may be removed No. 1 detecting tube is used and operated as follows:

(1) Collodion film of the tube is broken and the sealed glass tube is snapped at neck.

(2) The detecting paper in the glass tube is moistened with the reagents in the sealed glass tube.

(3) The right end of the detecting tube is inserted in a rubber stopper of a rubber bulb.

(4) The rubber bulb is operated by hand ten times and color change of the detecting tube is compared with the standard paper and the chance to get off gas mask is judged.

b. Identification of main poison gases.

(1) For temporary gases (phosgene, chlorpicrine, hydrocyanic acid, and hydrogen arsenide) To identify of main poison gases, we operate as follows:

No. 2, No. 3 and No. 4 detecting tube are fitted altogether to the rubber stopper as described above and operate rubber bulb. Kinds of gases are identified by colors produced.

(2) For persistent gases (except yperite) No. 6 and No. 7 detecting tubes are used. Two tubes are fitted to rubber stopper at right hand side of the rubber bulb. Lewisite and N-yperite are identified by color changes.

A large detector kit was designed for use at headquarters. A description of it may be found in the Report on the Scientific Intelligence Survey in Japan, Vol IV, Scientific and Technical Advisory Section, AFPAC, page CW-11-6.

2. Navy Kits

The Navy gas detector equipment is completely described in Report on the Scientific Intelligence Survey in Japan, Vol IV, AFPAC, page CW-21-5. Samples have been taken so no details will be included in this report.

F. Decontamination Methods

1. Army Work

Research work on this subject has been completed so only the standardized procedures are given.

a. Clothes

A total of five methods for the decontamination of clothing were approved by the Japanese Army. Each of these methods has certain advantages and while the superheated steam process was known to be the most effective, other methods were retained as substitutes when steam was not available.

(1) Saturated Steam

Contaminated clothing was placed in a saturated steam for a period of twenty minutes. It was relatively simple to use this method even in the field, but the fiber of the clothing subjected to this treatment is weakened. This weakening was caused by the condensed water from the steam and acids from the decomposed gas.

(2) Superheated Steam

With superheated steam and ammonium hydroxide, clothing can be decontaminated by ten minutes steaming at 350°C. In this way decontamination is accomplished in a very short time and though the clothing shrinks, its strength of fiber is not materially affected. This method was found to be the most effective. The M-1 Type A, horse-pack type decontaminating equipment, and M-99 Type B decontaminating vehicle were both equipped to use this method.

(3) Hot Air

Using hot air, clothes can be decontaminated in about two hours if the air is at a temperature of 100° C. This process is effective but rather slow considering the large amount of equipment it uses.

(4) Sun Light

By exposure to sun beams for one or two days in the summer time clothing can be decontaminated. This process takes a long period and is entirely dependent on the time of year and weather conditions. However, no special equipment is necessary.

(5) Chemicals

By washing the clothes in gasoline or carbon tetrachloride for about ten minutes and then hanging them in the air to dry decontamination is accomplished. This method is effective but requires large quantities of chemicals.

In addition to the approved methods attempts were made to decontaminate clothing by using Chlorine in a chamber filled with clothes. Also bleaching powder was experimented with but when used in effective strength to decontaminate, the powder destroyed the clothes.

b. Munitions

Metallic parts of munitions were wiped out with a cotton cloth which had been soaked in solvent, usually kerosene. Wooden parts were decontaminated by rubbing with a paste made of 70% bleaching powder and 30% water. The paste did not prove to be effective on wood but was the best available.

c. Shoes

(1) Solvent

The shoes are soaked in gasoline or carbon tetrachloride for ten minutes and then dried in hot air. This method is effective but it requires much solvent and tends to injure the leather.

(2) Hot Air

By blowing hot air for about one and a half hours at 75°C. This process is most effective and will completely decontaminate even gas that has penetrated the leather. Also this method does not injure the material.

(3) Bleaching Powder

The contaminated parts are rubbed with either the bleaching powder itself or a paste made of bleaching powder. This is effective only on the gas on the surface and material treated with the powder loses its usefulness.

The approved method for shoes as well as for all other clothing was hot air or superheated steam.

d. Buildings

External parts of buildings were to be left to the sun light for decontamination. In some cases washing with large quantities of water served to hasten the action of the sun and wind.

Handles, doors or anything which was necessary to touch was wiped out with kerosene, carbon tetrachloride or bleaching powder paste. If none of these materials were available, water could be substituted. For the inside of rooms vaporization by fuming charcoal was recommended.

e. Airplanes and Airfields

Body parts and wings were decontaminated with water or soap. For the motor and machine parts kerosene or carbon tetrachloride were used.

Bleaching powder was effective when scattered over the ground. If bleach was not available, covering the gassed area with fresh earth, weeds or grass would be partially effective and was recommended.

f. Personal Decontaminations

(1) Two types of protective ointment were approved for use:

(a) Old Type

Potassium Permanganate	60%
Magnesia	40%

(b) New Type

Chloramine T	20%
Talc	10%
Zinc Oxide	65%
White Clay	5%

Both of these decontaminating agents were issued in metal containers with a cloth bag for carrying. 100 grams of the agent were in each can. Production of these agents was negligible due to shortage of necessary chemicals.

The only agent available in sufficient quantity for actual use was bleaching powder. It was issued to the soldier in a rubber pouch which contained 150 grams of bleach. In event of contamination the first step was the removal of the larger drops of gas using one of the five pieces of gauze included in the pouch. Then the bleaching powder was mixed with water and applied to burned area. This mixture was to be rubbed 30 times to insure thorough decontamination. Immediately after rubbing, the bleach was washed off. If gas could still be noticed by odor on the skin the procedure was repeated.

(2) Experimental Protective Ointment

(a) Anthranilic Acid Methyl Ester

In the attempt to discover a more effective ointment for the treatment of mustard contamination experiments were conducted at the Army Medical School and at the Sixth Military Laboratory. Results of these tests showed the methyl ester of anthranilic acid to be effective. If applied within the first two minutes after contamination, it has the same decontaminating effect as chloramine-T. In the event of a lapse of time of over two minutes between the contamination and the treatment anthranilic acid ester is considered better. It was found that chloramine-T has a beneficial effect on a burn up to five minutes after contamination while the acid may be used with beneficial results up to thirty minutes. Even when applied as late as one hour after contamination, it reduced the size of the burned area. Medical officers were notified of the effectiveness of this compound, but no production of this product was undertaken.

Results of the Japanese Research on Anthranilic Acid

(1) Animal test

Five mgs. of mustard gas were dropped on the sheared backs of albino rabbits and at varying times the area was rubbed with wool saturated with anthranilic acid. The following results were obtained. Five rabbits were used in each group.

Group	Elapsed Time	Degree of Swelling of the Skin: 1 hr.	3 hr.	6 hr.	10 hr.	24 hr.	48 hr.	Effect
I	3 min.	-	-	-	-	-	-	≠ ≠ ≠
II	5 min.	-	-	-	-	-	-	≠ ≠ ≠
III	10 min.	-	-	≠	≠	≠	≠	≠ ≠
IV	15 min.	-	≠	≠	≠≠	≠≠	≠≠	≠
V	20 min.	-	≠	≠≠	≠≠	≠≠≠	≠≠≠	≠
VI	30 min.	≠	≠	≠≠	≠≠	≠≠≠	≠≠≠	≠
VII	1 hr.	(≠)	≠≠	≠≠≠	≠≠≠	≠≠≠≠	≠≠≠≠	-
Control-No Rubbing		-	-	-	-	-	-	/////

(2) Human test

The doctors and their assistants participated in the test voluntarily. In the first experiment 3 mg. of mustard was dropped on the inside of their forearms and ten minutes later the area was rubbed with anthranilic acid. In the second phase the time element remained the same, but the amount of mustard was increased to 3 mg. Results were read from 24 to 48 hours after the application of the mustard.

USE OF .3 mg. OF MUSTARD

TOTAL PARTICIPANTS	EFFECT: NO WOUND OR SLIGHT EDEMA	1 mm. RUBELLA OR EDEMA	2mm. SMALL BLISTER OR REMARKABLE RUBELLA OR EDEMA	LARGE BLISTER 2 cm.
10	5	1	3	1

USE OF 3 mg. OF MUSTARD

TOTAL PARTICIPANTS	EFFECT: NO WOUND OR SLIGHT EDEMA	RUBELLA OR EDEMA	MANY BLISTERS 1 - 2 mm.	LARGE BLISTER 2 cm.
30	20	3	6	1

CONCLUSION(DRAWN BY THE JAPANESE)

Anthranilic acid methyl ester is an effective method of preventing or lessening the injurious effects of liquid mustard gas on the human skin, but it must be used within ten minutes after contamination.

g. Gas Proofing of Buildings

The problem of gas proofing any portion of a typical Japanese building presents difficulties due to many openings and lightness of construction. The following conclusions were reached on the subject but no large scale application was ever attempted. First the most suitable room in the house is selected and then made air tight. Larger openings, as doors and windows, are sealed by double buffer plates using wood, felt and rubber sheets. Windows are sealed using paper or oil clay. When it is possible to obtain them, filter boxes and ventilators are installed. A higher pressure of purified air is kept inside the room thus preventing the low pressure outside air from entering.

h. Dugouts and Caves, Gas Proofing

There were no special measures for use in the field for protection against gas. It was expected that the individual soldier would wear his protective clothing. Entrances to caves and shelters would be closed by wooden plates, rubberized cloth, or any other means at hand. These measures were intended only as temporary ones. It was realized that filter boxes and ventilators were necessary, but they could not be made available.

As a result of this shortcoming special research was carried out regarding the use of special gas proof cloth. This special cloth is one that has a layer of powdered activated charcoal covering silk cloth. By experiment this cloth was found effective against mustard gas.

i. Gas Proofing Tanks

Research on this subject was carried out about ten years ago. It was never carried past the experimental stages.

Principle involved was that by maintaining a positive pressure of 2 to 3mm. inside the tank the gas in the outside air could not enter. Purified air for inside the tank was passed through a filter box using an air blower. To maintain this pressure inside the tank large quantities of air were needed and the necessary equipment to control this could not be fitted into the limited space in the tank.

2. Navy Work

Research on this subject was done by the Naval Laboratory at Sagami Arsenal and resulted in the standardization of six agents. Of these agents, number five was the only one available in sufficient quantity for actual use. Research was not pressed, for the production lag caused disinterest in research. The newest ointment T-Toyaku was not listed by the Japanese with the other decontaminating agents. It contains 10% of gum mastic and 90% of water glass.

Decontaminating Agent #1 contains 150 grams of potassium permanganate. It is used with decontaminating agent #2. Decontaminating Agent #2 contains 1000 grams of scaly sodium hydroxide. These agents are to be dissolved separately and added to sufficient water to make 30 liters of solution. Decontaminating Agent #3 contains bleach and was to be used against liquid blister agents. Decontaminating Agent #4 contains 10 grams of chlorine dissolved in 40 grams of carbon tetrachloride. When the bottle is broken, this agent reacts with sneezing and blister vapors and neutralizes them. One vial per thirty cubic meters of air was recommended. Decontaminating Agent #5 contains 16% Chloramine-T, 81% Bentonite and 3% of Sea water Soap. When mixed with twice its weight of water it formed a cream to be used on the body. When mixed with three times its weight of water, it formed a cream to be used on clothes to decontaminate blister agents. Research on this agent centered about the minimum amount of Chloramine-T which would be effective against blister agents. Decontaminating Agent #6 contained:

Decontaminating Agent		10
1st Reagent -	Hightest bleach	1 Gm.
	Barium peroxide	8 Gm.
	Ferric Sulfate	9 Gm.
2nd Reagent -	Calcium carbonate	8 Gm.
	Active Carbon	4 Gm.
	Filtering Bag	1
	Filtering Cloth	2
	Detecting Tube	25
	Test Paper	
	Test Tube	1
	Pincette	
	Color Comparison Table	
	Accessories	

Arsenic compounds precipitate by producing additive compounds with ferric ion or by coprecipitation with colloidal ferric hydroxide. The detecting tube contains a sodium lead alloy which forms arsine in the test. The test paper is a mercuric bichloride paper which changes color in the presence of arsine.

Interviews with Japanese Naval research leaders indicated that Chloramine-T or bleach had been accepted for all decontamination procedures, for personnel, clothes, munitions, and ships. It was impossible for the Navy to obtain sufficient Chloramine-T for distribution, and bleach was the only available decontamination agent. Further research for decontamination materials was thought useless as bleach would work. The difficulty of obtaining production for new agents, should they have been found, contributed to their lack of interest.

The Navy was disinterested in gasproofing buildings for land based personnel. Certain sections of their larger ships had collective protectors. The compartments of ships are gasproof in nature, but the entire ventilation system would have to be made into a giant collective protector to completely gas proof the ship. As this was practically impossible, some of the vital control rooms were gas proofed with collective protectors. The other parts of the ship would have to be decontaminated if necessary.

3. Protection Methods in the Imperial Palace Grounds

An investigation was conducted in the Imperial Palace grounds to determine the protective methods against gas attack used there. A report on this subject will be submitted after the information obtained has been translated.

G. Toxic Chemical Agents

Introduction

For over twenty years the Japanese Army and Navy were independently engaged in work on toxic chemical agents. This work has included the search for new agents, the production of agents, and studies on the toxicities of the compounds. The main amount of work was done between 1930 and 1941 with the greatest effort being expended in 1935. After 1941 the search for new agents was intensified. After the beginning of the war with the United States the Japanese requested information from the Germans concerning new toxic agents. The Germans revealed that the Russians had a nitrogen mustard and phosgene oxime, but they did not disclose any information concerning their own agents.

The subject of agents is covered in "Report on Scientific Survey in Japan" Volume II, dated 1 November 1945 by the Scientific and Technical Advisory Section, AFPAC. Certain material from that report is included in this one for the sake of completeness.

1. Agents used by the Japanese

The Japanese Army produced or had plans for the production of the following toxic agents:

a. Mustard (dichlorodiethyl sulfide)
   (1) Thiodiglycol process
   (2) Sulfur chloride process (distilled)
b. "Non freezable mustard"
c. Lewisite
d. Phosgene
e. Hydrogencyanide
f. Chloracetophenone
g. Diphenylcyanarsine

Whenever bombs were filled with vesicants, a mixture of mustard and lewisite (50 - 50% by volume) was used in order to prevent the freezing of the agent at low temperatures. It was planned, however, to replace this mixture with the non freezable mustard when adequate quantities of it became available.

The "non freezable mustard" was a mixture of the various chloroethyl, chloropropyl, and chlorobutyl sulfides. It is variously reported to freeze from -20°C. to -35°C.

The Japanese Navy produced the following toxic agents:

a. Mustard (thiodiglycol process)
b. Lewisite
c. Chloroacetophenone
d. Diphenylcyanarsine

For filling bombs the Navy thickened their mustard by adding 7% polyvinyl chloride and 2% methyl methacrylate. They did not mix mustard and lewisite to prevent freezing.

Samples of these materials have been obtained and are being forwarded to the United States where all the necessary analyses may be made. The Japanese have not been able to furnish satisfactory analytical results.

The production of the above agents is discussed in the report on "The Manufacture of Chemical Warfare Material by the Japanese" which is being written by this office.

It is believed that no toxic agents other than those listed above were considered beyond the laboratory stage.

2. Search for new toxic agents

The Japanese Army expended much effort, time, and money in trying to discover and develop new toxic agents. Considerable attention was given to the relation of certain molecular groups to the physiological activity of the toxic material. It is reported that no useful correlation was obtained by this work. In addition to the work being done at the Sixth Military Laboratory a group of workers at the Osaka Imperial University were engaged in looking for new agents. A list of 1000 compounds on which work was done has been obtained and was safehanded to the Chief, Chemical Warfare Service. A copy of the document does not exist in this office and cannot be appended to this report but certain information obtained from the document is summarized below. The list of compounds synthesized and tested include the following.

a. Inorganic compounds
b. Organic halogens
c. Nitrils
d. Isonitrils
e. Isocyanates
f. Phosgenes
g. Mercaptans

h. Ketones
i. Organic sulfides
j. Amines
k. Nitro compounds
l. Nitroso compounds
m. Organic fluoro compounds
n. Organic metallic compounds
o. Organic selenium compounds
p. Organic arsenic compounds
q. Phosphines
r. Alkaloids
s. Proteins
t. Oximes

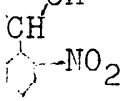
Cyanogen chloride was studied and toxicological tests were made, but apparently no further consideration was given it. Many analogues of mustard including sesqui mustard were studied but none were considered superior to mustard. HN-3 and its hydrochloride were studied, but HN-1 or HN-2 were apparently not considered. Nicin and acotine were considered as agents for darts, meta nitro phenyl dichlorarsine was studied, and so was nitroso methyl and ethyl methane.

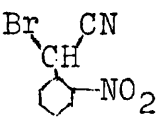
It is believed that the Japanese did no work on agents of the trilon group. From the information available it is also believed that no work was done on

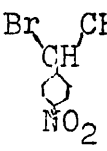
a. Cadmium compounds
b. Fluorophosphates
c. Fluoroacetates
d. Phosphine oxides

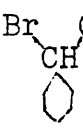
The Army concluded from their work that none of the compounds which they had studied were better than mustard, lewisite, phosgene, or hydrogen cyanide. They did believe, however, that the chloracetyl derivative of paracresol was twice as effective as chloroacetophenone (It wasn't manufactured due to the shortage of the necessary raw materials.). They also stated that they did not believe that any country had developed tomics superior to the above compounds. For further information on the compounds tested by the Army such as structural formula, state, boiling point, freezing point, and toxicities the list of 1000 compounds worked on by the Japanese which is now in the Office of the Chief, Chemical Warfare Service, Washington 25 D,C. should be consulted.

The Navy did not make as extensive a search for new agents as did the Army. They reported that in all only about 100 new compounds were synthesized. These are listed below.

1.  o-Nitrobromobenzylcyanide

2.  m-Nitrobromobenzylcyanide

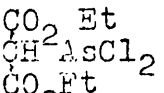
3.  p-Nitrobromobenzylcyanide

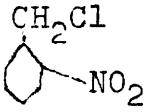
4.  Bromobenzylcyanide

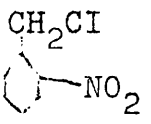
5. $Cn.CH_2COO\ Et$

6. $CN.CO_2CH_3$

7. $ICH_2.CO_2\ Et$

8. 

9. 

10. 

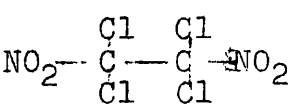
11. BrCN

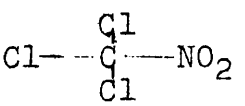
12. 

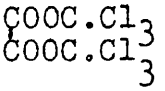
13. $H_4Fe(CN)_6$

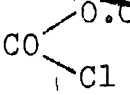
14. Diphenylarsinebromide

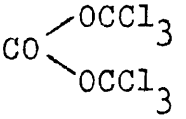
15. Diphenylarsine fluoride (difficult)

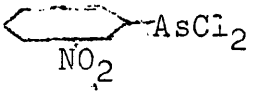
16. Tetrochlorodinitroethane 

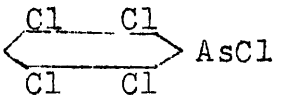
17. Chloropicrin 

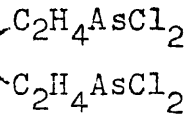
18. Hexachlorodimethyloxalate 

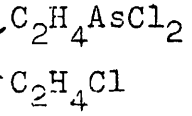
19. Diphosgene 

20. Hexachlorodiamethylcarbonate 

21. ClCH:CH $AsCl_2$ - COCl composition unknown
22. Bromolowisite
23. Fluorolewisite (HF) Very good
24. AsF_3
25. Fluorolewisite + NOCl
26. Bromolewisite + NOCl
27. Diphenylchbroarsine
28. Diphenylbromoarsine
29. Diphenyliodoarsine
30. Diphenylcyanoarsine
31. m-Nitrophenyldichloroarsine 

32. Tetrachlorophenyldichloroarsine 

33. 

34. 

35. o-Toluyldichloroarsine
36. m-Toluyldichloroarsine
37. p-Toluyldichloroarsine
38. o-Chlorophenyldichloroarsine
39. m-Chlorophenyldichloroarsine
40. p-Chlorophenyldichloroarsine
41. o-Bromophenyldichloroarsine
42. m-Bromophenyldichloroarsine
43. p-Bromophenyldichloroarsine
44. α-Naphthyldichloroarsine
45. β-Naphthyldichloroarsine
46. $S(CH_2CH_2Cl)_2$
47. $S(CH_2CH_2F)_2$
48. $S(CH_2CH_2Br)_2$
49. $S(CH_2CH_2I)_2$
50. Chloroacetophenone
51. o-Nitrochloroacetophenone
52. m-Nitrochloroacetophenone
53. p-Nitrochloroacetophenone
54. Dichlorodimethylether
55. Dibromodimethylether

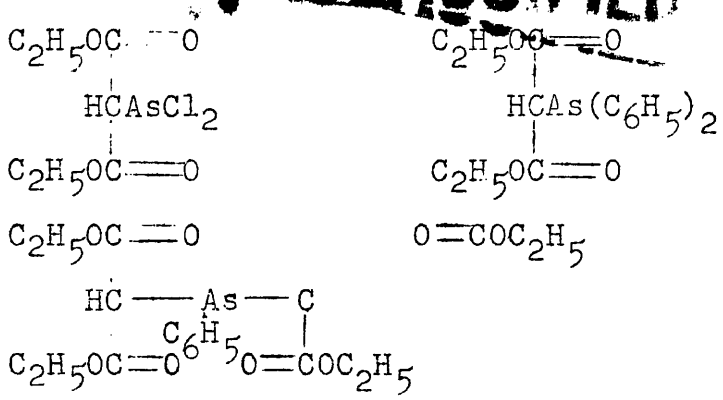
56. Diiododimethylether (negative)
57. Methylaminedichloride $CH_3.N.Cl_2$
58. Perchloromethylmercaptan
59. $CH_2.CH.CHO$ Acrolein
60. Phenylcarbaminechloride
61. Methyldichloroarsine
62. Ethyldichloroarsine
63. Propyldichloroarsine
64. Butyldichloroarsine
65. Amyldichloroarsine
66. Hydrozinehydrate
67. Chloroacetone
68. Bromoacetone
69. Iodoacetone
70. Chloromethylmercaptan
71. Dichlorodipropylsulphide
72. Chloroethylmercaptan
74. Ethylchlorsulphate
75. Methylchlorosulphate
76. ClCH:CH AsS (Ship Paint)
77. $ClCH_2$:Ch AsO
78. Diphenylarsinesulphide (Ship Paint)
79. Diphenylarsine organic acid derivatives(Ship Paint)
80. Diphenylarsine ferrocyanide (Ship Paint)
81. Diphenylarsine ferricyanide (Ship Paint)
82. Phenylphosphorousdichloride (didn't come out)
83. Dichlordiethylsulfone and its derivatives
84. Trichlorotriethylarsine, HCl, HBr $AsCl_3$ salts, and its derivatives
85. Bromopicrin $Br_3.C.NO_2$
86. Chloral Compounds
87. Dichlorvinylarsinchloride (cyanide)
88. Phosgene oxime
89. Hydroxylarsine
90. Tetranitrodichloroethane

Their comments on the compounds tested are as follows:

a. Nitro-derivatives of brom-benzyl-cyanide only slightly increase the lachrymatory effect. They all are irritating to the skin and all decompose in contact with metals (except lead). The synthesis was difficult, so it was concluded that the brom-benzyl-cyanide was preferred.

b. In CN compounds the toxicity depends only on the CN groups. HCN, BrCN, ClCN sometimes explode spontaneously.

c. Halogens-acetic acid esters caused some lachrymatory action, but this was reported in the literature.

d. 

and allied arsenicals are not as toxic as the original arsenicals.

e. Some nitro derivatives of benzyl chloride, o-compound give skin irritating action, but they tend to decompose in contact with metals. The lachrymatory effect is not improved.

f. Cyan-adarsite hydrolyses easily and is decomposed by explosion.

g. $H_4Fe(CN)_6$ produces the theoretical amount of HCN when heated slowly, but carbonizes when heated rapidly.

h. In the diphenylarsine series, the fluoride was difficult to synthesize. Others showed no difference in properties from the chlororcyan compounds.

i. In the chlor-nitro methane series the lachrymatory and lung irritant effect increases with their chlor-content, chlorpicrin being the most active. Dinitro-tetrachlor ethane is an excellent tear and lung irritant gas and is even better than chloropicrin. It decomposes easily on explosion, however.

j. In the phosgene series the lung irritant action depends only on the amount of phosgene produced, but diphosgene is somewhat inferior to the former. Hexachloro-dimethyl oxalate proved to be the most desirable as it is easy to work with (solid, low vapor pressure) and produces three $COCl_2$ and CO on the burst of the munition. The odor of phosgene homologues increase with increasing molecular weight.

k. Lewisite (primary) $ClCH{=}CHAsCl_2$ and its homologues were mixed with NOCl gas in a cool place. (See compound 21) A liquid without the lewisite odor and a non arsenic containing solid were formed. The liquid was twice as vesicant to the skin as lewisite (animal) but it gradually decomposed. It was easily hydrolized.

l. Halogen substitutes of lewisite, the fluor compounds, $ClCH{=}CHAsF_2$ were the most active with regard to toxicity, stability, and humidity.

m. Ary-arsine dichlorides were prepared but none were better than phenyl arsine dichloride.

n. The bromo and iodo acetone were better than the chloro compound, but none was as effective as chloroaceto-phenone.

o. Nitration of chloroacetophenone increases the skin irritancy but the lachrymatory effect and the thermal stability are decreased.

p. Halogenated methyl or ethyl ethers have no value as chemical warfare agents.

q. Methyl amine dichloride decomposes in such a way as to produce probably polymerized HCN products which decompose in some cases violently.

r. Aeroleine and crotonylaldehyde were not good lachrymators.

s. Methyl and ethyl arsine dichloride are perhaps better agents than lewisite but the lack of production equipment dictated that they not be manufactured. Bromo compounds have too low a vapor pressure. Iodo compounds decompose too easily. The propyl or amyl arsine dichlorides are too active and have too low a vapor pressure.

t. Dichlorodipropyl sulfide has low vapor pressure and proved to be a good persistent agent. Its vesicant toxicity is $\frac{1}{2}$ to 1/3 of mustard, but it is sometimes mixed with mustard to lower the freezing point.

u. Dichlorodiethyl selenide has a bad odor, but is not as effective as mustard.

v. Dichlorodiethyl sulfone and its derivative is not as easily decomposed by bleaching powder as mustard but they are not as toxic and are solids.

w. Trichloro-triethylamine and its salt ($HClAsCl_3$ $ClCH\ CHAsCl_2$ were thought better than mustard even though it is less toxic because it is not easily hydrolized, it lacks odor, and is difficult to decontaminate.

x. Dichlorodivinyl arsine chloride and cyanide were not effective as diphenyl-arsine compounds.

y. Phosgene oxime was not considered of importance due to the ease of its hydrolysis.

The Navy concluded that all things considered no new agent superior to mustard, lewisite, chloracetophenone, hydrocyanic acid, and diphenylcyanarsine were studied and planned to produce only those compounds.

3. Stabilization of Agents

Storage tests indicated that mustard manufactured by the thiodiglycol process, lewisite, phosgene, chloroacetophenone, and diphenyl cyanarsine were stable. Consequently, no work on the stabilization of these materials was carried out by the Japanese.

a. Hydrocyanic acid (HCN)

The Japanese Army recognized that hydrocyanic acid was unstable and in 1933 initiated work to stabilize this material after containers of HCN exploded. By 1937 copper had been accepted as a satisfactory stabilizer. After the beginning of the war with the United States, copper became difficult to obtain, and work on the

development of new stabilizers was initiated. Due to the explosion of some copper-stabilized HCN filled containers, some dissatisfaction with copper existed so a better stabilizer was desired at the same time. Besides the work which was done at the Sixth Military Laboratory certain professors at the Osaka and Kyoto Imperial Universities were put to work on the problem.

HCN is believed to be unstable if alkaline materials resulting from incomplete purification of the HCN are present. Water in amounts greater than two percent was believed to make the material unstable. Quantities less than two percent were not considered harmful. Recently oxygen was suspected as the cause of the instability. The Bakelite used to coat the inside of some munitions if not properly hardened was believed to be deleterious, but otherwise it was considered to have no effect. Metallic materials such as iron, tin, and copper were believed to have no bad effects and, particularly the case of copper, they were considered to be beneficial. Lead is believed to be detrimental to the stability of HCN. Work on other metals such as aluminum was done, but the records were burned and the results of the tests are not known.

Experiments with the following materials (3 percent by weight added to the HCN) were carried out:

(1) Acids
H_2SO_4: HCl: $ClHSO_4$: HNO_3: CH_3COOH: HCOOH:
(2) Dehydrating agents
$CaCl_2$: Active carbon: Silica gel: Alumina
(3) Smoking Agents
$AsCl_3$: $SnCl_4$: $TiCl_4$
(4) Organic solvents
$CHCl_3$: CCl_4: C_6H_6: $C_6H_5CH_3$
(5) Copper gauze, copper powder

The following conclusions were made from the above experiments:

(1) The best stabilizers
H_2SO_4, $AsCl_3$, copper gauze and copper powder
(2) The fair stabilizers
HCl, HCOOH, $CaCl_2$
(3) None of the others were satisfactory

It should be noted that these experiments were carried out in glass.

In the case of copper as the stabilizer, storage tests indicated that the HCN was stable for approximately five years if the copper was of sufficient purity. The use of $AsCl_3$ was believed to make the HCN stable for three years. Storage tests on this material have not been completed so its actual value is not known. Work on the use of SO_2 as the stabilizer was started late in the war.

When two percent was added to the HCN, accelerated aging tests indicated that the material would be stable for three to five years. (It was considered by the Japanese that 100 hours at 50°C. was equivalent to three years at room temperature) Tests were carried out in which HCN containing two percent SO_2 was stored in shells for two years. After this time the contents of the shell had not changed in color and no precipitate had formed.

From this work it was concluded that SO_2, $AsCl_3$, and copper are the best stabilizers for HCN with SO_2 being the preferred one. It was further concluded that the life of the stabilized agent was from three to five years.

The Japanese had a policy to redistill the HCN every three years, but such a procedure had not been put into effect before the war ended.

The Japanese Navy has done only a small amount of work on the stabilization of HCN. $AsCl_3$ (5 - 10% by weight) was added to the HCN and more satisfactory results were obtained. Tests with this stabilizer were not in progress long enough to determine definitely the value of this method. In all work with HCN filled bombs or shell the inside of the munitions was covered with bakelite.

b. Mustard

The mustard manufactured by the French method (Ethylene plus sulfurchloride) was known to be unstable and all the material manufactured by that process was distilled before storage or use.

c. Mustard-Lewisite Mixture (50 - 50% by vol.)

Instability of the mixture resulted when French process mustard was mixed with Lewisite. This problem was solved by either using German process mustard or distilled French process mustard to mix with the lewisite. The Navy did not use this mixture.

d. Thickened Mustard

No trouble was encountered with the munitions filled with thickened mustard (7% polyvinyl chloride and 2% methyl methacrylate). All the munitions tested however were coated on the inside with a Bakelite type resin.

e. Inside coatings for munitions

The Army used a phenol resin varnish for coating the inside of its munitions. It was considered effective for all chemical agents except HCN and was adopted as standard. For HCN bare metal was believed to be more satisfactory.

The Navy did practically no work on linings for their shell or bomb. A Bakelite coating was considered satisfactory.

4. Toxicological Data

As this report has previously pointed out, the Japanese did a thorough job of destroying the records of the chemical warfare research and development work carried out by them. The toxicological data contained herein are, consequently, estimates and opinion obtained from the Japanese and are subject to inaccuracies.

The procedures and the laboratory equipment used by the Army and Navy in making their toxicological studies were crude in comparison with those used in the United States and do not warrant detail study. Their gas chambers varied in size with the largets being 12 to 15 feet in diameter. The gas in these chambers was circulated by means of a fan located at the top of the chamber. No apparatus existed for maintaining constant temperature or humidity, and there was no completely satisfactory method of setting up toxic gas concentrations. As test animals mice, guinea pigs, rabbits, and occasionally dogs or monkeys were used. Birds (uroleuca domestica) were also employed on occasion. As a measure of toxicity the Ct (the product of concentration and time) required to kill 50 percent of the test animals was used. In general the time was held constant (at 10 - 30 minutes except for quick acting toxics such as HCN where 2 to 10 minutes was used) and the concentration was varied. For any particular test it was desired to hold the concentration constant, but usually there was a decrease with time.

The Japanese do not admit having used either Japanese or allied prisoners in their toxicity studies and no information has been obtained to lead to the belief that they have.

Toxicological data on the common agents are given below:

Name	Ct Mg min/m^3 (50% mortality)			
	Man*	Rabbit	Guinea Pig	Pigeon
Mustard	2000	5500	2300	1500
Non freezable mustard	?	7000	3000	2000
Nitrogen Mustard $(ClCH_2CH_2)_3N$	2500-6000	6000	2500	1800
Lewisite	2000	5000	2000	1000
Phosgene	2000	5000	2000	1000
Diphosgene		12000	2500	24000
Hydrogen Cyanide	2000	700	1500 to 3000	200 - 250
Chlorine		30000	10000	20000
Arsine	dog 20000	75000	75000	75000

*The data for man are only estimates which varied somewhat with different individuals. The values given are believed to represent the opinion of the best informed Japanese

research men. The data on the other animals were based on an exposure period of 10 minutes (except for HCN when exposure period was 2 minutes) and an observation period of seven days. Approximately five animals were used per exposure.

Comments on various agents and additional information concerning the common ones are as follows:

a. Hydrocyanic Acid

In general the Japanese believed that HCN was their most toxic agent (Personnel at the Narashino CW School, however, thought the toxicity was much lower than generally believed and fixed its value at 5,000 to 10,000 mg/min/m^3). The lowest effective dosage was believed to be around 300 mg/min/m^3. The gas was usually effective in 30 to 60 seconds when lethal dosages were inhaled. The Japanese recognized the ability of the body to detoxify small quantities of HCN indefinitely and also had noted the increase in breathing rate which resulted from inhaling HCN.

b. Phosgene

Although the Japanese considered this one of their standard agents, they exhibited little interest in it.

c. Mustard

The Japanese had made few studies on the effects of mustard Particularly in the case of mustard vapor was the work slighted despite the fact that frequent casualties resulted from the manufacturing operations. They report that some work was carried out a number of years ago using a continuous flow vapor cup, but the results were not remembered.

Even though experimental work was not carried out the Japanese estimated a dosage of 1000 mg/min/m^3 of mustard vapor was required to blind a man, and a Ct of 8000 to make a casualty of a man with mask but no protective clothing. The values given are for temperate climates. They believed that the dosage required to produce casualties in hot weather would be reduced approximately 1000 mg min/m^3 for the 8000 figure. This conclusion was reached because the workers in the manufacturing plants received more and worse burns in the summer. It was supposed that the Ct required to blind was not a constant but varied with the concentration - for constant Ct the higher the concentration the more damage was done to the eyes. They found that the genitals were affected first followed by the axillae, neck, and tender tissue.

The toxicity of the non freezable mustard had been only slightly studied. They reported that for liquid on the skin it was 50 to 75 percent as effective

as the dichlorodiethyl mustard. No work had been done on its vapor effects.

The Navy had practically no understanding of the real effects that could be obtained with mustard vapor. They were requested to fill out a chart on the dosages required to produce injuries and reported that they had made no experiments on this and could not fill in the chart.

d. Lewisite

The Japanese believed that lewisite was really more toxic than mustard, but due to its rapid hydrolysis the LCt (50) was considered the same for both. For unknown reasons most of the well informed CW personnel preferred mustard over lewisite. The Japanese believed that lewisite sprayed on rice crops would poison the rice due to its arsenic content.

e. Nitrogen Mustard

$(ClCH_2CH_2)_3N$ was the only nitrogen mustard compound worked on. Its lethal Ct had not accurately been determined and values ranged from 2500 - 6000 mg min/m^3. The skin injuries caused by nitrogen mustard are not as severe as those due to mustard and they heal more rapidly. The injury to the eyes was believed to be the same as those caused by mustard.

f. New Compounds

The list of 1000 compounds referred to previously contains the toxicological data for all the new compounds and should be referred to for information on the subject.

H. Processes and Methods of Production of Chemical Warfare Agents

The Army and Navy of Japan worked separately in developing processes for production of chemical warfare agents. Information was exchanged freely until the processes were as good as European processes used during the first World War.

After that time, the relations between the Army and Navy Research Departments were not as good as before although the exchange of information was still carried on.

The development work done by the Army and the Navy on methods of production is given in parts a and b of this section.

1. The work done by the Japanese Army on processes for manufacturing of chemical warfare agents mentioned in this section was conducted by the First Section of the Sixth Military Laboratory under the supervision of Military Engineer Shigeru Hayashi.

The following consists of methods of production and information pertaining to the production of several chemical warfare agents used by the Sixth Military Laboratory.

a. Production Method for "Anti-freeze" Mustard

STEP I: Production of ethylene-propylene mixture

Coal gas, containing 40% - 50% hydrogen and 2% - 4% ethylene and propylene mixture is liquified and fractionated to recover the hydrocarbon mixture. This mixture consists of 1 volume of ethylene to 2 volumes of propylene.

STEP II: Synthesis of ethylene chlorhydrine and propylene chlorhydrine

The reactor for the second step is a jacketed iron tank with a ferrosilicon lining and equipped with a stirrer which rotates at 300 r.p.m. The bottom of the reactor has a porous plate made of sintered glass so as to break the gaseous reagents into small bubbles for quick reaction. The volume of the reactor is 4 cubic meters.

The reactor is filled with water which is agitated. Chlorine gas and the mixture of ethylene and propylene are bubbled into the water slowly. The temperature is kept between 20° and 25°C. and the bubbling of the gaseous reagents is continued for 10 hours. By this time the concentration of the chlorhydrines is 7% - 8% and the reaction is stopped.

Reaction:

$$3Cl_2 + C_2H_4 + 2C_3H_6 + HOH \longrightarrow$$

$$ClC_2H_4OH + 2ClC_3H_6OH + 3HCl$$

The solution contains a trace of free chlorine, a trace of dichlorethane and 3.5% HCl, which is neutralized with sodium carbonate.

STEP III: Synthesis of the thiodiglycol and thiodipropylene glycol

Ethylene chlorhydrine, formed from ethylene from ethyl alcohol, and the mixtures, of ethylene chlorhydrine and propylene chlorhydrine from the coal gas, are mixed in equal portions and reacted with 5% excess sodium sulphide. The reaction gives a mixture consisting of the following:

$CH_3CHOHCH_2-S-CH_2CHOHCH_3$ (Thio-Dipropylene Glycol) 15%

$CH_3CHOHCH_2-S-CH_2CH_2OH$ (Thio-Propylene Glycol-Ethylene Glycol) 35%

$OHCH_2CH_2-S-CH_2CH_2OH$ (Thio-Diglycol) 50%

STEP IV: Synthesis of Anti-freeze Mustard

Chlorination of the thio-glycol mixture is accomplished by reacting them with 36% HCl.

Four volumes of the HCl are used for one volume of the thio-alcohol.

The resulting mixture constitutes "anti-freeze mustard".

$CH_3CHClCH_2-S-CH_2CHClCH_3$	15%
$CH_3CHClCH_2-S-CH_2CH_2Cl$	35%
$ClCH_2CH_2-S-CH_2CH_2Cl$	50%

These percentages are approximate and the mixture contains other impurities. The freezing point of "anti-freeze mustard" is minus 35°C. and the effectiveness is said to be 50 - 75% of that of regular mustard gas.

Remarks: The reactor described in Step II is used at Mitsui Chemical Industry Co., Omuda, Fukuoka Prefecture. There are five such reactors.

b. Lewisite

The Army carried out research to find a process which would reduce the amount of secondary and tertiary lewisite formed.

At first, the secondary lewisite was converted to primary lewisite by reacting it with arsenic trichloride with an iron catalyst.

Later it was found that, if a cuprous chloride catalyst was used, acetylene would react with arsenic trichloride to form primary lewisite with little of the secondary and tertiary lewisite being formed.

Additional work pertaining to processes done by the Sixth Military Laboratory:

(1) The aluminum oxide catalyst used to make ethylene from ethyl alcohol was prepared in a special way.

Aluminum hydroxide was purified by reacting it with 50% sulphuric acid to form aluminum sulphate. The aluminum hydroxide was dehydrated at 300°C. to form aluminum oxide which is used as a catalyst. The aluminum oxide catalyst is said to have 1000 hours catalyst life or twenty times the life as acid-earth catalyst. It was pointed out that the sulphuric acid must be 50% and the ammonium hydroxide step carried out at 50°C. No reason was given.

(2) Chlorination of Mustard Gas

A continuous chlorination process for converting thiodiglycol to mustard gas by feeding thiodiglycol and hydrochloric acid into coils of glass tubing was developed. No details are believed necessary.

(3) Production of diphenylcyanarsine

The Sixth Military Laboratory developed the following process to eliminate several steps in the production of diphenylcyanarsine:

Phenyl arsenous oxide was reacted with phenylarsenic acid at 180°C. in the presence of concentrated sulphuric acid to produce diphenylarsenous oxide. Reaction:

$$2C_6H_5AsO + 2C_6H_5AsO_3H_2 \xrightarrow{H_2SO_4} (C_6H_5)_2As)_2O + 2HOH + As_2O_5$$

The diphenyl arsenous oxide is then reacted with liquid hydrocyanic acid to make diphanylcyanarsine.

Reactions: $((C_6H_5)_2As)_2O + 2HCN \longrightarrow 2(C_6H_5)_2AsCN + HOH$

This process was still in pilot plant scale at the end of the war.

(4) Synthesis of Hydrocyanic Acid

The Japanese had very little sodium cyanide so it was necessary to synthesize hydrocyanic acid by other means.

A method of producing hydrocyanic acid by the reaction of methane with ammonia at 1000°C. using a catalyst composed of aluminum oxide and thorium oxide converted 80% of the ammonia to hydrocyanic acid.

Reaction: $CH_4 + NH_3 \xrightarrow[1000°C.]{Al_2O_3 \; ThO_2} HCN + 2H_2$

By reacting carbon monoxide with ammonia at 600°C. with aluminum oxide catalyst to make hydrocyanic acid, a yield of 40% was obtained. An ammonium sulphate-aluminum sulphate catalyst gave a yeld of 70%.

Reaction: $CO + NH_3 \xrightarrow[600°C.]{CAT.} HCN + HOH.$

Another method of passing ammonia through charcoal at 1000°C. without a catalyst gave a yield of 35%.

Reaction: $NH_3 + C \xrightarrow{1000°C.} HCN + H_2$

2. Processes and Methods of Production of Chemical Warfare Agents Developed by the Japanese Navy

The production methods of chemical warfare agents have been worked on by the Navy Chemical Study Department later named the Chemical Experimental Department of Sagami Naval Arsenal at Hiratsuka. Most of the pilot plant work

was done by the First Factory of the First Department of Sagami Naval Arsenal at Hiratsuka. The synthesis of agents and small scale production experiments were carried out by the Chemical Experimental Department. Naval Capt. S. Tsuruo was in charge of both the First Department and the Chemical Experimental Department.

The following consists of methods of production and information pertaining to the production of several chemical warfare agents developed by the Navy.

a. Pilot Plant Work on Mustard Gas

The First Factory of the First Department of Sagami Navy Arsenal performed the pilot plant work on mustard gas.

From 1932 to 1936, the production method of mustard gas worked on by the First Factory was the following:

Ethylene chlorhydrine was produced by bubbling chlorine and ethylene into a tower containing water which was agitated by a mechanical stirrer. The resulting ethylene chlorhydrine solution was concentrated by evaporation of the water. Sodium sulphide was added to the solution producing thiodiglycol by the following reaction: $2Cl\text{-}C_2H_4OH + Na_2S \longrightarrow S(C_2H_4OH)_2 + 2NaCl$

The pilot plant was constructed for this process in 1933. The mechanical stirrer used corroded so badly that the process was changed using a continuous flow method without a stirrer. Uniform concentration of the chlorhydrine was difficult to obtain also.

The process was changed in that the ethylene chlorhydrine formed was decomposed by sodium hydroxide forming ethylene oxide. The ethylene oxide was then reacted with hydrogen sulphide to produce this diglycol.

The process is as follows:

STEP I: Production of ethylene

Ethyl alcohol is vaporized by a steam heated evaporator and passed through a furnace-heated generating pipe which contains an acid clay catalyst heated to 400° - 450° Centigrade. The alcohol is split into water and ethylene.

The vapor mixture of ethylene and water is cooled by a partial condenser which separates the water and allows the ethylene to flow to the storage tank. Reaction:

$$C_2H_5OH \xrightarrow[\text{Catalyst}]{\text{Heat}} C_2H_4 + H_2O$$

STEP II: Synthesis of Ethylene Chlorhydrine

The reactors consist of six porcelain cylinders with a diameter of 250 mm. and 2500 mm. high. The apparatus is filled with water which is circulated

by a pump. Chlorine and ethylene are added at the rate of 20 Kg and 6.5 cubic meters per hour respectively and allowed to react at 20° - 25° for 2½ hours until the solution becomes 5% chlorohydrin. At this point water, chlorine, and ethylene are added at the rates of 311 liters, 13.2 Kg, and 513 cubic meters per hour respectively. Five percent chlorhydrine solution is drawn off continuously. The solution is neutralized with sodium carbonate until only slightly acid. The capacity of the apparatus is approximately 7000 liters of 5% chlorohydrin solution per day.

Reaction: $C_2H_4 + Cl_2 + HOH \longrightarrow ClC_2H_4OH + HCl$

The yield is 70% - 75% based on chlorine and 80% - 90% based on the ethylene.

STEP III: A. Generation of Ethylene Oxide.

Five hundred liters of ethylene chlorhydrine solution are pumped into a steel tank, capacity 2000 liters, and maintained at 80°C. by steam heating at a reduced pressure of 560 mm. Hg. Thirty percent caustic soda solution is poured in slowly, generating ethylene oxide by the reaction:

$ClC_2H_4OH + NaOH \longrightarrow C_2H_4O + NaCl + HOH$

The steam is separated from the ethylene oxide by a condenser. Average yield is 50%.

STEP III: B. Generation of Hydrogen Sulphide

Fifty percent sulphuric acid solution is added to a 40% sodium sulphide solution which generates hydrogen sulphide. The hydrogen sulphide is stored in a gas holder. Yield is 90%.

STEP IV: Synthesis of Thiodiglycol

Three hundred liters of 0.5% - 1% caustic soda solution are pumped into a 1000 liter, lead lined, iron tank. The solution is maintained at 50°C. by steam heat and agitated with a mechanical stirrer. The ethylene oxide and the hydrogen sulphide are added at a gas volume ratio of 3 5 to 1. The hydrogen sulphide is absorbed by the caustic solution and reacts with the ethylene oxide forming thiodiglycol by the reaction:

$H_2S + 2C_2H_4O \longrightarrow S(C_2H_4OH)_2$

When the solution is 50% thiodiglycol, the reaction is stopped and the solution is pumped to a steam heated still where it is concentrated under 10 - 20 mm. Hg. pressure until it is 95% thiodiglycol.

STEP V: Synthesis of Mustard Gas

200 Kg. of thiodiglycol and 550 Kg. of 36% HCl are pumped into the reaction tank and heated to 90°C. The reagents are stirred slowly for 4 - 5 hours forming mustard gas by the reaction:

$S(C_2H_4OH)_2 + 2HCl \longrightarrow S(C_2H_4Cl)_2 + 2HOH$

The mustard and water formed are cooled and pumped by vacuum to a settling tank. After settling, the upper layer, which is mostly water, is decanted and decontaminated. The lower layer, which is crude mustard gas, is neutralized with sodium carbonate.

Remarks: The First Factory was used as a pilot plant to produce mustard gas so as to solve the problems of production prior to starting large scale production in other factories. The other factories were converted to produce glycol, diglycol, and styrol, so, when an urgency for the production of mustard gas arose during the middle of the war, the pilot plant was operated as a production plant to produce mustard gas for military use. At the beginning of 1945 the pilot plant was converted to produce diglycol for smokeless powder and to produce ethylene oxide for the production of styrene.

In the splitting of water from ethyl alcohol to make ethylene, it was reported that Al_2O_3 had a catalyst life 20 times the acid clay catalyst which was used originally.

b. Mustard Gas From Monochloro Sulphide

100 Kg. of S_2Cl_2 are charged into a porcelain vessel and agitated constantly. Ethylene gas is bubbled into the S_2Cl_2 forming mustard gas directly by the equation: $S_2Cl_2 + 2C_2H_4 \longrightarrow S(C_2H_4Cl)_2 + S$. The reaction is exothermic so the reactor was held at 45° - 50°C. by external cooling.

The free sulfur deposited sinks to the bottom of the vessel. The mustard gas is removed and diluted with water to decompose the excess S_2Cl_2. The mustard gas is then separated from the water by settling and decantation.

Many problems were encountered so that this process has not been put into production.

The main problem is that any small amount of water present in the reagents causes the mustard to form into a brownish black paste.

c. Production of Chloracetophenone

Chloracetophenone was first produced by the pilot plant by the process using $ClCH_2COCl$ and C_6H_6 with $AlCl_3$ to catalyze the reaction. The product was impure so they began to make acetophenone using as reagents acetic acid and benzoic acid with calcium hydroxide as the catalyst. The acetophenone formed was chlorinated with liquid chlorine.

Because of the shortage of benzoic acid and the inefficiency of the process, the method of manufacturing chloracetophenone by synthesis with acetyl chloride and benzene was adopted in 1935. The pilot plant was run by this process to produce chloracetophenone for

training purposes and filling of Naval gun shells until 1944. The process is as follows:

STEP I: Synthesis of Acetophenone

850 Kg. of $AlCl_3$ are added to 1500 liters of benzene and agitated. 450 Kg. of acetyl chloride are added slowly. The reaction tank is cooled and kept at 19° - 20° by a brine cooling system. The reaction continues for five hours at which time the temperature is raised to 40°C. for about three hours to complete the reaction.

Reaction: $C_6H_5 + CH_3COCl \xrightarrow[(Cat)]{AlCl_3} C_6H_5COCH_3 + HCl$

The product is poured slowly into a decomposition tank which contains 2,000 Kg. of ice and water. The mixture separates into two layers, the lower one being discarded and the upper one being transferred to the still. The benzene fraction is removed at 80°C. The pressure is lowered to 50 mm. Hg. and the acetophenone fraction is separated at 120° - 130°C. The yield is 55%.

STEP II: Synthesis of Chloracetophenone

400 Kg. of water and 100 Kg. acetophenone are charged to the reaction tank and the temperature is maintained at 50° - 55°C. 55 Kg. of chlorine is bubbled into the tank in three hours.

Reaction: $C_6H_5COCH_3 + Cl_2 \longrightarrow C_6H_5COCH_2Cl + HCl$

The lower layer, containing chloracetophenone, is pumped by vacuum to the crystallizing tank and cooled. The chloracetophenone crystals formed are removed from the liquid by filtration and centrifuging.

Remarks: The acetophenone equipment was being converted, after 1944, to produce styrene with benzene and ethylene oxide. This conversion was not completed by the end of the war.

d. Diphenylcyanarsine - Production Methods

Work was begun in 1931 to produce diphenylcyanarsine from diphenylchlorarsine which was prepared from benzene diazonium chloride by the complicated German process. (Reference: "Chemicals in War" - Prentiss, p. 204) By this process a pilot plant was erected in 1933

An effort was made to produce diphenylcyanarsine by treating chlorbenzene and arsenic trichloride with metallic sodium, forming triphenylarsine which, in turn, was heated with more arsenic trichloride to produce diphenylchlorarsine. This would be converted to diphenyl cyanarsine by reaction with sodium cyanide. Neither of the above mentioned processes were efficient and the use of metallic sodium was dangerous so the diphenylcyanarsine was produced by the following process:

STEP I: Formation of Aniline Hydrochloride and Benzene Diazonium Chloride

To 200 liters of water and 400 liters of 36% HCl, 150 Kg. of aniline are added in one hour. The solution is agitated during that period and is left to agitate for ten extra minutes. Reaction:

$$C_6H_5NH_2 + HCl \longrightarrow C_6H_5NH_2 \cdot HCl$$

The solution is then transferred to the diazo-reaction tank. A solution of 100 Kg. of sodium nitrite dissolved in 350 liters of water is added slowly to the aniline hydrochloride solution. The time required is 1½ hours and the temperature is maintained at 0° - 3°C. Reaction: $C_6H_5NH_2 \cdot HCl + NaNO_2 \longrightarrow C_6H_5N_2Cl + NaOH + HOH$

STEP II: Formation of Sodium Arsenite Solution

400 Kg. of sodium carbonate are dissolved in 200 liters of water and maintained at 80°C. and agitated in a reactor. 200 Kg. of arsenous oxide are added to the solution. Reaction: $3Na_2CO_3 + As_2O_3 \longrightarrow 2Na_3AsO_3 + 3CO_2$

The sodium arsenite solution formed is made up to 350 liters and cooled.

STEP III: Synthesis of Sodium Phenylarsenate

The benzene diazonium chloride solution of Step I is added slowly (4 hours) to the sodium arsenite solution and agitated in a reaction tank. The agitation is continued for 30 minutes after the addition and then neutralized with HCl. Reaction: $C_6H_5\text{-}N_2Cl + Na_3AsO_3 \longrightarrow C_6H_5AsO_3Na_2 + NaCl + N_2$

The total solution is filtered and the filtrate pumped to the reduction tank.

STEP IV: Formation of Phenylarsenous Oxide

The sodium phenylarsenate solution is made slightly acidic to form phenylarsenic acid: Reaction: $C_6H_5AsO_3Na_2 + 2HCl \longrightarrow C_6H_5AsO_3H_2 + 2NaCl$

The total solution is then warmed to 75° - 80° C. and 300 Kg. of sodium hyposulphite powder are thrown in from the manhold. The temperature is maintained for 15 minutes and the solution is agitated. The solution is left to settle for 48 hours; the phenylarsenous acid formed sinks to the bottom. Reaction: $C_6H_5AsO_3H_2 + Na_2S_2O_5 \rightarrow 2C_6H_5AsO_2H_2 + Na_2SO_4 + H_2SO_4 + H_2O$

The top layer of water and acid is drawn off and the phenylarsenous acid is dehydrated by steam coils which

produces phenylarsenous oxide. The yield is about 300 Kg. $C_6H_5AsO_2H_2 \xrightarrow[\text{heat}]{} C_6H_5AsO + HOH$

STEP V: Formation of Phenyldichlorarsine

216 Kg. of 36% HCl are put into an acid proof double kettle. 100 Kg. of phenylarsenous oxide are added. The solution is warmed to 80°C. and agitated for five hours. It is then allowed to separate into two layers, the lower one being phenyldichlorarsine. Reaction: $C_6H_5AsO + 2HCl \longrightarrow C_6H_5AsCl_2 + HOH$.

The yield is 110 Kg.

STEP VI: Synthesis of Diphenylchlorarsine.

200 Kg. of phenylarsenous oxide and 85 Kg. of phenyldichlorarsine are melted in a kettle be steam and a gas flame at 90°C. As soon as they become liquid, agitation is begun and 13 Kg. of concentrated H_2SO_4 are slowly poured in. The solution is maintained at 90° - 100° C. by passing water through the steam coils. The reaction continues for one hour; the liquid then is cooled, pumped by vacuum to another tank, and settled. The upper layer is siphoned to a crystallizer and cooled to 8° - 10°C. The crystals are separated by a centrifuge from the liquor and are diphenylchlorarsine of 98% purity. Reaction: $3C_6H_5AsO + C_6H_5AsCl_2 \longrightarrow 2(C_6H_5)_2AsCl + As_2O_3$.

STEP VII: Synthesis of Diphenylcyanarsine

To 250 Kg. of diphanylchlorarsine in a reaction tank, 60 Kg. of sodium cyanide, dissolved in 250 liters of water are added. It is slowly agitated at 40° - 45°C. for 20 minutes and then allowed to settle. The lower layer of diphenylcyanarsine is transferred by vacuum to the still where it is removed at 180° - 200°C. at the pressure of 5 - 10 mm. Hg. It is the product. Reaction: $(C_6H_5)_2AsCl + NaCN \longrightarrow (C_6H_5)_2AsCN + NaCl$.

Remarks: The diphenylcyanarsine was used for filling shells for the Navy. The pilot plant production was stopped in 1943 to convert the plant to the production of alcohol from sweet potatoes. The conversion was not accomplished.

e. Production Method of Lewisite

Lewisite was manufactured from 1933 until 1938 be the process of passing acetylene through arsenic trichloride using aluminum chloride as a catalyst. This process produced secondary and tertiary lewisite to considerable extent so it was changed to the following process, using cuprous chloride as a catalyst in 1938.

Process:

150 Kg. of cuprous chloride are dissolved in 600 Kg. of 23% hydrochloric acid to act as a catalyst. To this solution, 150 Kg. of arsenic trichloride are added and the solution is agitated. Acetylene is bubbled for 24 hours at 40°C. The amount of acetylene used is 1½ times theoretical.

Reaction: $AsCl_3 + C_2H_2$ ——— $ClCH{:}CHAsCl_2$

The crude lewisite layer is pumped by vacuum to a still and evaporated from the unreacted arsenic trichloride and secondary lewisite. 85 - 90% primary lewisite is obtained.

I. Effectiveness of Toxic Gases and Testing of Gases in the Field

1. Objectives

Work on the field behavior of toxic agents was carried out with several objectives; to study the nature of the agents, to instruct in the technique and tactics of use, and to determine the ammunition requirements.

2. Organizations

The most important work in this connection was done by the Sixth Military Laboratory at the direction of Maj. Gen. Akiyama. A mathematical "theory of effectiveness" was developed by Maj. Sakagami, and the calculated results were compared with actual field tests of gas cylinders, shell, bombs, and spray.

A branch of the Sixth Military Laboratory was set up as the Chemical Department of the Kwantong Army at Chichiharu, Manchuria, its main function being cold weather researches.

Tropical tests were conducted at Kato Airfield in Formosa by the Sixth Military Laboratory, with assistance from the Chemical Section of the Narashino Army School.

In connection with training and studies on tactics, the Narashino Army School performed simple field tests with all chemical warfare munitions.

All agents in shell were tested by the Artillery School at Yotsukaido, Chiba-Ken.

The Mikatagahara School of Gas Defense (Air Force) at Mikatagahara Field near Hamamatsu, performed various field tests, mostly on mustard spray, and cooperated with other organizations where airplanes were required.

The Shimashiju School for Observers (Air Force) participated in spray tests with the Narashino School.

Tests by the chemical section of the Air Force Laboratory (later the Third Army Air Technical Laboratory) seem to have been directed towards munitions development rather than towards the field behavior of agents.

The Sagami Naval Research Department at Hiratsuka was the only organization in the Navy doing field tests

on chemical agents. Experiments were with mustard bombs and with CN and DC shell.

It was claimed that the records of all the above organizations were destroyed at the end of the war, and all information included here was obtained by interview or by reports prepared from memory by the Japanese. The best such report, prepared by Maj. Sakagami and describing the whole program of the Sixth Military Laboratory, is attached to this report as Appendix A.

3. Theoretical Work

Maj. S. Sakagami of the Sixth Military Laboratory was responsible for a detailed mathematical theory of atmospheric diffusion. This work is completely described in Appendix A, and will only be summarized here.

The purpose of the theory is to describe how the concentration of gas at any given point varies with time according to the munition expended and the meteorological condition. A certain distribution of concentration is set up by the functioning of the munition, and the subsequent behavior of the agent is simply a matter of the diffusion phenomena in free air or in a geographical feature.

A differential equation of diffusion is developed upon the following basic assumptions:

a. In vertical diffusion near the surface of the earth the momentum transport theory holds, and the vertical diffusion coefficient is linear with height above the surface.

b. In horizontal diffusion the velocity transport theory holds, and the horizontal diffusion coefficients are isotropic and constant.

This differential equation is then solved for the conditions of an instantaneous point source of gas with coordinates moving with the velocity of the wind.

Transformation is made to fixed coordinates, resulting in a fundamental equation expressing concentration at any time and position downwind from an instantaneous point source of gas.

This fundamental equation is set up in several different ways for integration (approximate*) with respect to time and with respect to the horizontal coordinates, giving formulae for the following:

a. Total Ct at any position downwind from an instantaneous point source of gas.

b. Concentration and total Ct at any position downwind from a continuous point source (applicable to the discharge of non-persistent gas from a single cylinder)

* The integrations are simplified by considering as constant certain terms which are variable to a lesser degree.

c. Concentration and total Ct at any position downwind from a continuous line source (applicable to discharge of non-persistant gas from a line of cylinders arranged perpendicular to the wind direction).

d. Concentration at any time and position for a continuous plane source (applicable to the vaporization of persistant gas from an evenly contaminated area). This formulae required a table of numerical values for certain integrals, but the table was destroyed and would require nine months for assembling.

An expression for the exponential decrease upwards of gas from the explosion of non persistent bombs or shells is combined with the same fundamental equation for concentration used above. This combination is integrated (approximate*) with respect to time and the three coordinates in a number of different ways to give the following results:

a. Concentration and total Ct for an instantaneous 3-dimensional source (applicable to a single non persistant bomb). The required numerical table for integrals was not supplied.

b. Concentration and total Ct for an instantaneous 3-dimensional source (applicable to the dropping of a number of non-persistent bombs with one point of aim).

c. Concentration and total Ct for an instantaneous 3-dimensional source (applicable to the uniform dropping of a number of bombs on an area).

d. Concentration and total Ct for a continuous 3-dimensional source (applicable to the firing of shell with one point of aim).

The use of the above formulae depends on field tests to establish the value of the diffusion coefficients and to determine the initial conditions of concentration set up by the various munitions. The diffusion coefficients were found to depend upon wind speed, but vertical temperature gradient was considered to be of less influence than was previously supposed. The greater effectiveness found in tests of gas under inversion conditions is explained by the absence of the frequent wind shifts which are associated with lapse conditions. It was believed, however, that with large scale use of gas on the battle field the effect of wind shifts would be much less.

Several examples of practical results based on the formulae are included.

a. A nomograph for determining munitions requirements for the discharge of gas from a line of cylinders.

b. A set of figures showing the calculated Ct 2000 isolines for the uniform dropping of HCN bombs under various conditions.

c. A set of figures showing the calculated Ct 2000 isolines for the firing of HCN shell at one point of aim.

4. Methods and apparatus used in field tests

a. General

Field tests were usually carried out with gridded sampling areas of one to sixteen hectares and with 5 to 25 yards between sampling positions. Total dosage and interval samples were taken and rabbits, guinea pigs, marmots, and doves were used to check the chemical sampling. Dosages were expressed as Ct (mg.min. /M^3), and dosage isolines were drawn - usually for Ct of 2000, which was considered to be the effective dosage for mustard, lewisite, phosgene, and HCN. Wind speed and direction, air temperature at several heights (for example 0.5, 1, 3, 5, and 10 M), ground temperature, and humidity were observed in an area adjacent to the test area.

b. Special apparatus used in field tests

(1) Gas inspiratory device

An accordian type bellows is used to draw a sample of air through the gas absorbers. The bellows is 50 cm. in diameter and 70 cm. in length when extended, giving a volume of over 100 liters. An electrically operated lever releases the 20 Kg. weight attached to the bottom, and air is drawn through orifices of different diameters (1 - 5 mm.) to give flow rates from 1 - 10 liters/min. The orifice is usually 2.5 mm. in diameter for a flow rate of 3 liters/minute, this rate being maintained within $\pm$5% for about 20 minutes.

(2) Air sample distributor

A 12-way clock operated stop-cock is used to regulate the flow of samples through the absorbers. The time interval may be varied from 5 to 60 seconds, and sometimes 2 or 3 of these stop cocks are connected in series.

(3) Absorbers

Two general types of absorbers are used. For mustard and lewisite, or for their mixtures, the sample is drawn through a 10 X 80 mm. glass tube containing 10 - 12 mesh silica gel. For phosgene and HCN, the sample is passed through appropriate solutions in 5 X 20 cm. glass bubblers.

(5) Concentration recording meter

An instrument for the continuous recording of gas concentration consists of three main parts - atomizer, amplifier, and recording milliammeter. An atomizer operated by compressed air (0.2 atm.) draws contaminated air into a glass chamber along with a

spray of absorbing solution. Platinum electrodes are inserted in the stream of absorbing solution, one pair before the atomizer and one pair after. The difference in electrical conductivity of the absorbing solution at these two points is amplified by an alternating current Wheatstone bridge. The unbalance of this bridge is measured with a recording milliammeter. Before each test, the apparatus is calibrated in a gas chamber the concentration of which is determined by ordinary analysis.

For HCN the absorbing solution is 5% NH_4OH. The sensitivity of the apparatus depends on the ratio of the resistances in the Wheatstone bridge, and gas concentration ranges of 50 to 2000 mg/M^3 or 200 to 4000 mg/M^3 are generally used.

For phosgene the absorbing solution is 0.05% NH_4OH, and a measuring range of 50 to 3000 mg/M^3 is available.

Mustard vapor concentrations cannot be tested.

(6) Meteorological Instruments

No unusual meteorological instruments were used. Ordinary measurements were made with Robinson type anemometors, recording wind vanes, and Assman's aspirated psychrometers and thermojunctions. For special measurements, wind speed was recorded at several heights with a hot wire anemometer consisting of a 0.025 mm. platinum wire, a Wheatstone bridge, and a recording milliammeter. For wind direction, the motion of an "inertialess" wind vane was recorded by a spark discharge between a needle and an axially moving paper covered metal cylinder.

c. Methods of analysis

(1) Phosgene

The bubbler absorbing solution of 5% NH_4OH hydrolyzes the phosgene, and chloride ion is determined by the silver nitrate (Volhardt's) method for solutions of high concentration or by the mercury nitrate method for solutions of low concentration.

(2) HCN

For high concentrations, the absorbing solution of 4% NH_4OH is analyzed by Denige's method, and for low concentrations the absorbing solution of 2% NaOH is analyzed by Schlek's method.

(3) Mustard

For chemical analysis, the mercury nitrate method was used. Silica gel from the adsorption tube is transferred to a flask and the tube is washed into the flask with 30 cc. of absolute alcohol. Five cc. of 30% H_2O_2 and 5 cc. of $NaHCO_3$ solution are added and the mixture is reflexed for one half hour. The solution

is decanted into another flask and the gel is washed with 30 cc. of water. Finally the solution is titrated with n-HNO_3 to pH of 3 or 4 (bromphenyl blue turns pink).

For liquid mustard drops, test plates and test dishes are used. The test plate is prepared from Japanese paper which is painted with a reagent of the following approximate composition:

nigrosin	0.1 parts
ZnO_2	25.0 parts
glue	1.0 parts
water	100.0 parts

Nigrosin dissolves in liquid mustard and gives black spots on the plates which may then be compared with standard plates.

The test dish is of standard size and contains a mixture of concentrated H_2SO_4 and 1% aqueous solution of SeO_2. Mustard drops are caught in the solution, which is then warmed for one half hour. The pink color produced by reduction of SeO_2 is compared with standard colors.

(4) Lewisite

Usually lewisite is in mixture with mustard and the same chemical procedure described above for mustard is used to determine the total chlorine. The arsenic from lewisite is then determined by Gutzeit's method.

Test plates and test dishes for lewisite or for mixtures of mustard and lewisite are the same as described above for mustard only. Standard test plates, however are different. The test dish solution must be analyzed separately for lewisite by the Gutzeit method.

5. List of Field Tests with Description and Results where available

a. Sixth Military Laboratory

Mai. Sakagami's report (Appendix A) describes ten field tests conducted by the Sixth Military Laboratory on the island of Honshu since 1940:

(1) Test of HCN trench mortar shell at Ojyoji, Miyagi-Ken in May, 1940.

(2) Test of HCN trench mortar shell at Ojyoji, Miyaga-Ken in December, 1940.

(3) Test of HCN trench mortar shell at Fuji, Shizuoka-Ken in February, 1943.

(4) Test of phosgene trench mortar shell at Fuji, Shizuoka-Ken in June 1941.

(5) Test of phosgene and diphosgene shell (static) at Numata, Gumma-Ken in December 1942.

(6) Test of 500 Kg. HCN bomb at Hamamatsu, Shizuoka-Ken in September 1943.

(7) Test of HCN trench mortar shell at Numata, Gumma-Ken in November 1943.

(8) Test of phosgene cylinders at Ippongi, Iwate-Ken in June 1943.

(9) Test of HCN airplane spray at Hamamatsu, Shizuoka-Ken in October 1944.

(10) Test of liquid projection of HCN against pill boxes and tanks (carried out several times between 1940 and 1945)

Col. Ichino prepared from memory a report on field tests of 50 Kg. HCN bombs in June, 1938. His report follows:

Gas Effect Testing in Field of 50 kg HCN bomb
(Colonel Ichino)

(This is not correct data, because the report was burned)

Objective:

Objectives of this experiment are to judge the value of use and to search the necessary number of bombs per one hectar (100 m X 100 m) to kill the man.

Date: June, 1938

Procedure of Experiment:

Number of bombers	------	3
Number of bombs	------	15 (each experiment)
Air area	------	100m x 100 m
Flying height	------	1000 m
Throw down distance	------	20 m
Beside distance of bombers	-	30 m
Kind of bomb	------	92 type 50 kg HCN bomb
Amount of fillings	------	9 kg
Equipment for gas	------	Gas catch instrument and
effect testing	------	small animals (rabbit, pigeon)
Times of experiments	------	3 times

Results:

Results of the experiments are shown in figures I,II, & III

Conclusion:

1. When it will be thrown down 15 bombs for one hector at the best condition of meteorology, the man and horses who are stay in this area are killed instantaneously.

2. The gas effect changes by the meteorological condition, especially it changes remarkably by the wind velocity.

View:

It is difficult to use the 50 kg HCN bombs always, because the gas effect changes by the meteorological conditions remarkably.

Figure II

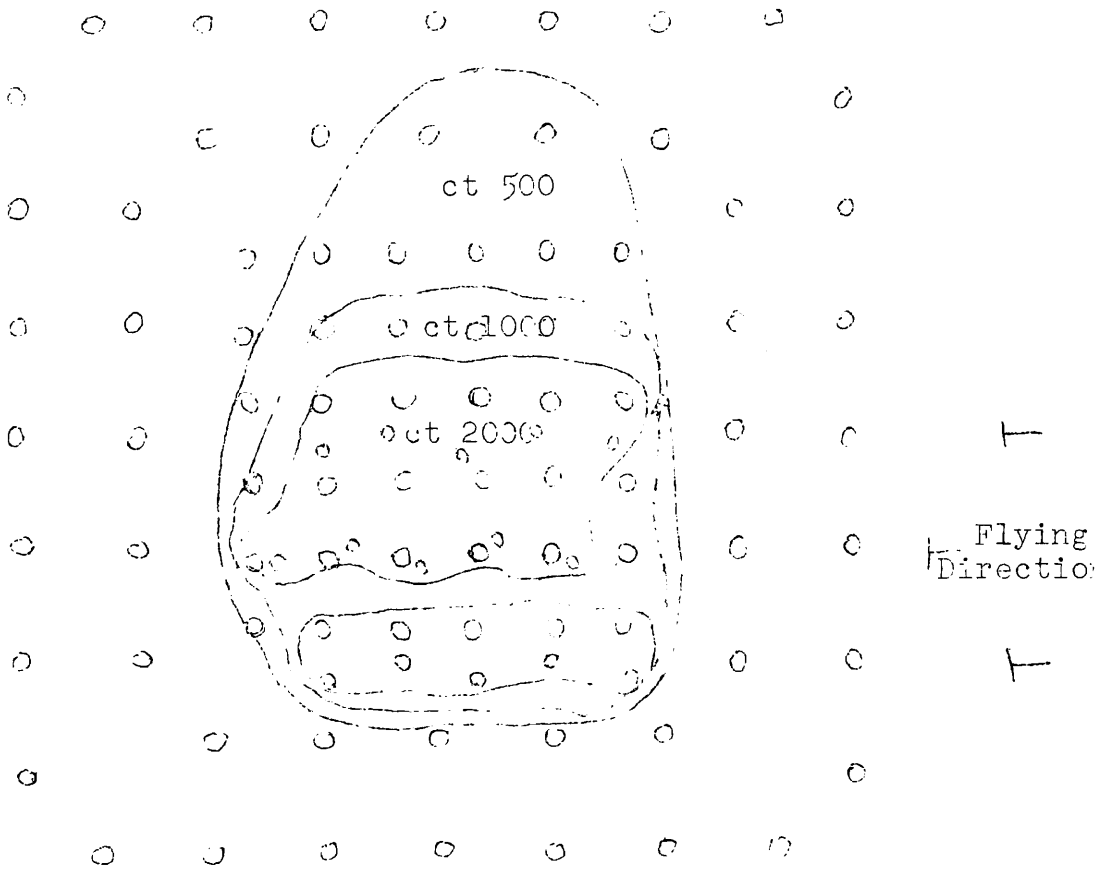
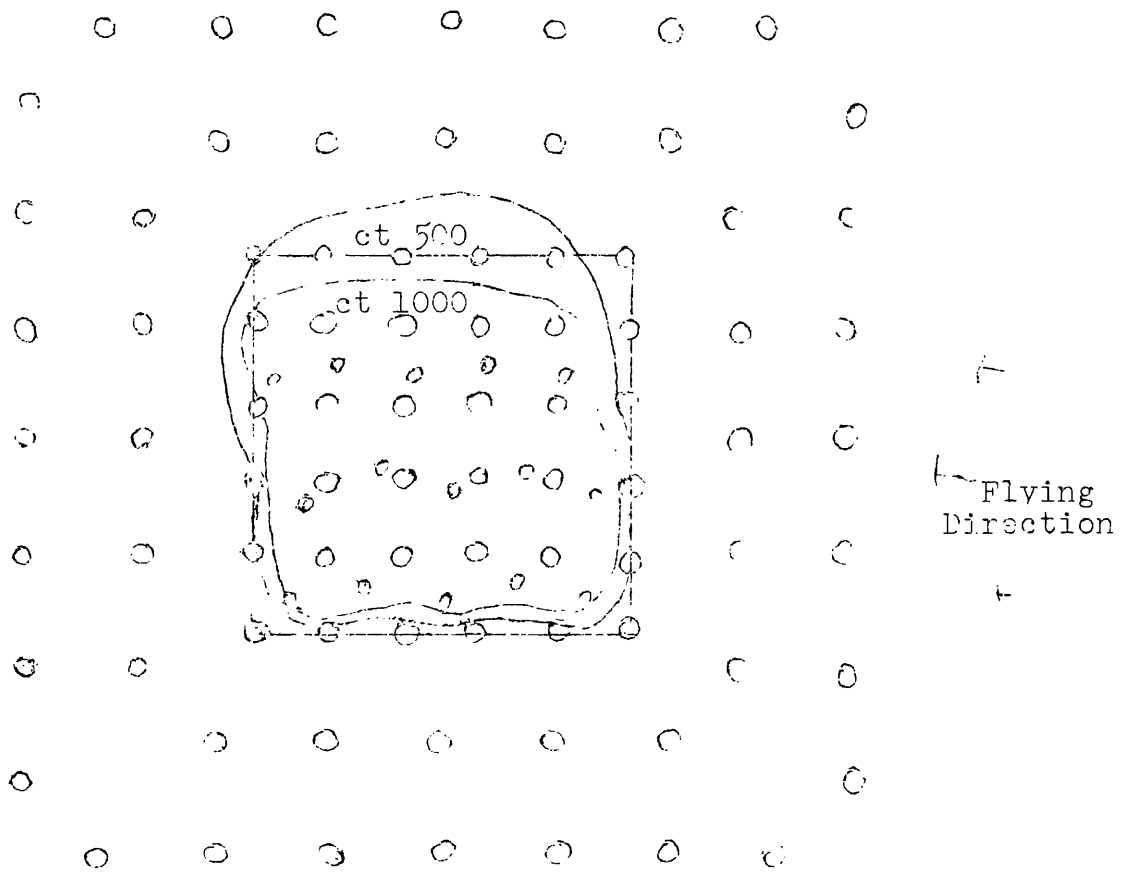


Figure III



b. Chemical Department of the Kwantung Army at Chichiharu, Manchuria(a branch of the 6th Military Laboratory)

(1) Gen. Akiyama was in charge of extensive research projects on the effect of cold weather on the use of gas (See ATIG* Report No. 271). Some of the more important conclusions are summarized as follows:

(a) Gases in the vapor state are more effective in cold weather because they stay closer to the ground.

(b) In cold weather, air chemical attack is more feasible than ground attack.

(c) HCN is not satisfactory in cold weather because it has to be mixed with anti-freeze and a sufficiently high concentration of gas cannot be produced with the diluted HCN.

(d) Ordinary mustard is not suitable for cold weather but lewisite, mixtures of lewisite and mustard, or "non-freezable mustard" are suitable. The rate of hydrolysis of lewisite is slower in cold weather.

2. Col. T. Okada of the Japanese Air Force described tests at Hokuzyashi, Manchuria in October, 1942 for the comparison of mustard spray and bombs (See ATIG Report No. 196), but no results were included.

3. A description of field tests of HCN bombs near Hokujoshi, Manchuria in July 1943 is included here in the form of Gen. Akiyama's report.

* ATIG - Air Technical Intelligence Group, Far Eastern Air Forces.

The Field Experiment of the HCN Bombs (Manchuria)

Written by Maj. Gen. K. Akiyama

Time: July 1943
Place: Heidai (near Hakujoshi) Manchuria
Chief of the testing troop: Colonel K. Akiyama
Organization of the testing troop: Colonel K. Akiyama
Commissioned officers 8
Non-commissioned officers and soldiers. .100 ca.

Object of the experiment: To obtain the effectiveness of the 100 type HCN bombs in field.
Munitions and other materials used:

a. 100 type 50 kg HCN bombs --- 80 ca.
(Each bomb contains 6 kg ca of HCN liquid and 2 kg ca of methyl formic acid)
Total quantity of HCN --- 480 kg ca.

b. Aircraft --- 97 type heavy bombers 7

c. Gas catching apparatus (Lantern type) 49
Rabbits . . . . . 100 ca
Pigeons . . . . . 200 ca

Procedures:

a. Bombing method
Formation of heavy bombers - - - - - close order
Height - - - - - - - - - - - - - - - 1500 m.
Simultaneous bombing
Time - - - - - - - - - - - - - - - - immediate after the sun rise

b. Gas catching period - - - - - - - more than 15 minutes
Height of gas catching position - 50 cm ca above the ground

c. Meteorological observation
Fair (There were few clouds)
Calm (1.5 m/sec)
Temperature 15°C.
Inversion of temperature (between 0.5 m and 3 m above ground) plus 0.3 to 0.5°C.

d. Geographical features:
Flat and open
grass-height - - - - - - - 30 to 40 cm.
quality of ground - - --- medium hardness

The result is shown in Fig. 1. In the range where bombs dropped, there are few points at which the value of Ct show more than 2000 but generally it was concluded that the area of Ct more than 1000 was about 4 hectares.

Discussions

We expected that when 30 HCN bombs (400 kg ca of HCN) are dropped in 4 hectares, the area of Ct more than 2000 would be more than 4 hectares. But in the experiment, the result was a half of this expectation.

This result was considered mainly affected by meteorological conditions:-specially the wind-velocity of 1.5 m/sec

If the wind velocity were less than 1 m/sec and there was the inversion of temperature, the area of Ct more than 2000 would have been more than 4 hectares.

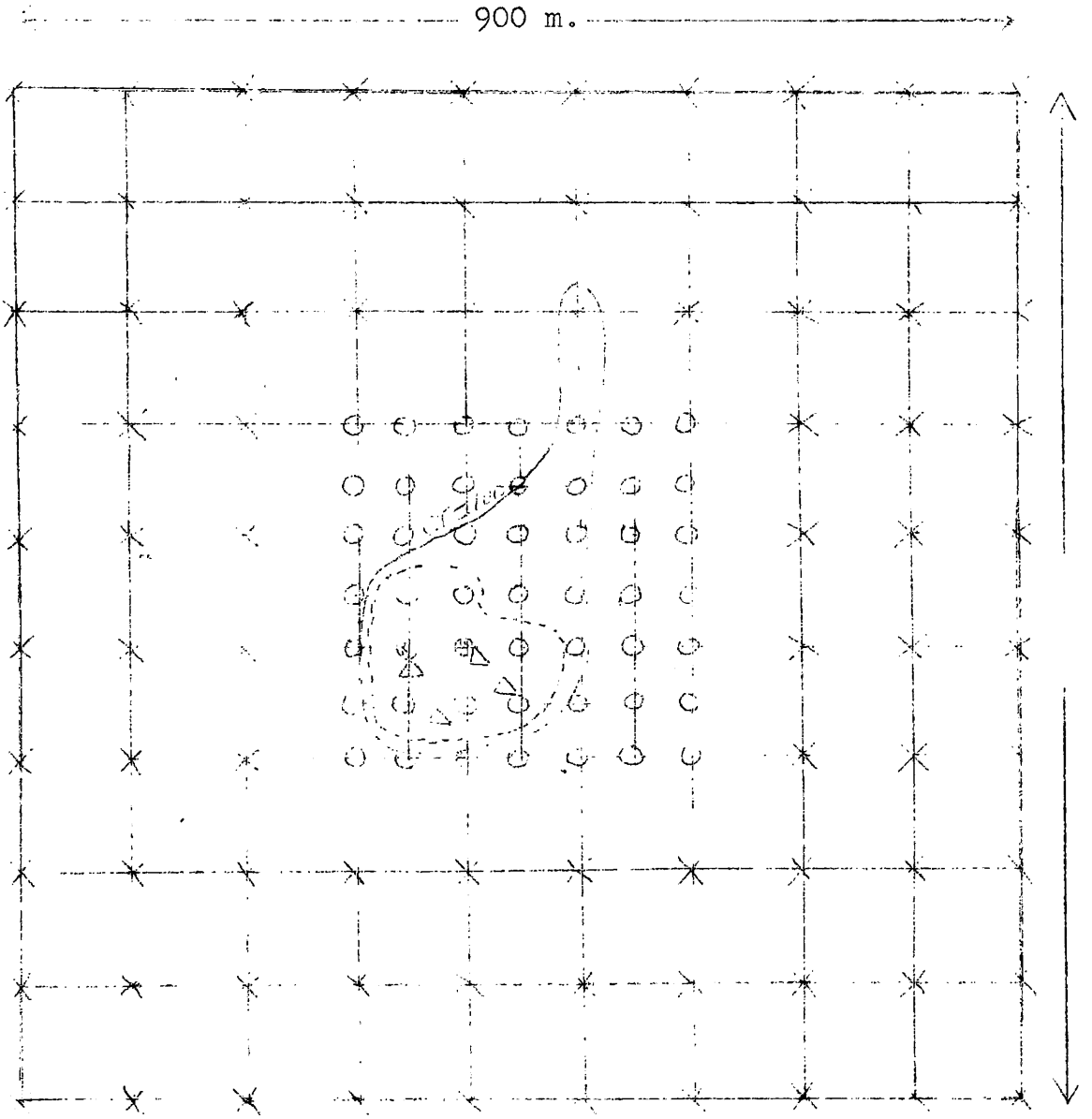
When the bombs exploded, the height of the explosion clouds was 25 to 30 m. This was concluded as a cause of diminishing the value of Ct near the ground.

Conclusions

HCN bombs can be available in good meteorological conditions for the purpose of killing men and animals in the narrow area by heavy bombers.

It is necessary 20 ca HCN bombs for each hectare when the wind-velocity is less than 1 m/sec, 40 ca HCN bombs when the wind-velocity is 1 to 2 m/sec. As a heavy bomber has 15 HCN bombs, a company of heavy bombers (9) is ought to aim 3 to 6 hectares. When the wind-velocity is more than 2 m/sec. this bomb is considered as unavailable. As when formic acid methylester is mixed as anti-freezing agent the quantity of HCN diminishes, it is superior to use HCN only than to use this mixture. Therefore, it is considered not to use HCN bomb in cold season.

Fig. 1 - Results



Gas catching apparatuses, rabbits, and pigeons

Testing papers and pigeons

Range of Ct 1000

Range where bombs dropped

Sections where bombs dropped densely

Positions where the gas catching apparatueses were ruined

c. Formosa tests (conducted by the Sixth Military Laboratory with the Narashino Army School)

Tropical weather tests were first carried out near Kato Airfield, Formosa in about 1930, and again in the same vicinity in the summer of 1941. Included were tests on mustard shell, bombs, and spray, phosgene shell, tear gas spray, and self projecting toxic smoke candles.

Col. Saiki, of the Sixth Military Laboratory described one unsucessful mustard gas spray test (See ATIG 127), but no significant results were included.

d. Narashino Army School

The Narashino Army School did not have any projects of its own for research on the field behavior of toxic gases, but sometimes gave assistance (weapons and personnel) to the Sixth Military Laboratory and the Mikatagahara School. Some field operations carried out at the Narashino School were in the nature of demonstrations for the study of tactics and defense against gas.

e. Mikatagahara School of Gas Defense at Mikatagahara Field, near Hamamatsu

The Mikatagahara School of Gas Defense conducted mustard spray tests for the purpose of training students in May and October of 1944 at Tenryu River Delta, and in February and July of 1945 at Mikatagahara. These tests are described by Maj. Chiken, of this school, (See ATIG* Report No. 196) but no significant results were included.

f. Sagami Naval Research Dept. at Hiratsuka, Kanagawa Ken

(1) Tests to determine the munitions requirements for mustard bombs were carried out by the Sagami Naval Research Department. A brief description of the procedure and result follows.

Ten 60 kg. mustard bombs (containing pure mustard) were dropped in an area 100 meters square. The vapor concentrations in the area were determined by use of animals, detector paper, gas absorbers, and vacuum bottle samplers. Several such tests were made and the conclusion reached was that 10 mustard bombs per 100 meter square will produce effective vapor concentrations for 2 - 3 days at 15 - 20°C. and for one half day at 30°C.

(2) The Laboratory conducted tests at Kure in about 1938 to determine the effect of CN and of diphenylcyanarsine shells exploded in the interior of ships. It was learned that ship rooms so contaminated are unbearable without gas masks, that diphenylcyanarsine sometimes breaks the gas mask canister, and that decontamination is very difficult.

(3) Tests of tear gas shells were carried out at Heisaura in April 1945, the object being to determine the practical value of these shells in woods and in open fields. Trench mortars were used to fire the shell, and gas samplers were operated during the firing. The experimenters entered the field after firing had ceased. The conclusion was that tear gas shells are ineffective in the open, and of moderate effect in the woods.

(4) Field tests on the design of a wooden body mustard bomb were carried out at Heisaura from May to August of 1944. The purpose of the tests was to examine the functioning of the bomb, and soil samples were collected at 81 points to determine the area of effective contamination. The wooden bomb contained 23 kg. of mustard, and contamination of about 1000 square meters with the density of 5 gm/m^2 was attained.

J. Incendiary Research

The investigation of Japanese incendiary munitions is the responsibility of the Air Technical Intelligence Group, Advance Echelon, FEAF, and is being reported separately by that organization. Copies of their reports are available at Air Documents Division, T-2, Wright Field, Dayton, Ohio. A brief summary of Japanese research on this topic has been abstracted from information supplied by FEAF to the Office of the Chief Chemical Officer, AFPAC, and appears below. A description of standardized Japanese Army and Air Force incendiary bombs will be found in Report No. 197 of Air Technical Intelligence Group.

In 1942 - 43 Navy Capt. Kizo Hiratsuka developed the WP Naval bomb for plane-to-plane bombing at Sagami Arsenal. Field tests were conducted at the Air Technical Department, Yokohama (probably the 1st Naval Air Technical Arsenal). WP and "special rubber" (thiokol impregnated with thermit) were the main incendiary agents used by this organization. The development of the "special rubber" compound occurred in 1942.

Colonel Ichino of the Sixth Military Laboratory developed various incendiary munitions between 1938 and 1940. These included a hand grenade, 75 mm artillery shell, and 95 mm mortar shell. The incendiary material used was rubber pellets in a solution of white phosphorus and carbon disulfide (mixed in equal proportions). These shells were not considered so effective as ordinary incendiary shells.

The chief research on incendiary bombs was conducted by the Third Air Force Laboratory. According to reports by the Scientific Intelligence Survey, GHQ, AFPAC, dated 1 Oct. 45, 5 Oct. 45, and 11 Oct. 45, this Laboratory worked on the following projects: Three major types of

incendiary bombs were developed. The first was an ordinary 50 kg bomb, filled with a mixture of WP and CS_2 in which pellets of crude rubber were suspended. The second type also used the 50 kg casing, but was filled with "flame thrower fuel", oil in which scraps of rag or sawdust were suspended. The bomb was ignited by WP. The third type was the midget (1 kg) elektron (magnesium - 90%, aluminum - 10%) bomb, which was to be dropped in clusters of 16 bombs. An attempt was also made in 1943 - 44 to reduce penetration of 50 kg bombs by equipping the bomb with a rubber nose. This was unsuccessful. The Japanese interrogated by this Survey had never heard of using auxiliary gas tanks as flame bombs.

K. Experimental Weapons

1. Gas Rocket Shell

Development work was being done on gas rocket shells, carrying from six to ten liters of agent. Diameters varied from fifteen to twenty centimeters, and lengths from 105 to 250 centimeters (including propellant and fins). A burster in the warhead dispersed the agent. The propellant was "G-1" of the following composition:

Nitroglycerine	30%
Nitrocellulose	65%
Centralite	3%
Graphite	2%

The launcher consisted of two guide rails 15 centimeters apart and two meters long, six sets of rails comprising the multiple launcher. The range of the rockets varied from 2000 to 3000 yards.

2. "Masuka Dan"

The "Masuka Dan" is a bursterless shell 8 centimeters in diameter and 40 centimeters in length, weighing 4 kilograms and carrying one kilogram of either HCN or $TiCl_4$. The shell is fired from an unrifled recoil-less gun weighing about 80 kilograms and designed for carrying by hand. A metal cup and a small bag of sand were expelled from the breach end of the gun to absorb the recoil upon firing. The soft steel body of the shell fractured on impact with the target. With good hits, Ct's of 5,000 to 6,000 were obtained inside tanks.

3. Flame Throwing Tank

A light, 12 ton tank was developed to carry five flame guns, three standard long barrel guns and two pistol type guns. All five guns are fed from a single 700 liter fuel tank by compressed air from two cylinders. Platinum-asbestos and hydrogen ignite the fuel mixture of 3% crude rubber in diesel fuel. The range of these guns is about 70 meters.

4. Gas Fog Emitter

A device for dispersing a very fine spray of HCN was developed. Liquid HCN from a 900 liter steel tank is forced through a vortex type nozzle by a pump or by compressed air from a cylinder (20 atm.). A pressure regulator and a quick opening valve were in the air line between the pressure cylinder and the gas tank. Much experimentation was required to develope a nozzle which produced a spray sufficiently fine to remain airbourne. The whole apparatus was mounted on a four wheeled trailer.

The 900 liters of HCN was dispersed in about two minutes. It was estimated that from 20 to 40 of the emitters would be required per 1000 meters of front to give effective concentrations 500 - 1000 meters downwind.

5. Mustard Spreading Trailer

Studies were made from 1929 - 1932 of a track-laying trailer 1.9 meters in width and 2.8 meters in length carrying a 300 liter tank of vesicant agent. A tank of compressed air at 1.3 atmospheres was used to spray the vesicants for a width of 7 meters behind the trailer. Operation of the pressure and spraying mechanism was by remote control from the armored car drawing the trailer.

6. Wooden Mustard Bomb Cases

Experiments were made with wooden cases for mustard bombs in an effort to conserve steel. The wooden cases contained a larger proportion of agent than did the ordinary steel cases.

7. The 9 cm. Mortar Smoke Shell

A 9 cm. mortar smoke shell was designed to detonate at a height of 30 - 60 meters above the ground. Six HC smoke candles were ignited and ejected from the base of the shell, falling to the ground in an area about 10 meters in diameter. The burning time of the candles was 2 minutes, and a screen about 100 meters long was produced. The range of the shell was 1700 meters.

8. HCN Projecting Tank

The type 97 flame throwing tank was experimentally used for projecting liquid HCN. The only modification involved was in making the gas container (fuel tank) more vapor tight. No attempt was made to use thickened HCN, and the range was about 70 yards. This range was not considered satisfactory, but greater pressure did not seem feasible in the flame throwing equipment, and experiments were discontinued.

9. Portable HCN Projector

Ordinary portable flame throwers were tested with liquid HCN, but no significant results were obtained.

10. Parachute Mustard Spraying Bomb

A few tests were made with bombs which sprayed liquid mustard as they descended by parachute.

L. Treatment of Gas Casualties

Two organizations within the Japanese Army worked on the treatment of gas casualties and related subjects. The Army Medical School studied both the mechanism of action of toxic agents and the treatment of gas casualties with the emphasis being placed on the latter subject. The Medical Section of the Sixth Military Laboratory worked on toxicology, first aid for gas casualties, and the mechanism of action of toxics. Work on these subjects has been in progress since the laboratory was established, but only in the last few years has the subject been studied earnestly. The work on this problem was greatly handicapped apparently by the inability of the group to consult with and enlist the help of chemists.

The Navy did its work at the Chemical Experimental Department. Work on the subject was started in 1922. By 1936 the procedure for the treatment had been decided upon and little further work was done except to study the application of the procedures to the occasional accidental casualties obtained during the operation of the toxic plants. The procedures adopted were in general taken from the literature published shortly after World War I.

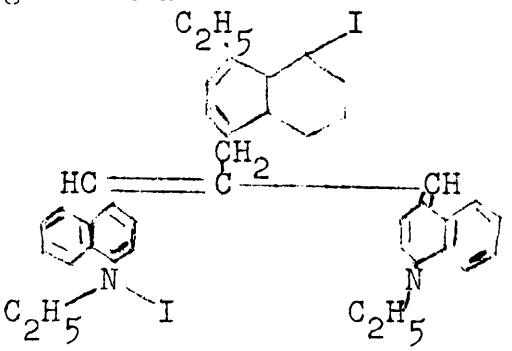
1. Mustard

The Army authorities believed that mustard reacts with the SH group (probably glutathione) of the body. This was substantiated by the fact that the reaction proceeds fairly rapidly in the test tube and by the experimental fact that after mustard (10 mg) was injected subcutaneously into the body of rabbits, it was found that the quantity of glutathione in the blood (as determined by Woodward's method) decreased. It was also believed that the mustard might react with the amino acid methionine in a similar manner.

In view of the fact that no method of reversing the above reactions could be found, the theory developed was of no practical value. No work using radioactive tracer materials in studying this problem was carried out.

To prevent the toxic action of mustard vapor, the Japanese worked on the injection of calcium thiosulfate subcutaneously in the body of rats prior to exposure to mustard vapor in the hope that the mustard might react with the thiosulfate rather than with the glutathione. It was concluded that the injection of these sulfate salts have some antitoxic action against the poisoning of mustard. For data see Report on Scientific Intelligence Survey in Japan, Vol IV, 1 November 1945, GHQ, AFPAC, page CW-22-21.

Injection of the thiosulfates after a liquid mustard burn was thought to cause the injury to be milder. Compounds to decrease the healing time of mustard burns were not studied extensively. In general they believed in letting the burns heal naturally. After the Seventh Military Laboratory reported that a compound called Ko Ha with the following formula



was good for the treatment of frost bite, thermal burns, or leprosy, some work was initiated (April 1945) using this material to treat mustard burns. The work consisted of placing drops of mustard on the ears of guinea pigs, administering "Ko Ha" either subcutaneously or orally, and watching the course of the skin injury. They believed that the number of burns, the severity of the burns and the healing time of the burns were lessened by the use of "Ko Ha". These tentative conclusions were made on a very small amount of data and are not necessarily believed even by the Japanese. Sulfonamide, $KMnO_3$, Glutazion, etc. were also tried on rabbits and guinea pigs which had inhaled mustard gas, but none were satisfactory.

For the list of medicines used by the Navy in the treatment of vesicant casualties see page CW-3-11 of the report referred to above.

2. Lewisite

The medical officers of the Army believed that the mechanism of lewisite action on the body was the same as that of mustard. Some work was done on the injection of thiosulfates prior to an exposure to lewisite as was done with mustard. The results were inconclusive. No work was done using thio alcohols. Even though the Japanese supposedly considered lewisite as effective as mustard and expected to use it if necessary, practically no work was done on the treatment of lewisite casualties. The reasons for this are obscure.

3. Hydrogen Cyanide

The Japanese gave considerable attention to the study of HCN poisoning. Particularly during the first part of the war energetic efforts were made to obtain therapeutics and prophylactics for HCN poisoning.

They tried approximately sixty materials. The principle ones were as follows:

For Antidotes
- methylene blue
- sodium subnitride (for changing haemoglobin into methaemoglobin)
- colloidal sulfur (for converting HCN into HCNS)

For heart drugs
- strichnin
- digitalis
- strophantin

For respiration center stirrings
- coramin
- Lobermin

Rabbits were chiefly used in this study. After being exposed for a certain time or until a certain effect had been obtained, the animals were removed and treated with the material being tested and the percentage of animals recovering was determined. Control animals were used. Studies were carried out where mixtures of the material were used. For the approximate data obtained see Report on the Scientific Intelligence Survey - Japan, Volume II, page CW-12-10. The conclusions reached from these tests were that methylene blue, sodium thiosulfate, and sodium subnitride were somewhat effective. The most effective measure however was found to be artificial respiration carried out at a very rapid rate (100 times a minute).

4. Phosgene

Little work was carried out on the treatment of casualties resulting from phosgene poisoning. The Japanese recommended venesection and oxygen therapy.

IV. Discussion

A. The Probable Effectiveness of Toxic Agents

Interrogation of the Japanese concerning the probable effects if the United States had used gas revealed that they believed gas had been used against them - after their radio communications had been knocked out on such islands as Iwo Jima. It was admitted, of course, that no proof existed for such a belief and that it was only speculation.

Capt. Tsuruo, the Chief of the Navy's Chemical Warfare Research Department, stated, "If a toxic gas such as mustard had been used against any of the islands such as Kwajalein, the Japanese troops would have suffered very much due to the lack of decontaminating materials and the lack of knowledge by the troops concerning the effects of mustard vapor." Maj. Gen. Akiyama, commanding the Sixth Military Laboratory, thought that if gas had been used against islands such as Iwo Jima, the islands could have been occupied with the minimum of fighting by the United States forces. Personnel of the Narashino Chemical Warfare School felt that the use of gas against the Japanese would have produced disastrous results for them. Maj. Sakagami, probably the best informed officer in the Japanese Armed Forces on the behavior of toxic agents in the field, stated that the use of mustard against Japanese troops on islands such as Iwo Jima would have reduced United States casualties very considerably and the Japanese forces would probably have been decimated to the point where American decontamination groups could have gone ashore and decontaminated the areas prior to the debarkation of the main body of troops.

Against cities, however, the Japanese felt that the incendiaries produced better results than gas would have done.

It is realized that the above statements are only opinion. They have been included mainly for interest and for showing the attitude and awareness of the top Japanese CW personnel to the probable effects of gas.

B. Trend of the Research and Development work

Prior to the initiation by the Japanese of war with the United States the Armed Forces of Japan had carried out considerable research on both offensive and defensive chemical warfare problems. Design for the needed munitions in most cases was completed and field tests had been carried out to determine the best methods of use. With the Japanese successes at the beginning of the war the main amount of emphasis seems to have been placed on offensive work. In 1943 - 44 however, the change in the course of the war forced the Japanese to concentrate on the defensive. From

then until the end of the war the emphasis was placed on the development of defensive materials. During this period work on production of toxics was stopped except for a little development work on methods of production using non critical materials.

The Japanese at this time adopted a fatalistic attitude toward chemical warfare. In the words of a colonel connected with chemical warfare in the Army Ordnance Administration Headquarters, "It was decided that the United States would not use toxics against us unless the situation became a stalemate and if toxics were used we would be powerless to survive the attack." This attitude admitted defeat and dictated that all the resources allocated to chemical warfare be used on defensive measures. This realized inability to wage effective warfare was due to two factors: (1) the lack of enough qualified technical personnel to carry out the development and (2) the lack of sufficient resources. The second reason by far outweighed the first and was the factor which determined the trend of all of the work. This shortage of material forced the Japanese in practically every case to work not on the development of the best munition or equipment, but on the development of the materials which could be made with the resources at hand. This is a primary reason why little of the Japanese work is of any real significance or value to the CWS.

Since the trend of their research was based on necessity and was not the logical outgrowth of scientific inquiry, it should have no influence on the development of chemical warfare material by other countries, and to discuss the course of development of particular munitions is consequently unecessary.

Mainly as a matter of interest the Japanese Army and Navy chemical warfare authorities were asked to discuss the future of chemical warfare in view of the development of the atomic bomb and of other special weapons and materials. In every case these authorities felt that the atomic bomb would probably replace incendiaries as the weapon used in attacking cities. These people, however, were mightily impressed with the job the incendiary had done. Further they all admitted that little definite information had been obtained or was known by them concerning the effects of the bomb so these statements were speculation only. Special weapons such a flame throwers they believed would continue to be of value. They appeared uncertain as to the future value of area attacks with toxic chemicals.

The belief that no new chemical agents or that no radically different chemical munitions would be discovered or developed seemed to be held by most Japanese CW officers. It is not clear whether this view existed prior to the end or the war or not.

C. Personnel working on Chemical Warfare problems

The Japanese were always handicapped in their research and development work by a lack of qualified and competent scientific personnel. To offset this large numbers of laborers and non technical personnel were employed in their laboratories. They also adopted the reasonable procedure of taking graduates from the technical schools and assigning them to particular fields of work in the laboratory. Some of these men were officers and others remained civilians. In both cases, however, the technical man worked on subjects related to his field. This procedure developed specialists who were very competent in their jobs. It was not always followed, and many of the people responsible for work on certain subjects showed a surprising lack of understanding of the problems existing. Possibly a cause for this was the necessity, due to the shortage of technical personnel, of putting men on a particular problem for a while until some solution - any workable solution in many cases - to the problem was reached and then changing their assignment to another entirely separate problem. Along with the scarcity of certain materials this in large part accounts for many of the poorly designed munitions.

D. Reliability of the Information

It was pointed out in the introduction to this report that most of the information is based on interrogations of the Japanese and on reports written by them for submission to this office. Few documents or original reports have been obtained at this time. As a consequence of the fact that the information herein is in general not based on recorded data, errors in details probably exist. It is believed, however, that the overall information contained in the report is correct. It is altogether possible that certain information known to the Japanese has not been brought out during the interrogations. Efforts to prevent such occuring if possible have been made, however. In many cases the Japanese authorities have apparently spoken openly and frankly concerning the research work. However, throughout the period of interrogation the Allied authorities have been arresting Japanese as war criminals. This has tended to make the people questioned very cautious in their statements; moreover, it has made the Japanese emphasize their defensive CW work while stating that practically no offensive work was carried out. Instances have occurred, however, when definite, and probably intentional, misstatements of fact have occured. In spite of these it

is believed that this report gives an accurate account of all of the research and development work and that probably the Japanese have not witheld their most important data.

E. Other organizations doing primary chemical warfare intelligence work in Japan

Besides the groups whose chemical warfare intelligence work has been directed by the Chemical Officer, GHQ, AFPAC, two other organizations have done work on this subject. The Chemical Section of the Air Technical Intelligence Group has worked on the following specific subjects:

a. All matters pertaining to incendiaries
b. All matters pertaining to CW organizations attached
c. Defensive tactics which apply to Air Forces such as decontamination of airfields, airplanes etc
d. Information concerning all munitions and equipment used solely by the Air Forces
e. Supply of CW materials to Air Forces
f. Inspection of Air Chemical Proving Grounds
g. Study of Air Forces plans and policy pertaining to Chemical Warfare
h. Study of the tactical application of smoke, spray, and gas bombs

Reports on these subjects are being written at Wright Field, Dayton, Ohio. They should be obtained for detailed information.

The Naval Technical Mission to Japan, Nav Tech Jap, has also carried out some investigation of chemical warfare activities. These reports will be issued by the Navy.

F. Relation of the Japanese with Germans in Chemical Warfare matters

Little real evidence exists which would indicate that there was effective liaison between the Germans and the Japanese on chemical warfare matters. The Japanese have said that information concerning new toxic agents was requested from the Germans, but in answer the Germans only submitted information of probable agents which were being developed by the United States or Russia. The Japanese Navy admits having received a sample of a decontaminating agent from the Germans, but states that its composition was not given and that they could not determine it. In the case of spray tanks the Japanese stated that no tanks or design information had been obtained from the Germans. Subsequent investigation revealed several German spray tanks in storage at the laboratory. Under such circumstances it is difficult to assume or believe that the statements made by the Japanese were other than deliberate mis-statements of fact. Their reasons for so doing are

somewhat obscure. In spite of these instances the design of the Japanese munitions and their research work show little German influence.

V. Conclusion

It is concluded that no further investigation of the chemical warfare research and development activities of the Japanese Armed Forces is necessary except to furnish specific information which may be requested after a study of this report.

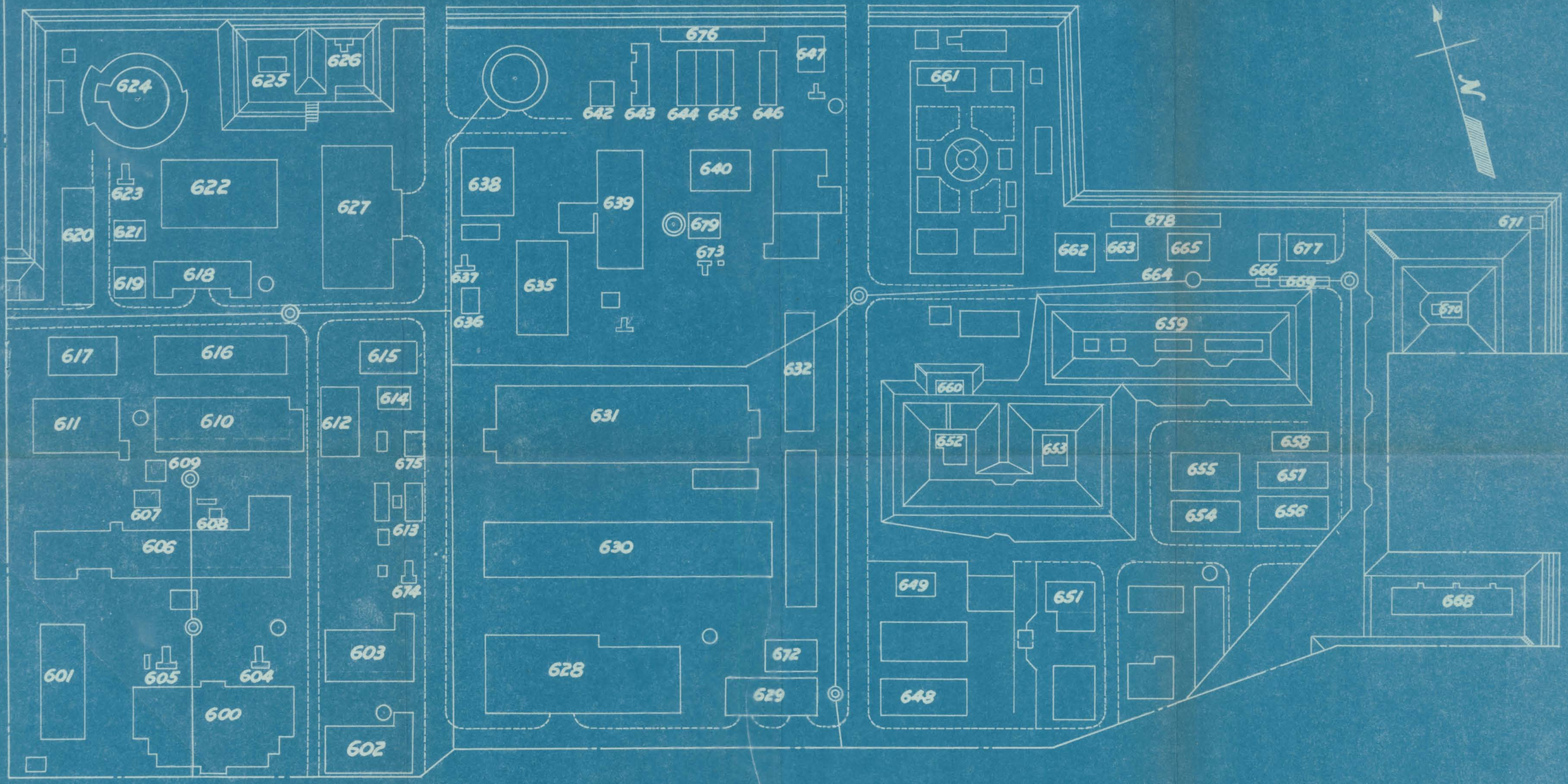
Sixth Military Laboratory

No. of Building	Use	Remarks
600	Research on chemistry, especially for protection	
601	For intendance business	
602	The 3rd Factory	The 8th Military Laboratory used. Burned up by air raid.
603	Research on protective materials	Burned up by Air Raid
604	Ventilation and neutralizing air.	
605	Ditto	
606	X-ray examination for tested animals	Repair shop moved to No. 641 building since it was destroyed for protective measure from air raid suffering.
607	Motor house for ventilator	
608	Neutralizing tower of air through experiment room	
609	Motor house for ventilator	
610	The 1st Factory Warehouse	
611	Wood-working shop	
612	Mess house for commissioned officer and official	
613	Fire-engine house	Burned up by Air Raid
614	Storage house of fats and oils	
615	Storage house of chemicals	
616	Printing	
617	Research on flame throwing tank.	
618	cooking for all persons	One part of it was burned up by Air Raid
619	Warehouse	It was destroyed for protective measure from air raid suffering
620	Ditto	Ditto
621	Motor house for ventilator	
622	Research on physical chemistry	
623	Neutralizing tower of air through experiment room.	
624	The 1st Test Chamber for explosion of shell.	
625	Magazine	
626	Ditto	
627	Lecture hall and recreation club.	

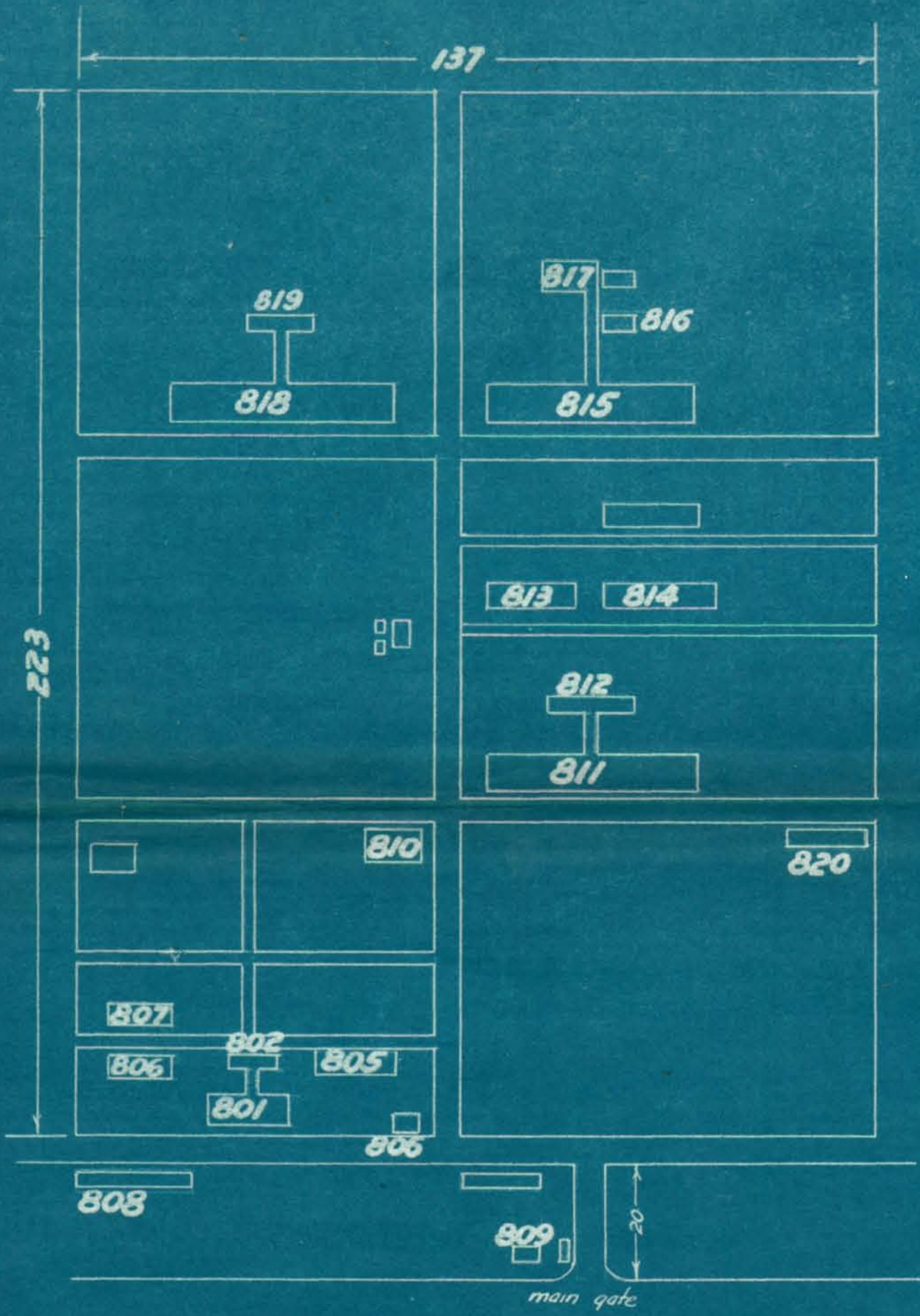
No. of Building	Use	Remarks
628	Medical research. Also used for library.	
629	Power Station	
630	Mess house for non-coms and official. Used for gas chamber and warehouse	
631	Business rooms for general affairs. Research on chemical analysis and synthesis	
632	Garage	
633	Neutralizing tower of air through experiment room	
634	Motor-house for ventilator	
635	Fire-man's rest house	
636	Warehouse	
637	Neutralizing tower of air	
638	Warehouse	It was destroyed for protective measure from air raid suffering
639	The 5th Factory	
640	Warehouse	
641	Repair Shop	
642	Shaking test chamber	
643	Warehouse	
644	Ditto	
645	Storage of poison gas	
646	Ditto	
647	Gas discharge room	Burned up by Air Raid
648.	Warehouse	It was destroyed for protective measure from air raid suffering
649	Warehouse of fodder for testing animal	
651	Garage	It was destroyed for protective measure from air raid suffering
652	Warehouse	
653	"	
654	"	
655	"	It was destroyed for protective measure from air raid suffering
656	"	Ditto
657	Wind tunnel experiment room	
658	Warehouse	It was destroyed for protective measure from air raid suffering
659	Heating test chamber and magazine	

No. of Building	Use	Remarks
660	Warehouse	
661	Watchman's house for testing animal	Burned up
662	Photograph house	Ditto
663	Frafts room	
664	Neutralizing tower of air	
665	The 2nd Test Chamber for explosion of shell	
666	Warehouse	
669	Ditto	
676	Warehouse of cylinder	
677	Metallic material Warehouse	
678	Ditto	

GROUND LAYOUT OF THE 6TH TECHNICAL LABORATORY



8TH TECH. LABORATORY



1 AMMUNITION STORAGE
2 MATERIAL STORAGE
3 TOXIC MATERIAL STORAGE
4 SURPLUS MATERIAL STORAGE
5 DECONTAMINATION TANK
6 DUMPING PLACE
7 STOREHOUSE OF DANGEROUS CHEMICALS
8 TANK
9 CHEM. STORAGE
10 HEATING EXPERIMENT TANK
11 DANGEROUS CHEMICAL STORAGE
12 STOREHOUSES
13 HYDROCHLORIC ACID STORAGE
14 TEMP. PRODUCING SHED.
15 AIRTIGHT EXPLOSIVE APPARATUS
16 EXPLOSIVE TESTING TANK
17 TESTING BOXES
18 HYDROCHLORIC ACID STORAGE
19 TESTING TABLE
20 SMOKE SCREEN TESTING BOARD
21 INSTRUMENT STORAGE
22 FIRE EXTINGUISHER
23 WATCH TOWER
24 VENTILATOR DECONTAMINATION TOWER
25 DRYING PLACE
26 TEMPORARY STOREHOUSE
27 #3 RESERVOIR
28 HEAVY OIL TANK
29 GAS TANK
30 EXHAUSTING DECONTAMINATION TOWER
32 INSTALLED TESTING APPARATUS
33 STOREHOUSE
34 VENTILATOR of TESTING EQUIPMENT
35 #3 TEST CHAMBER
36 #2 TEST CHAMBER
37 WATER POOL
38 FISCAL DEPT. STOREHOUSE
39 STOREHOUSE
40 "
41 "
42 #1 WATCH TOWER
43 LANDLORDS' HOUSE
44 DINING ROOM
45 DORMATORY
46 EXPERIMENTAL MANUFACTURING ROOM
47 ADMINISTRATION BLDG.
48 GARAGE
49 ELECTRO-TRANSFORMATION PLANT
50 FUNDAMENTAL TEST ROOM
51 APPLIED TEST ROOM
52 APPARATUS & MATERIAL STORAGE
53 #1 PLANT
54 STEEL YARD
55 LUMBER YARD
56 #3 STORAGE FOR TOXIC MATERIALS
57 STORAGE FOR SPECIAL CHEMICAL AGENTS
58 OIL TANK
59 CART SHED
60 KENNEL
61 #4 STORAGE FOR TOXIC MATERIALS
62 ANIMAL SHED
63 #5 STORAGE FOR TOXIC MATERIAL
64 MUNITION STORAGE
65 YARD
66. STOREHOUSE FOR STRONG ACID

· SYMBOLS ·

	CONCRETE WALL
	RAILWAY
	PERMANENT STRUCTURES
	TEMPORARY BUILDINGS
	DESTROYED BUILDING

CHEMICAL EXPERIMENT DEPARTMENT OF SAGAMI NAVAL ARSENAL.

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