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THE FUMIGATION OF SHIPS WITH LISTON'S CYANIDE FUMIGATOR[1].

(Its safety and efficiency compared with the Dumping Fixture.)

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(With Plates II—V and 3 Plans.)

I. INTRODUCTION.

IN a paper "On the use of Hydrocyanic Acid gas for fumigation" which was published in April, 1920 (*Indian Journal of Medical Research*, VII, 778 *et seq.*), one of us (Liston) detailed the advantages of hydrocyanic acid gas over other gases commonly used for fumigation.

In this paper some of the methods used for fumigating with hydrocyanic acid gas were described, and particular notice was taken of the "Dumping Fixture" which had yielded remarkably good results in the hands of Creel and other American workers, especially in killing rats on ships.

Attention, however, was drawn to certain accidents which had occurred when the dumping fixture was used. Grubb's endeavour to minimise these accidents by "ventilation after fumigation" was also referred to.

It was stated that a careful perusal of the available literature on the subject showed that very few, if any, accidents have occurred when the gas is generated in the open air, for example, when the gas is used in connection with the extensive practice of fumigating citrus trees in California, or oranges in Australia, and that the majority of accidents, which undoubtedly have occurred, have been associated with ships, houses or closed spaces.

The explanation of this important and strikingly different experience in the use of the gas in the two cases was attributed to the fact that it is difficult to obtain a sufficient concentration of the gas in the open air to poison men. It was pointed out that this experience accorded with that obtained during the war when hydrocyanic acid gas was used as a poison gas. It was stated that men are comparatively less susceptible to the poison than other animals. Birds, for example, are very susceptible. Among mammals, dogs are killed in half an hour when exposed to about eight parts of the gas in 100,000 parts of air, cats require 12 parts, rabbits 15 parts, rats 20 parts to kill them, while goats and monkeys require nearly 25 parts. A man requires at least as much as a monkey to kill him.

In low concentrations the gas causes a very disagreeable sensation in the throat and eyes so that it is avoided by persons brought in contact with it.

[1] The expenses of this enquiry were defrayed by the Indian Research Fund Association.

A man becomes unconscious only when exposed to a higher concentration, and, if the concentration which just causes unconsciousness is not increased, a comparatively long latent period supervenes before death. A person, who becomes unconscious when exposed to moderate concentrations of HCN, recovers rapidly when placed in the open air. The gas acts much like an anaesthetic such as chloroform. However, exposure to high concentrations may cause instant death, probably through the action of the poison on the heart.

The deductions drawn from these facts were: (1) that the gas should be generated in the open air if it is to be used with safety, (2) that dumping fixtures should be avoided, not only because they must be placed within the space to be treated, but also because the gas, when generated in this apparatus, is evolved with almost explosive rapidity so that high, and therefore dangerous, concentrations are developed. The necessity for handling the corrosive and poisonous waste in a closed space is an additional drawback to the use of the dumping fixture.

A machine for fumigating with HCN was described which eliminated these drawbacks. The gas is generated in this machine while it is placed in the open air. The poison gas is rapidly and freely diluted with air as soon as it is generated. This air is drawn into the generating box by a fan through an inlet pipe connecting the generating box with the compartment under treatment. The fan, at the same time, drives the air, after poison gas has been added to it, along an outlet pipe from the machine, back into the compartment again. This outlet pipe is fitted with numerous branches, so that the diluted poison gas is liberated at a number of different points in the compartment. As more poison gas is generated, more air is withdrawn from the compartment into the machine, and, after the addition of the poison gas, is passed through the fan, along the outlet pipe, back into the compartment. The air and poison gas in the compartment are thus continuously circulated through the machine. Poison gas is added to the air till a concentration has been obtained sufficient for the purpose required, *i.e.* the destruction of rats, or it may be, the destruction of bugs, or fleas, or other vermin. The concentration of the poison gas in the circulating air can be determined by a delicate chemical test. When a sufficient concentration has been obtained, further addition of poison gas can be stopped, or more can be added at will if the concentration falls. The air mixed with the poison gas is circulated through the machine for such a time as is deemed necessary for the purpose aimed at. When this time is completed the inlet pipe to the machine can be withdrawn from the compartment, or detached from the machine, so that fresh air is substituted for that previously obtained from the compartment. The air mixed with the poison gas is thus gradually replaced by fresh air. A system of artificial ventilation is, in fact, established which materially assists the natural ventilation which is effected after opening up the compartment.

At the time Liston's paper was written an opportunity had not occurred to test his machine on a ship. Through the assistance of the Port Health

Officer, Bombay, and the kindness of the officer in command of the Royal Indian Marine Dockyard, Bombay, the present writers were able to test the efficiency of this fumigator and compare it with that of the dumping fixture so successfully used by the American port authorities.

The present paper deals with these experiments, but, before proceeding to detail them, it may not be out of place to describe the fumigator in greater detail, and, in any case, it is necessary to give a brief description of the ship on which the experiments were carried out.

II. A DESCRIPTION OF THE CYANIDE FUMIGATOR.

The fumigator consists of a box in which the poison gas is generated. On the lid of this box a fan, a petrol motor, and a chemical cabinet are fixed (see Plate II, figs. 1, 2). The petrol motor is capable of driving the fan at 3600 revolutions per minute and at this rate of revolution the fan can deliver 1200 cubic feet of air per minute along a length of pipe at a pressure of 6 inches on a water gauge. The chemical cabinet is divided into three compartments (see Plate II, fig. 2). The compartment on the left is occupied by two glass "containers." These are conveniently made from Winchester quart bottles from which the bottom has been removed. The mouth of each bottle is fitted with a rubber cork through which a glass tube passes. The inverted bottles are placed in a stand. Between the two bottles there is a hole in the lid of the generating box, and, in this hole, a rubber cork is fitted. The cork is perforated by two holes in which two glass tubes are inserted. A connection is made with rubber tubing between the glass tubes in this cork and the glass tubes inserted in the mouths of the inverted bottles, one bottle being connected to one glass tube in the cork, and the other bottle to the other tube. A screw clamp is fixed to each piece of rubber tubing (see Plate III, fig. 4). The glass tubes, which pass through the cork in the lid of the generating box, overhang a sloping platform or channel which passes from the cork, downwards and outwards, to the side of the box. The sloping channel is fitted with small baffle plates so that the fluids, flowing from the containers are thoroughly mixed, as they flow along the channel. One container is reserved for a solution of sodium cyanide, while the other is used for a strong solution of sulphuric acid. The bottom of each bottle is replaced by a slightly hollowed and perforated lead cover. These lead covers serve to strain off particles of matter (sawdust, straw, etc.) which may be suspended in the solutions and, if not filtered off, might block the glass or rubber tubing leading from the containers to the interior of the box; they also serve to prevent drops of the solutions in the containers being splashed out owing to the vibrations caused by the motor when working. The gas is generated within the box by allowing 50 per cent. solutions of sodium cyanide and sulphuric acid to flow at an equal rate upon the sloping channel within the box by so adjusting the clamps, above referred to, that the fluids in the two containers fall at the same rate in line with one

another[1]. The solutions of sodium cyanide and sulphuric acid are readily prepared in stoneware jugs. The sodium cyanide and concentrated sulphuric acid are put up in charges each weighing $\frac{1}{2}$ kilogramme, approximately $1\frac{1}{10}$ lbs. Care has to be taken that the sulphuric acid is added to the requisite quantity of water and that water is not added to the concentrated acid. Two charges require water to be added to 2 litres, a little more than $3\frac{3}{4}$ pints. This is a convenient quantity to make up and fill into each container at one time.

The middle section of the chemical cabinet is occupied by a fitting which can be removed (see Plate III, fig. 3). This fitting contains a Winchester quart bottle filled with a dilute solution of caustic soda in distilled water to which a few crystals of potassium iodide have been added. The fluid in this bottle is used for absorbing the HCN gas from the sample of air to be tested. The fitting also contains one bottle filled with a standard solution of silver nitrate, and another with a solution of caustic soda. There are also two gas absorption bottles in the fitting. An enamelled iron filler is also provided. A drawer will be found below the bottles, in which can be kept a tape measure, various spare parts to replace broken glass tubing in use with the apparatus, a pair of scissors, some spare rubber tubing, keys, spanner and spare parts required for the motor.

The section of the cabinet on the right contains two copper vessels, which are used to aspirate a measured quantity of the poison-charged air from the compartment under treatment. The vessels are of such a capacity as to deliver 5 litres of water from the one to the other, when the small tubes fixed near the bottom of the vessels are connected together by means of rubber tubing, and, when the one containing the water is placed on top of the empty vessel. A small tube, fixed near the top of each vessel, enables either of them at will to be connected to a gas absorption bottle. This bottle, in turn, can be connected to a tube introduced into the compartment under treatment, or to a pipe which is fixed at the back of the chemical cabinet. The connections of this pipe are so arranged that it is possible to obtain a sample of the HCN charged air passing through the outlet pipe of the fumigator. The quantity of air allowed to pass through the gas absorption bottle is measured by the water, 5 litres, which passes from the one copper vessel to the other, when properly adjusted (see Plate III, fig. 4). The concentration of hydrocyanic acid gas present in the 5 litres of the air is ascertained by estimating the quantity of sodium cyanide which is formed in the alkaline solution through which the air has been bubbled[2]. A standard solution of silver nitrate is used for this purpose[3]. It is added to the alkaline solution in the gas absorption bottle

[1] The chemical reaction which takes place when the fluids mix is represented in the following formula:

$$2NaCN + H_2SO_4 = Na_2SO_4 + 2HCN.$$
$$98 \quad + \quad 98 \quad = \quad 142 \quad + \quad 54$$

[2] The chemical reaction which takes place here is represented in the following formula:

$$Air + HCN + NaOH = NaCN + H_2O + Air.$$

[3] The standard silver nitrate solution used contains 1·897 grammes of $AgNO_3$ in 1 litre. 1 c.c. of this solution represents 10 parts of HCN per 100,000 parts of air when 5 litres of air are *drawn for estimation* at normal temperature and pressure (0° C. and 760 mm.).

from a small burette which is fixed on the left-hand side of the chemical cabinet near the glass containers (see Plate III, fig. 4). The standard solution of silver nitrate is added till a faint, but permanent, yellow turbidity is obtained after thorough shaking or stirring. This solution is made up of such a strength that the number of cubic centimetres, required to obtain the first permanent trace of yellow turbidity, multiplied by ten gives the number of parts of HCN in 100,000 parts of the air[1].

When the fumigator is not in use the lid of the box is removed and placed on the ground while the box is inverted over the top of the engine, fan, and chemical cabinet. The box thus serves as a cover and protection for these parts of the machine. The pipes which convey the gas from the outlet pipe of the fumigator into the different parts of the compartment under treatment are packed in sections in special boxes. Another box is used to carry other accessories, such as the metal junction-pieces to connect the sections of pipe together (see Plate III, fig. 3). In this box space is provided for a 2 gallon tin of petrol and a $\frac{1}{2}$ gallon tin of oil for the motor. It also accommodates the stoneware jugs for making the solutions of the chemicals, and a set of three pails for carrying water. A fabric sheet is provided to cover the entrance into the compartment under treatment. This sheet has two sleeves to allow the outlet and inlet pipes to the fumigator to be inserted through the sleeves into the compartment. The box, in addition, contains one dozen charges each of sulphuric acid and sodium cyanide, packed in special receptacles. There is also room for certain other accessories such as string, nails, hammer, wooden battens, etc.

Each machine is thus completely equipped to deal at one time with a maximum of 60,000 cubic feet or 1700 cubic metres using 1 kilogramme or approximately $2\frac{1}{5}$ lbs. of sodium cyanide for every 10,000 cubic feet or 283 cubic metres. A number of machines or units are therefore required to fumigate a ship. They should be worked simultaneously in each section of the ship. A Port Health Officer will require to be provided with ten machines to be efficiently equipped. The fumigator can be used also for fumigating the sheds, stores, or godowns in which cargo is stored preparatory to lading or when unloaded. The quantity of cyanide required per cubic foot for this

[1] The chemical reaction which takes place here may be described as follows:

On adding silver nitrate solution drop by drop to a neutral or alkaline alkali cyanide a white precipitate is formed when the two liquids first come in contact with one another but on stirring it redissolves owing to the formation of a soluble double cyanide of silver and sodium,

$$AgCN + NaCN = AgCN.NaCN.$$

As soon as all the cyanogen is transformed into the double cyanide the next drop of silver solution will produce a permanent turbidity owing to the formation of silver cyanide which is insoluble in water,

$$AgCN.NaCN + AgNO_3 = 2AgCN + NaNO_3.$$

1Ag corresponds to 2CN and the end-point of the reaction is shown by the formation of a permanent precipitate. The addition of potassium iodide to the solution increases the sharpness of the end-point. The precipitate then consists of silver iodide of which one molecule will dissolve in two molecules of *sodium cyanide* just as silver cyanide does.

purpose will generally be greater, but much will depend on the structure of the sheds or stores, and on the ability to make them more or less air tight.

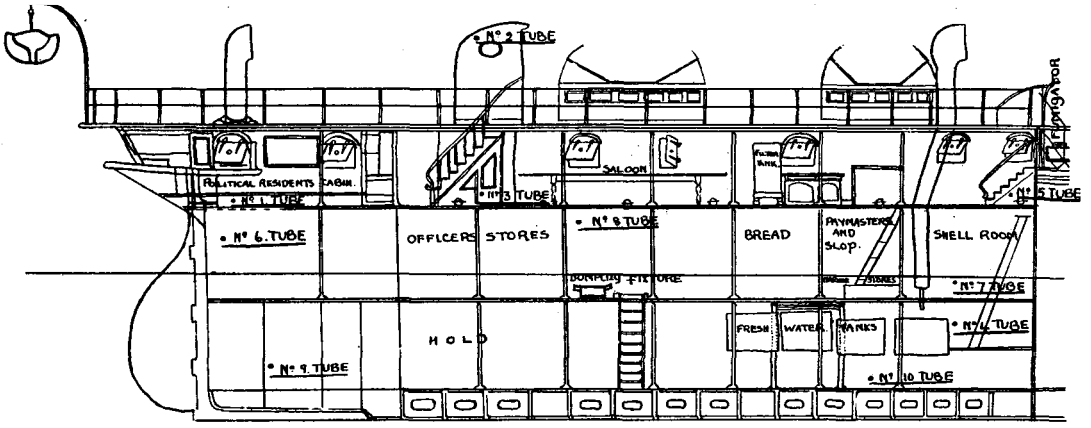
III. A DESCRIPTION OF THE SHIP ON WHICH THE EXPERIMENTS WERE CARRIED OUT.

The experiments, which will be detailed presently, were carried out on the Royal Indian Marine ship "Canning." The ship had been used by His Majesty's Political Resident in the Persian Gulf. It can be divided into three completely separated sections, viz. a stern portion, where the majority of our experiments were done; a central portion, including the engine room, and a bow section, very similar to the stern section. Plans of the stern section are attached to this paper.

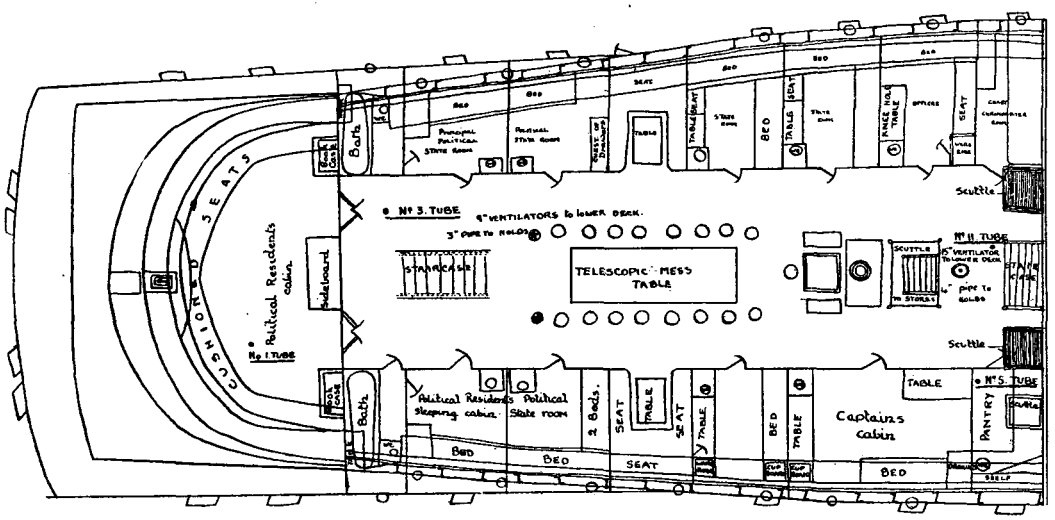
Plan I shows that the ship has three spaces between the decks, *i.e.* one between the upper and main deck, one between the main and lower deck, and a hold below the lower deck. A water-tight bulkhead completely separates the engine room from the stern section. Through the upper portion of this bulkhead a companion way leads to the main deck. The site selected for the fumigator was at the head of this companion way. There is a second companion way aft which leads from the main to the upper deck. Two large skylights admit light and air to the saloon; while three large ventilators, one forward and two aft, also carry air to the spaces between the decks.

Plan II shows that a number of cabins are ranged along each side of the large central saloon on the main deck. There is also a large cabin for the Political Resident in the stern. The cubic capacity of the space between the upper and main decks is approximately 13,000 cubic feet. Gratings are shown on either side of the main staircase. These gratings cover the only access to a specially enclosed compartment in which ammunition is stored. The dimensions of this "shell room" are more clearly shown in Plan III, but it should be noted that this space is completely cut off from the other parts of the ship except through the gratings above referred to. The shell room has a cubic capacity of approximately 1000 cubic feet. The lower deck is reached by a staircase a little aft of the main staircase.

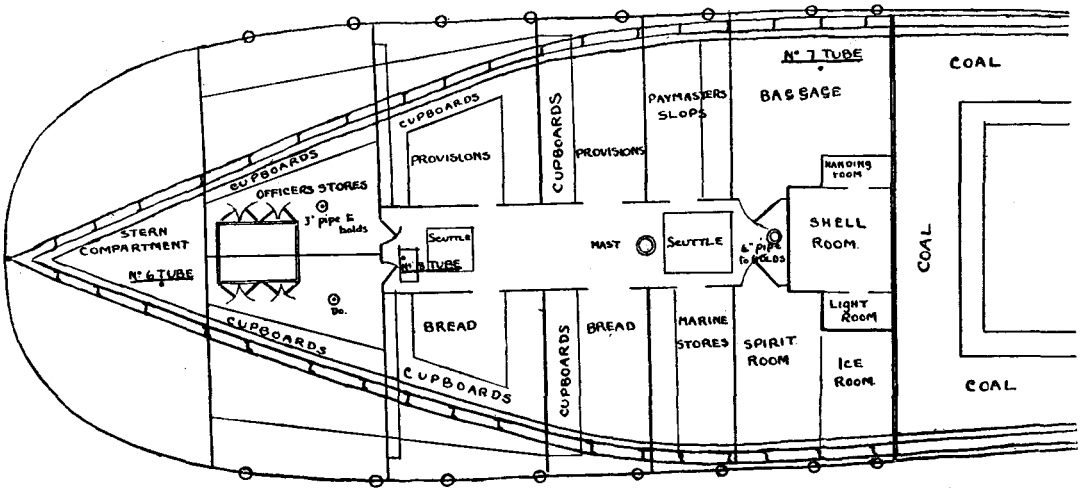
Plan III shows that a passage runs fore and aft along the middle of the lower deck and ends at a bulkhead. Two doors in this bulkhead lead into two separate compartments used for officers' stores. Still further aft another bulkhead is encountered. An oval opening in this bulkhead, 2 feet in vertical diameter, and 3 feet in horizontal diameter, permits entrance to a compartment having a cubic capacity of 858 cubic feet. This compartment is completely shut off from the rest of the ship except through the opening above mentioned. It will be referred to later, when the experiments are detailed, as "the stern end of the lower deck." The spot selected for the dumping fixture is shown on this plan at the stern end of the central passage. It should be noted that two 9-inch ventilators pass through the roof of the compartments used for



Plan I. Vertical section through the stern section of R.I.M.S. "Canning."



Plan II. Plan of the main deck.



Plan III. Plan of the lower deck.

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officers' stores into the saloon on the main deck. These ventilating openings are not far distant from the site of the dumping fixture. On either side of the central passage there are compartments for stores. These compartments are provided with sliding doors. The total cubic space between the main and lower deck is 10,000 cubic feet.

The hold is reached by two openings, one aft and one forward. The former is close to the site selected for the dumping fixture, while the latter is situated at the foot of the staircase leading from the main to the lower deck, and, here, in the hold, are situated the water tanks. The cubic capacity of the hold, including the water tanks, is approximately 9000 cubic feet. The total capacity of the three spaces between the decks is therefore made up as follows:

Above the main deck	13,000	cubic	feet
Below the main deck	10,000	,,	,,
The hold	9,000	,,	,,
Total	32,000	,,	,,

or a total capacity of approximately 30,000 cubic feet when allowance is made for furniture, fittings, etc.

The description of the stern section of this ship shows that it is eminently fitted to test the efficiency of any process of gaseous fumigation.

IV. THE EXPERIMENTS.

Two preliminary experiments were carried out with the fumigator, the first in the stern section and the second in the bow section of this ship. In these experiments samples of the air in the section under treatment were taken from three points by means of glass tubes which could be connected to an aspirator. The three points selected were situated one on each deck, and the samples were taken at intervals during the course of the experiment.

The tabular statements referring to experiments 1 and 2 show the concentration of HCN in parts per 100,000 present in the samples taken from the three selected points at different times during the course of the experiments. In both of these experiments rats were placed in a number of situations or were allowed to run free. They were all killed by the gas except the rats, in the second experiment, which were placed in a cage in a closed, almost air-tight, drawer.

The preliminary experiments were designed to show how simply, safely, and efficiently, the fumigator could be worked on a ship. We had the pleasure of demonstrating the working of the fumigator to Dr Heiser of the Rockefeller Foundation during the first experiment.

The third experiment was designed to compare the dumping fixture with the fumigator. It was carried out in the stern section of the ship. Samples were taken from a certain number of points in addition to those selected in the first two experiments, as will be seen in the table referring to this experiment. The quantity of cyanide and acid used was that recommended by the

Experiment No. 1, *on R.I.M.S.* "*Canning*," *Stern Section, on* 29*th June,* 1922. Fumigator used.

The figures in this table represent the number of parts of HCN in 100,000 parts of air.

Time at which the test was started ...	12.5	12.20	12.30	12.50	1.0	1.10	1.20	4.0	4.10	4.20	4.30	4.50	5.0	5.10	5.20	5.40	5.55
Position at which test was taken:	1 kilo used	3 kls. used	—	—	4 kls. used	5 kls. used	—	—	—	—	—	—	6 kls. used	7 kls. used	opened	—	—
Main deck	8	24	—	—	64	—	—	—	26	—	26	24	—	—	—	—	—
Lower deck	—	—	38	—	—	66	—	—	—	28	—	—	—	—	—	—	—
Hold	—	—	—	60	—	—	84	30	—	—	—	—	30	60	62	28	18

REMARKS. This preliminary experiment was carried out to test the working of the fumigator and for the purpose of demonstrating the use of the fumigator to Dr Heiser of the Rockefeller Foundation who visited the ship at 5 o'clock. At this time more cyanide and acid were added to show how this was done. The increase in the concentration of HCN at 5.10 and 5.20 in the hold will be noted. All rats were killed.

Experiment No. 2, *on R.I.M.S.* "*Canning*," *Bow Section, on* 3*rd July,* 1922. Fumigator used.

The figures in this table represent the number of parts of HCN in 100,000 parts of air.

Time at which the test was started	1.10	1.35	1.45	1.55	2.6	2.20	2.32	4.40	5.2	5.11	5.20
Position at which test was taken:	1 kilo used	3 kls. used	5 kls. used	—	—	—	—	opened	—	—	—
Main deck	—	122	—	154	—	—	78	26	—	—	—
Main deck closed cabin	—	—	—	—	50	—	—	—	—	10	—
Lower deck	—	—	—	—	—	114	—	—	—	—	22
Hold	20	—	60	—	—	—	—	—	16	—	—

REMARKS. Four rats placed in a cage which was hung up at the head of the companion way on upper deck were found dead. Two rats in a slightly opened locker were dead. Four rats let loose on lower deck were all found dead. Two rats in a cage placed in a closed drawer in a cabin on main deck were both alive. Four rats in a cage placed in a partly open locker on lower deck were all dead.

Experiment No. 3, *on R.I.M.S.* "*Canning*," *Stern Section, on 7th July*, 1922. Dumping fixture used.

Space treated, 30,000 cubic feet.
Quantities of chemicals used: Sodium cyanide, 7 lbs.; Sulphuric acid 10½ lbs. (vol.); Water, 14 lbs.

The figures in this table represent the number of parts of HCN in 100,000 parts of air.

Time at which the test was started	11.50	12.2	12.11	12.13	12.26	12.36	12.46	1.1	1.11	1.19	1.32	1.40	4.10	4.18
Position at which test was taken:														
Main deck Political Resident's cabin	—	—	—	—	—	10	—	—	—	—	—	—	8	—
Main deck closed cabin aft	—	—	—	—	10	—	—	—	—	—	—	—	—	8
Main deck open cabin aft	—	—	—	—	—	—	—	—	—	—	10	—	—	—
Main deck open cabin forward	—	—	—	—	—	—	18	—	—	—	—	—	—	—
Main deck closed cabin forward	—	142	—	—	—	—	—	—	30	—	—	—	—	—
Lower deck aft	220	—	—	—	—	—	—	84	—	—	—	—	—	—
Lower deck forward	—	—	—	—	—	—	—	—	—	—	—	36	—	—
Hold aft	—	—	—	10	—	—	—	—	—	18	—	—	—	—
Hold forward	—	—	not working	—	—	—	—	—	—	—	—	—	—	—

REMARKS. The cyanide was dumped at 11.45. The ventilators were opened at 4.25. Two rats were placed in a cage which was hung near roof of main deck at forward bulkhead, both dead by 11.57, 12 minutes after dumping. Two rats in a cage hung near the top of after companion way, both dead at 12.15. Four rats let loose on main deck, two of these were seen alive and running about during the experiment, one seemed very sick but none were found dead at close of experiment.

Experiment No. 4, *on R.I.M.S.* "*Canning*," *Stern Section, on* 10*th July*, 1922. Fumigator used.

Space treated 30,000 cubic feet.
Quantities of chemicals used: 4½ kilos sodium cyanide; 4½ kilos sulphuric acid; Water to 50 % in each case.

The figures in this table represent the number of parts of HCN in 100,000 parts of air.

Time at which the test was started	12.22	12.30	12.45	12.55	1.5	1.25	1.40	1.50	1.57	2.5	4.15	4.37	4.57	5.10	5–17
Position at which the test was taken:															
Main deck Political Resident's cabin	64	—	—	—	—	54	—	—	—	—	26	—	—	—	—
Main deck closed cabin aft	—	120	—	—	—	—	—	—	—	—	—	—	—	—	—
Main deck open cabin aft	—	—	—	—	—	—	27	—	—	—	—	—	—	—	—
Main deck closed cabin forward	—	—	—	—	—	—	—	—	55	—	—	—	—	—	—
Lower deck aft	—	—	—	—	65	—	—	—	—	—	—	23	—	—	—
Lower deck forward	—	—	—	—	—	—	—	62	—	—	—	—	—	—	—
Hold aft	—	—	128	—	—	—	—	—	—	—	—	—	12	18	12
Hold forward	—	—	—	—	—	—	—	—	—	31	—	—	—	—	—
Ammunition compartment	—	—	—	15	—	—	—	—	—	—	—	—	—	—	—
At main companion way	—	96	133	101	102	—	—	—	—	—	21	16	—	—	—

REMARKS. Started running in solutions at 11.15, completed at 12.15. Fan stopped at 1 p.m. Space opened at 4.15 p.m., 5 hours after starting. All rats dead, even those in two cages placed under the cushions in Political Resident's cabin.

American workers. The cyanide was dumped at 11.45, and a sample was taken from a point a little aft of the situation of the dumping fixture five minutes later. A concentration of 220 parts of HCN per 100,000 parts of air was noted. The second sample was taken from the pantry near the forward bulkhead on the main deck. The door of this pantry was closed. We were surprised to find that a concentration of 142 parts of HCN per 100,000 was present in this closed space about a quarter of an hour after dumping the cyanide. Be it noted that this pantry is situated at a considerable distance away from the dumping fixture, and on the deck above it. Our surprise was the greater when subsequent samples, taken from other places on the main deck and in the hold, showed so low a concentration as 10 parts per 100,000. A study of the table referring to this experiment shows, that high concentrations were recorded only on the lower deck and in the closed pantry on the main deck. Rats were rapidly killed which were placed in cages in a number of situations. Those for example placed near the roof of the main deck close to the pantry were dead in 12 minutes. Those placed in the companion way aft were dead in half an hour. While this was the case, we were able to observe, through the windows, that the rats we had released from cages on the main deck were running about. One of them indeed appeared to be very sick, but, when the section was opened some hours later, the rat had recovered, for no dead rats were found, although a search was made. After some consideration we came to the conclusion that the poison gas generated in the dumping fixture passed very rapidly along the roof of the lower deck, through the companion way leading to the main deck, then, rising to the roof of the main deck, it passed forward and aft. The passage of the gas forward was checked by the forward bulkhead. The rats placed here were soon killed. The gas, checked at this point, seems to have passed through the ventilating screen above the door of the closed pantry causing a high concentration to be developed in that closed space. The poison gas passed aft along the roof till it came to the companion way leading to the upper deck; it rose in the companion way producing a sufficient concentration to kill the rats placed there in less than half an hour. Meanwhile, the poison gas became more and more diffused and diluted with air, so that in no part of the main deck or hold, where samples were obtained, did the concentration of the HCN rise above 18 parts per 100,000. It was not, therefore, to be wondered at that the rats let loose on the main deck remained alive.

In the fourth experiment the fumigator was used. Samples were taken from the same points as in the previous experiment in which the dumping fixture was used, except that, in place of the sample taken from an open cabin on the main deck forward, a sample was taken from the Ammunition Room, a portion of the ship which we considered would not get much poison gas because of its seclusion. In addition, a second aspirator was used, and with this aspirator samples were taken consecutively from a point near the inlet pipe to the fumigator, *i.e.* just in front of the curtain which closed the com-

panion way leading to the main deck. It should be noted that, when using the fumigator in this experiment, considerably more cyanide was employed than in the first dumping fixture experiment. The quantity of cyanide used was 4½ kilos or approximately 9·9 lbs. contrasting with 7 lbs. used with the dumping fixture. In this case rats were placed in two cages under the cushions on the seat surrounding the Political Resident's Cabin, as well as in the other situations mentioned above. The maximum concentration of HCN was above 27 parts in 100,000 at all points tested, except in the ammunition compartment. The sample taken from this room showed only 15 parts of HCN per 100,000 half an hour after starting. A higher concentration may have developed here a little later, but no sample was subsequently taken. The section was opened up 5 hours after starting, and it was found that all the rats were killed.

Our next experiment, the fifth, was designed to test whether the dumping fixture was more efficient when a larger quantity of cyanide was used, than in the first dumping fixture experiment. The first dumping fixture experiment, we have seen, had been only partially successful. The quantity used in this experiment was very slightly in excess of that used with the fumigator, to wit, 10 lbs. of sodium cyanide in place of 9·9 lbs. used in the fumigator. The concentration of the poison gas was tested in samples taken from the same places as in the previous experiment, with an additional sample from an open cabin forward, quite close to the closed cabin or pantry, which, in the first dumping fixture experiment, showed a very high concentration of the poison gas. The experiment was remarkable in confirming our previous finding, namely, that the poison gas, generated in the dumping fixture, rose rapidly to the highest point in the section. Checked in its passage along the roof of the main deck by the forward bulkhead, it filled the closed cabin or pantry near that bulkhead, causing a high concentration of the poison gas to be developed here. A pocket of poison gas was thus formed. For example, immediately aft of the dumping fixture on the lower deck a concentration of 143 parts of HCN in 100,000 was recorded 10 minutes after dumping the cyanide. Fifteen minutes later 181 parts of HCN in 100,000 parts was recorded at this point, while half an hour later, as much as 288 parts of HCN per 100,000 parts were found in the closed pantry. At this very time, only a yard or two distant, but shut off by a door, at a point near the foot of the main staircase 20 parts of HCN per 100,000 parts was noted. So far as rats were concerned the experiment was as successful as the previous one, when the fumigator was used, that is to say, all rats were killed.

In any subsequent experiment we were impressed with the need of obtaining consecutive and contemporaneous estimations of the concentrations of the poison gas in the air taken from a number of points in the section of the ship under treatment. Accordingly, arrangements were made to fix up ten aspirators, and to take ten samples at one and the same time. Plate IV, fig. 6, shows that we used one gallon Mobiloil tins as aspirators. They were connected together in pairs, and 4700 cubic centimetres of water, approxi-

Experiment No. 5, on R.I.M.S. "Canning," Stern Section, on 12th July, 1922. Dumping fixture used.

Space treated, 30,000 cubic feet.
Quantities of chemicals used: Sodium cyanide, 10 lbs.
Sulphuric acid, 15 lbs. (vol.).
Water, 20 lbs.

The figures in this table represent the number of parts of HCN per 100,000 parts of air.

Time at which the test was started	2.15	2.30	2.38	2.45	3.0	3.15	3.23	3.30	3.39	3.47	3.55	4.5	4.12	4.17	4.30	4.39	4.47	4.56	5.3	5.13
Position at which the test was taken:																				
Main deck Political Resident's cabin	—	—	—	—	—	—	—	36	—	—	27	—	—	—	—	—	—	—	—	—
Main deck closed cabin aft	—	—	—	—	—	—	—	—	—	33	—	—	—	—	—	—	—	—	—	—
Main deck open cabin aft	—	—	—	—	—	—	—	—	—	—	20	21	—	—	—	—	—	—	—	—
Main deck open cabin forward	—	—	—	—	—	—	—	—	—	—	—	38	—	34	—	—	—	—	—	—
Main deck closed cabin forward	—	—	—	288	—	—	—	—	98	—	—	—	56	—	—	—	—	—	—	—
Lower deck aft	143	181	—	—	146	—	132	—	—	—	—	—	—	52	—	—	—	—	—	—
Lower deck forward	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	45	—	42	—	—
Hold aft	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	39	—	—	—
Hold forward	—	—	—	—	—	—	25	—	—	—	—	—	—	—	—	—	—	—	—	22
Ammunition compartment	—	—	—	—	—	22	—	—	—	—	—	—	—	—	—	—	—	—	21	—
At main companion way	25	28	21	20	19	19	—	21	—	19	—	—	—	—	—	—	—	—	—	—

Remarks. The cyanide was dumped at 2.10. Note more cyanide was used in this experiment than the quantity recommended by the American workers, but almost the same quantity as was used in the previous experiment with the fumigator. The space was opened at 5.20, approximately 3 hours after starting the experiment. All rats were found dead.

mately equal to one-sixth of a cubic foot, was allowed to flow from one tin, placed at a higher level, into the other, at a lower level, when a spring clip, on the rubber tubing connecting the two tins together, was released. Each aspirator was connected to one of a series of glass tubes which passed to ten different points in the ship through the screen covering the main gangway. Plate V, fig. 7, shows the view on the inner side of the screen closing the main gangway. The inlet pipe to the fumigator will be noticed on the left, while, immediately to the right, is the outlet pipe from the fumigator. As we have seen, this pipe conducts the poison gas to different parts of the ship. One branch pipe is shown conveying gas to the main deck, while the larger pipe passes down the gangway to the lower deck and the hold, where branch pipes are given off. Still further to the right, a bunch of glass tubes will be noted. These tubes lead to a number of different parts of the ship, and are the means by which samples of the air in different parts are secured. Each of these glass tubes is ultimately connected to one of the aspirators shown in Plate IV, fig. 6. These arrangements enabled us to take a number of samples simultaneously from different parts of the ship every 15 minutes, so that we could study the changes in the concentration of HCN in the section of the ship under treatment during the course of the experiment.

The sixth experiment, as the table referring to this experiment shows, was carried out with the dumping fixture. The same quantity of cyanide was used

Experiment No. 6, *on R.I.M.S.* "*Canning*," *Stern Compartment, on* 14*th July*, 1922. Dumping fixture used.

Quantities of chemicals used: Sodium cyanide, 10 lbs.
Sulphuric acid, 15 lbs. (vol.).
Water, 20 lbs.

The figures in this table represent the number of parts of HCN in 100,000 parts of air.

Time at which the test was started		2.48	3.2	3.15	3.30	3.45	4.0	4.15	4.34	5.50
Number of minutes after starting experiment during which sample was taken		1–7	15–22	30–37	45–52	60–67	75–82	90–97	106–113	182–189
Tube										
1	Main deck Political Resident's cabin	2	16	20	40	46	52	**60**	42	36
2	Main deck companion way aft	18	36	**82**	38	64	30	44	24	28
3	Open cabin on main deck	2	24	34	32	**38**	32	36	34	32
4	Ammunition compartment	10	8	14	18	24	26	28	**30**	30
5	Closed pantry on main deck	88	**730**	414	244	176	134	112	96	56
6	Stern end of lower deck	28	134	**190**	184	182	156	154	134	104
7	Forward end of lower deck	10	50	**258**	226	176	148	124	112	68
8	Over dumping fixture lower deck	**608**	216	246	240	196	164	146	118	78
9	Stern end of hold	4	22	26	42	48	62	68	**78**	58
10	Forward end of hold	14	66	98	108	**110**	106	102	94	70

REMARKS. In this experiment ten aspirators were used. Tests were taken simultaneously from ten different parts of the ship. The tests were repeated every 15 minutes. The cyanide was dumped at 2.47 and the space was opened at 5.57, 3 hours later. The maximum concentration found over the generating box was 608 parts per 100,000. A pocket was formed in the closed cabin on the main deck forward where a concentration of 730 parts per 100,000 was noted within the first 20 minutes of the experiment. The lowest maximum concentration in any part of the ship was found in the ammunition compartment about 2 hours after the starting of the experiment. The quantity of cyanide used in this experiment was the same as that used in the previous experiment, *i.e.* rather more than is recommended by the American workers. All rats were killed. No record was taken of the rate at which the gas disappeared from the ship after the ventilators were opened.

as in the previous successful experiment, *i.e.* 10 lbs. This experiment brings out, more clearly than the previous experiment, the rapid evolution of gas at the site of the dumping fixture. The table referring to this experiment shows, that a concentration of 608 parts of HCN in 100,000 was obtained at this point during the first 7 minutes after dumping the cyanide. Between 15 and 20 minutes after dumping, the concentration of HCN here had fallen to 216 parts per 100,000, while, at that time, it had risen to as much as 730 parts per 100,000 in the closed pantry on the main deck at the forward bulkhead. Again a pocket of poison gas had formed at this point. Within the next 15 minutes, 82 parts of HCN per 100,000 was recorded at the head of the after companion way. The lowest maximum concentration of HCN, 30 parts per 100,000, was found in the ammunition compartment, about 2 hours after starting the experiment, showing that some time was required for the gas to reach this somewhat remote and enclosed part of the ship. Rats placed in cages in different parts of the ship were all killed.

In the seventh experiment the fumigator was used with $4\frac{1}{2}$ kilos of cyanide or 9·9 lbs. The section was closed for 2 hours only, but the fan continued to work for 2 hours longer assisting the natural ventilation. A study of the table referring to this experiment will show: (1) That the maximum concentrations of the poison gas in all parts were obtained within $1\frac{1}{4}$ hours after starting; (2) That the maximum concentration in any part was not higher than 217 parts per 100,000; while the lowest maximum concentration in any part was obtained in the ammunition compartment, where 22 parts of HCN per 100,000 was noted. The second lowest maximum was found in the stern compartment on the lower deck (52 parts per 100,000). Both these compartments, as we have explained, are inaccessible and shut off from the rest of the ship except by narrow openings. The artificial ventilation, caused by the working of the fan, materially assisted the rapid clearing of the poison gas from the ship. The ventilation of the ship was sufficiently completed in 4 hours to allow it to be handed over to the crew without danger of accidents.

The eighth experiment was a repetition of the seventh, but, in this case, an attempt was made to obtain higher concentrations of the poison gas in the ammunition and stern compartments. With this object in view, the arrangement of the pipes conducting the gas to different parts of the ship was altered, so that a pipe of smaller diameter conveyed the gas to the main deck, while a branch 2 inches in diameter led the gas into the ammunition compartment. The pipe conveying gas to the stern end of the lower deck was also extended further into the compartment for officers' stores, which is adjacent to the remote and enclosed stern compartment on the lower deck. As a result of this rearrangement of pipes, the table referring to this experiment shows that a high concentration, as much as 540 parts of HCN per 100,000 parts was obtained in the ammunition compartment, and 92 parts of HCN per 100,000 in the stern compartment contrasting with 22 and 52 parts of HCN per 100,000 respectively in these compartments in the previous experiment. It is thus

Experiment No. 7, on R.I.M.S. "Canning," Stern Section, on 15th July, 1922. Fumigator used.

Space treated, approximately 30,000 cubic feet.
Quantities of chemicals used: 4½ kilos sodium cyanide.
4½ kilos sulphuric acid.
Water to 50 % added in each case.

The figures in this table represent parts of HCN per 100,000 parts of air.

Time at which the test was started		2.47	3.0	3.15	3.30	3.45	4.0	4.15	4.30	4.47	5.0	5.15	5.30	5.48	6.0	6.15
Number of minutes after starting experiment during which sample was taken		1–7	16–22	30–37	45–52	60–67	75–82	90–97	105–112	120–127	135–142	150–157	165–172	180–187	195–202	210–217
Tube	Number of charges in kilos passed into generating box	2	2½	Total 4½ kilos in half an hour.												
1	Main deck Political Resident's cabin	15	46	91	**120**	104	91	82	71	60	26	11	3	4	3	3
2	Main deck companion way aft	13	106	79*	**102**	62	54	84	43	53	10	10	6	4	5	4
3	Open cabin on main deck	10	62	103	**105**	99	91	79	73	64	22	14	12	4	4	4
4	Ammunition compartment	6	7	10	17	**22**	20	19	21	**23**	17	16	14	10	6	10
5	Closed pantry on main deck	6	30	76	117	**123**	107	98	89	75	**41**	23	21	16	15	22
6	Stern end of lower deck	15	27	42	44	47	**52**	49	53	50	49	**43**	40	30	30	28
7	Forward end of lower deck	10	22	48	80	**83**	82	81	74	68	62	52	43	32	26	25
8	Over dumping fixture on lower deck	123	216	**217**	165	134	112	98	87	72	50	34	30	23	20	20
9	Stern end of hold	76	129	**144**	118	105	91	84	65	67	55	47	33	30	27	25
10	Forward end of hold	28	130	**155**	122	108	92	92	83	73	66	53	42	37	27	23

REMARKS. This experiment was started at 2.47. The last readings were made at 6.30. The space was opened up at 4.47, 2 hours after starting. The fan continued working till 6.30. The ship was then fit to be used, less than 4 hours after starting. The maximum concentration obtained in this experiment was 217 parts per 100,000 in the middle of the lower deck. The maximum concentrations were obtained in all parts between 30 and 60 minutes after starting except in the ammunition compartment and the compartment at the stern of the lower deck. The lowest maximum concentration in any part was 23 in the ammunition compartment. All rats were killed. The quantity of cyanide used was rather less than 10 lbs. while only 10 lbs. by weight of H_2SO_4 were used.

* No. 2 tube leaking a little.

Experiment No. 8, on R.I.M.S. "Canning," Stern Section, on 18th July, 1922. Fumigator used.

Space treated, approximately 30,000 cubic feet.
Quantities of chemicals used: 4½ kilos sodium cyanide.
4½ kilos sulphuric acid.
Water added in each case to 50 %.

The figures in this table represent parts of HCN per 100,000 parts of air.

Time at which the test was started		2.45	3.0	3.15	3.29	3.45	4.0	4.15	4.30	4.45	5.0	5.15	5.30	5.45	6.0	6.15	6.30	6.45
Number of minutes after starting the experiment during which the sample was taken		1–7	16–22	30–37	45–52	60–67	75–82	90–97	105–112	120–127	135–142	150–157	165–172	180–182	195–202	20–217	225–232	240–247
Number of charges in kilos passed into generating box		3	1½	Total 4½ kilos in ½ hour.														
Tube																		
1	Main deck Political Resident's cabin	4	7	20	47	56	**57**	55	38	43	14	8	5	5	2	2	2	—
2	Main deck companion way aft	4	37	87	**95**	82	73	73	62	39	10	4	7	3	6	2	2	4
3	Open cabin on main deck	4	29	63	63	72	66	60	27	28	11	6	3	4	4	4	2	5
4	Ammunition compartment	251	**540**	325	205	162	134	122	100	91	59	50	43	28	28	24	20	14
5	Closed pantry on main deck	4	29	87	123	134	**138**	122	115	64	18	12	11	8	8	4	6	6
6	Stern end of lower deck	26	86	**92**	86	86	84	77	76	73	72	58	55	44	38	35	32	28
7	Forward end of lower deck	365	**496**	306	207	163	139	119	108	70	38	33	25	19	17	18	13	12
8	Over dumping fixture on lower deck	91	**279**	234	204	163	141	128	111	100	54	61	48	41	36	28	23	23
9	Stern end of hold	45	**147**	141	127	105	101	95	87	82	74	46	38	33	28	23	21	23
10	Forward end of hold	25	**144**	127	106	94	82	79	84	80	70	64	55	50	41	36	34	29
11	At inlet to machine	40	141	**155**	141	135	120	104	97	28	14	18	5	3	4	7	6	4

Remarks. This experiment started at 2.45 and closed at 6.45. The space was opened 2 hours after starting and it was ventilated by the fan for 2 hours. This experiment is a repetition of the previous experiment with a different distribution of pipes delivering gas. In this case a 2-inch pipe, for example, was passed into the ammunition compartment, hence the high concentrations in that compartment. A 2-inch tube also led the gas well into the room immediately forward of the almost completely closed compartment in which Tube 6 was placed. Two 3-inch tubes led the gas into the hold, each of those giving off two 2-inch tubes fore and aft in the hold. The high concentration developed early will be noticed in these places where large pipes conducted the gas to them. All the maximum concentrations were obtained within an hour and a quarter of starting the experiment. The ship was practically safe for occupation 4 hours after starting. All rats were killed.

possible, at will, to regulate the concentration of the gas in any compartment which may require special attention. All the maximum concentrations were obtained within 1¼ hours after starting. The section was opened up 2 hours after starting, natural ventilation being assisted by the fan for 2 hours longer. The ship was then ready to be handed back to the crew. All rats were killed, as might have been expected, for the concentration of the poison gas in every part of the ship was considerably in excess of that required for this purpose.

The remaining experiments were designed to show whether a smaller quantity of cyanide could be used with success. In the ninth experiment 7 lbs. were used with the dumping fixture. As usual a very high concentration, 586 parts of HCN per 100,000, was obtained at once over the dumping fixture, while 61 parts of HCN per 100,000 were obtained within 20 minutes in the closed pantry on the main deck. Except in, and near, this cabin a sufficient concentration of the poison gas to kill rats was not obtained on the main deck. While rats placed in a cage at the roof near the forward bulkhead were soon killed, those in the after companion way, although seriously ill, recovered. All the other rats placed on the main deck remained well. The maximum concentrations were not obtained in some places till nearly 2 hours after starting the experiment. The maximum concentration obtained in any place was 586 parts per 100,000 over the dumping fixture; and the lowest maximum was found in the main deck companion way, where only 20 parts of HCN per 100,000 were obtained. The section was opened 2 hours after starting, but high concentrations, *i.e.* between 30 and 40 parts of HCN per 100,000, were still obtained 2 hours later in the closed pantry on the main deck, on the lower deck, and in the hold. The ship was not safe to be handed over to the crew at the end of 4 hours.

The tenth experiment was carried out with the fumigator, using only 6 lbs. of cyanide, or rather less than the quantity used in the last experiment with the dumping fixture. The pipes conveying the poison gas were so arranged that a 4-inch pipe distributed the gas on the main deck, and a 1-inch branch from this served the ammunition room. The other 4-inch pipe distributed gas to the lower deck and the hold. A reference to the table concerned with this experiment will show; (1) that the maximum concentrations in every part were obtained within three quarters of an hour after starting: (2) that the highest maximum concentration of the poison gas was only 154 parts per 100,000, and that the lowest (33 parts per 100,000) was obtained in the inaccessible stern compartment on the lower deck. Even this concentration of the poison gas was well above that needed to kill rats; (3) that the section was opened up 2 hours after starting; and (4) that with the assistance of the artificial ventilation, created by the fan, the ship was fit to be handed over to the crew 3 hours after starting the experiment. All rats were killed, even those placed in cages beneath the cushions in the Political Resident's cabin.

Experiment No. 9, on R.I.M.S. "Canning," Stern Section, on 19th July, 1922. Dumping fixture used.

Space treated, approximately 30,000 cubic feet.
Quantities of chemicals used: Sodium cyanide, 7 lbs.
Sulphuric acid, 10½ lbs. by vol.
Water, 14 lbs.

The figures in this table represent parts of HCN in 100,000 parts of air.

Time at which the test was started		2.48	3.0	3.15	3.30	3.45	4.0	4.15	4.30	4.45	5.0	5.15	5.30	5.45	6.0	6.15	6.30	6.45
Number of minutes after starting the experiment during which the samples were taken		1–7	16–22	30–37	45–52	60–67	75–82	90–97	105–112	120–127	135–142	150–157	165–172	180–187	195–202	210–217	225–232	240–247
Tube																		
1	Main deck Political Resident's cabin	6	7	9	10	15	15	16	**22**	16	16	8	4	2	3	5	3	2
2	Main deck companion way aft	5	11	20	19	20	out of order											
3	Open cabin on main deck	4	9	11	14	13	17	19	**22**	22	12	2	6	4	7	2	3	10
4	Ammunition compartment	7	9	23	25	28	29	30	**31**	27	20	12	12	11	8	7	6	6
5	Closed pantry on main deck	13	**61**	53	41	36	34	32	29	30	35	36	36	26	24	24	11	20
6	Stern end of lower deck	21	79	**91**	86	84	77	67	68	63	61	60	55	52	50	50	49	44
7	Forward end of lower deck	121	**293**	189	100	116	100	90	82	73	68	58	57	50	46	40	39	43
8	Over dumping fixture on lower deck	**586**	218	179	138	124	112	105	96	90	72	70	59	53	42	41	38	36
9	Stern end of hold	5	47	81	**92**	87	83	79	72	62	58	54	47	40	38	35	34	33
10	Forward end of hold	7	64	**120**	112	107	93	82	80	69	62	60	48	42	39	35	31	32
11	At the main companion way	16	34	38	34	**41**	37	37	34	23	5	5	3	4	3	3	3	3

Remarks. This experiment was started at 2.48 and abandoned at 6.45, 4 hours later. In this dumping fixture experiment the quantities of acid and cyanide used were those recommended by the American workers. Only some of the rats exposed to the gas were killed. Those placed under the cushions in the Political Resident's cabin and those in the companion way near Tube 2 survived. The latter were very sick but recovered. The concentration was very high over the dumping fixture, also in the forward end of the lower deck and in the closed pantry. The slow rate at which the gas was eliminated is clearly shown when the figures are compared with those recorded in the previous experiment in which the fumigator was used. The maximum concentration in the main deck cabins did not appear till nearly 2 hours after starting the experiment, even then the concentration of HCN was not sufficiently high to kill rats. The lowest maximum concentration obtained in any place was 20, while the highest concentration was 586. The ship was not safe for occupation 4 hours after starting, when the experiment was abandoned.

Experiment No. 10, *on R.I.M.S.* "*Canning,*" *Stern Section, on 24th July,* 1922.

Fumigator used.

Cubic space treated, approximately 30,000 cubic feet.
Quantities of chemicals used: Sodium cyanide, 6 lbs.
Sulphuric acid, 6 lbs. by weight.
Water to make up 50 % solution of each.

The figures in this table represent parts of HCN in 100,000 parts of air.

Tube	Time at which the test was started	2.48	3.3	3.18	3.33	3.48	4.3	4.18	4.33	4.48	5.3	5.18	5.33	5.48
	Number of minutes after starting the experiment during which the sample was taken	1–7	16–22	30–37	45–52	60–67	75–82	90–97	105–112	120–127	135–142	150–157	165–172	180–187
1	Main deck Political Resident's cabin	8	13	33	**56**	48	40	35	32	19	9	10	2	0
2	Main deck companion way aft	7	7	**53**	46	46	42	35	32	29	18	7	4	5
3	Open cabin on main deck	5	55	**77**	58	49	43	35	32	12	6	3	3	3
4	Ammunition compartment	4	26	39	**39**	31	29	32	27	20	18	14	15	10
5	Closed pantry on main deck	7	39	**88**	76	65	57	48	42	29	21	15	12	14
6	Stern end of lower deck	7	19	**33**	23	24	27	25	22	20	17	16	16	14
7	Forward end of lower deck	8	**119**	104	88	67	60	56	50	43	32	25	21	18
8	Over dumping fixture on lower deck	24	**118**	107	99	73	63	57	53	44	35	29	26	22
9	Stern end of hold	9	69	**85**	77	69	65	55	50	49	39	22	31	26
10	Forward end of hold	5	60	**87**	76	72	64	60	52	48	42	34	29	26
11	At the main companion way	135	**154**	99	68	71	62	50	49	15	5	3	3	1

REMARKS. This experiment was started at 2.48 and completed in 3 hours when the ship was fit for occupation. It is a repetition of Experiments 7 and 8 with the following important differences. The quantity of cyanide used was much reduced, 1 lb. less than the Americans recommend. The distribution of the pipes was altered.—A 4½-inch pipe supplied the gas to the main deck while a similar pipe conveyed the gas to the lower deck and hold. A 1-inch pipe led gas into the ammunition chamber while a 2-inch pipe allowed the gas to escape near the main companion way. A 3-inch pipe with branches carried the gas further aft than previously towards the Political Resident's cabin. One 3-inch pipe with two 2-inch branches carried the gas to the lower deck and a 3-inch pipe with two 2-inch branches to the hold. All rats were killed. The maximum concentrations were obtained in less than half an hour. The rapid decrease in the concentration of the poison gas after the section was opened at 4.48 is in marked contrast to the results obtained in the previous experiment where the dumping fixture was used. The lowest maximum concentration obtained in any place was 33 and the highest not more than 154.

V. CONCLUSIONS.

(1) These experiments prove that the fumigator is safer to use than the dumping fixture, because high concentrations of the poison gas are avoided, so that dangerous pockets are not developed.

(2) The poison gas is more evenly distributed over the different parts of the section of the ship under treatment.

(3) High concentrations, however, can be developed at will in any part which requires special attention.

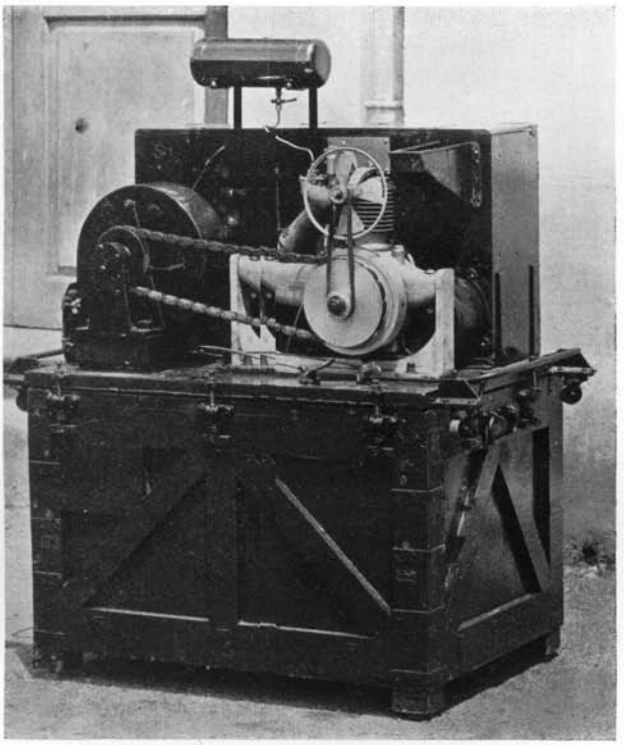

Fig. 1

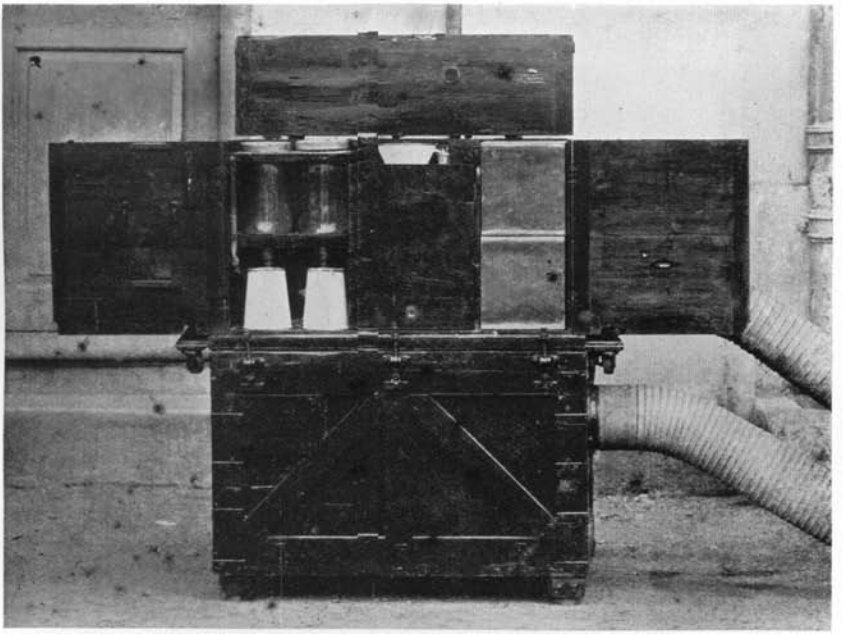

Fig. 2

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(4) The maximum concentrations of the poison gas were obtained in every part of the section in a shorter time, when the fumigator was used, than when the dumping fixture was employed.

(5) The artificial ventilation caused by the fan, which is capable of blowing into the section 500 to 1000 cubic feet of fresh air per minute, according to the speed of the motor, materially assists the rapid clearing of the poison gas from the ship, after it has accomplished its work. It is thus possible to complete the fumigation and ventilation of a ship in 3 hours using the cyanide fumigator, while more than 4 hours are required for the dumping fixture.

(6) Even more important is the fact that smaller quantities of cyanide can be used with greater efficiency in the fumigator, than larger quantities, with less efficiency in the dumping fixture.

(7) The general conclusion is arrived at, that, from the point of view of efficiency, safety and economy, the fumigator is superior to the dumping fixture. Creel has shown that, in respect to the time required for completing the fumigation, and in respect to the thoroughness of the process, both in killing rats and insects, the dumping fixture is superior to the Clayton gas machine. It follows, therefore, that the cyanide fumigator is very much superior in these respects to the Clayton gas machine.

EXPLANATION OF PLATES II—V.

PLATE II.

Fig. 1. Shows motor, fan and chemical cabinet placed on the generating box. The attachments for the inlet and outlet pipes, as well as the sloping channel on which the fluids are mixed within the generating box are shown as they are packed when covered by the generating box, *i.e.* not in their working position.

Fig. 2. Shows the chemical cabinet opened but not unpacked. The inlet and the outlet pipes are attached in the working position.

PLATE III.

Fig. 3. Shows the chemical cabinet unpacked. The articles contained in the central compartment are placed on the box provided for other accessories.

Fig. 4. Near view of chemical cabinet. Aspirator arranged to take a sample of gas.

PLATE IV.

Fig. 5. Shows inlet and branching outlet pipes. Only a few branches are shown.

Fig. 6. Shows the arrangements made to take ten samples simultaneously every 15 minutes. Note the fabric screen covering the main companion way. The outlet pipe from the fumigator is shown passing through the sleeve in this curtain.

PLATE V

Fig. 7. Shows the arrangement on the inner side of the fabric screen. Note the inlet pipe on the left and the branching outlet pipe on the right. Also the glass tubes for collecting samples passing up through the curtain.