# REPORT ON THE INVESTIGATION INTO THE DESTRUCTION OF VERMIN BY HYDROGEN CYANIDE, WITH ESPECIAL REFERENCE TO BED BUGS

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PLATE II

This investigation was carried out at the request of the Liverpool Port Sanitary Authority.

The work was done with the collaboration of Professor W. H. Roberts, Drs. W. Hanna and F. C. White.

The object of the enquiry was to determine the efficacy of various strengths of Hydrogen Cyanide in the destruction of vermin, especially bed bugs, under natural conditions on board ship.

Preliminary experiments with this gas were conducted in a lethal chamber on the roof of the Public Health Laboratory, the final experiments on board ship.

A summary of the experiments is given on p. 117, and recommendations as to the use of Hydrogen Cyanide on p. 118.

## HAUNTS OF THE BED BUG

Certain bug-infested houses and quarters on board ship were inspected for the purpose of ascertaining the various conditions under which these insects live. The conditions observed were, as far as possible, reproduced in the test experiments with the hydrogen cyanide.

Bed bugs, as their name suggests, are to be found chiefly in bedrooms and sleeping quarters, places which will afford them an

opportunity of feeding on their host (man) during the night. Being insects which shun light, they withdraw during the day to any retreat which will give them shelter from the light. From these places they come out only at night for the purpose of feeding. The eggs are laid in their day-time haunts.

In houses, the situations favoured by these insects are :—cracks between woodwork fittings and the wall, such as are afforded by brackets or racks nailed or screwed on to the wall ; by badly fitting door frames and mantel-pieces ; behind pictures, especially underneath the paper backing where this is broken ; behind old wall-paper which is peeling off the walls ; cracks in plaster ; hangings, such as curtains, or mantel-covers ; bed-frames, especially in the case of bedsteads with hollow or tubular iron frames.

In ships similar conditions will afford shelter to the bugs, but one or two special ones require attention. Thus the tongue and groove boarding, which so often covers the partitions, or two thicknesses of which form the actual partition, forms a very good refuge, especially when there is a certain amount of air space behind the tongue and groove boarding, into which the bugs can penetrate.

The frame-work of the bunks also seems to be of some importance. In one ship that was investigated, the bunks were put up in sections, and the joints were furnished with collars with slots (see Plate II, fig. 1), in which accumulations of cast skins and living bugs were found. Of greater importance, however, was the fact that the frames of certain types of bunks were hollow tubes with small openings at the ends (fig. 3, B). In the case of the upright stanchions (fig. 3, C), the top end fitted loosely into a socket, whilst the bottom end was let into the deck. The loose fitting socket at the top was of such a nature as to allow the bugs easy access into the tube, whilst the gas, owing to its lightness, would penetrate down the tube only slowly and with difficulty.

A third form of refuge on board was found in a pile of life-jackets observed on one ship. In the folds of the canvas covering of these, bugs were found, and it was thought possible that the insects might penetrate to their interior. Piles of bedding, old clothes, and other such articles might form a similar refuge.

Most of the situations which have been mentioned—crevices in wood-work, cracks in plaster, etc., do not afford the bugs efficient

protection against the gas. Three cases, however, required special attention :— (1) match-boarding with a cavity behind, into which the bugs could retreat ; (2) tubular iron bunk frames ; (3) life-jackets, piles of bedding, old clothes, etc. The first of these cases was investigated by means of a specially constructed box which will be described below ; the second, by means of glass tubes, as will also be described below ; and the third, by using similar life-belts.

## DESCRIPTION OF APPARATUS USED

*Pill Boxes* (card-board). Those used were about 5 cms. in diameter, and 3·5 cms. in height. They proved to be readily permeable to the Hydrogen Cyanide, and appeared to afford no protection to the bugs.

In the first experiments, in order that some sort ot protection from the gas should be afforded, the bugs were placed between two layers of felt in the bottom of the pill box, which was then loosely packed with cotton wool, flannel, paper, etc. This packing appeared to make no difference to the efficacy of the gas.

*Glass Jars* (fig. 1). In many of the experiments the pill boxes were placed inside glass jars of the type used for preserving fruit. These jars had a capacity varying between 930 and 960 c.cs., having

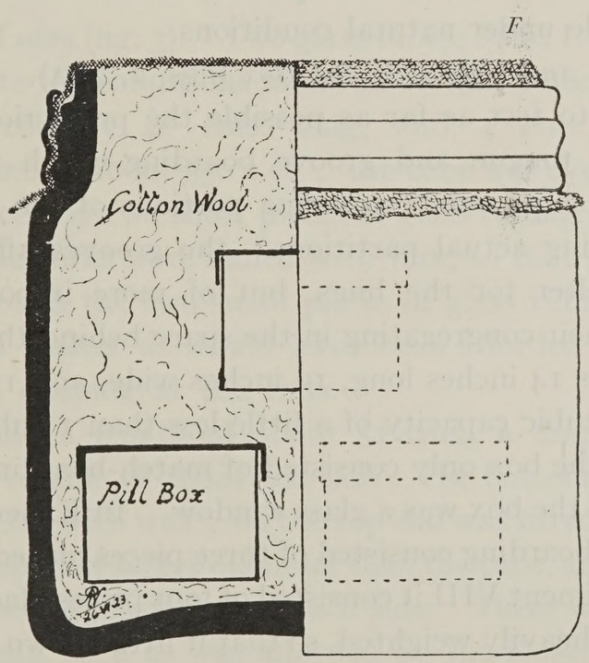


Fig. 1. Section and elevation of the glass jar used in the experiments. *F.*—Flannel covering.

a height of about 12 cms. and a diameter of about 10 cms. In ordinary use the grooved metal ring clamps down a flat metal disc over the top of the jar, thus hermetically sealing it ; for the purpose of the experiment, the flat metal disc was replaced by a piece of flannel readily permeable to the gas.

The jars were used in two ways :—

(1) The pill boxes containing the bugs were placed on the bottom of an empty jar, the mouth of which was closed with flannel as described above.

(2) The pill boxes were placed in the middle of cotton wool which filled the jar, as is shown in fig. 1.

*Lethal Chamber.* In the Experiments I-VIII, the exposure to the Hydrogen Cyanide was effected by placing the various pieces of apparatus containing the bugs in a strong wooden chest, referred to as the ' Lethal Chamber.' For a description of this and details of the strength of gas used and method of generation see the Chemist's report (p. 118).

The apparatus so far described, was designed for a preliminary test of the efficacy of the gas, and the protection afforded to the bugs in no way closely imitated the protection available to them in their natural haunts on board ship. The pieces of apparatus to be described below were designed especially to imitate certain of the refuges available under natural conditions.

*The Tongue and Groove Board Box* (figs. 2, 2, A). This box was made in order to test as far as possible the protection afforded to insects by the tongue and groove boarding which is used more particularly in ships, either covering portions of the ' skin ' of the vessel, or forming actual partitions ; the grooves afford a certain amount of shelter for the bugs, but of more importance is the possibility of their congregating in the space behind the boarding.

The box was 14 inches long, 10 inches wide, and 12 inches high, having thus a cubic capacity of a little less than 1 cubic foot. One of the sides of the box only consisted of match-boarding, and on the opposite side of the box was a glass window. In Experiments V and VII the match-boarding consisted of three pieces placed horizontally, whilst in Experiment VIII it consisted of four pieces placed vertically.

The lid was heavily weighted, so that it fitted down closely on the top of the box, and the grooves formed practically the only means by which the gas could penetrate to the interior of the box.

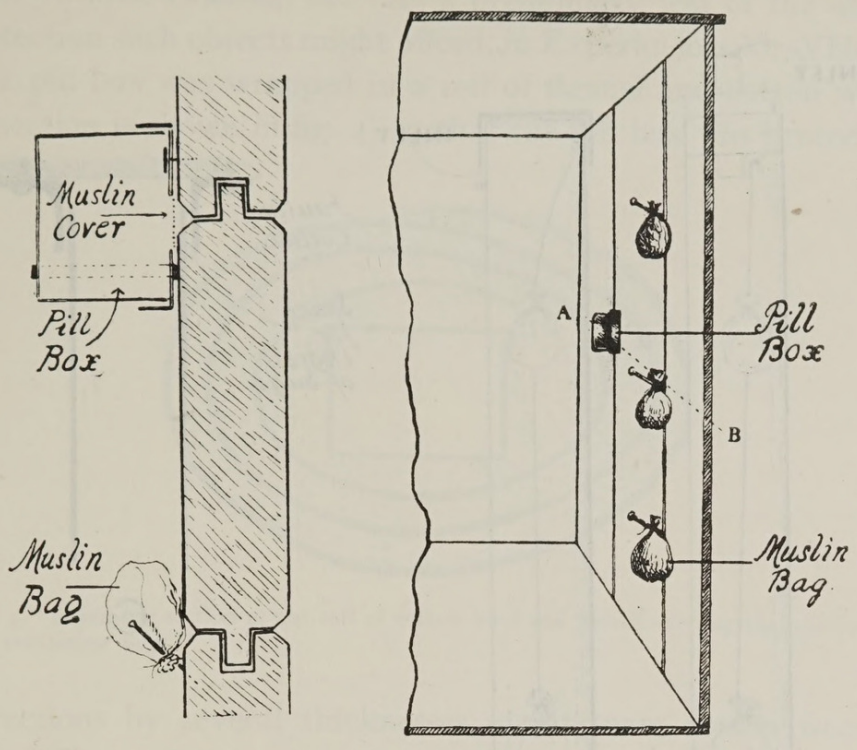


FIG. 2. Tongue and groove board box: section of part of the interior showing the relative positions of the pill box and muslin bags containing bugs. 2A.—section of the tongue and groove boarding (scale ½), showing the positions of the pill box and muslin bag in relation to the joints of the timber.

*The Glass Tubes* (fig. 3). Two glass tubes, I and II, were arranged so as to imitate the conditions found in certain bunks (see fig. 3, B). Tube I was roughly 48 cms. long, and 4 cms. in diameter, having a volume of about 530 c.cs.; the tube was closed at each end by corks, pierced by two short pieces of glass tubing about 8 mm. in diameter. The corks were sealed with wax, so that gas entered the tube only through the two small pieces of glass tubing. This gave the bugs such shelter as would have been afforded by those bunk tubes with an opening at the ends.

Tube II had a length of about 51 cms., a diameter of about 4 cms., and a volume of about 590 c.cs. The bottom end was closed by a cork covered with wax; on the top end was fitted the lid of a pill box, having a slightly larger diameter than the tube, and raised from it by a small piece of plasticine on each side. There was thus a small inlet for the gas, such as was afforded by the loosely-fitting socket of the upright stanchion of the bunk (fig. 3, C).

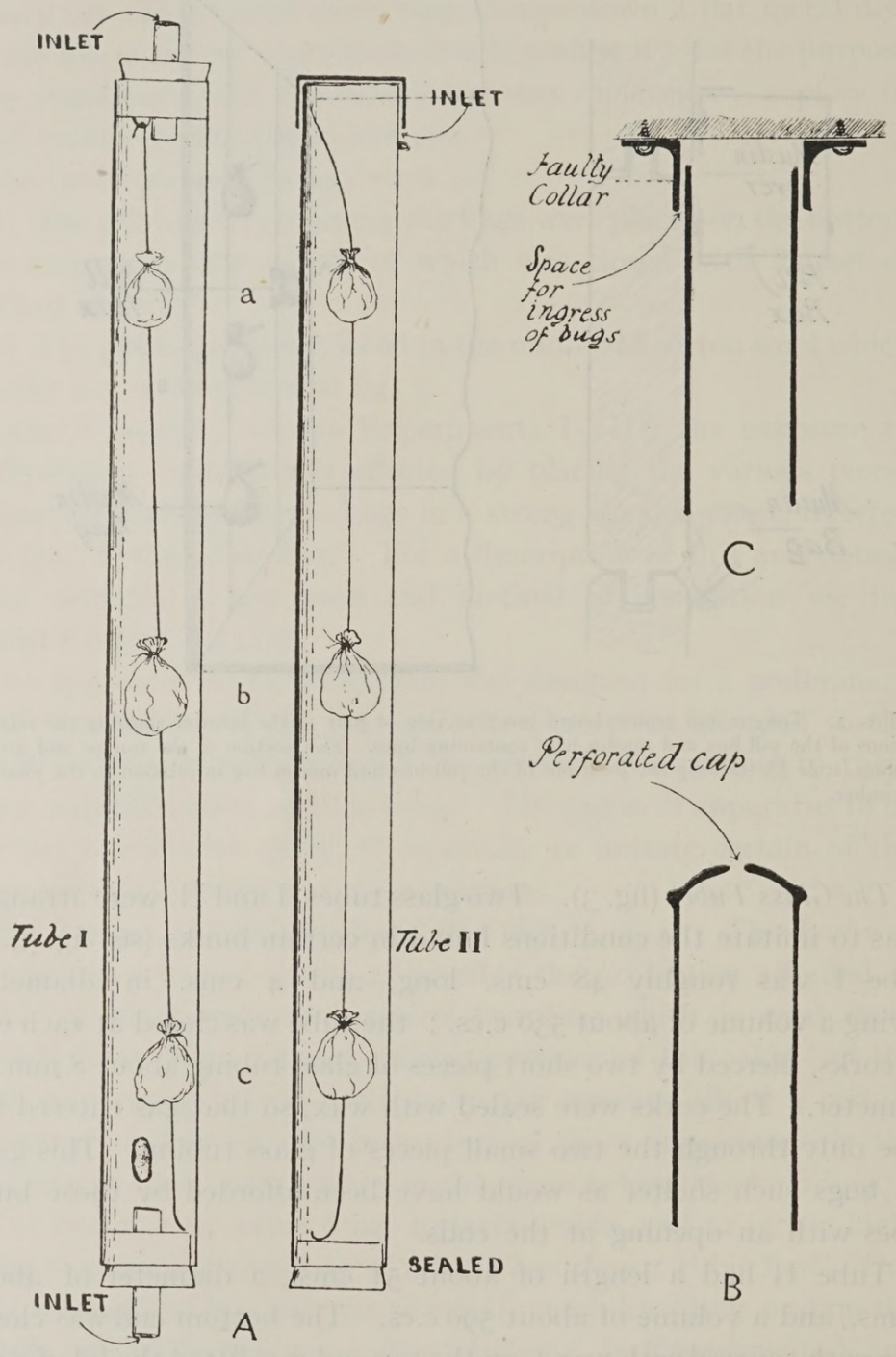


FIG. 3. *A*.—The glass tubes used in the experiments to test the viability of the bugs and the powers of diffusion of the gas under conditions illustrated in *B* and *C*. *a*, *b*, *c*—muslin bags containing bugs. *B*.—Schematic section of the end of a tubular iron bedstead (faulty type), showing the perforated cap through which the bugs gain access to the tube. *C*.—Schematic section of the tubular stanchion with loose-fitting (faulty) collar, leaving space for the ingress of bugs.

*Life-Jackets, Bedding, etc.* As a preliminary test of the amount of protection such objects might afford, in Experiments Vc, VIIc, and IXb, a pill box was wrapped in a roll of flannel and cotton wool (a cross section is shown in fig. 4) so that the pill box was protected in

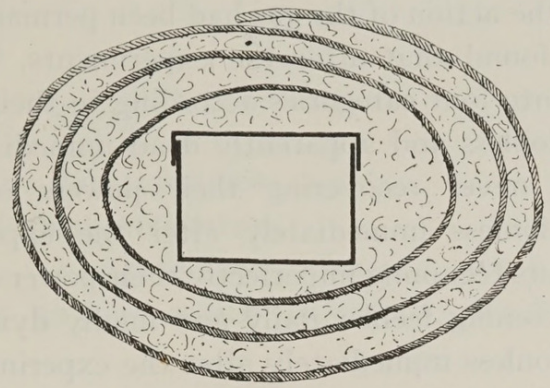

Fig. 4. Schematic section of the roll of cotton wool and flannel showing the position of the pill box containing bugs.

all directions by several thicknesses of alternate cotton wool and flannel. This protection being proved to be of no value to the bugs, sterner tests were carried out.

In Experiment VIIf, a life-jacket (Plate II, fig. 2), 2 ft. 8½ in. long, 10½ in. wide, and 3 in. in height was used. This life-jacket was stuffed with tightly-packed Kapok (a vegetable product resembling raw cotton). The pill box was placed inside the middle portion (Plate II, fig. 2x), and the end portion tied firmly over the middle portion, the resultant being a compact roll, 10 in. by 10½ in. Even this failed to prevent a fatal concentration of gas reaching the bugs.

In Experiment IXk, a third test was carried out, the pill box being inserted in the interior of a straw-stuffed mattress. This, too, failed to protect the bugs against the gas.

## LABORATORY METHODS OF DEALING WITH BUGS

In the Laboratory the bugs were kept between layers of dark-green baize in glass jars 3½ in. by 2 in., or tubes 3 in. by 1 in., covered with a layer of cotton voile, and the jars and tubes placed in an incubator at a mean temperature of 25° C. At intervals of about a week the bugs were given an opportunity of feeding on the shaved abdomen of a rabbit. The voile-covered jars were applied to the

host's skin, and the bugs had no difficulty in feeding to repletion in this way. We are indebted to Dr. J. W. Scott Macfie for conducting these operations. In addition many batches of larval bugs were fed on the investigators.

Great care had to be taken in deciding whether bugs which had been exposed to the action of the gas had been permanently affected or not. It was found that after the experiments, bugs could be divided roughly into four categories according to their condition :—

(1) Bugs motionless and apparently dead immediately after the experiment, and never recovering their powers of movement.

(2) Bugs motionless immediately after the experiment, after the lapse of 24 hours regaining imperfectly their powers of movement, but after this becoming feebler daily and finally dying.

(3) Bugs motionless immediately after the experiment, but after about 24 hours completely regaining their powers of locomotion, after which they continue to live in a normal way.

(4) Bugs which are quite active and apparently healthy immediately after the experiment and remain so.

There was no doubt that bugs belonging to categories 1 and 2 were killed by the gas, but it was less easy to decide whether those in 3 and 4 had not suffered some permanent injury which would result in their ultimate destruction. The surviving bugs of categories 3 and 4 were, therefore, kept under observation for several days and tested to see whether they were able to feed, and produce fertile eggs, before they were considered to have recovered completely from the effects of the gas. Several batches of eggs obtained from the survivors were allowed to hatch and the larvae which emerged were quite healthy and fed readily when placed upon a host. It was abundantly evident from these observations that the bugs were in no way injured by the gas and would have been quite capable of continuing the infestation of either houses or ships.

At the beginning of the investigation controls were used for both adults and eggs of *C. lectularius*. These were put into receptacles similar to those containing the experimental specimens and taken to the place where the experiment was conducted, remaining near the lethal chamber till the close of the experiment. This was done in order to test the effect of the sudden lowering of temperature upon the bugs. As the control bugs remained entirely unaffected, we

considered it unnecessary to use them for the adults and nymphs in later experiments, the stock lot of bugs serving for comparison with the survivors during the period of observation. In the case of eggs, however, control eggs laid on the same day were kept under observation to insure that there was no defect inherent in the eggs to prevent their hatching.

EXPERIMENT I. 7.6.23.

*Material used in this experiment.*

Bed bugs (*Cimex lectularius*).

*A* and *C*. 12 bugs in each. *Controls:* for *A* and *C*. 12 bugs.
*B* and *D*. 12 eggs in each. *Controls:* for *B* and *D*. 13 eggs.

*Conditions.*

*General.* The material was exposed for two hours to a concentration of Hydrogen Cyanide of about 0·3 per cent.

*Details.* *A* and *B*. The specimens were placed between two layers of green felt in chip-boxes, and the latter filled loosely with flannel. The boxes were placed in a glass jar, covered with flannel.

*C* and *D*. The specimens were placed between two layers of green felt in chip boxes and the latter packed with cotton wool. The boxes were placed in a glass jar which was also packed with cotton wool and covered with flannel.

*Results.*

*A*, *B*, *C*, and *D*. Both bugs and eggs were all killed in each case.

*Controls.* Bugs. All were alive on the next day and had laid seven eggs during the night after the experiment. Eggs. 10 out of 13 (77 per cent.) hatched between 10th and 12th June.

EXPERIMENT II. 8.6.23.

*Material used in this experiment.*

Bed bugs (*Cimex lectularius*).

*A*. 12 eggs. *Controls:* 12 eggs (laid same day).
*B*. 6 bugs. *Controls:* 6 bugs.
*C*. 9 eggs. *Controls:* 9 eggs (laid same day).

*Conditions.*

*General.* The material was exposed for one hour to a concentration of Hydrogen Cyanide of about 0·3 per cent.

*Details. A.* The specimens were placed between layers of green felt in a chip box, and the latter loosely filled with flannel, and placed in an empty jar.

*B* and *C.* The specimens were placed between layers of green felt in a chip box, the latter packed with cotton wool, and placed in a jar also packed with cotton wool.

*Results.*

*A.* All the eggs were killed.
*Controls.* All hatched.

*B.* Of the 6 bugs, 3 survived.
*Controls.* All were quite normal on the morning after experiment.

*C.* All the eggs were killed.
*Controls.* 5 out of 9 (55 per cent.) hatched.

EXPERIMENT III.

Head louse (*Pediculus capitis*).
*A.* Adults and eggs. *Controls:* eggs.

Body louse (*Pediculus corporis*).
*B.* Adults.

*Conditions.*

*General.* The material was exposed for two hours to a concentration of Hydrogen Cyanide of about 0·3 per cent.

*Details.* The specimens were placed in chip boxes in petri-dishes and the dishes filled up with tightly-packed cotton wool and covered with one layer of flannel.

*Results.*

The eggs and adults were all killed by the experiments.
*Controls.* The eggs hatched normally.

EXPERIMENT IV. 13.6.23.

*Material used in this experiment.*

Bed bugs (*Cimex lectularis*).

*A*. 30 bugs. *Controls:* 6 bugs.
*B*. 6 bugs. *Controls:* 4 bugs.
*C*. 45 eggs. *Controls:* 12 eggs.
*D*. 11 eggs. *Controls:* 10 eggs.

Head lice (*Pediculus capitis*).

*E*. Eggs. *Controls:* eggs.

Body lice (*Pediculus corporis*).

*F*. Adults. *Controls:* adults.

*Conditions.*

*General.* The material was exposed for three hours to a concentration of Hydrogen Cynaide of about 0·2 per cent.

*Details. A* and *C*. The specimens were placed between two layers of baize in chip boxes and the boxes filled up tightly with cotton wool; the boxes were placed in jars and the jars packed with cotton wool and covered with a layer of flannel (see fig. 1).

*B* and *D*. The specimens were placed between two layers of baize in chip boxes and the boxes filled up with flannel and then placed in otherwise empty jars covered with flannel.

*E*. The eggs attached to the hairs on which they had been laid, were placed in glass-bottomed pasteboard boxes with tight-fitting pasteboard lids.

*F*. The lice were among the folds of a garment which was rolled up and placed in a glass jar covered with flannel.

*Results.*

*A*. 10 out of 30 bugs were killed.
*B*. 2 out of 6 bugs were killed.
*C*. 12 out of 45 eggs hatched (i.e., 27 per cent.).
*Controls:* 8 out of 12 hatched (i.e., 67 per cent.).
*D*. 6 out of 11 eggs hatched (i.e., 54 per cent.).
*Controls:* 7 out of 10 hatched (i.e., 70 per cent.).
*E*. All the eggs hatched.
*F*. None of the adults was killed.

EXPERIMENT V. 19.6.23.

*Material used in this experiment.*

Bed bugs (*Cimex lectularius*).

*A*. 20 bugs. *Controls:* 12 bugs.

*B*. 48 eggs. *Controls:* 29 eggs.

*C*. 20 bugs. *Controls:* those used for *A*.

*D*. 20 bugs. *Controls:* those used for *A*.

Black Rats.

*E*. 3 living rats from ship.

*Conditions.*

*General.* The material was exposed for three hours to a concentration of Hydrogen Cyanide of about 0·2 per cent.

*Details. A* and *B*. The specimens were placed between folds of green baize, in a chip box with two holes in the lid, over which had been pasted voile. The box was then pinned inside the match-boarding box (fig. 2, A), so that the two holes in the lid of the former were lying opposite the groove between the match-boarding of the latter.

*C*. The specimens were placed between folds of baize in a chip box, and the latter wrapped up in cotton wool and flannel (see fig. 4), forming a roll of about 4 inches in diameter, in the centre of which was the chip box.

*D*. The specimens were placed in a chip box between folds of baize. The lid of the chip box was perforated with small holes, and the chip box placed on the floor of the lethal chamber.

*E*. The rats were placed in a small cage on the floor of the lethal chamber.

*Results.*

*A*. Bugs. The whole number (20) recovered by the next morning.

*B*. Eggs. 37 out of the 48 (77 per cent.) hatched.

*Controls*. Of the 29 eggs, 28 hatched.

*C*. Bugs. 19 of the 20 completely recovered by the next morning.

*D*. Bugs. All were killed.

*A*, *C*, and *D*. *Controls*. Bugs. All 12 quite normal on the next morning.

*E.* The three rats were stiff when taken out of the lethal chamber. From them were collected the following :—9 ♂ ♂ and 4 ♀ ♀ of the plague flea (*Xenopsylla cheopis*), all of which were dead.

EXPERIMENT VI. 22.6.23.

*Material used in this experiment.*

*A.* 15 rats from a warehouse ' black rats.'

*B.* One rat's nest.

*C.* 10 larvae of the rat flea (*Ceratophyllus fasciatus*).

*Conditions.*

*General.* The material was placed in the lethal chamber for three hours and the concentration used was about 0·2 per cent. of Hydrogen Cyanide.

*Details. A.* The 15 rats were placed in lethal chamber in a stout unbleached calico bag.

*B.* The rat's nest was wrapped in paper, which was pierced with slits.

*C.* 10 larvae of *Ceratophyllus fasciatus* were placed in a tube, the mouth of which was closed by cotton wool, in the rat's nest.

*Results.*

*A.* The 15 rats were quite dead, and from them were collected :— 3 ♂ ♂ and 5 ♀ ♀ of *Ceratophyllus fasciatus*, also dead.

*B.* From the rat's nest we obtained :—One adult *Ceratophyllus fasciatus*, dead, and two larvae, dead.

*C* Of the 10 larvae in the tube, all were dead when examined on the 22nd and 23rd of June, whilst control larvae were still alive.

EXPERIMENT VII. 25.6.23.

*Material used in this experiment.*

Bed bugs (*Cimex lectularius*).

*A.* 20 bugs.

*B.* 50 eggs. *Controls:* 60 eggs (laid same day).

*C.* 20 bugs.

*D.* 10 eggs.

*E.* Tube I. (*a*), (*b*) and (*c*), 10 bugs. ($b^1$), 25 eggs.
Tube II. (*a*), (*b*) and (*c*), 10 bugs. ($b^1$), 25 eggs.

*Control:* for *D* and *E*, 23 eggs.

*F.* 20 bugs.

*Conditions.*

*General.* The material was exposed for two hours to a concentration of Hydrogen Cyanide of about 0·3 per cent.

*Details. A* and *B.* The specimens were placed between layers of green baize in a chip box, which was put inside the tongue and groove board chest as in Experiment Va.

*C* and *D.* As in Experiment Vc.

*E.* The specimens were placed in muslin bags, (*a*), (*b*), (*b*$^1$) and (*c*), and these suspended, (*a*) at the top, (*b*) and (*b*$^1$) in the middle, and (*c*) at the bottom, of two glass tubes, I and II (see fig. 3, A and description of apparatus, p. 95).

*F.* The specimens were placed in a chip box in the usual manner, and the chip box placed inside a life-belt (see Plate II, fig. 2, and description of apparatus, p. 97).

*Results.*

*A.* Bugs. 14 out of 20 (70 per cent.) survived.

*B.* Eggs. 42 out of 50 (84 per cent.) hatched.
*Controls.* 47 out of 60 (78 per cent.) hatched.

*C.* Bugs. All were killed.

*D.* Eggs. All were killed. *Controls.* All except 2 hatched.

*E.* Tube I. Bugs. (*a*), (*b*), and (*c*). All were killed in each case.
Eggs. (*b*$^1$). All were killed.
Tube II. Bugs. (*a*) All (10 out of 10) were killed.
(*b*) 9 out of 10 were killed.
(*c*) 1 out of 10 was killed.
Eggs. (*b*$^1$) 17 out of 25 (68 per cent.) hatched.
*Control.* Eggs. All hatched except 2 (91 per cent.).

*F.* Bugs. All were killed.

Experiment VIII. 13.6.23.

*Material used in this experiment.*

Bed bugs (*Cimex lectularius*).
*A*, *B*, (*a*), (*b*), (*c*) ; *C* (*a*), (*b*), (*c*). 10 bugs in each.
*B* (*b*$^1$) and *C* (*b*$^1$), 20 eggs in each. *Controls :* 8 eggs (laid on same day).

*Conditions.*

*General.* The material was exposed for three hours to a concentration of Hydrogen Cyanide, of about 0·3 per cent.

*Details. A.* The specimens were placed in an open voile bag in a chip box as used in Experiment Va, and the box placed under the same condition as in that experiment.

*B.* The specimens were placed in voile bags (*a*), (*b*), (*b*$^1$) and (*c*), in a glass tube (see fig. 3, A), (*a*) and (*c*) being at each end and (*b*) and (*b*$^1$) in the middle. The tube was supported horizontally in the lethal chamber in such a position that bag (*a*) was nearest to the point of evolution of the gas.

*C.* The specimens were placed in voile bags (*a*), (*b*), (*b*$^1$) and (*c*), which were pinned against the groove on the inside of the match-boarding box (see fig. 2), (*a*) being at the top, (*b*) and (*b*$^1$) in the middle and (*c*) at the bottom.

*Results.*

*A.* 4 out of the 10 bugs were killed.

*B.* (*a*), (*b*), (*c*). All were killed.

*B.* (*b*$^1$). None of the eggs hatched. *Controls:* all hatched.

*C.* (*a*) and (*b*). 5 out of 10 bugs were killed in each case.

*C.* (*c*). 9 out of 10 bugs were killed.

*C.* (*b*$^1$). 12 out of 20 eggs hatched. *Controls:* all hatched.

## EXPERIMENTS ON BOARD SHIP

Experiment IX. 20.7.23. *Fumigation of the s.s. 'Lady Emerald.'*

*Material used in this experiment.*

*A-K.* Ten voile bags, each containing 10 bugs, were used.

*L* and *M.* Two cages of rats, containing 4 and 3 respectively.

*Conditions.*

*General.* The material was exposed for two hours to a concentration of Hydrogen Cyanide produced by 8 oz. of Sodium Cyanide per 1,000 cubic feet (i.e., about 0·3 per cent. Hydrogen Cyanide). The gas was generated in tubs, in the usual manner, in the two places fumigated (the seamen's and the firemen's quarters); the position of these tubs in relation to the dispositions of the material may be seen quite readily from figs. 5 and 6.

There were no traces of bugs in the ship, but the food-lockers were very much infested with mice.

*Details* (see figs. 5 and 6). *A-K.* The voile bags containing the bugs were, for convenience, placed in chip boxes, and these were disposed as follows :—

*In the Seamen's quarters* (see fig. 5).

*A*, *B* and *C* were placed, in the match-boarding box used in previous experiments, on a bench, raised about two feet off the floor.

*D* was placed in a roll of cotton wool and flannel (as used in Experiment Vc.) on the floor beneath the bench mentioned above.

*I* was placed near to it, to serve as a control.

*E* was placed in the food-locker, about four feet from the ground.

*F* was placed on the table in the mess-room.

*G* was placed on a beam just under the roof.

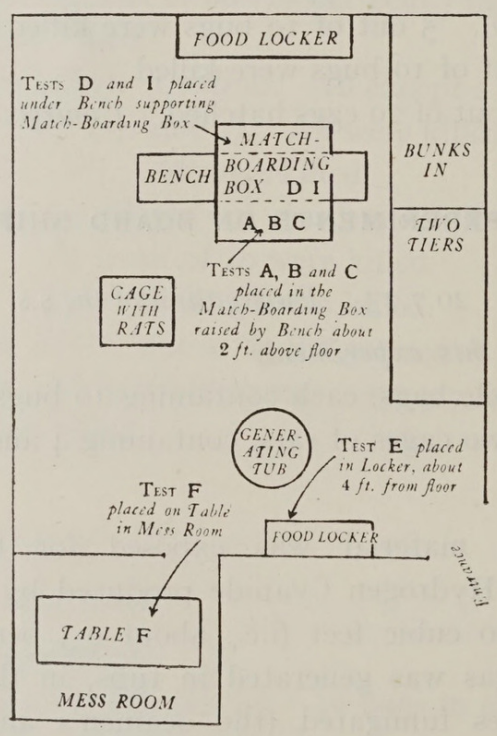


Fig. 5. Schematic plan showing the relative positions of the tests placed in the Seamen's quarters, Experiment IX.

*In the Firemen's quarters* (see fig. 6).

*H* was placed in a situation similar to that of G.

*K* was placed in the straw stuffing of a mattress lying on the bottom bunk on the left-hand side.

*L* and *M*, the two cages of rats, were placed, one on the floor of the seamen's quarters (see fig. 5), and the other on a bench, raised about 1½ feet above the ground in the firemen's quarters (see fig. 6).

*Results.*

*A*. All the bugs survived except one.

*B*. All the bugs survived except two, though this lot showed a quicker rate of mortality, subsequently, than did either *A* or *C*.

*C*. All the bugs survived.

*D*. All the bugs were killed.

*E*. 3 bugs only out of the 10 survived.

*F*. 1 bug only (a 3rd stage larva) survived.

*G*, *H*, *I*, and *K*. All the bugs were killed.

*L* and *M*. All the rats (7) were killed, and from them were taken 2 specimens of *Ceratophyllus fasciatus* (♀ ♀) and a number of lice, also dead.

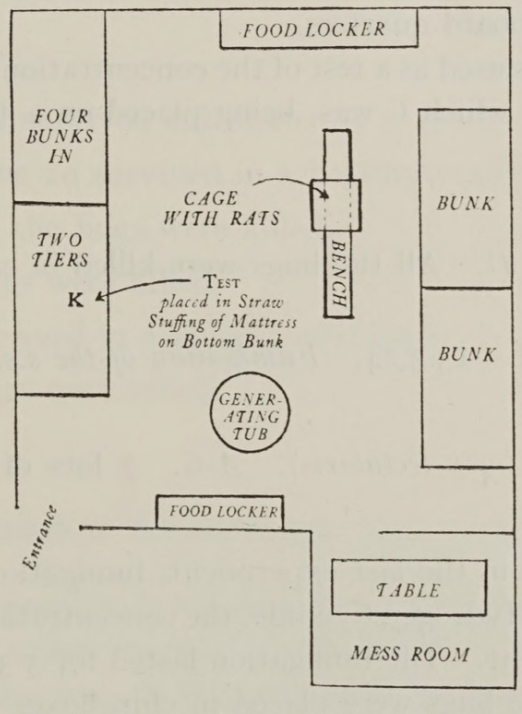


Fig. 6. Schematic plan showing the relative positions of the tests placed in the Firemen's quarters, Experiment IX.

EXPERIMENT X. 23.2.24. *Fumigation of the s.s. 'Montcalm.'*

*Material used.*

Bed bugs (*Cimex lectularius*).

*A*, *C* and *D*. 10 bugs.

*B*. 14 bugs.

*Conditions.*

*General.* The passenger accommodation only was fumigated. The fumigation was effected by spraying liquid Hydrogen Cyanide, $2\frac{1}{2}$ oz. per 1,000 cubic feet, giving an average concentration of about 0·27 per cent. HCN. The duration of exposure was from 3-$3\frac{1}{2}$ hours.

*Details.* The bugs were placed in chip boxes loosely packed with pieces of green felt.

*A*. The chip box was placed behind the skirting-board of a cabin in the stewards' quarters, amidships. The skirting-board was open underneath, and had a couple of large circular holes, the one directly in front of the chip box being closed by means of a pillow.

*B*. This chip box was used as a control for *A*, being placed on a table in the cabin, to test the concentration of the gas outside the skirting-board.

*C*. The chip box was placed in a cupboard in a cabin in the passengers' starboard quarters.

*D*. This was used as a test of the concentration of the gas outside the cupboard in which C was, being placed on a table in the same cabin.

*Results.*

*A*, *B*, *C* and *D*. All the bugs were killed in each case.

EXPERIMENT XI. 13.3.24. *Fumigation of the s.s. 'City of Paris.'*

*Material used.*

Bed bugs (*Cimex lectularis*). *A-G*. 7 lots of 10 bugs.

*Conditions.*

*General.* As in the last experiment, fumigation was effected by spraying liquid Hydrogen Cyanide, the concentration produced being about 0·2 per cent. The fumigation lasted for 3-$3\frac{1}{2}$ hours.

*Details.* The bugs were placed in chip boxes with a little green felt and newspaper packing.

*A* and *B*. The two chip boxes were placed in the rudder post locker, in the firemen's fo'castle. This structure was formed by tongue and groove boarding, about one and a quarter inches thick, with a closely-fitting door, which was closed. The capacity was about 50 cubic feet. The temperature in the fo'castle was fairly high.

*C* and *D*. These two chip boxes were placed on chests in the firemen's fo'castle, near the rudder post locker. They served as tests of the concentration of gas outside the locker.

*E*. This chip box was placed in the space under a chest of drawers, in a passenger cabin on the port side of the bridge deck. As this structure was built into the side of the cabin, the only way the gas could penetrate into the space was by means of the crack between the bottom drawer and the framework of the chest of drawers.

*F*. This chip box was placed in the bottom drawer of the above-mentioned chest of drawers.

*G*. This chip box was placed on the shelf of a toilet apparatus in the same cabin as *C*. It formed a test of the concentration of the gas in the air outside the chest of drawers.

*Results.*

*A*. 1 bug only survived out of 10.

*B*. 3 out of the 10 survived in a healthy condition.

*C* and *D*. All the bugs were killed.

*E*. All the bugs were killed.

*F*. 2 bugs survived in a healthy condition.

*G*. All the bugs were killed.

## DISCUSSION OF RESULTS AND TABLES

In all the experiments, the action of the gas was not considered to be satisfactory unless every bug was killed. This attitude was adopted because one bug, if it happened to be a fertilised female, would be quite capable of starting a fresh infection.

TABLE I.

Summary of experiments on Bed Bug (*Cimex lectularius*).

Experiments I-IV.

| No. of experiment | Conditions of experiment | | | Experimental material | | Control material | |
|---|---|---|---|---|---|---|---|
| | Average concentration of gas | Length of exposure | Conditions | Number of specimens | Percentage killed | Number of specimens | Percentage died |
| | % | | | | % | | % |
| IA ... | 0·3 | 2 hours | In pill boxes in empty glass jar, unprotected | 12 bugs | 100 | ... | ... |
| IB ... | 0·3 | 2 hours | In pill boxes in empty glass jar, unprotected | 12 eggs | 100 | 13 eggs | 3 |
| IC ... | 0·3 | 2 hours | In pill boxes in glass jar, protected by cotton wool | 12 bugs | 100 | ... | ... |
| ID ... | 0·3 | 2 hours | In pill boxes in glass jar, protected by cotton wool | 12 eggs | 100 | 13 eggs (as used for IB) | 3 |
| IIA ... | 0·3 | 1 hour | In pill boxes in empty glass jar, unprotected | 12 eggs | 100 | 12 eggs | 0 |
| IIB ... | 0·3 | 1 hour | In pill boxes in glass jar, protected by cotton wool | 6 bugs | 50 | ... | ... |
| IIC ... | 0·3 | 1 hour | In pill boxes in glass jar, protected by cotton wool | 9 eggs | 100 | 9 eggs | 45 |
| IVA ... | 0·2 | 3 hours | In pill boxes in glass jar, protected by cotton wool | 30 bugs | 33 | ... | ... |
| IVB ... | 0·2 | 3 hours | In pill boxes in empty jar, unprotected | 6 bugs | 33 | ... | ... |
| IVC ... | 0·2 | 3 hours | In pill boxes in glass jar, protected by cotton wool | 45 eggs | 73 | 12 eggs | 33 |
| IVD ... | 0·2 | 3 hours | In pill boxes in empty jar, unprotected | 11 eggs | 46 | 10 eggs | 30 |

Table I summarises the results obtained in the preliminary experiments where the only protection afforded to the bugs was that of the cotton wool in which they were packed. A concentration of 0·3 per cent. of gas, acting for two hours, was sufficient to kill both bugs and eggs, whether protected or not (Experiment I). It did not, in one hour, kill bugs when protected by cotton wool (Experiment II). A concentration of 0·2 per cent. of gas, even though allowed to act for three hours, failed to kill either bugs or eggs whether protected or not (Experiment IV).

In the following table, which for convenience has been divided into three sections, are seen the results obtained in the lethal chamber, when forms of protection resembling more nearly those of their natural conditions were afforded to the bugs.

TABLE II.

Summary of the Experiments on Bed Bugs (*Cimex lectularius*).

Section A. Experiment V

| No. of experiment | Conditions of experiments | | | Experimental material | | Control material | |
|---|---|---|---|---|---|---|---|
| | Average concentration of gas | Length of exposure | Conditions | Number of specimens | Percentage killed | Number of specimens | Percentage died |
| | % | | | | % | | % |
| VA ... | 0·2 | 3 hours | Pill box pinned inside tongue and groove board box | 20 bugs | 0 | ... | ... |
| VB ... | 0·2 | 3 hours | Pill box pinned inside tongue and groove board box | 48 eggs | 23 | 29 eggs | 3 |
| VC ... | 0·2 | 3 hours | Pill box inside cotton wool and flannel roll | 20 bugs | 5 | ... | ... |
| VD ... | 0·2 | 3 hours | Pill box with perforated lid on floor of lethal chamber | 20 bugs | 100 | ... | ... |

From this section it will be seen that a concentration of 0·2 per cent., acting for three hours, failed to kill bugs protected by tongue and groove boarding, or by the flannel and cotton wool roll; it succeeded, however, in killing them completely when they were exposed without any means of protection (Experiment V).

TABLE II—*Continued*

Section B, Experiment VII

| No. of experiment | Conditions of Experiments | | | Experimental material | | Control material | |
|---|---|---|---|---|---|---|---|
| | Average concentration of gas | Length of exposure | Conditions | Number of specimens | Percentage killed | Number of specimens | Percentage died |
| | % | | | | % | | % |
| VIIA ... | 0·3 | 2 hours | Pill box pinned inside tongue and groove board box | 20 bugs | 30 | ... | ... |
| VIIB ... | 0·3 | 2 hours | Pill box pinned inside tongue and groove board box | 50 eggs | 16 | 60 eggs | 2 |
| VIIC ... | 0·3 | 2 hours | Pill box inside cotton wool and flannel roll | 20 bugs | 100 | ... | ... |
| VIID ... | 0·3 | 2 hours | Pill box inside cotton wool and flannel roll | 10 eggs | 100 | 23 eggs | 9 |
| VIIE, I(*a*) | 0·3 | 2 hours | Voile bag suspended at top of Tube I | 10 bugs | 100 | ... | ... |
| VIIE, I(*b*) | 0·3 | 2 hours | Voile bag suspended in middle of Tube I | 10 bugs | 100 | ... | ... |
| VIIE, I(*b*$^1$) | 0·3 | 2 hours | Voile bag suspended in middle of Tube I | 25 eggs | 100 | 23 eggs (same as used in VIID) | 9 |
| VIIE, I(*c*) | 0·3 | 2 hours | Voile bag suspended at bottom of Tube I | 10 bugs | 100 | ... | ... |
| VIIE, II(*a*) | 0·3 | 2 hours | Voile bag suspended at top of Tube II | 10 bugs | 100 | ... | ... |
| VIIE, II(*b*) | 0·3 | 2 hours | Voile bag suspended in middle of Tube II | 10 bugs | 90 | ... | ... |
| VIIE, II(*b*$^1$) | 0·3 | 2 hours | Voile bag suspended in middle of Tube II | 25 eggs | 32 | 23 eggs (same as used in VIID) | 9 |
| VIIE, II(*c*) | 0·3 | 2 hours | Voile bag suspended at bottom of Tube II | 10 bugs | 10 | ... | ... |
| VIIF ... | 0·3 | 2 hours | Pill box inside life-belt | 20 bugs | 100 | ... | ... |

This section shows that even 0·3 per cent. of the gas failed to kill bugs behind match-boarding in two hours. This concentration also failed, in that period, to penetrate even to the middle of Tube II

in sufficient quantity to kill the bugs. It did, however, succeed in killing completely all those bugs placed inside the flannel and cotton wool roll, in Tube I (the tube open at both ends), and in the interior of the Life-Jacket (Experiment VII).

TABLE II—*Continued*

Section C, Experiment VIII

| No. of experiment | Conditions of experiments | | | Experimental material | | Control material | |
|---|---|---|---|---|---|---|---|
| | Average concentration of gas | Length of exposure | Conditions | Number of specimens | Percentage killed | Number of specimens | Percentage died |
| | % | | | | % | | % |
| VIIIA ... | 0·3 | 3 hours | Pill box pinned inside tongue and groove board box | 10 bugs | 40 | ... | ... |
| VIIIB (*a*)... | 0·3 | 3 hours | Voile bag at end of Tube II furthest from the gas | 10 bugs | 100 | ... | ... |
| VIIIB (*b*)... | 0·3 | 3 hours | Voile bag in middle of Tube II | 10 bugs | 100 | ... | ... |
| VIIIB (*bI*) | 0·3 | 3 hours | Voile bag in middle of Tube II | 20 eggs | 100 | 8 eggs | 0 |
| VIIIB (*c*) | 0·3 | 3 hours | Voile bag at end of Tube II nearest the gas | 10 bugs | 100 | ... | ... |
| VIIIc (*a*) | 0·3 | 3 hours | Voile bag pinned at top of groove of tongue and groove board box | 10 bugs | 50 | ... | ... |
| VIIIc (*b*)... | 0·3 | 3 hours | Voile bag pinned in middle of groove of tongue and groove board box | 10 bugs | 50 | ... | ... |
| VIIIc (*bI*) | 0·3 | 3 hours | Voile bag pinned in middle of groove of tongue and groove board box | 20 eggs | 40 | 8 eggs (used in VIIIB (*bI*)) | 0 |
| VIIIc (*c*)... | 0·3 | 3 hours | Voile bag pinned at bottom of groove of tongue and groove board box | 10 bugs | 90 | ... | ... |

Here it is shown that a period of three hours, even, was not sufficient for 0·3 per cent. of the gas to kill the bugs behind tongue and groove boarding, although it did allow the gas to penetrate into Tube II, when placed horizontally, in sufficient concentration to kill all the bugs in it (Experiment VIII).

An interesting fact, brought out by the experiments summarised in the above two tables, is that the eggs of bugs are not more resistant to the action of hydrogen cyanide than are the other stages.

TABLE III.

Summary of Experiments on Bed Bugs (*Cimex lectularius*).

Experiments IX-XI.

| No. of experiment | Conditions of Experiments. | | | Experimental material | |
|---|---|---|---|---|---|
| | Average concentration of gas | Length of exposure | Conditions | Number of specimens | Percentage killed |
| | % | | | | % |
| IXA ... | 0·3 | 2 hours | Pill box at top of groove of tongue and groove board box | 10 bugs | 10 |
| IXB ... | 0·3 | 2 hours | Pill box in middle of groove of tongue and groove board box | 10 bugs | 20 |
| IXC ... | 0·3 | 2 hours | Pill box at bottom of groove of tongue and groove board box | 10 bugs | 0 |
| IXD ... | 0·3 | 2 hours | Pill box in roll of cotton wool and flannel | 10 bugs | 100 |
| IXE ... | 0·3 | 2 hours | Pill box in a food-locker | 10 bugs | 70 |
| IXF ... | 0·3 | 2 hours | Pill box on a table in small mess-room | 10 bugs | 90 |
| IXG ... | 0·3 | 2 hours | Pill box on a beam under ceiling | 10 bugs | 100 |
| IXH ... | 0·3 | 2 hours | Pill box on a beam under ceiling | 10 bugs | 100 |
| IXI ... | 0·3 | 2 hours | Pill box unprotected, near to IXD | 10 bugs | 100 |
| IXK ... | 0·3 | 2 hours | Pill box in straw stuffing of mattress | 10 bugs | 100 |
| XA ... | 0·27 | 3-3½ hours | Pill box behind skirting-board of cabin | 10 bugs | 100 |
| XB ... | 0·27 | 3-3½ hours | Pill box on table in same cabin as XA | 14 bugs | 100 |
| XC ... | 0·27 | 3-3½ hours | Pill box in cupboard in cabin | 10 bugs | 100 |
| XD ... | 0·27 | 3-3½ hours | Pill box on table in same cabin as XC | 10 bugs | 100 |

TABLE III—*continued*

| No. of experiment | Conditions of Experiments | | | Experimental material | |
|---|---|---|---|---|---|
| | Average concentration of gas | Lengths of exposure | Conditions | Number of specimens | Percentage killed |
| | % | | | | % |
| XIA ... | 0·20 | 3-3½ hours | Pill boxes in locker | 10 bugs | 90 |
| XIB ... | 0·20 | 3-3½ hours | Pill boxes in locker | 10 bugs | 70 |
| XIC ... | 0·20 | 3-3½ hours | Pill boxes on chests near locker | 10 bugs | 100 |
| XID ... | 0·20 | 3-3½ hours | Pill boxes on chests near locker | 10 bugs | 100 |
| XIE ... | 0·20 | 3-3½ hours | Pill box in space under bottom drawer of chest of drawers | 10 bugs | 100 |
| XIF ... | 0·20 | 3-3½ hours | Pill box in bottom drawer of chest of drawers | 10 bugs | 80 |
| XIG ... | 0·20 | 3-3½ hours | Pill box on shelf in same cabin as XIE and XIF | 10 bugs | 100 |

The experiments summarised in this table were carried out on various ships ; in the first one, fumigation was effected by the dumping method, and in the second and third ones, by using liquid Cyanide with a spray.

In Experiment IX, the concentration was calculated at about 0·3 per cent. of the gas, and the fumigation lasted about two hours ; this failed, again, to kill the bugs behind the tongue and groove boarding ; it failed, also, to penetrate into a food-locker. This experiment illustrates the disadvantage of the dumping method, in that the concentration of the gas is not distributed uniformly throughout the space to be fumigated ; thus, whilst bugs in various positions, including the interior of a straw-stuffed mattress, were killed, some exposed on a table in a small mess-room just off the main one (see fig. 6, p. 107) were not killed.

In Experiment X, a concentration of about 0·27 per cent., acting for three to three-and-a-half hours, was completely successful, all the bugs being killed ; the protection afforded was not very great, the skirting-board being open at the bottom, and the cupboard (*C*) not very air-tight.

Experiment XI shows, again, that a concentration of 0·2 per cent., even when acting for three to three-and-a-half hours, is too low to kill bugs if any kind of protection is afforded (e.g., *A*, *B* and *F*), although it does kill those exposed.

TABLE IV.

Summary of Experiments on Lice, Fleas and Rats.

| No. of experiment | Conditions of Experiments | | | Material | Results |
|---|---|---|---|---|---|
| | Average concentration of gas | Lengths of exposure | Conditions | | |
| IIIA ... | % 0·3 | 2 hours | In pill box in petri-dish filled with cotton wool | Head lice and eggs | All were killed. *Control.* Eggs were normal |
| IIIB ... | 0·3 | 2 hours | In pill box in petri-dish filled with cotton wool | Body lice | All were killed |
| IVE ... | 0·2 | 3 hours | In glass-bottomed paste-board pill-boxes | Head louse eggs | None were killed |
| IVF ... | 0·2 | 3 hours | In garment stuffed into glass jar | Body lice | None were killed |
| VE ... | 0·2 | 3 hours | In an iron cage | 3 black rats | All killed—13 dead fleas found |
| VIA ... | 0·2 | 3 hours | In a stout calico bag | 15 black rats | All killed—8 dead fleas found |
| VIB ... | 0·2 | 3 hours | Rat's nest wrapped up in paper pierced by slits | Fleas and larvae | 1 flea and 2 flea larvae found dead |
| VIC ... | 0·2 | 3 hours | In a small glass tube plugged with cotton wool, inside the rat's nest | 10 flea larvae | 10 larvae all dead. *Controls* remained alive |
| IXL ... | 0·3 | 2 hours | In a cage on the floor | 4 black rats | All were killed, and 2 fleas and a number of lice were found dead on the rats |
| IXM ... | 0·3 | 2 hours | In a cage on a bench | 3 black rats | |

From this table it appears that, in the case of lice, a concentration of 0·3 per cent., for one hour, was sufficient to kill both adults and eggs (Experiment III), whilst a concentration of 0·2 per cent., for three hours, was not sufficient (Experiment IV). It is interesting to note that a few of the lice used in this experiment, on the 13th of June, were still alive on the 20th, having spent the seven days off the human body at ordinary room temperature, without any food. They were all dead on June 21st.

Both fleas (adults and larvae), and rats, are killed by a concentration of 0·2 per cent., for three hours, (Experiments V, VI, and IX).

## SUMMARY

1. A concentration of 0·2 per cent. of Hydrogen Cyanide does not, even if allowed to act for as long as three hours, with certainty kill every bug.

2. A concentration of 0·3 per cent. of the gas, acting for only one hour, is not sufficient to kill every bug.

3. A concentration of 0·3 per cent. of the gas, acting for three hours, will kill all the bugs present, except where they can retire behind tongue and groove boarding.

4. Eggs of bugs are not more resistant to Hydrogen Cyanide than are the adults.

5. A concentration of 0·3 per cent. of the gas, acting for one hour, is sufficient to kill lice, both adults and eggs ; but a concentration of 0·2 per cent. of gas, even acting for three hours, does not do so.

6. A concentration of 0·2 per cent. of the gas, acting for three hours, is sufficient to kill both fleas (adults and larvae), and rats.

7. Spraying with liquid Cyanide gives better results than does the dumping method, in that it tends to give a more uniform concentration throughout the area, although not ensuring this absolutely.

## RECOMMENDATIONS

1. That a concentration of 0·3 per cent. of Hydrogen Cyanide, acting for a period of three hours, should be used.

2. That where match-boarding is present, one or two boards should, if possible, be removed, in order to allow the gas easy access into the cavity behind.

3. That where bunks with hollow metal frames are present, they should be taken to pieces, when this is practicable, and the tubular portions laid horizontally, so that the gas can penetrate easily into their interior. Or better, as a preventative, the ends of the tubing should be hermetically sealed, as illustrated on Plate II, fig. 1.

## APPENDIX I

## NOTE ON LETHAL CHAMBER AND CHEMICAL METHODS EMPLOYED

BY

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The material to be treated was placed inside a rectangular wooden chamber of internal dimensions 100 × 60 × 60 cms., closed with a lid, which, when clamped in position, rendered it air-tight. On the floor of the chamber and in one corner was placed a large porcelain dish containing dilute sulphuric acid. The lid was closed and the necessary quantity of potassium cyanide solution was run into the dish from a dropping funnel through a bent glass delivery tube passing through the wall of the chamber.

Two minutes later, sodium carbonate solution was run in from the same funnel, this being in order to expel all dissolved hydrogen cyanide gas from solution.

In the top of the opposite wall of the chamber was a glass delivery tube connected to a long length of india-rubber tubing. This and the inlet tube were now firmly clamped and the material left exposed for the time of the experiment.

In opening up the chamber the inlet tube was attached to a foot-bellows and slight pressure applied. Both clamps were now removed and air blown through for 15 minutes. At the end of this period the box could safely be opened.

To give a concentration of 0·3 per cent. HCN gas in the chamber, the following reagents were used :—

15 c.cs. $H_2SO_4$ (1 in 3 by volume).

3·2 grms. KCN (98 per cent.) dissolved in about 20 c.cs. of water.

followed by :—

20 c.c. of a 10 per cent. $Na_2CO_3$ solution.