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A STUDY OF ENDEMIC PELLAGRA IN SOME COTTON-MILL VILLAGES OF SOUTH CAROLINA[1]

An Abstract

By JOSEPH GOLDBERGER and G. A. WHEELER, *Surgeons*, EDGAR SYDENSTRICKER, *Statistician*, and WILFORD I. KING, *Special Consultant in Statistics*, with the cooperation of WM. S. BEAN, Jr., R. E. DYER, J. D. REICHARD, P. M. STEWART, *Surgeons*, M. C. EDMUNDS, *Assistant Surgeon*, R. E. TARBETT, *Sanitary Engineer*, DOROTHY WIEHL, *Assistant Statistician*, and JENNIE C. GODDARD, *Senior Statistical Clerk, United States Public Health Service*

As a part of the field investigations of pellagra conducted by the Public Health Service there was begun in the spring of 1916 a study of the relation of certain social, hygienic, sanitary, and economic factors to pellagra incidence in some representative South Carolina textile-mill communities, so-called cotton-mill villages, in which the disease was believed to be endemic. On a varying scale, but without interruption, this study was continued until the fall of 1921; that is, during a period of about five and a half years.

During 1916 this study was carried on in 7 villages. As it progressed it was more and more felt that the mass of data being collected would prove to be too small to afford entirely convincing indications with respect to certain important phases of the investigation. For this reason and because it seemed desirable to observe the possible fluctuations in the incidence of the disease from year to year and to study some of the factors possibly related to such fluctuations, it was arranged to continue the study, and for at least one year to carry it out on a much larger scale. Accordingly, early in January, 1917, a considerable number of additional villages were taken under observation, and by the end of February, 17 villages in addition to the 7 of 1916 were settled upon for study. These 24 villages were kept under surveillance for pellagra throughout the year 1917.

With the beginning of 1918 the scale of the investigation was reduced to about that of 1916, surveillance of 18 of the 24 villages studied during 1917 being discontinued. Of the 6 continued under observation during 1918, 2 had been among the 7 studied in 1916. At the beginning of 1919 the scale of the investigation was further reduced by discontinuing observation of all but 1 of the villages.

[1] The complete report will appear in Hygienic Laboratory Bull. No. 153.

This 1 village (*In.*) was 1 of the original 7 and was continued under surveillance throughout 1919, 1920, and up to October 15, 1921—or, in all, for about five and a half years.

The results of the first year's study have already been published.[1] In the present communication, much delayed by, among other reasons, the pressure of other continuing studies, we desire to record certain of the results of that phase of the subsequent study concerned with the incidence of the disease and the relation of this incidence to certain social, climatic, sanitary, economic, and dietary factors.

During 1917 in an aggregate population of 22,653 individuals, 1,147 cases of pellagra (an incidence rate of 50.6 per 1,000) were observed. Of the 4,104 households among which that population was distributed, 18.5 per cent had at least one member affected by the disease in that year.

Pellagra (in an endemic locality) is very much (two to six times) more prevalent than the experience of the physicians of the locality would seem to indicate.

The fatality rate of the endemic disease, when definitely marked cases of all grades of severity are considered, would appear not to exceed 3 per cent.

Striking peculiarities of age and sex distribution of the disease were observed.

The observations of age incidence appear to indicate, what seems not to have been recognized heretofore, that endemic pellagra is preponderatingly a disease of children of from 2 to 15 years of age.

Explanations of the peculiarities of age and of sex incidence are suggested.

The single woman, as compared with the married, widowed, or divorced, is relatively exempt from the disease. In the population group under consideration, the single woman is usually a wage earner, which may place her in a somewhat more advantageous position with respect to diet than her married or widowed sister.

The incidence of the disease was found to be markedly seasonal; 80 to 90 per cent of all cases had their "onset" within the period April to July, inclusive. One explanation suggested, in view of the proved dietary relation of the disease, is the variation in diet brought about by the seasonal modification of the food supply.

The seasonal incidence of cases distinguished by their occurrence singly or otherwise in a household, and as initial and recurrent attacks, was studied.

The disease was found to have a marked and very sharply limited season of prevalence the curve of which, with a slight lag, paralleled that of incidence.

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[1] Public Health Reports, Mar. 19, 1920 (Reprint No. 587), July 9, 1920 (Reprint No. 601), July 16, 1920 (Reprint No. 603), Nov. 12, 1920 (Reprint No. 621).

The study failed to disclose any consistent correlation between sanitary conditions and pellagra incidence. Such association as may at times be observed is regarded as accidental and to be explained by the intimate relation of the endemic disease to economic status, of which the sanitary condition may be an index.

The study reveals the existence of a striking inverse correlation between the incidence of the endemic disease and family income.

The continuous study of a selected village during a period of nearly six years appears to demonstrate that income shortage was a fundamental, though indirect, controlling factor in relation to the year-to-year fluctuation in the incidence of the disease. It is therefore inferred that the year-to-year fluctuations in the incidence of the endemic disease are bound up with fluctuations in economic conditions that influence the ability of a certain section of the population to procure an adequate diet.

Marked seasonal variations in the food supply of a selected village are demonstrated. A relation of this variation in food supply to the striking seasonal incidence and prevalence of the disease is suggested

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FUMIGATION WITH CYANOGEN PRODUCTS

Report of Experiments Conducted with Cyanogen Products Used in the Fumigation of Vessels for Quarantine Purposes at the New York Quarantine Station, Rosebank, Staten Island, N. Y.

By C. V. Akin, *Surgeon*, and G. C. Sherrard, *Acting Assistant Surgeon, United States Public Health Service*

During the period February 15 to May 29, 1926, an extended series of experiments was conducted at the New York quarantine station to determine the relative efficiency of certain cyanogen products used in the fumigation of vessels for the destruction of rats. Tests of all products under consideration were made, both under control in the laboratory and under practical conditions on board ship.

For the conduct of this work an informal board of officers on duty at the station was formed, consisting of Surg. C. V. Akin, Acting Assist. Surgs. G. C. Sherrard and G. H. Guth, and Chief Pharmacist B. E. Holsendorf. All of the experimental work reported herein was done by Surg. C. V. Akin and Acting Assist. Surg. G. C. Sherrard.

The general purposes of the tests were to determine with reasonable exactness the relative merits of several cyanogen products used in ship fumigation for the destruction of rodents, from the standpoints of (1) lethal efficiency, (2) safety to fumigators and others, and (3) cost.

PRODUCTS TESTED

The following products were tested:

(1) Liquid hydrocyanic acid (96 to 98 per cent):

(*a*) A mixture of 80 per cent liquid HCN and 20 per cent of cyanogen chloride (CNCl), an irritating warning-giving component.

(*b*) Liquid hydrocyanic acid (96 to 98 per cent).

(2) Hydrocyanic acid gas generated from a mixture of sodium cyanide, mineral acid, and water.

(*a*) Sodium cyanide, sodium chlorate, hydrochloric acid, and water in proportions designated by the quarantine regulations of the Public Health Service.

(*b*) Sodium cyanide, sulphuric acid, and water in proportions designated by the quarantine regulations of the Public Health Service.

NOTE.—Formula (*a*) in (2) above gives a mixture of HCN and tear gas, CNCl; while formula (*b*) gives HCN only.

(3) Zyklon-B, a product of German manufacture, containing liquid hydrocyanic acid and, in various lots, 10, 6, and 4 per cent of chloropicrin, an irritating warning-giving gas.

(4) Calcium cyanide, a cyanogen product of American manufacture, in the form of a fine dust, one-half of the total volume by weight of which is HCN.

DESCRIPTION OF PRODUCTS USED

Liquid hydrocyanic acid.—Commercial liquid hydrocyanic acid averaging from 96 to 98 per cent HCN, with from 2 to 4 per cent of water, slightly aciduated with sulphuric acid.

Liquid hydrocyanic acid-cyanogen chloride mixture.—Commercial hydrocyanic acid to which has been added 20 per cent of liquid cyanogen chloride for lachrymatory effect.

Sodium cyanide (NaCN, 96 to 98 per cent).—Egg sodium cyanide containing approximately 52 per cent cyanogen and showing less than 2 per cent chlorides.

Sulphuric acid.—Commercial sulphuric acid 92 to 94 per cent pure (66° Baumè), free from nitric acid and metals.

Hydrochloric acid.—Commercial hydrochloric acid, 20° Baumé.

Sodium chlorate.—Sodium chlorate crystals.

Zyklon-B.—Zyklon-B is the trade name given to a chemical preparation of German manufacture composed of liquid hydrocyanic acid absorbed in a porous granulated earthy substance, named diatomite.

The mixture consists of equal, or nearly equal, parts of liquid hydrocyanic acid and diatomite (by weight), plus small quantities (about 5 per cent) of one of two irritating gases which have a markedly lachrymatory effect, and which serve the double function of warning exposed persons and of stabilizing the HCN in the product. Additional stabilization is secured through the diatomite and a small amount of sulphuric acid.

Zyklon-B is marketed in heavy tin cans which withstand a pressure test of five atmospheres. The cans are filled with a guaranteed HCN content of 20 grams, 100 grams, 500 grams, 1,000 grams, or 1,200 grams, which makes the "dosing" of a compartment of any size an easy matter.

When the can is first opened, Zyklon–B has the appearance of dried or only slightly moist particles of sandy clay, varying from a pale reddish yellow to an orange-yellow color. The amount of appreciable moisture varies from that in the small can, the content of which is thoroughly dry, to that in the larger cans, containing from 500 to 1,200 grams HCN, wherein the material is of the consistency of moist sawdust.

In all sizes of cans the material runs freely from a comparatively small opening (1 inch to 1½ inches), as the contents of the cans are being emptied into the holds of a vessel or spread on the floor of a smaller compartment.

The large surface afforded by the carrying material, diatomite, promotes rapid evolution of the HCN gas even when the product is exposed in relatively thick layers up to three-eighths of an inch in thickness. Under all ordinary circumstances the HCN content is quickly given off, and by the end of a two-hour fumigation period the residue is practically inert. (See Public Health Reports, vol. 42, No. 50 (Dec. 16, 1927), p. 3071.) While there is no tendency for the residue to retain or take up HCN in gaseous form, it is well to remove the residue after fumigation, especially in the quarters or superstructure of a vessel, as a marked ordor and some tear effect are noted for a considerable time if the residue be not removed.

The opening of the cans is easily accomplished with a special hammer having a tempered cutting head which cuts a 1½-inch opening through the top of the can with one stroke. Cone-headed peen hammers or sharpened chipping hammers are used for this purpose. Two or three such openings permit the discharge of the contents of the largest cans in 15 to 20 seconds. A small air hole should be punched in the opposite end of container to facilitate emptying its contents.

In dosing holds the contents of the requisite cans are poured from deck down through the hatches and spread over the floor of the hold with a sowing motion. In the holds the residue may be swept up and thrown overboard if desired, or it may be allowed to remain without danger. The dose for superstructure compartments is thinly and evenly spread on protecting sheets of paper previously laid on the floor. The subsequent removal of this residue is then easy to accomplish.

Calcium cyanide.—Calcium cyanide is a cyanogen carrier of the formula Ca (CN_2) 2HCN, formed by the reaction of hydrocyanic acid containing a slight amount of water on calcium carbide, with the formation of calcium cyanide and liberating acetylene.

According to the manufacturers, the product contains only such impurities as are common to calcium carbide, together with the small amount of polymer which is responsible for the light tan color of the compound. It is in a very fine state of subdivision, passing freely through a 300-mesh screen.

The product is extremely sensitive to moisture, being decomposed, with the liberation of hydrocyanic-acid gas, as follows:

$$Ca(CN)_2 2HCN + 2HOH = 4HCN + Ca(OH)_2$$

The usual moisture in the air quickly sets up the above reaction upon exposure, and a satisfactory liberation of HCN gas takes place when the humidity is 25 per cent or even less.

The material used for these tests was packed for shipping in 1-gallon tin buckets with friction tops. As a precaution against accidental opening, the tops were spotted in place with solder.

Each bucket contained 4 pounds of a light tan powder of the approximate consistency of the finest wheat flour. This powder is so dry and finely divided that a dust cloud is formed by the slightest agitation or draft. The odor of hydrocyanic acid gas can be noted the instant the powder is exposed to the air.

There is no appreciable change in the color or consistency of the powder after prolonged exposure, nor can the amount of HCN evolved be estimated by change in weight.

The manufacturers state that the cyanogen content ranges between 50 and 55 per cent, averaging about 53 per cent. In computing the test "doses" it was assumed that one-half of the calcium cyanide, by weight, was available HCN.

"Calcium cyanide" may be applied either in the form of a dust, through being blown into the compartment to be fumigated, or by being laid down in very thin layers. The most efficient action of the product is promoted by "dusting," as a more general distribution is secured and the HCN gas more promptly liberated. Satisfactory gas evolution is obtained, however, in layers up to one-sixteenth inch in thickness, as slightly over 95 per cent of the HCN content is given off in two hours when so distributed.

Owing to the fact that, roughly, 5 per cent of the HCN content remains in the residue at the end of a two to four hour fumigation period, and, further, because the reaction is reversible and HCN is taken up by the residue, it is essential that as much as possible of the residue be removed at the end of fumigation. When the powder is dusted into a compartment its subsequent removal is a practical impossibility, and this method of "dosing" superstructure compartments is further contraindicated, for the dust which settles on and clings to everything exposed to it is disfiguring. This criticism would not, of course, obtain when the powder is used in the hold of a vessel. When the material is distributed in thin layers on sheets of paper, the removal of the residue is easily accomplished.

LOCATION OF EXPERIMENTAL ROOMS

Satisfactory experimental rooms were available in a vacant building on Hoffman Island, a part of the New York quarantine station. Several rooms, averaging between 1,180 and 1,185 cubic feet capacity, were selected and prepared for the tests by carefully sealing all cracks and openings, no matter how small. As the walls, ceilings, and floors of these rooms were covered with cement mortar and painted over, there was little opportunity for leakage.

In order to test the diffusion of gases, two adjoining rooms were connected by introducing a number of 2-inch metal pipes through the partition wall. These pipes could be plugged gas-tight or opened as desired, and the number and location of the pipes afforded a variety of combinations to test gas circulation.

TEST ANIMALS

A large number of white rats which had been bred on Hoffman Island were available as test animals. Adult white rats were used in all tests both on the island and on shipboard.

No direct evidence was obtained as to the relative resistance or susceptibility of these animals to HCN gas as compared with wild rats; but a considerable variation in resistence between these white rats was noted when several animals were simultaneously exposed to the same concentration of gas. For this reason two or more white rats were used in all of the more delicate tests, such as when the effects of greatly reduced doses were being studied.

PROGRAM OF PROPOSED EXPERIMENTAL WORK

(1) Diffusion of gas from one compartment to another of equal size through relatively small orifices located at various levels.

(2) Retention of HCN gas in residues of certain fumigants.

(3) Reabsorption of HCN gas by residues of certain fumigants.

(4) Fumigating with reduced dosages of cyanogen products to determine the minimum lethal rat dose and to compare the lethal efficiency of the various preparations tested.

(5) Absorption and holding of HCN gas by absorptive materials exposed to fumigation.

(6) Penetration by gaseous fumigants of porous materials used to protect test animals.

(7) Miscellaneous tests of cyanogen products to secure information as to the properties, behavior, etc., of HCN gas.

(8) Fumigation of ships without cargo with various cyanogen products controlled with test animals.

(1) DIFFUSION OF GAS WITHIN A SINGLE COMPARTMENT AND FROM ONE COMPARTMENT TO ANOTHER OF EQUAL SIZE THROUGH RELATIVELY SMALL ORIFICES

Adjoining rooms of 1,181 and 1,185 cubic feet air capacity, respectively, were made to communicate through three short sections of 2-inch iron pipe which perforated the intervening partition wall at equal intervals along the mid-perpendicular line from ceiling to floor.

An attempt was made to have these rooms thoroughly gas-tight by plastering and pasting all openings in the walls, ceilings, and floors, and by papering over windows and doors at the time of fumigation. We proposed to determine the regular or average rate of diffusion from one compartment to another through such orifices as above described and to observe to what extent the passage of gas was affected by changes in temperature, artificially operated air currents, etc.

Room temperatures could not be made to fluctuate during the actual fumigation, but by utilizing steam heat and coal-oil stoves a considerable difference in the temperature of the adjoining test rooms was secured and maintained. Briefly, four temperature combinations were tried: (1) Both rooms equally chilled (50° F. or lower); (2) both rooms equally warmed (70° F. or higher); (3) room A (in which total amount of gas for both rooms was introduced) chilled while room B (containing test animals) was kept at least 20° F. warmer; and (4) room A (gas room) warmed while room B (test animals) was kept at least 20° F. colder.

Artificially induced air currents were supplied by a 10-inch electric fan operated for one series of tests in room A (gas room) and for another series of tests in room B (test animals).

For all tests the standard dosage of 2 ounces HCN per 1,000 cubic feet of space was used. In testing diffusion, sufficient gas was introduced or generated in room A to furnish an average of 2 ounces HCN per 1,000 cubic feet for both rooms A and B.

In all of these tests four test animals were placed in open-mesh wire cages in room B, two at the ceiling and two at the floor level, in opposite corners of the room, so as to afford the maximum distance from the gas intakes represented by the pipe orifices in the partition wall.

Twenty separate experiments were conducted, in which the several cyanogen products under consideration were used. Liquid HCN (80 per cent) CNCl (20 per cent) mixture was used as the standard of comparison.

Results.—(1) With exposures of from four to seven hours not enough gas passed from room A to room B through one, two, or three 2-inch pipes to affect the test animals when both rooms were otherwise tightly sealed.

(2) When small openings were left around the window frames and the wind blew directly against the windows, a lethal quantity of gas passed from room A to room B within from one to four hours.

(3) No variation in the temperature secured between the two rooms modified the passage of gas from room A to room B through the 2-inch pipes when both rooms were otherwise tightly sealed.

(4) No observable effect was produced by the air currents set up by a 10-inch electric fan running at full speed alternately in room A and room B.

A visual check on the experiences noted in Nos. 1 to 4 above was secured by burning double the standard amount of sulphur in room A and watching for the passage of the smoke through the pipes leading into room B. The first smoke seen came through the pipe nearest the ceiling 18 minutes after the sulphur had been ignited. No smoke was seen to pass through the middle and lower pipes. At no time during the 5-hour experiment was there more than a very faint cloud in room B, and at the end of the time none of the test animals in room B showed any effect.

(5) Diffusion of gas *within* the room into which it was introduced or generated indicated clearly that when no gross air currents were present, HCN gas, whether alone or mixed with "tear gas," showed a constant tendency to rise. Test animals exposed at the ceilings were invariably killed before the animals placed directly beneath them on the floor. This observation holds good only when the rats on the floor were at least as far from the center of gas generation as those at the ceiling level. In our experiments, liquid hydrocyanic acid (alone and mixed) was sprayed into the test rooms through a prepared vent in the door which made the gas distribution more or less central, while Zyklon-B was placed on the floor, as were the buckets for generating HCN from sodium cyanide and acid.

Conclusions.—Hydrocyanic acid gas shows little tendency to flow or diffuse from one compartment to another through small apertures when both compartments are otherwise tightly sealed. The importance of this conclusion is apparent when applied to conditions ordinarily existing in holds and other parts of ships.

It is a well-known fact that rats escape cyanide fumigation as fumigation is usually done, and the reason for this becomes clear when it is seen that a lethal quantity of the gas will not flow through small openings into tightly closed sections not primarily exposed to the gas. The practical proof of this was witnessed on shipboard when test animals, concealed in the covered bilges, closed drawers, and similarly tight compartments, were unaffected by standard amounts of cyanide during the course of a two-hour fumigation.

The movement of HCN gas from one room into the other through small openings as a result of the action of extraneous air currents was clearly demonstrated in those tests in which the communicating compartments were not sealed equally tight and were subject to the influence of natural ventilation. As the movement from room A (gas room) to room B (test-animal room) occurred only when the wind came directly at small outside openings and did not occur when the air in the gas chamber was agitated by a fan inclosed in the tightly sealed chamber, it appears that the diffusion or flow of gas through small orifices (2-inch pipes) resulted from the movement of the total volume of gas-air mixture in room A and the air in room B rather than from localized movements in either or both rooms.

Observations on the behavior of gas within tightly sealed rooms indicate clearly that the natural flow or diffusion of HCN and HCN mixtures is primarily upward, which emphasizes the importance of locating the center of gas generation at the lower rather than the upper part of large compartments. Even if this were not invariably true, it is obvious that the highest gas concentration in ship deratization should be contrived and maintained at or near those points where rats are most numerous and where rats have the greatest opportunity for escape; i. e., the lower parts of the ship. This detail will be further developed in the section relating to the generation method.

The conclusions regarding hydrocyanic gas diffusion in usual fumigation procedures may be briefly summed up by stating that no ordinary concentration and no ordinary exposure time will insure the infiltration of gas into so-called dead spaces commonly communicating with compartments under gas through such small openings as are customarily used by rats. The opening up or complete elimination of such small contiguous spaces and the competent blocking of such escape openings must therefore be considered as of equal, if not greater, importance than the gas dosage, the exposure time, or the kind of fumigant used. A vessel not thus properly prepared for fumigation will more or less nullify the potential good effects of the most careful gassing.

(2) RETENTION OF HYDROCYANIC ACID GAS IN RESIDUES OF CERTAIN FUMIGANTS

Residues remaining after fumigation by the generation method and following the use of Zyklon-B and calcium cyanide were considered from the standpoint of residual or unexpended cyanogen which might render dangerous subsequent human habitation of the fumigated compartment.

(*a*) *Generation method.*—All residues of sodium cyanide and acid mixtures are dangerous, as they contain varying amounts of HCN. The mere removal of containers used in the generation of HCN and the proper disposal of contents effects the necessary safeguard. The residual or unexpended HCN in such residues often comes off freely when the residue is agitated, as during careless removal, but otherwise is given off slowly.

(*b*) *Zyklon-B.*—A negligible quantity of HCN remains in the diatomite residue at the end of two to four hour exposure, even when the material is spread in very thin layers. By concentrating relatively large amounts of residue into small, tight containers, test animals were rarely killed by exposures varying from 4 to 12 hours. (See Public Health Reports, vol. 42, No. 50 (December 16, 1927), p. 3071.)

(*c*) *Calcium cyanide.*—Tables prepared by the manufacturers of calcium cyanide show that the major portion of the HCN content of this product is given off rapidly, but that the rate of evolution is modified by the thickness of the layer in which the material is distributed. Under optimum conditions, with layers only one-sixteenth inch in thickness, 79.2 per cent of HCN is given off in 1 hour, 95.7 per cent in 2 hours, 95.9 per cent in 4 hours, 96.9 per cent in 8 hours, and 97.5 per cent in 24 hours. It will be seen that 3 or 4 per cent of available HCN (one-half of material by weight) remains after a period much greater than any afforded under practical conditions in ship fumigation. These figures serve to confirm preliminary experimental findings which showed the lethal effects of this residue before the exact figures were available, in which relatively large amounts of residue exhausted for 35 hours and concentrated in small, tight containers, killed test animals in from 30 minutes to 1 hour.

(3) REABSORPTION OF HYDROCYANIC-ACID GAS BY RESIDUES

Residues of Zyklon–B and of calcium cyanide were tested to determine whether or not they were inert in the presence of hydrocyanic acid gas. Quantities of these products sufficient to fumigate rooms of 1,000 cubic feet capacity were exposed until all HCN had been exhausted. The residues were then exposed to standard doses of HCN (gas from the liquid HCN-CNCl mixture) for two hours. The residues were then separately concentrated into small, tight containers and test animals directly exposed. The animals exposed to the Zyklon–B residue survived all exposures, while the calcium-cyanide residue killed test animals in 30 minutes.

This result indicates that the reaction of calcium cyanide in giving off HCN in the presence of atmospheric moisture is reversible to the extent that the residue will take up HCN when the atmospheric content of HCN exceeds that of the residue.

Conclusions.—The results outlined in the last two sections above indicate clearly that, while the residues from both Zyklon–B and especially from calcium cyanide should be removed carefully following fumigation, the residue of Zyklon–B is apparently much less dangerous than that of calcium cyanide.

Of additional importance is the time saved in "clearing" the vessel of gas when the residue is removed soon after opening up following fumigation. There is an apparent persistence of tear effect in Zyklon–B residue which can be accounted for only by the fact that the irritating gases are more slowly released from the diatomite than are the hydrocyanic acid component.

(4) TESTING THE LETHAL EFFECT OF REDUCED DOSES OF CYANOGEN PRODUCTS AS THE BEST MEANS OF COMPARING EFFICIENCY

The most interesting and perhaps the most fruitful tests performed in our series of tests with cyanide products were those undertaken with reduced doses or fractional parts of the standard dose of 2 ounces per 1,000 cubic feet.

It is obvious that when a concentration of 2 ounces of HCN per 1,000 cubic feet is provided, a substantial overdose is insured. The question is not whether 2 ounces of HCN per 1,000 cubic feet will kill, but whether with the materials in the proportions used, the desired dose of cyanogen is made available in the compartment under fumigation.

In all of our tests, liquid hydrocyanic acid (96 to 98 per cent) was used as the standard of comparison. This eliminated the constant variability of the generation method and the uncertainty associated with the use of two comparatively new fumigants—Zyklon-B and calcium cyanide. Once the average working dose, the minimum lethal dose, and the threshold dose of liquid HCN were determined with reasonable certainty, the other cyanogen products were measured by this standard.

It was at once apparent that, if usual doses of the products to be tested were used, no real comparison of their performance would be afforded. Under all ordinary circumstances all test animals would be killed, the only variation being in the *time* required to kill. In view of the known difference in the resistance of rats to HCN gas, *the time required to kill* is of uncertain value unless several other factors are considered.

Before testing the action of reduced doses of cyanide, all test rooms were carefully sealed. Accepting 2 ounces of HCN per 1,000 cubic feet as the standard, fractional parts of this dose were used. Test animals were carefully selected as to size, and two animals were used in each test, one being placed at the ceiling and one at the floor level. It is interesting to note that, in these experiments, the animals at the higher level were always affected before those on the floor, which further indicates the natural tendency for HCN gas to rise.

Fifty-five separate fumigations were done, using the liquid HCN-CNCl mixture, liquid HCN alone, calcium cyanide, HCN-CNCl mixture generated, and HCN generated. As the smallest amount of Zyklon B available represented 20 grams of HCN, less than one-third of the standard dose per 1,000 cubic feet, it could not be used in certain tests. It is significant to note, however, that in all concentrations from double the standard dose down to a one-third dose, Zyklon-B gave results exactly comparable with liquid hydrocyanic acid (96 to 98 per cent).

Allowing for the variation in resistance in test animals, the average killing time for fractional doses when using liquid hydrocyanic acid, mixed and alone, may be accepted as follows:

One-eighth dose, or one-fourth ounce per 1,000 cubic feet, 15 to 20 minutes.
One-tenth dose, or one-fifth ounce per 1,000 cubic feet, 20 to 25 minutes.
One-twelfth dose, or one-sixth ounce per 1,000 cubic feet, 30 to 45 minutes.
One-sixteenth dose, or one-eighth ounce per 1,000 cubic feet, 60 to 180 minutes.
One-twentieth dose, or one-tench ounce per 1,000 cubic feet, overnight.
Animals withstood smaller doses for as long as 36 hours without ill effect.

In doses between one-twelfth and one-twentieth of the standard 2 ounces per 1,000 cubic feet, liquid hydrocyanic acid is slightly more lethal than the liquid HCN-CNCl mixture. For all practical purposes, however, there is no choice between the two preparations.

From the above experience we feel justified in concluding that much less than the present standard dose of liquid hydrocyanic acid will serve to kill rats directly exposed to its fumes, and that a concentration as low as one-tenth ounce of HCN per 1,000 cubic feet must be considered as dangerous to human beings exposed over a long period of time. It is logical, therefore, to assume that a reduction in the amount of gas customarily used to fumigate living and sleeping quarters (superstructure) would effectually advance the safety of persons subsequently occupying them without materially interfering with a satisfactory deratization. Our experiences indicate clearly that rats which are well enough protected in living quarters to escape a dose of 1 ounce of HCN per 1,000 cubic feet will also survive a 2-hour exposure to the standard dose.

In the light of our findings with reduced doses it is obvious that the same results as those obtained with liquid hydrocyanic acid may not be expected from the generation method. This is particularly true as regards the HCN-CNCl mixture.

Making due allowance for the loss of time in generation, one is forced to the conclusion that much less than the theoretically obtainable amount of HCN is actually delivered in the course of the average fumigation. Our tests indicate that the generation method for the production of HCN is much more effective than the same procedure for the generation of the HCN-CNCl mixture. This is to be expected in view of the fact that 1 ounce, or 20 per cent less, of sodium cyanide per 1,000 cubic feet, is used in the production of the mixed gas, and in addition some of the CN liberated from the sodium cyanide is utilized in the formation of the irritating gas, CNCl. The more rapid evolution of HCN from sodium cyanide and sulphuric acid also plays a part, as maximum gas concentration is more rapidly reached. This is of importance when it is appreciated that a very brief exposure to a high concentration is more uniformly fatal than prolonged exposure to doses approaching the threshold concentration. It is desired at this point to emphasize the extreme importance of the length of exposure under circumstances where diffusion or circulation of gas is rendered difficult. This consideration is separate and distinct from the proposition of reduced dosage which, for the purposes of this discussion, is applicable only to the results to be expected when animals are exposed immediately and directly to the gas.

Based on the results of tests of reduced doses of HCN, the conclusion is reached that the relative lethal efficiency of the several products and methods under consideration warrants their listing in the following order:

(*i*) Liquid hydrocyanic acid (96–98 per cent).

(*ii*) Liquid hydrocyanic acid-cyanogen chloride mixture.

(*iii*) Zyklon-B (10 per cent irritating gases). Equal to the liquid HCN-CNCl mixture and compares favorably with straight liquid HCN.

(*iv*) Hydrocyanic acid gas generated by mixing sodium cyanide with sulphuric acid and water.

(*v*) Hydrocyanic acid-cyanogen chloride mixture generated by mixing sodium cyanide, sodium chlorate, hydrochloric acid, and water.

(*vi*) Calcium cyanide (50–55 per cent HCN).

It must be understood that the above arrangement is arrived at by considering lethal efficiency alone. In the proper place a final comparison will be made, in which other factors affecting the value of a fumigant will be considered.

(5) ABSORPTION AND HOLDING OF HYDROCYANIC ACID GAS BY ABSORPTIVE MATERIALS EXPOSED TO FUMIGATION

The absorption and subsequent holding of hydrocyanic acid (gas) by permeable materials, such as bedding, clothing, floor coverings, sacking, and baled goods exposed to fumigation, is of more than ordinary interest on two accounts: First, the presence of considerable amounts of such material lengthens the time required to clear a given compartment of gas and, consequently, increases the time required for completion of fumigation; second, the retention of minute quantities of HCN in such materials as are always found in sleeping quarters represents a distinct hazard for persons who, without assuming all necessary precautions, subsequently occupy the quarters.

Conclusions.—The conclusions drawn from our experimental work along this line are as follows:

(*i*) Owing to the ready solubility of HCN in water, moist materials take up more HCN than dry materials. Materials dry to the touch, however, will take up a lethal quantity of HCN, and for purposes of safety no distinction should be drawn on the basis of supposed moisture content.

(*ii*) Hydrocyanic acid taken up by moist or wet materials will be held longer and given off more slowly than is the case with dry materials.

(*iii*) The *quantity* of absorptive materials exposed is apparently of greater importance than the concentration of gas used.

(*iv*) When the hydrocyanic acid-cyanogen chloride mixtures are used, the presence of moist materials or of actual collections of water in the fumigated compartment or in the bilges of a vessel, gives rise to a persistence of HCN after all "tear effect" has disappeared. This is more nearly constant for liquid HCN–CNCl mixtures and for sodium cyanide-sodium chlorate-acid mixtures than Zyklon–B (10 per cent irritator content), as in the instance of the latter the character of the irritating gases makes for persistence of the "tear effect." (See PUBLIC HEALTH REPORTS, vol. 38, No. 27 (July 6, 1923), p. 1532.)

(*v*) When using liquid hydrocyanic acid it is of the greatest importance to avoid spraying or pouring the acid directly on bedding, permeable floor coverings, or clothing. The danger is greatly increased if the materials are moist.

(*vi*) Proper aeration and drying of absorptive materials exposed to cyanide fumigation in sleeping quarters is of vital importance. In most instances this can be accomplished by exposure of from one to two hours in the open air. The process is expedited by beating and shaking the materials, or exposure to the warmth of the sunlight.

(*vii*) In view of the customary carelessness and disregard for these precautions by crews, and on account of the inclement weather which frequently occurs during and after fumigation, it would obviously be much safer if all bedding, floor mats, etc., were removed from sleeping compartments prior to fumigation. This is particularly true of crew's quarters, which, owing to location, are frequently poorly ventilated and damp.

(*viii*) The reduction of dosage for fumigation of sleeping quarters is worthy of serious consideration, as rats are killed with much less than the standard dose (2 ounces HCN per 1,000 cubic feet) of gas, and the hazard to human life diminishes with the amount of hydrocyanic acid introduced.

(6) PENETRATION OF PERMEABLE MATERIALS SERVING TO PROTECT RATS

It is our belief, based on numerous experiments, that rats which escape fumigation do so either because at the time gas is introduced they are safely ensconsed in the gas-free atmosphere of a "dead" space, or, through minor structural defects, they get away from the gas into otherwise well-closed spaces not directly affected by fumigation. It is in such spaces that ship's rats naturally harbor, and it is to such places that they instinctively turn when menaced by the introduction of gas or disturbed by the preparations incident to the proposed fumigation.

To a much lesser extent do rats find protection in cargo and the dunnage customarily found in ship's holds and compartments. Both the quantity and kind of cargo must be considered, however, and the quantity and arrangement of dunnage require attention if the vessel is to be properly prepared. The mere presence or absence of cargo and dunnage does not, in the final analysis, determine the efficacy of fumigation, but rather the quantity of material and its disposition, as hydrocyanic acid gas will penetrate either bagged or loosely boxed parcels if the gas is permitted to *surround* the container.

In testing penetration various materials with various sized perforation were used to "protect" the test animals. Included in the list are wooden boxes made gas-tight except for a predetermined number of quarter-inch holes, gas-tight containers in which the animals were protected by layers of gunny sacking varying in number from 10 to 80, blankets, rolls of matting, mattresses, and heavy paper sacks. Not only did these devices serve to check the penetrating power of measured concentrations of HCN, but they permitted a rigorous comparison of the fumigations afforded by the several cyanogen preparations under consideration.

Details of penetration tests.—(*i*) Boxes: A number of tightly jointed wooden boxes, with gas-tight doors for admitting test animals, were used. A series of such boxes was prepared by boring from none to four quarter-inch holes through one end. Adult white rats were placed in the boxes and exposed to fumigation with 2 ounces of HCN per 1,000 cubic feet. A 2-hour fumigation with liquid HCN-CNCl mixture, Zyklon-B, generation method, and calcium cyanide invariably killed all rats in boxes with two or more holes, whereas all rats in boxes with no holes were spared.

(*ii*) Gunny sacking: Test animals in open-mesh wire cages were placed in gas-tight buckets of about one-half cubic foot capacity. The tops of these buckets were covered with pads of new gunny sacking varying from 10 layers to 80 layers in thickness. These pads were so affixed that it was necessary for the gas to go through the sacking to get to the animal in the bucket. In one series of tests the pads of sacking were used *dry* and in another *wet*.

When dry sacking was used, test animals were invariably *killed* through 70 layers. Eighty layers always protected.

When *wet* sacking was used, test animals were invariably *protected* by 40 layers. Wet sacks were prepared by saturating them in water, wringing them as dry as possible, and then hanging them in the air for one hour, by which time their moisture content seemed uniform.

(*iii*) Paper sacks: 8, 10, and 12 pound sacks of kraft paper were used. By slipping one sack inside another, from one to four layers of sacking were secured, and after the rats had been introduced into the bags, the open ends were tightly pasted up.

When using 2 ounces of liquid HCN–CNCl mixture per 1,000 cubic feet, test animals were killed by a 2-hour exposure when sealed up in four sacks.

Rats protected by from 16 to 20 layers of blankets, and others rolled in matting or hidden in piles of loose sacking were invariably killed by the standard dose and exposure.

The use of artificial protection afforded a definite comparison of the lethal efficiency of the cyanogen products tested.

The liquid hydrocyanic acid-cyanogen chloride mixture (80–20 per cent) gave a slightly higher percentage of kills than Zyklon-B, but both are more lethal than calcium cyanide and the sodium cyanide-sodium chlorate-mineral acid mixture. It is apparent that the superiority of the liquid gas and Zyklon-B rests on the higher proportion of HCN gas evolved within the permissible fumigation time, and the additional fact that a higher gas concentration is reached more promptly. With accurately proportioned doses, calcium cyanide will furnish as much HCN per 1,000 cubic feet, but the maximum gas concentration is reached more slowly. The generation method is not only the slowest of the four, but actually much less HCN in gas form is produced, much HCN remaining in solution or unexpended.

(7) MISCELLANEOUS TESTS TO SECURE ADDITIONAL INFORMATION OF PROPERTIES AND BEHAVIOR OF CYANOGEN FUMIGANTS

ZYKLON-B

(*A*) *Gas leakage from small openings in containers.*—A Zyklon-B can containing 20 grams of HCN (approximately five-eighths the standard dose) was inclosed with test animals in a tightly sealed room. Five punctures were made in one end of the can with an 8-penny nail. The gas leakage from these holes was insufficient to affect test animals in three hours.

To check the potency of the contents this can was then opened in a gas-free room and the Zyklon-B spread in a thin layer on the floor. Exposed test animals were killed in 10 minutes.

(*B*) *Evolution of gas from Zyklon-B.*—To test the evolution of gas from Zyklon-B three sets of conditions were arranged: (1) Material spread in thin layers; (2) contents of can poured into one small compact pile; (3) can thoroughly opened, but material left in. Three rooms were used.

(1) Material spread in thin layers: Can of Zyklon-B containing 20 grams HCN was opened and contents were spread on the floor in thinnest possible layer. Exposed test animals were killed in nine minutes. Residue was then collected and placed in small gas-tight container with rat. Animal was unaffected after one hour, residue showing almost complete exhaustion of gas.

(2) Material spread in thick layer: Can of Zyklon-B containing 20 grams of HCN was opened and contents were carefully dumped so as to form pile of least circumference. Exposed test animals were killed in 23 minutes. Residue was then collected and placed in small gas-tight container with rat. Animal killed in 1-hour exposure.

(3) Can opened but contents left in: Can of Zyklon-B containing 20 grams HCN opened by cutting away the entire end. Contents of can were not disturbed. Exposed test animals were killed in 39 minutes. Contents of can were then poured into a small gas-tight container with rat. Animal was killed in two minutes.

(*C*) *Resistance of Zyklon-B containers to hard usage.*—Cans of Zyklon-B containing 20 grams and 100 grams of HCN and weighing (gross) approximately 200 grams and 400 grams, respectively, were dropped from a 45-foot tower to concrete pavement and thrown by a man with full force against solid brick walls without causing leakage. Test for leakage was made by placing these cans together with test animals in small gas-tight containers. The animals were unaffected after three hours' exposure.

(*D*) *Increase of pressure within Zyklon-B containers.*—Some pressure was exerted within in about one-half of the cans of Zyklon-B handled in all sizes from 20 to 1,200 grams HCN, as indicated by bulging ends. A number of cans with unbulged ends were heated by direct exposure to sunlight on the steel deck of a vessel. With the increase in pressure due to temperature, the ends of these cans bulged with loud popping noises, but no leakage occurred.

The tests outlined above (*A*)–(*D*), indicate the safety with which Zyklon-B can be handled. No apprehension need be felt when transporting it through crowded streets, as, even if the transporting vehicles were wrecked, the small, strong containers would hardly be opened up; and if they were the relatively slow escape of gas into the open air would be without danger to the public.

(*E*) *Persistence of "tear effect" with Zyklon-B.*—Repeated observations and experiments indicate definitely that the "tear effect" produced by the irritating gases included with HCN in Zyklon-B is always effective as long as a dangerous quantity of HCN is present in the fumigated compartment. When large amounts of the material are used, as in holds, the "tear effect" persists for some time after the HCN has disappeared. This conclusion is based on combined human and rat tests wherein the test animal is lowered into the hold at the same time the officer goes below.

The claim of the manufacturers in this connection seems to be sufficiently substantiated: "The tear gas contained in Zyklon-B is intended only as a rear guard, and not as an advance guard; it being so much heavier than HCN, its rate of diffusion is much slower. Its useful function is as a warning when airing fumigated compartments, as during the period of fumigation it has time to develop fully, and remains irritant for some time after all traces of HCN have disappeared."

Our experience with the mixtures secured for test assures us that from 4 to 6 per cent of irritating gas affords ample protection. The mixture containing 10 per cent of irritating gas so prolongs the clearing of the larger compartments as to necessitate the holding of a vessel much longer than demanded by safety.

It is well here to insert a comparison with the cyanogen chloride mixture (HCN-CNCl) and to discuss the general proposition of protective gases. The writers are firmly of the belief that, when used in connection with liquid HCN, none of the irritating gases exert a dependable *pre-warning* effect. In the slower gas evolution of the generation method, time is sometimes given for escape, but this may not be relied upon. Cyanogen chloride does serve an important function during the process of active fumigation, as even the uninitiated would not get far into a compartment filled with the HCN-CNCl mixture. It is our opinion, however, that, with the present fumigating routine, the most dangerous phase of the operation is after the vessel has been opened up. The ideal warning gas is one which will deter both fumigators and other persons from entering a gassed compartment until all traces of HCN have disappeared.

While thoroughly appreciating the theoretical integrity of the HCN-CNCl mixture, we have been forced to the conclusion that, in certain comparatively rare instances, considerable amounts of HCN did remain in moist, poorly ventilated holds after all tear effect had disappeared. This was confirmed experimentally by fumigating compartments in which were placed quantities of moist materials and subsequently testing for tear effect and retained HCN. On numerous occasions, not only was the presence of HCN easily detected by odor and taste, but test animals have been killed by direct exposure to the fumigated materials long after all traces of tear effect had disappeared. It was further observed that dry materials retained lethal quantities of HCN after the tear gas had been dissipated.

We feel that we can not too urgently stress the importance of not placing too much reliance on "tear effect." When using HCN alone, an experienced cyanide fumigator can, with the aid of test animals, declare a vessel safe for human occupancy with every assurance that no trouble will follow. On the other hand, no fumigator, regardless of his experience, is warranted in declaring a vessel safe merely because his eyes did not water when he inspected the sleeping quarters and holds. This applies particularly to the HCN-CNCl mixture; but even when using Zyklon-B the testimony of one's senses should be supplemented by exposing test animals at the danger points.

(8) SPECIAL CONSIDERATIONS OF THE USEFULNESS AND ADAPTABILITY OF VARIOUS CYANIDE PRODUCTS AND VARIOUS METHODS OF FUMIGATION

Liquid hydrocyanic acid, alone and mixed.—Considered only as a lethal agent, liquid hydrocyanic acid is the fumigant of choice. When public safety and ease of handling are likewise considered, it is not better than, if as good as, Zyklon-B. After all mechanical and other preparations are made and liquid HCN is placed on board in suitable applicators, one finds that fumigation has been simplified to the utmost degree. To gas a hold containing 120,000 cubic feet of air space one opens a valve, and when the indicator on a hand scale shows that 15 pounds of the material have entered the hold the valve is closed. Fifteen minutes will suffice to gas a cargo vessel of from 3,000 to 5,000 tons capacity. The dosing of superstructure, however, comprising some large and numerous small compartments, develops one of the major problems incident to the use of liquid HCN. As yet, no instrument has been devised which will rapidly and accurately deliver small doses of the gas; and until the cyanide fumigator is given an accurate dosing machine, the fumigation of quarters will be a matter of guesswork.

In the light of our experiences, the tendency to overdose small compartments is constant. The danger of this practice is obvious, and in the absence of the suggested mechanical equipment can be counteracted only by deliberate underdosing. This perplexity is entirely overcome through the use of Zyklon-B with accurately measured doses of from 20 grams to 100 grams HCN always at hand.

Considerable mechanical equipment is required for handling liquid hydrocyanic acid. It is transported by truck from the manufacturer to the station using it, in large (75 pound) I. C. C. cylinders. The application of air pressure is required to pipe the liquid from these tanks to smaller (10 and 15 pound) cylinders used as applicators. These in turn have to be "pumped up" to a pressure sufficient to expel the liquid gas in the form of a fine spray. Numerous mechanical and chemical problems were met in connection with the applicators. These were successfully overcome, as regards administering large doses for hold fumigation, by the manufacturers of liquid cyanide, and the personnel of the New York quarantine station prior to the beginning of the studies dealt with in this report.

The explosive instability of liquid hydrocyanic acid has been recognized for many years. In addition to the explosion of gaseous mixtures of HCN and air, it is known that liquid hydrocyanic acid undergoes violent decomposition produced entirely by exothermic reactions occurring in the liquid in a closed container. The nature and mechanism of the exothermic polymerization and decomposition of liquid hydrocyanic acid has been carefully studied by the research chemists of one of the largest American chemical corporations, and the findings of these experts were such as to give rise to the following statement from the manufacturers: "This investigation and others made by the same company led to the conclusion that not enough is known about ways and means of stabilizing liquid hydrocyanic acid to warrant its shipment by *common carrier*. The —— Chemical Company will continue indefinitely its present policy of shipping liquid hydrocyanic acid only under such conditions that its employed representatives may supervise and be entirely responsible for the product until it passes into the care of the ultimate consumer or of some equally responsible party." It is significant of the high character of the organization concerned that, at the time the above determination was expressed, the shipment of liquid hydrocyanic acid by common carrier was permitted under the regulations of the Interstate Commerce Commission.

From the standpoint of station fumigation, such findings regarding liquid HCN sharply define the responsibility accepted in storing and transporting the material.

Considered on a cost basis, liquid HCN is one of the least expensive of fumigants. The purchase price of the material is relatively low, there is no waste, the amount of cyanogen paid for is actually delivered into the compartment to be fumigated, and about one-half the personnel required for a generation method of cyaniding is needed. If the material were absolutely stable, and an easily portable and accurate device were available for delivering small doses, liquid hydrocyanic acid would be the ideal fumigant.

Zyklon-B.—All of the objections to liquid HCN are met and overcome with Zyklon-B. At the present time Zyklon-B is manufactured only in Germany, but the price per pound of HCN content is the same as that of the liquid HCN manufactured in the United States.

Compared on the basis of weight and bulk of materials required for fumigation, Zyklon-B runs a close second to liquid HCN. Prepared for fumigation, the liquid HCN applicators represent twice the weight of available HCN. The average package of Zyklon-B represents three times the weight of contained HCN. This is equivalent to saying that for a 3,000-ton ship, 75 pounds gross weight is carried for liquid cyanide fumigation and 114 pounds for Zyklon-B fumigation. The difference in weight is offset by the fact that when using Zyklon-B, empty cans and residue are thrown away so that there is no load on the return trip. As only four men are required for a liquid cyanide or Zyklon-B fumigation of a cargo vessel up to 5,000 net tons, the personnel cost is the same. All things being equal, the transportation costs of handling liquid cyanide and Zyklon-B would be about equal; but the complete safety with which Zyklon-B can be handled permits the use of much simpler and less expensive transport.

There is every assurance that Zyklon-B will be manufactured in the United States at an early date; and it is reasonable to assume that the cost of the product can be greatly reduced by local manufacture.

Generation method.—Results secured experimentally and on a large scale lead us to the conclusion that HCN generated by the barrel method is relatively much more efficient than the HCN-CNCl mixture similarly generated. So far as can be determined, this is due to the fact that the standard formula for the mixed HCN-CNCl gas produces less HCN than does HCN alone. Twenty per cent less sodium cyanide is used per 1,000 cubic feet, and the production of cyanogen chloride naturally utilizes some of the available cyanogen. In view of the fact that the "tear effect" of cyanogen chloride does not persist any longer than, if as long as, the HCN, even in proportions from 20 to 40 per cent, it is believed that its usefulness as a warning gas is thereby seriously vitiated.

We are firmly of the opinion that the generation method for the production of hydrocyanic acid gas for ship fumigation can not be justified in comparison with the liquid gas method and Zyklon-B method, when the items of cost, handling, and transportation are considered.

The excessive quantity and weight of equipment in the generation method necessitates the use of large trucks for transportation and a larger personnel than either of the other methods. Having arrived at the vessel to be fumigated, approximately four times the amount of time is required to get the ship under gas; and when the fumigation is completed, an equal length of time is required to remove barrels, buckets, etc., and to prepare them for return to the station. This loss of time not only affects the fumigating squads, which are frequently needed for other ships, but the vessels as well; and it is the loss of ship time after all that is of the most serious moment.

The least expensive item of generated HCN fumigation is that for the chemicals used. It is self-evident, however, that if such use of material is not uniformly productive of the results desired, i. e., a maximum rat kill, waste ensues which inevitably adds to cost, even though it is not immediately apparent.

An item of constant and increasing expense is that for barrels and buckets, which quickly break down under wear and tear and exposure to the diluted acid. The cost of heavy truck transportation plus depreciation adds to the steadily mounting expense, exclusive of the greater personnel required.

Calcium cyanide.—As has been previously stated, calcium cyanide compares favorably with both liquid HCN and Zyklon-B in killing efficiency when HCN content is used as the basis of comparison. It is most effective when applied in the form of a dust; but when applied in layers the rapidity of the evolution of HCN is, within limits, proportional to the thickness of the layers. For all practical purposes, calcium cyanide can not be dusted into vessels, as the residue is objectional, and unless laid down on sheets of paper or otherwise so that it can be completely removed, its use must be criticized not only on grounds of cleanliness, but because a variable proportion of its HCN content is retained for periods greatly in excess of the time permitted in routine ship fumigation.

Inasmuch as only one-half the volume of calcium cyanide, by weight, is HCN, its present price of $1 per pound gross weight is excessively costly. We understand that reductions in cost up to 15 per cent are made on large quantities, but even so the cost of HCN content will then be about $1.70 per pound as compared with $0.90 to $1 for liquid HCN and Zyklon-B.

In this connection, we wish to state that none of our experimental work substantiated the claim of the manufacturers of calcium cyanide that in lethal efficiency, it was the equivalent of liquid cyanide "pound for pound."

If the points of objection raised were of no moment, a competent fumigation with calcium cyanide would be acceptable, but as the material has no qualities superior to the other cyanogen products tested, we do not recommend it for prior consideration at this time.

GENERAL ASPECTS OF FUMIGATION WITH SPECIAL REFERENCE TO THE APPLICABILITY OF CYANIDE FUMIGANTS AT VARIOUS QUARANTINE STATIONS OF THE SERVICE

A sincere effort has been made to view the question of cyanide fumigation from the angle of the small and sometimes isolated quarantine station with limited personnel and equipment. While we have dealt only with cyanogen products, we have not lost sight of the fact that some such stations are not yet, and may not for a long time be, ready for this type of fumigation. We believe, however, that if ship fumigation is ever to reach the plane of a scientifically controlled procedure, some radical changes will have to be made, and these involve the selection and development of a highly lethal agent which can be handled with comparative safety under all circumstances.

If managed with due care and proper respect, hydrocyanic acid is the best of all fumigants for rodents. Careless use of it will be attended by human fatalities, but it will kill rats under conditions that the use of sulphur can not meet; and it is obvious that if fumigation does not kill rats, time and money are wasted.

It is apparent that the present-day routine fumigation does not kill all of the rats in a vessel even when cyanide is used. This is hardly a criticism of HCN as a lethal agent (as it has been shown that even one-fifteenth of the standard dose is uniformly fatal to exposed rats), but points rather to the fact that usual procedure, method of application, and other factors on board the ship operate against complete success.

It is certain that, if the concentration of gas theoretically obtained by introducing a predetermined number of pounds or ounces of HCN reaches the rats on board a vessel, the rats will be killed. It is no less certain that, if the animals survive, the expected concentration and the rat did not meet. Proper preparation of a vessel for fumigation (and this includes the fulfillment of certain structural requirements from the time the keel is laid) is absolutely essential if gaseous fumigation is ever to become a more exact rat-eradicative measure. So long as there are contiguous dead air spaces or pockets into which rats may escape, only partial results will be secured. No gas, no matter how lethal nor in what concentration used, can be expected to follow comparatively long and tortuous rat runs nor to pass through small openings into practically dead air spaces by diffusion within the two hours usually allotted for fumigation.

Successful fumigation also depends largely on proper location and distribution of the gas generation centers. To insure maximum efficiency the gas should be introduced as near as possible to rat-harboring places, and several well distributed small "shots" in a large compartment are far more efficacious than one big one. When using the generation method, containers should be placed on the floor of the lower hold and on the "between decks" and not swung from the hatch coamings as has been suggested and advocated heretofore.

To kill rats is the prime object of ship fumigation. To accomplish this purpose in the interest of the public welfare, the most thorough and painstaking measures are warranted. If, however, it could be known that there were very few or no rats on board a vessel, the fumigation of the vessel would be unjustifiable. It is believed that it is usually possible to determine by competent inspection whether or not a significant number of rats infest a vessel at a given time. It seems evident that further experimentation along this line will be productive of fruitful results as the cooperation and support of shipping interests can be counted on for the furtherance of a plan which would promise definite relief from unnecessary delay and expense. With inspection as the basis for determining the fumigation status of a vessel, only such vessels as showed evidence of rats would be fumigated, and these would be handled in a thoroughly competent manner. After adequate preparation, repeated protracted fumigations would be undertaken for the purpose of *ridding* the vessel of rats. These vessels would not be fumigated again until evidence of rats showed renewed infestation. Shipping companies could be depended on to prosecute active rat trapping, rat-proofing, and other eradicative measures as the best means of deferring fumigation. The fact must not be lost sight of that it is the presence of rats on board and not merely the plague status of ports of departure, nor the interval since the last fumigation, which defines the potential infectiousness of a vessel.

Liquid cyanide can be used only at certain of the larger quarantine stations having trained personnel and adequate mechanical facilities. Supplies of liquid gas must also be procurable from nearby depots and "service stations," for such equipment must be readily available. At stations where liquid cyanide is used, supplies of Zyklon-B should be maintained for the fumigation of superstructure compartments, where the demand for accurate small doses of HCN is constant. The combination of liquid cyanide for the holds and Zyklon-B for the sleeping quarters and deck compartments is almost ideal.

Zyklon-B will meet every requirement of the smaller stations. It is compact and easily stored. The package withstands rough handling and lasts indefinitely or until punctured. Convenient doses of HCN are provided, and dosing with the material is practically "foolproof." Because of the granular consistency and the free-running quality of the material, highly satisfactory gas distribution is accomplished without effort. Three men can fumigate a 3,000- or 4,000-ton empty cargo vessel in less time than can six men using the generation method. When fumigation is completed, empty cans and residue are thrown overboard, so there is no return load.

For stations not yet ready to relinquish sulphur as a fumigant, a useful combination will be found in sulphur for the holds and Zyklon-B in all upper deck compartments where the destructive effects of sulphur are objectionable. Such stations should be encouraged in the use of cyanide, however, as a sulphur fumigation is time consuming and, except in the instance of unusually well-prepared vessels, does not compare with cyanide.

Hydrocyanid acid gas does not affect metals, fabrics, or foodstuffs. Its relatively high rate of solubility in water, however, indicates the advisability of pouring out all drinking water and other beverages directly exposed to the gas during fumigation, and the prompt pumping out of bilges following fumigation.

All persons directly engaged in cyanide fumigation should be equipped with an efficient anticyanide gas mask and compelled to wear it both while dosing and opening up compartments. In entering holds to test gas, the mask should be carried in such a position that it can be instantly applied. If gas is encountered in a hold, panic should be avoided. Apply the mask and *walk* to the well-ventilated area immediately beneath the hatch opening. Do not attempt to climb the hold ladders immediately, but wait until the head is clear, the heart beat steady and slow, and the knees are strong. When leaving the hold, climb slowly.

The subject of ship fumigation is one of the greatest sanitary importance. Until a more efficient method for the eradication of potentially plague-infected rats is devised and its specificity proved beyond any reasonable doubt, fumigation will stand as the procedure of choice. It will repay all who are concerned to study the subject carefully to the end that the manner of its performance and the measures used are made more efficient.

The lessons learned in the course of the experimental work covered in this report point insistently to one conclusion: FUMIGATE FEWER SHIPS BETTER.

COURT DECISION RELATING TO PUBLIC HEALTH

Occupational disease held not compensable.—(Maine Supreme Judicial Court; Dillingham's Case, 142 A. 865; decided August 20, 1928.) The Maine workmen's compensation act provided:

> If an employee * * * receives a personal injury by accident, * * * he shall be paid compensation.