7 The Demise of Sulphur

Crowned with the sophisticated invention and application of the Aparato Marot, the history of sulphurization came to a gradual end in the third decade of the twentieth century. The history of Clayton's enterprise appeared to have already ended in 1910. Overwhelmed with debt, the Clayton companies had to declare bankruptcy and their shares were swallowed by their debtors.[1] While the precise cause for the sudden end of his global manufacturing company remains unclear, Clayton's bankruptcy certainly anticipates the demise of sulphur-based disinfection and disinfestation methods. Traces of Clayton's life and work thereafter become scattered. Passenger lists and passport applications from 1907 and 1909 indicate frequent traveling between New York and his branches in Paris and London, but with the end of his company at age 53, his public life as manufacturer of fumigation machines ended.[2] However, his machines would remain in use through WWI, and it was only in the 1920s that a new method began to replace the apparatus to which Clayton had lent his name, and which had defined the sulphuric utopia.

Paradoxically, given the demise of the Clayton Company in 1910, by 1920, sulphur dioxide and its various derivates had become the chemical of choice for maritime sanitation. As a result of the introduction of the Fresch method, sulphur was cheap to obtain across the globe. The resulting gas had been proved harmless to most goods, fabrics, and merchandise exposed to it in the process of fumigation. Due to its significant smell, the gas was also noticeable by the personnel carrying out the disinfection work, and was thus considered safe to use. And with the right kind of machinery, questions of pressure, density, and circulation were refined to guarantee the highest levels of efficiency. Finally, perhaps the most important quality of sulphur-based fumigation was that it was internationally agreed to be destructive to pathogens, as well as to insect vectors and rats, providing an instrument of what came to be established as the trinity of hygienic utopianism: disinfection, disinsectization, and deratization.

So what was it that led to sulphur's demise as a fumigant in the 1920s? It has already been noted that SO_2 had some persistent problems: some derivatives were inflammable, the stench was often considered a lasting nuisance, while the chemical also proved to be highly corrosive to silver and gold. Furthermore, the weight of the gas was repeatedly an issue, as it tended to sink to the ground of fumigated holds, allowing rats to climb to safety, or seek refuge in rat-permeable infrastructures (called "rat harborages" in relevant literature) where the gas was unable to penetrate. All this made the efficacy of SO_2 as a fumigant a much-contested subject. This was especially so as, in the aftermath of World War I, the priorities of fumigation and, more broadly, maritime sanitation appeared to shift from disinfection to disinfestation. This proved to be a critical moment in the history of fumigation and the hygienic utopias that had until then propelled the entanglement of experimental systems, maritime regulation, imperial competition, and trade interests around sulphur. For as we have examined at length so far, the success of sulphuric fumigation was predicated on the way in which it appeared to provide an optimal solution to a combined hygienic goal: the destruction of germs and their vectors. This chapter will examine how the gradual abandonment of germicide as a goal of maritime sanitation and the refocusing of fumigation singularly on deratization led to new entanglements between scientific, engineering, economic, and political goals and processes. These found material grounding in the shift from sulphur to cyanide as the fumigant product of choice, initially in the United States and, by the late 1920s, across the globe.

The Rat Refocused

As historians of sanitation in the United States have noted, the image of the rat developed in North America during the first half of the twentieth century was heavily racialized and dependent upon prebacteriological investments of filth and decay.[3] The opening paragraph of the Farmers' Bulletin 896, published by the US Department of Agriculture in 1917, gives a clear image of the entanglement of these notions with the specter of plague:

> The rat is the worst animal pest in the world. From its home among filth it visits dwellings and storerooms to pollute and destroy human food. It carries bubonic plague and many other diseases fatal to man and has been responsible for more untimely deaths among human beings than all the wars of history.[4]

Such narratives weaved an image of rat's relation to humanity as one underlined by human culpability. Not only was humanity seen as hitherto unable to battle the rat in an efficient manner, it was also accused of actively aiding its encroachment into humankind's realm: "For centuries the world has been fighting rats without organization and at the same time has been feeding them and building for them fortresses for concealment."[5]

Writing in 1913, R. H. Creel, the Passed Assistant Surgeon of the US Public Health Service, opened his review of the rat as "a sanitary menace and an economic burden" by stating that "of all the parasites that have their being in and around the habitation of man the rat has less to justify its existence than any other."[6] Seen as "devoid of any redeeming traits," the rat was condemned as "a greater pest" even to the fly "because of its depredations and its possibilities for harm in the transmission and perpetuation of bubonic plague in a community."[7] In accordance to this narrative, sylvatic sources of plague, such as ground squirrels or marmots, posed no significant threat to human health in themselves but only insofar as they were "the source of a continued reintroduction of the disease, among the neighboring rat population."[8] The doctrine developed, not only in the United States but across the globe, was summarized in the slogan "No rats, No plague":

> *PLAGUE, RAT, FLEA, MAN, PLAGUE, RAT, FLEA, AND MAN AGAIN*, so the cycle runs unless interrupted. *KILL THE RAT AND THE FLEA* and there will be no plague.[9]

If, as Creel noted, "a ratless country seems almost Utopian"; a "crusade against the rat" could be a means of "safeguarding the country from any possible plague invasion."[10] *"IT IS NOT TOO LATE TO BEGIN THE WARFARE NOW"*—declared the famous dermatologist, leprosy expert, and veteran president of the American Medical Association, Isadore Dyer, in a 1912 bulletin issued by the Medical Plague Conference Committee of New Orleans for public instruction and wide publication across the medical and lay press: "*NO RATS, NO FLEAS; NO FLEAS, NO PLAGUE! MAKE THAT THE SLOGAN!.*"[11]

Growing concerns about rats and maritime trade built up over the first decade of the twentieth century. They were particularly fueled by studies showing the rat's ability to jump, swim, and tightrope-walk, as well as by ideas that plague occurred in rats in a chronic form, and observations regarding the propensity of plague-sick rats in particular to remain in bales or other cargo in the process of loading and unloading.[12] A South African report from 1909 stressed:

> A rat sick from Plague may enter and die in a skeleton crate or in a bale of forage, and the carcasses may be carried long distances by sea of rail. On arrival of the bale or crate at its destination local rats investigate its contents, perhaps devouring the carcass of the dead rat or becoming inoculated by fleas which have left the carcass and thus become infected.[13]

Indeed by 1910 the connectedness between ship and rat had assumed almost mythic proportions. Scientific works attempted to link rats and humans in a way that did not simply reflect what, following medical anthropologists Hannah Brown and Ann Kelly, we may call the "material proximities" of their interspecies existence, but also seemed to foster a world-historical connection between the two species.[14] Referring to the journey of Noah's ark, William Hobdy's contribution to the voluminous work *The Rat and Its Relation to the Public Health*, published by the US Public Health and Marine-Hospital Service in 1910, began thus, inextricably linking humanity's and rat's destiny:

> Since men first went down to the sea in ships the rat's voyage-making tendencies have been known, and their fecundity is as well established as their fondness for travel. The record does not state that there were more than a pair on the ark at the beginning of her voyage, but the chances are better than even that her skipper began that voyage with more rats than his manifest showed; but whether he did or not, we can be sure he had more at the end of the voyage than at the beginning. Whether or not succeeding generations inherited from their forbears on the ark this well-known wanderlust is undetermined, but it is a fact that the intimacy and companionship established and begun then have been persistently maintained by the rat ever since. His travels have been coextensive with man's, until to-day there is not a port on earth where the rat is not present.

From Sulphur to Hydrocyanic Acid

William J. Simpson's 1905 influential *Treatise on Plague* brought the rat systematically and forcefully into the center of the modes of dissemination of plague. There, he considered the Clayton apparatus to be a "weapon of utmost value" to the destruction of rats and fleas in the holds and cargo of infected ships.[15] But, as a report from 1910 indicates, Simpson must have also considered the adaption of hydrocyanic acid gas in British India for the means of plague control in the final years of the nineteenth century.[16] During his investigations in British India, he ordered experiments to be undertaken to determine what density was required to use hydrocyanic gas to exterminate bedbugs. As William David Henderson Stevenson explains in his 1910 report on the *Killing of Rats and Rat Fleas by Hydrocyanic Gas*, the bugs were found regularly in premises in which plague had occurred. Simpson briefly considered the bedbug to be one possible vector of plague and thus encouraged its experimental destruction.[17] But due to the relative decline of plague in India and the departure of Simpson from the subcontinent in 1898, experiments had been discontinued and widely forgotten. In May 1909, upon the suggestion of a Captain W. Glen Liston, Stevenson began new experiments to determine the capacity of the gas to kill fleas and rats. The report stands as the first systematic investigation into the capacities of the hydrocyanic acid gas to kill rats, as well as rat fleas, in enclosed compartments.

As observed by Stevenson, and established through work of the Government Entomologist at the Cape of Good Hope, however, the gas did not seem to affect plague bacteria. Nonetheless, Stevenson carried out two series of tests with the gas, which was put into action to disinfect the clothing of travelers on railways, to destroy fleas and rats, and to disinfect plague-stricken houses.[18] For the first experiment, Stevenson mixed potassium cyanide with sulphuric acid and water. He heated the solution over a Bunsen flame and used tubes to direct the undiluted gas directly into a room in which the clothing was stacked. Through a second pipe, air was introduced into the mixture. The room was sealed, and he could quickly establish that a sufficient penetration of clothes was achieved when they were hung up, and that a short period of exposure—sometimes just five minutes—was enough to show all fleas to be killed. The second series of tests was conducted on plague houses, which were sealed as much as possible. The houses had floors of stumped earth, with rat burrows meandering through the floor's subsurface and leading to small openings on the ground. Both rats and fleas were kept in the burrows, the whole setup being designed to resemble the setup of Captain Gloster, which had been originally designed for experiments with the Clayton apparatus. Pumping the gas into the house yielded satisfying results. But it also created noxious vapors around the building during and after the experiment. Stevenson considered the use of hydrocyanic acid as capable for killing fleas and rats in such environments, but did not recommend its application in real settlements, as possible effects on bystanders and neighbors were highly probable.[19]

Historically, hydrocyanic gas had found its way into pest control by American entomologists, who were familiar with the substance from botanical and agricultural deployment. The gas had been used in agriculture in the United States since 1886. In California, Coquillet had originally devised a method to apply cyanide, whose properties were well known to gold and silver washers, to the task of fumigating citric trees so as to rid them of "Cottony Cushion Scale."[20] After all other existing gases and common substances like sulphuric gases had been shown to have adverse side-effects or no effect at all, Coquillet devised a method of dissolving cyanide in sulphuric acid with water to effectively fumigate trees with the resulting hydrocyanic acid gas. Soon after, the gas was picked up by South African government entomologists who conducted experimental fumigations of prisons in order to rid them of *Acanthia lectularia*, the bedbug. Although the particular gas was considered too dangerous for house disinfection, it was used in 1900—by request of the Colonial Office—to fumigate the Worcester jail. In 1901, Tokai and Kimberley, two other prisons in South Africa, were treated in the same manner. Although these trials were considered successful, the amount of potassium cyanide required proved to be expensive both to purchase and to use.[21] Nonetheless, the colonial authorities proceeded to experiment with the cyanide-based fumigation on rail carriages to destroy vermin of all kinds.

In the field of botanical application, some experience had been gathered on the correct proportions and the particulars of using and controlling the dangerous substance. For Stevenson, the relationship between potassium cyanide, sulphuric acid, and water should follow the already established "1-2-4 formula," which left enough water to dissolve potassium cyanide fully and was also seen as a proportion in which the temperature of the solution would yield to the most desirable effects.[22] For the application in boats and buildings, Stevenson remarked for his experiments in Calcutta, the preparation was largely comparable to the established routines of fumigating with sulphuric acid. But particular attention was given to the containers in which the chemicals were to be mixed. The carrier pot needed to be made of glazed earthenware or china washhand vessels, as other surfaces tended to crackle and tin cans were seen to dissolve. Once the pot was placed in the middle of the fumigated compartment, the water was mixed with the sulphuric acid. Adding potassium cyanide to set the mixture off was a risky procedure: "at once drop in the potassium cyanide at arm's length, and run out of the room."[23] Some suggested to wrap acidic salt in paper so as to extend the time it took for the activation of the solution. Others built string and pulley constructions with which the salt could be lowered into the pot from outside the fumigated room. The gas disseminated quickly and was recognizable up to one hundred feet from buildings, utmost attention therefore being needed to restricting humans from entering the zone of danger. Following the gassing, the duration before opening of the compartments depended on a variety of factors.[24]

Insects, rats, fleas, eggs of insects, and lower animals were immediately killed or, as Stevenson called it, "devitalized."[25] As previous application in botanics had shown, the effects on plants and grains, as much as on food and water, was harmless, and later ingestion of all of the above was inconspicuous. But as experiments with various cultures of streptococci, typhus, coli, and plague bacilli showed, the gas had almost no effect on bacteria. Almost all cultures seemed unaffected and continued to grow on agar after extensive exposure to the gas. Nonetheless, according to Stevenson, this did not rule out the use of hydrocyanic acid for the prevention of plague. It was an excellent, cheap, and quick method for disinfecting clothing and fabrics, ridding them of fleas, and also for exterminating rats in rooms, holds, and compartments. Hydrocyanic acid gas was seen as a superior pulicide and as a widely effective instrument of deratization. If its application was followed by the book and supervized by experienced operators, its otherwise immense danger to humans could be effectively controlled.

In terms of the practices and procedures, the utilization of hydrocyanic acid gas in maritime sanitation appeared to be highly compatible with the much older, but still practiced, method of burning sulphur directly in the holds of ships. Following the 1903 sanitary conferences in Brussels and Paris, US port authorities had continued to utilize sulphur in its simplest form, or so-called SO_2 "pot method," for fumigating vessels.[26] Mostly used in ports not equipped with a Clayton machine, or for ad-hoc fumigations beyond the capacities of quarantine stations, the practice had been a widely used alternative to the mechanized procedures of the Clayton. In the words of Hodby, the Passed Assistant Surgeon at Angel Island Quarantine, "For an empty vessel nothing is so satisfactory as the pot and pan method of generating the gas. It has the following advantages; is more rapid than any other, is cheaper, is more effective, and is equally applicable to the largest and the smallest vessel afloat."[27] Hobdy calculated that the best method involved the use of a six-inch-deep pot with a wider mouth than base (at a 24:16 inch ratio), which would then put in a tub of galvanized iron (diameter: thirty inches) containing a small amount of water. Pots should be filled with sulphur shaped in such a way that the top was hollowed into a small crater, where four to six ounces of alcohol was added. The latter was ignited with the help of a match and the compartment closed allowing the gas to seep through.[28] Circulars of fumigation and corresponding instructions to companies operating vessels sailing into US ports from plague-suspect origins, such as Havana, specified the amount of sulphur to be used in accordance to the pot method, as well as timing and other practical requirements to great detail.[29] In reality, however, the use of this method was found time and again to leave much to be desired. This was especially so when it came to the destruction of rats. In the reporting year July 1911 to June 1912, the New Orleans port authorities inspected 110 vessels derived from suspected or infected "plague ports," out of which thirty-one were found to be "comparatively free from rats."[30] The authorities applied "fumigation with sulphur," resulting in the death of 537 rats. Most interestingly, the report of the New Orleans Quarantine Station affords an image of the less-than-neat reality of fumigation:

> There were several instances of vessels discharging large numbers of rat eaten sacks, and very few or no dead rats having been found; and of rats taking to the boats when vessels were being fumigated. On several Nitrate boats, it was stated, that the rats not being able to endure the fumes from the cargo, took refuge in the engine room and cola bunkers, and in that way escaped death by fumigation.[31]

Another contemporary report, this time from the port of New York, evinced a similar ambivalence in its account of the fumigation of 127 ships over the previous twelve-month period aimed at the destruction of rats and the protection of the port against plague.[32] As a result of this operation, 1,934 rats were recovered, out of which an astonishing but no less unusual 1,224 were examined in the lab, with seven cases "showing suspicious forms," leading however to no positives in inoculated guinea pigs.[33] If this all sounds pretty ordered and neat, a different picture arises from the description of the fumigation process itself. The report confirmed that the number of rats recovered far from corresponded to the total number of rats destroyed as a result of the operation: "In many cases all the rats killed are not found. Eleven of the ships subjected to fumigation were fumigated at quarantine on their way to sea and the sulphur gases being not sufficiently clear from the hold to allow a search for dead rats, the vessels were permitted to depart."[34]

The practical problems facing fumigation, as evident from the archives of the US Public Health and Marine-Hospital Service, were epitomized by the fact that vessels did not possess structures that would allow for the fumigation of their holds. The New York & Porto Rico Steamship Company was thus urged to take urgent measures of retrofitting its boats so that each and every part of them would be "either capable of being opened up for examination or to allow the free circulation of sulphur fumes."[35] This required port authorities to train shipping companies to read their vessels in relation to rats:

> The ceilings in the holds for instance is an excellent rat harbor, the planking is usually spiked down or very securely fastened so that it is very difficult to remove any of them. The pipe casings in the holds also are securely nailed and are not only rat harbors, but serve as runways for rats from one part of the ship to the other. On your vessels it frequently requires three or four hours work by the carpenter to open up these places preparatory to fumigation, and I would suggest that panels be placed in the ceilings, each panel with sufficient ring-bolts, so that say a quarter of the entire area could be removed easily.[36]

A more elusive problem concerned operating on vessels that had been subjected to different methods of fumigation at their origin and in their intermediate stations. For example, the British *SS Bessie Dollar* arrived on July 26, 1912, at the quarantine station of Angel Island. A portion of the vessel had been fumigated in Manila, the Philippines, though it was not detailed which parts of the ship this included. Later, when the vessel stopped in drydock in Hong Kong, the harbor master did not allow fumigation; as a result she was subjected to fumigation with "sulphur gas" upon arrival at Angel Island. As, however, the vessel "was fumigated while loaded it was not practicable to search her for rats," the result of the process being simply declared to be "unknown."[37]

Steamship companies in the United States were keen to avoid fumigation. Despite evidence to the contrary, they continued to stress that this was impractical insofar as their vessels were rarely if ever empty of cargo, alleging that fumigation would damage the latter. A series of responses by

This is a portion of the eBook at doi:10.7551/mitpress/12437.001.0001

steamship companies to the US Public Health and Marine-Hospital Service from the summer of 1909 indicated that rat-catching by professional teams and the use of poisons, as used by themselves on a regular basis, were a sufficient alternative.[38] Objections raised against fumigation included opinions regarding the rat's ability to escape the fumes to other compartments, as well as concerns that rats dying as a result of fumigation did so in places from which they could not be retrieved.[39]

Another tactic by shipowners and captains involved invoking the presence of cats on board as sufficient protection against rats. In a rather morbid display, Surgeon G. M. Corput responded to such claims by publishing photographs of the outcome of fumigating the British ship *Ethelhilda*, which arrived in the quarantine station of New Orleans on March 18, 1914. The captain of the boat had boasted that his vessel's cabin held no rats as a result of "the presence of an exceptionally good cat." Forcing the boat (including its cabin) to be fumigated, Corput displayed a morbid photo of the resulting twenty-four dead rats alongside the carcass of the unfortunate if now famous cat (figure 7.1).[40]

CAT AND RATS FROM CABIN OF S. S. ETHELHILDA.

Figure 7.1
Photograph of the display at the Upper Quarantine Station in New Orleans, outlining the uselessness of cats as protection against rats.
Source: Anonymous, "Ship rats and plague," *Public Health Reports (1896–1970)* 29, no. 16 (April 17, 1914): unnumbered plate following p. 928.

This does not however mean that all companies followed such evasive tactics. The Boulton Bliss & Dallett Company, for example, reported that its steamers were "fumigated regularly every four weeks. Those which call at San Juan are fumigated at Puerto Rico, while those that do not call at that port, are fumigated at New York."[41]

Indeed, Puerto Rico proved to be an important locus for US developments in maritime fumigation. The 1912 plague epidemic on the island, where an overall fifty-five human cases occurred, led to concerted efforts to halt not only the spread of plague from San Juan to the US mainland, but also to prevent the disease from moving inland in the island itself, and thus to form permanent reservoirs, as had recently been the case in California.[42] Resisting calls to burn down the infected Puerta de Tierra barrio (on account of this resulting only in the rats escaping and contaminating other areas of the city), among the measures taken was fumigation with a new agent, aimed at overcoming the lengthy exposure needed when using SO_2: "cyanide gas" as hydrocyanic acid was commonly known. This was used "either on lighters or in a galvanized iron shed for this purpose."[43] Given the success of the operation in Puerto Rico, cyanide fumigation gradually moved from being considered a method too dangerous for general employment to a serious alternative to sulphurization. Key to this transformation was the 1914 plague outbreak in New Orleans. After outbreaks in Puerto Rico and Cuba in 1912, authorities in New Orleans had already ordered a preemptive rat-catching and trapping campaign and had within days found rodents indeed infected with plague. But despite steadily increased antirat activities, human cases appeared in June 1914, and a modest outbreak escalated over the following months. The outbreak triggered an unprecedented antirat campaign, with over 380 men inspecting 6,500 railcars and 4,200 buildings, fully fumigating 101 ships, trapping 20,000 rodents, laying nearly 300,000 poison baits, and discovering seventeen infected rats.[44]

Norman Roberts described two cyanide fumigation methods employed in New Orleans in 1914, both of which involved the decomposition of potassium or sodium cyanide by sulphuric acid ($KNC + H_2SO_4 = HCN + KHSO_4$) at a ratio of "1 ounce of KCN . . . for each 100 cubic feet with 1⅔ ounces (about 1 fluid ounce) of sulphuric acid, and 3 fluid ounces of water."[45] The first method, known as the "crock" or "solid cyanide" method, was used for smaller spaces, such as living quarters or storage rooms. It involved the dilution of sulphuric acid in water, whereupon the solid cyanide was dropped. This was applied to a sealed compartment, with the cyanide being dropped through an aperture that was then quickly sealed. Though practical in small compartments, this method was not employed in the holds of ships as, first, that would require an extended presence of the cyanide operators in the high-risk area, and, second, it would allow the gas to escape from the top of the hold. The second method, applied to holds, was known as the "barrel" or "liquid cyanide" method. It involved the dilution of cyanide with water in a barrel positioned at the lowest possible point in the hold, with the help of a rubber hose. After pouring the acid from a safe distance (the operators being positioned on the deck of the vessel), a strong sodium carbonate solution was added, its purpose being to expel "part of the dissolved hydrocyanic acid from the waste and reduc[e] the remaining acidity, thus economising on the expensive cyanide and rendering the waste less poisonous, corrosive, and troublesome."[46]

Again, hydrocyanic acid was praised for its ability, upon being mixed with air at 0.4 percent, to exterminate rodents and insects, in particular fleas: "for use against plague it has the great advantage that it penetrates most articles of cargo without damaging them, killing the vermin, no matter how deeply hidden."[47] The main worry as regards the application of this method arose from the fact that, as the particular gas is lighter than air, it risked escaping from the upper parts of the fumigated spaces, while at the same time being too low in concentration in the lower parts for it to kill the target organisms. Proposed solutions to this problem included the operation of a fan that would obstruct the rise of the gas.

Deemed to be superior to sulphur dioxide, insofar as the process involved no fire while its gas evinced better penetration without any damage to the cargo, and to carbon monoxide, insofar as it killed fleas (and also required no fire), in practice the employment of hydrocyanic gas was nonetheless initially limited. To give one example in the context of anti-plague work in New Orleans in the week ending November 28, 1914, only two vessels were fumigated with the gas, in comparison to twenty-four fumigated with sulphur and ten with carbonic monoxide. As the instructions by the US Surgeon General for the use of this fumigation method indicate, the likely reason was the high danger of the gas to humans, which required highly skilled labor and a disproportional degree of attentiveness by the operating agents by comparison to the other methods.[48]

Also important was the high price of potassium cyanide and sulphuric acid, especially in purified form. To try and alleviate this obstacle, experiments on a reduced percentage of the gas were carried out by Creel on rats trapped in wire cages and placed in different positions in ship storerooms and holds filled with personal objects and cargo respectively. In sum, the results of the nineteen experiments conducted showed that it was not necessary to use ten ounces of potassium cyanide per 1,000 cubic feet of space but only five, at a cost of 8.50 USD to 12.50 USD for a space of 100,000 cubic feet, by comparison to a cost of sulphur fumigation for the same space being 13.00 USD.

Among other things confirmed by Creel's experiments, was the higher ability of the gas to penetrate cargo by comparison to SO_2: "Sulphur dioxide, while fairly effective, is not very penetrating. It diffuses very poorly, and in actual practice it has seemed that air pockets in articles of cargo or between packages will afford to rats a sufficient protection against the effect of the sulphur fumes."[49] The "dumping fixture" method of hydrogen cyanide (HCN), involving the lowering of a tin-plate canister containing half-ounce HCN discoids down the holds, and the opening of the lid with the help of a wire or rope, contrasted with the expensive and bulky apparatuses required in SO_2 and carbon monoxide fumigation methods alike. Hydrocyanic acid gas was praised as both the most penetrating and the most toxic among alternative fumigation gas, as well as for being "easily and quickly generated, requir[ing] very little apparatus, [and not being] destructive to inanimate objects."[50] Little attention was paid by comparison to the fact that "attempts to destroy bacteria with this fumigant were unsuccessful."[51]

Clearly in support of HCN over other methods, Creel thus proceeded to tackle the last remaining obstacle to the adoption of the gas by stating that "The element of danger to human life is more or less speculative, and will vary according to the care exercised in performing the fumigation."[52] In particular, he held that the gas posed no danger to the people operating the fumigation process, as long as they made a swift exit from the compartment, and after the fumigated space's apertures had been reopened for thirty minutes.[53] As was the case many years earlier, when the risk posed by the Clayton machine was discussed in Dunkirk (see chapter 3), in support Creel's health and safety reassurances was furnished a colorful anecdote involving a drunk sailor:

> An accident on board a ship at New Orleans throws further light on this subject. This occurred during the fumigation of a super-structure on board. The room had a capacity of approximately 1,000 cubic feet. The cyanide was placed in the acid solution and the doorway sealed. A drunken sailor coming aboard threw open the door and entered. How long the man was exposed is uncertain. The exposure was not more than 15 minutes, and possibly only 5 minute in duration. When discovered he was lying on the floor beside the cyanide container. It was likewise uncertain whether he had been overcome by the gas or had lain down in a drunken stupor. When removed from the room he was resuscitated.[54]

Emboldened by these results, but also uncertain about the application of experimental findings in real-life maritime fumigation, "however painstaking the attempt may be to simulate the natural," Creel proceeded to conduct what he called "a true test of efficiency . . . applied to the procedure as carried out in routine practice."[55] What in his opinion made this feasible were the particular circumstances in postepidemic New Orleans at the time: "first, the fumigation of a large number of vessels at the port of New Orleans and at the Service quarantine station at the mouth of the Mississippi River; second, the availability of a large and experienced force of trappers at New Orleans."[56] The latter were the result of concerted measures by the Public Health Service against plague in the city. Creel's plan was to take advantage of the intensive, systematic, and closely supervized rat trapping operations on vessels following fumigation, so as to ascertain the efficiency of different fumigation methods employed. The record involved 214 vessels out of which sixty-two were treated with SO_2 and 182 with cyanide. The results showed that the former method killed 77 percent of ascertained rats, while the latter killed 95 percent. The disparity between the two methods was accounted by their relative success in the case of "superstructure" (storerooms, crew quarters, cabins, etc.), where sulphur's efficiency was reduced to 55 percent, while cyanide's remained as high as 94 percent (by contrast the difference in empty holds was 96 percent to 99 percent, and 64 percent to 80 percent in loaded holds).

Maritime Fumigation after WWI

In the meantime and with the start of World War I, the chemical compounds used in fumigation were closely inspected for possible application to warfare. But both sulphuric acid gas and hydrocyanic gas were in principle incomparable with the practical if no less brutal requirements of chemical warfare, as both gases evaporated too quickly in open space.[57] A variant of hydrocyanic acid gas, concerns over hydrogen cyanide were a constant theme for most of the war, due to its high lethality and the known dangers surrounding its application in fumigation.[58] It was well known to experts on both sides of the war that the gas acted directly on the nervous system and that exposure to high levels of the chemical led to almost instant death. Stories abounded about the Germans developing cyanide bombs, and rumors spread that abandoned trenches were flooded with the gas, "so that the advancing Allies would die like rats."[59] But it is widely accepted that no deaths from cyanide gas were reported in World War I, as the compound was too light to ever be effectively used on the ground. When the French tried to build shells with the gas, they struggled with its low weight and failed to provide an operational weapon. By contrast, what appeared to be a chemical warfare method transferrable to deratization was the use of asphyxiating gases like chlorium and chloropicrin. In his doctoral thesis on the use of war gases for deratization, Étienne Grégoire recounted that chlorium was tested on rat burrows by the inspector general of hygiene in France, Dr. Bordas, in Nanterre, and by Dr. Tanon in the lab. An exposure of five seconds to the gas resulted in the death of experimental rats eight to ten hours later, and also to the immediate death of fleas. In turn, chloropicrin, CCl_3NO_2 (also known as nitrochloroform or trichlorononitromethane), was a substance discovered in 1848 by the Scottish chemist John Stenhouse whose lachrymatory properties made it one of the first chemical weapons to be used in the context of WWI. Whereas in small quantities the substance operates like a tear gas, in large quantities it has suffocating properties: "It was used chiefly because of its peculiar property of causing vomiting when inhaled, thus inducing the soldier to remove his mask and expose himself to the action of gases which penetrated the mask less readily."[60] It was for the latter that in 1917 two Italian scientists, Piutti and Bernadini, first tested the gas on vessel-borne rats.[61] At the same time, in wartime France, Gabriel Bertrand of the Institut Pasteur conducted his own experiments, which would be communicated—with a delay due to war-related secrecy—on February 9, 1920, to the French Academy of Sciences.[62] The follow-up experiments evinced the ability of the gas to kill weevils and rats, but even more its efficacy in the extermination of fleas. Following the condemnation of hydrocyanic acid by the Conseil supérieur d'hygiène publique in 1922, as a result of the experiments of Bonjean in Marseilles, chloropicrin rose in popularity in France.[63] A decade later, the US Principal Chemist, R. C. Roark, would summarize the advantages and disadvantages of the gas as follows:

> The advantages of chloropicrin as a fumigant are: High toxicity to many species of insects and rats; fungicidal and bactericidal properties; complete freedom from fire and explosion hazards; low solubility in water; ability to penetrate bulk commodities; non-reactivity with metals, fabrics, and colors under fumigating conditions; and a pronounced odor and lachrymatory effect which usually effectively warn of its presence. Its disadvantages are: Slowness in action, as compared to hydrogen cyanide; tendency to act detrimentally on living plants and seeds; difficulty in removing its odor from fumigated commodities and spaces; and nauseating effect upon the operator.[64]

However, at the same time as a plethora of sulphur-based apparatuses and processes were coming to replace the Clayton, HCN continued to lead the revolutionization of fumigation.[65] The true real-life test for HCN as a deratization fumigant in the United States came in 1921, when San Juan was struck by another plague outbreak, believed to have arrived from the Canary Islands.[66] This came to reinforce trust in HCN, whose use was employed in the harbor on all incoming Spanish vessels. This centrally involved fumigation of cargo in open lighters, where cargo was covered in tarpaulin in a tent-like manner, introducing cyanide gas underneath, or in closed lighters, where the gas was introduced after their openings had been sealed.[67]

Both the San Juan incident and the outbreak of plague in Barcelona, Spain, in 1922, led American authorities to adopt more diligent measures. In New York, this involved the institution of a strict procedure of fumigation, whereupon being visited by the chief of the fumigation division, it was decided that "the vessel can be fumigated without removing any cargo."[68] Fumigation of the entire vessel began at 9 a.m. This would involve an exposure to HCN for four hours with the help of an "aerothrust" blower, aimed at keeping the gas equally distributed.[69] For this process to be successful, all "enclosed space" (double walls, etc.) was ordered to be opened in preparation. Additionally, the port authority expected guards on watch to report any remaining live rats observed following the discharge of cargo; if such were seen, the vessel was subjected to refumigation. The same process of "fractional fumigation" was to be followed whenever the fumigating officer observed that "the cargo is such that the gas will not penetrate thoroughly."[70] The regulations also provided a solution for cases where the cargo of a given ship completely filled the holds, making fumigation difficult. Sufficient cargo being discharged and fumigated separately on lighters, the fumigation of the remaining cargo could be performed in the holds. In all cases, the ship was fumigated with cargo in situ. Following the unloading of the cargo on the harbor, the ship would be again subjected to fumigation on empty holds.

However, what proved more difficult was to ascertain the real number of rats killed as a result of these procedures. The Staten Island Quarantine Station Surgeon, Grubbs, brought this to the attention of the US Surgeon General already in early 1922. He stressed that the number of rats sent to his lab, resulting from cyanide fumigation of vessels, "is not as large as it apparently should be if we are doing good fumigation and if we are not over-fumigating certain vessels."[71] The problem, according to Grubbs, lay with the fact that stimulating interest among the crew in the recovery of killed rats proved very difficult. On the one hand, he surmised, this was due to the fact that once fumigation was complete, "the crew is in a hurry either to get to the next ship or to get back to the station and be checked out."[72] Efforts to elicit rivalry among the crew in rat recovery proved equally impotent.[73] However, another important factor, perhaps understressed in Grubbs's report, related to the fact that especially when it came to vessels from Puerto Rico or the Pacific coast of South America, frequent fumigation meant that no rats were resulting from such processes, something that "decrease[d] interest" in their recovery.

Following the conclusion of World War I, the continued integration of hydrocyanic acid gas, and the experimental testing of chlorocyanic gas, as well as fumigation with bromide sealed the fate of sulphur. With the disjuncture of disinfection and disinfestation in the practice of fumigation, efficiency in terms of the rapid destruction of pests and vermin became more important than the capacity to kill pathogens. With HCN at the forefront, the focus shifted to insects and rodents; bacteria, by contrast, were considered to be less of a concern, or could be taken care of through washing with carbolic acid. By contrast, combining the expertise of agricultural fumigation and maritime deratization, the application of cyanide compounds in the fight against rats and other rodents made a landfall in the United States. Large-scale campaigns against ground squirrels attempted to exterminate rodents from entire rural landscapes. The campaigns were partly motivated by the continued efforts to stop plague from becoming an endemic problem in the American West. Since 1906, antiplague efforts in California had begun to devise techniques of squirrel extermination that utilized the capacities of fumigation devices and substances in the underground burrow systems of the ground squirrel. Best applied in moist conditions, when the soil's capacity to hold large amounts of gas were highest, the campaign officers adapted various devices from maritime sanitation.[74] One device was built in particular to enhance squirrel destruction by means of either poisoning the animals with gas or by injecting an inflammable gas, which would then be ignited to kill all squirrels within the extended burrow systems. The device, called the "squirrel destructor," was developed within the US Marine Hospital Service and used throughout the extensive campaigns in California from 1906; it was utilized in the 1924 plague outbreak in Los Angeles and remained in use until at least the 1940s.[75]

The importance of HCN became all the more pressing after the 1926 International Sanitary Conference in Paris, where it was decided that all ships should have a certificate of rat destruction or that they have been inspected and found to be rat-free within the last six months. These were known as the Deratization Certificate and the Deratization Exemption Certificate. The relevant article of the convention (Article 28) decreed that if neither certificate could be procured, then the port authorities could themselves carry out or direct the carrying out of deratization. No specific technology was singled out, but it was stated that "It shall decide in each case the technique which should be employed to secure the practical extermination of rats on board, but details of the deratizing process applied and of the number of rats destroyed shall be entered on the certificates."[76]

The increasing preference of cyanization over suplhurization is furthermore evident in the first and second International Rat Conference. During the first conference (May 16–22, 1928), the two deratization methods were discussed as on par with regard to their efficacy, with authors like Colombani (director of public health in the French protectorate of Morocco) and Herminier (director of the School of Health Service for colonial troops in Marseilles) noting the relative advantages of the two methods, and generally leaning toward the well-tested method of sulphurization, as this demonstrated a guaranteed safety for operating staff and had a germicidal property lacking in HCN.[77] At the same time, HCN was already recognized by some delegates with respect to the number of rats it killed, its rapidity of action, and its nondamaging properties of metals. The Italian delegate, Lutratio, noted that, as a result, use of HCN in Italian ports had increased in the past five years from 26 to 46 percent.[78] In the course of the conference, delegates were invited to witness, on May 20, 1928, the demonstration of different maritime deratization techniques and technologies in the harbor of the Havre. Though the demonstration included the Clayton and the Marot, its main focus was a new HCN-based apparatus, which had only recently been approved for use in France: the Sanos generator (*Sanos générateur*).[79]

The August 8, 1929, Decree on the Deratization of Vessels of the French Republic fully authorized the use of HCN for maritime deratization, on the provision that: a) this was accompanied by a gas detector; b) proscribed procedures were strictly followed; c) a declaration by the ship's captain was provided, taking responsibility that during fumigation with HCN nobody is on board with the exception of deratization staff and the relevant health officials.[80] By the time of the Second International Rat Conference, held in Paris on October 7–12, 1931, little doubt remained over the superior efficacy of HCN. Though sulphurization still featured in the discussions, HCN enjoyed the unambiguous support of a key player: large navigation companies, like the Compagnie Générale Transatlantique, whose chief doctor, Chamaillard, provided a glowing review of cyanization.[81]

The employment of HCN led to a proliferation of cyanide-based fumigation machines and it enjoyed great popularity and success across the globe in the decades to follow.[82] A manual on the protection of Ceylon (Sri Lanka) from plague from 1931 points to the reasons for this.[83] Thoroughly informed about US studies and publications regarding the fumigant, in his review of the use of HCN fumigation in the Sri Lanka highlands, the City Microbiologist of the colonial capital of the island, Colombo, L. F. Hirst, reserved particular praise for one apparatus invented in British India, the Liston Cyanide Fumigator:

> Solutions of sodium cyanide and acid are run into the lead-lined generating box and the gas thus generated is diluted with air drawn, by means of a petrol driven fan, through the generating box, thence by means of flexible gas trunks to the compartment to be fumigated and back to the machine. The mixture of air and

> gas in the compartment is continually circulated. Samples of air can be readily drawn off from the outlet pipe and the concentration of HCN in the circulating gas speedily determined by Liebig's method or one of its modifications.[84]

Having been tried experimentally in lighters in Colombo's harbor, as well as in the laboratory, the advantage of this method comprised in it being performed in the open air, thus minimizing the risk of accident to the operating personnel. However, the small capacity of the machine required multiple apparatuses to operate in any given harbor. Liston's apparatus had been promoted by its inventor as an alternative to the "dumping fixture" method that had enjoyed particular success in the hands of Creel in the United States. This was because, according to Liston, "dumping fixtures should be avoided, not only because they must be placed within the space to be treated, but also because the gas, when generated in this apparatus, is evolved with almost explosive rapidity so that high, and therefore dangerous, concentrations are developed."[85] "The necessity for handling the corrosive and poisonous waste in a closed space," claimed Liston, "is an additional drawback to the use of the dumping fixture."[86]

The Ceylon report also mentioned another method of employing hydrocyanic acid for deratization. This involved a "German product," which consisted of "an infusorial earthy substance called diatomite absorbing about an equal weight of liquid HCN plus various amounts of chloropicrin (10 per cent., 6 per cent., or 4 per cent)"; this was meant to enable "the useful post-fumigation warning lachrymatory effect."[87] Sold in cans of various sizes, upon opening "the material can readily be poured out of the can into the compartment to be fumigated." The benefits of this new substance were briefly praised in the Ceylon report, though lack of detail suggests Hirst had no first-hand experience of its employment: "Owing to the great surface area of diatomite, evolution of the absorbed cyanide is very rapid and so complete that at the end of the customary two hour fumigation period the residue is therefore, be safely left *in situ* though it is advisable to sweep it up in order to obviate persistence of the chloropicrin odor and its tear effect."[88] The substance was no other than Zyklon B.

As Paul Weindling has demonstrated, historical scholarship tends to oversee the detailed and extensive history of the substance before it was applied in the gas chambers of the Holocaust. Indeed, developed as an improved derivative of hydrocyanic acid, the personnel at the Kaiser Wilhelm Institutes in Berlin had developed this commercially viable form "as a spin-off from defensive and offensive poison gas research under the chemist Fritz Haber."[89] The substance was essentially introduced into the market in 1915 as an easy-to-use variant of the acid, for application as a disinfectant in louse-infested compartments. Since 1917, the German and Austro-Hungarian military ran experimental research programs for the improvement of delousing procedures and pest control. Here, as well as in the United States, the gas was seen to be cheap, as well as harmless to fabrics, leather, and metal parts on uniforms, but it was also experimentally shown to be able to penetrate fabrics in all kinds of circumstances. Since April 1917, Weindling reports, the military had used hydrocyanic acid to disinfest over twenty-one million cubic meters of buildings by 1921.[90] But a number of incidents, reports of injuries and deaths prompted the further development of the substance to make it less dangerous to humans. Further complicated through the ban of "the use of asphyxiating, poisonous and other gases and all analogous liquids" in Germany (article 171 of the Treaty of Versailles), it took the invention of a further derivate and the addition of chlorine and bromide by the chemist Bruno Tesch, to finally arrive at Zyklon B in 1923: "Zyklon was thus endorsed as protecting public safety, overcoming the risks of hydrocyanic acid which continued to result in fatal accidents."[91]

Tesch, in collaboration with the Hamburg-based harbor physician Nocht, developed a code of conduct for disinfection works, and laid the groundwork for the special category of disinfectors—personnel trained to safely conduct the gasing with Zyklon B. Gas chambers were installed and refined throughout the 1920s for the purpose of commercial, occupational, and experimental disinfestation. Zyklon B's employment for deratization was not limited to Germany. The substance was also extensively tested in the United States.[92] An influential experiment on the deratization properties of cyanogenic fumigants led by Surgeon C. V. Akin and Acting Assistant Surgeon G. C. Sherrard in the New York Quarantine Station, unambiguously signaled that, by the late 1920s, maritime fumigation's goal was no longer disinfection in the sense of germicide, but disinfestation: "To kill rats is the prime object of ship fumigation."[93] It also pointed out the end of the era of sulphuric fumigation and the realization of its hygienic utopia by cyanide-based products instead:

> 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.[94]

Similarly, at the Second International Rat Conference, Chamaillard seemed confident about the efficacy of the substance, which had already been used to some acclaim as far back as 1928 in the port of Rotterdam.[95] However, Zyklon B was not as conclusive as perhaps its manufacturers would have hoped. For example, in a report published in the United States in 1931, Surgeon C. L. Williams admitted that "it was reluctantly, and only after considerable experimentation, that the writer turned from Zyklon back to liquid HCN for the fumigation of vessels which are either loaded with cargo or have protected rat harborages which are heavily infested."[96] This was because unless the discoids were carefully scattered on the 'tween decks, Zyklon B failed to acquire an adequate concentration in the far corners of the holds, which were believed to be preferable areas for "rat harborage."[97] Such distribution required staff to place the discoids manually, which Williams claimed they were generally unwilling to do. By contrast, liquid HCN could be introduced by an air-jet spray apparatus that could allow precise manipulation, and, by means of the pressure provided by the air jet (at 200 pounds), reach even the remotest corners of the holds (figure 7.2). Comparing the use of this apparatus on loaded ships to Zyklon B, Williams noted that it was difficult to acquire accurate doses of the gas by means of the latter.

Moreover, when it came to reaching rats scurrying away, the spray method provided an unprecedented advantage: "Where there exist rat harborages, into which it is unlikely that the gas will itself penetrate in lethal concentration, the nozzle of the gun may be passed through small openings and the spray projected directly into them, securing a penetration far deeper than could be expected by any other means now in use."[98] Accordingly, Zyklon B should only be used for routine fumigations, and in smaller stations, which could not use compressed-air apparatuses or lacked personnel trained in its use.

In 1931, Surgeon J. R. Ridlon of the US Public Health Service in San Francisco confidently declared that "the use of suitable cyanogen products has practically replaced the use of sulphur at all of the quarantine stations of the larger ports."[99] The use of cyanogen products thus marked

FIGURE 6.—Projecting HCN spray directly into rat-infested insulation of a cold-storage room. The apparatus shown is the first one used, in which the handle and valve were assembled separately. A strip of casing has been removed to permit direct application of fumigant to insulated space

Figure 7.2

Projecting HCN spray directly into rat-infested insulation of a cold-storage room. Source: C. L. Williams, "The air jet hydrocyanic acid sprayer," *Public Health Reports (1896–1970)* 46, no. 30 (July 24, 1931): plate II, figure 6.

the beginning of a gradual fumigation by means of large generators by individually held air-jet sprays that could directly "inject" fumigants into rat harborages. This followed a new doctrine in maritime sanitation, which, in Williams's words, relied on the fact that "it has been proved beyond the possibility of doubt that the mere release of a fumigant in an enclosed space does not insure penetration of the gas in lethal concentration in all retired locations and dead air spaces."[100]

Sulphuric Utopias

A History of Maritime Fumigation

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Citation:

Sulphuric Utopias: A History of Maritime Fumigation
By: Lukas Engelmann, Christos Lynteris
DOI: 10.7551/mitpress/12437.001.0001
ISBN (electronic): 9780262358194
Publisher: The MIT Press
Published: 2020

The open access edition of this book was made possible by generous funding and support from Arcadia – a charitable fund of Lisbet Rausing and Peter Baldwin

The MIT Press

The open access edition of this book was made possible by generous funding from Arcadia—a charitable fund of Lisbet Rausing and Peter Baldwin.

This book was set in ITC Stone Serif Std and ITC Stone Sans Std by Toppan Best-set Premedia Limited.

Library of Congress Cataloging-in-Publication Data

Names: Engelmann, Lukas, 1981- author. | Lynteris, Christos, author.
Title: Sulphuric utopias : a history of maritime fumigation / Lukas Engelmann and Christos Lynteris.
Description: Cambridge, Massachusetts : The MIT Press, [2019] | Series: Inside technology | Includes bibliographical references and index.
Identifiers: LCCN 2019029666 | ISBN 9780262538732 (paperback)
Subjects: LCSH: Ships--Fumigation--History--20th century. | Ships--Disinfection--History--20th century. | Chemical apparatus.
Classification: LCC VM483 .E64 2019 | DDC 628.9/6--dc23
LC record available at https://lccn.loc.gov/2019029666

10 9 8 7 6 5 4 3 2 1