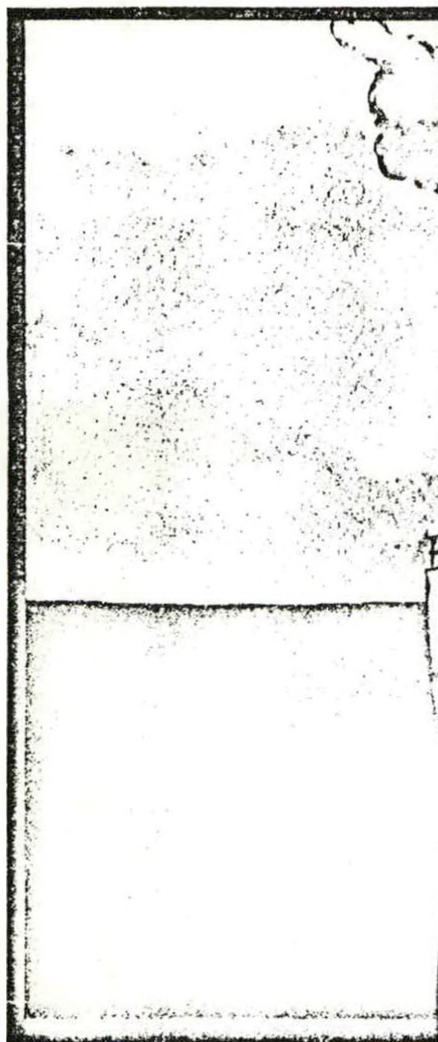


At-s
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U.S. ocean incineration is currently seen by some as a panacea for the hazardous waste problem. A voluminous series of reports on U.S. at-sea incineration, each publication quoting prior works as authoritative, is cited by proponents as confirmation of ocean incineration's success.

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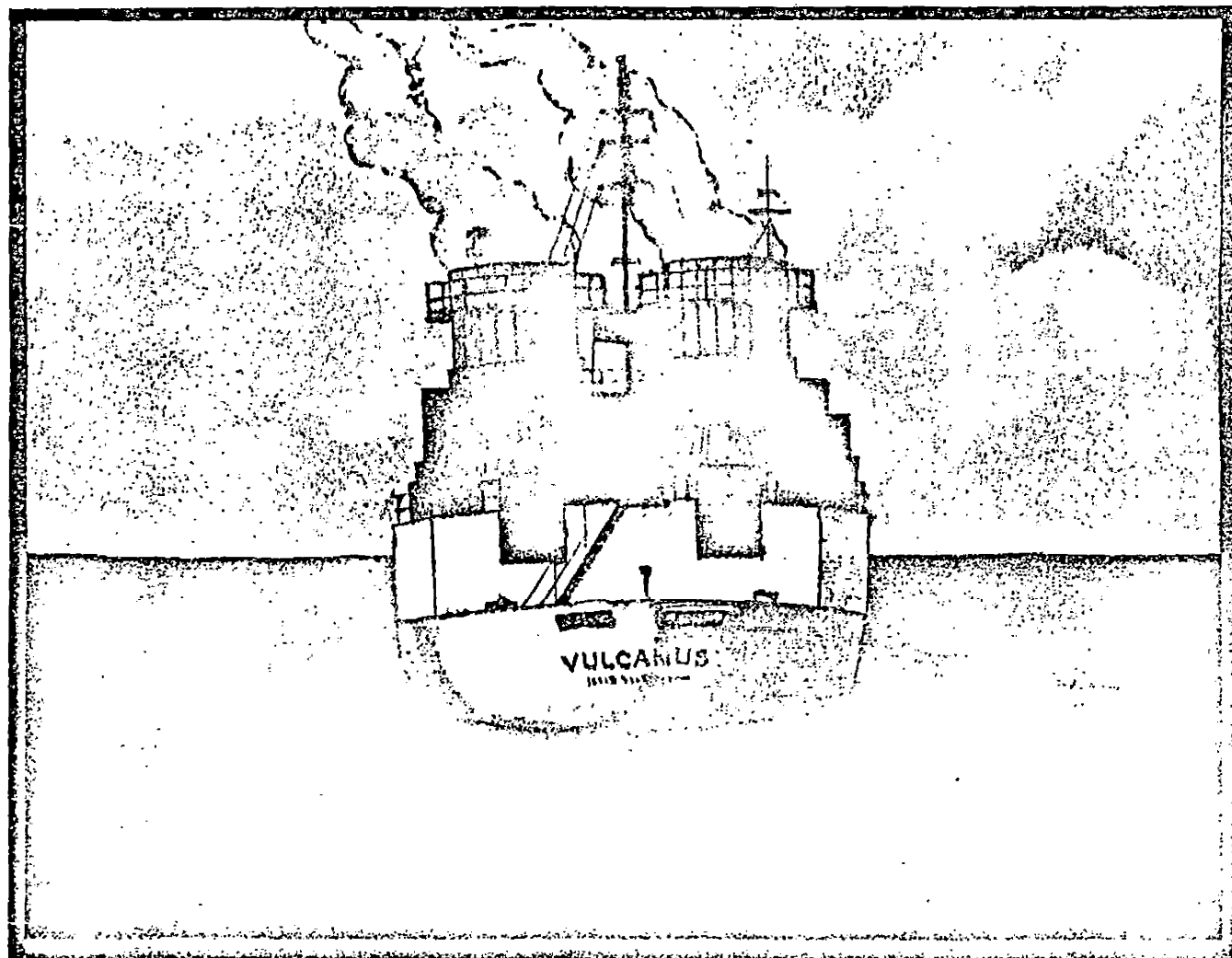
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At-sea incineration of hazardous wastes

The risk is yet to be justified



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In Europe, attention has since 1969 also been given to ocean incineration of chemical wastes. Initially, a small

tanker with an incinerator, Matthias I, was applied to this task, but was decommissioned in 1975. A larger, similarly modified tanker, the Matthias II, was then used by a German company, but was recognized to have drawbacks in its attempts at destruction of wastes (1-3). In particular, "the hydrocarbon content of the effluent stack gases, normally 5 to 10 mg/m³, occasionally rose to 50 mg/m³," and "at times, black smoke was observed in the stack" (4, p. 1-8).

Early in 1975, a large tanker, Matthias III, was modified for incineration, but "the first burn, actually a shakedown cruise, was not successful," and on the second burn, "flames and black smoke were visible above the stack of the incinerator during much of the burn. Because of the technical problems with the incinerator design, the Matthias III was decommissioned in April 1978" (4, p. 1-9). Other vessels incinerating with varying degrees of reported success in European waters have included the Vesta, Petra, Vulcanus I, and Vulcanus II.

Starting in 1972, and under international regulations—the LDC—the Vulcanus (later known as Vulcanus I) participated in the disposal of chemical wastes in European waters. Sailing the North Sea (under the flag of Singapore), the Vulcanus could "be spotted miles away because of the white smoke trail, lit at night by the red glare from the two incinerators; other ships are sometimes attracted to assist with what appears to be a fire" (5). Also noted in the European article are that ocean burns could contribute to the incidence of acid rains; further, no analyses were said to be available to prove reliable destruction of hazardous wastes, and the wastes are known to bioaccumulate through the food chain of marine life (5).

Under an EPA Research Permit, the first two shiploads of U.S. chemical wastes (totaling 8400 metric tons) for ocean incineration were disposed of during the period between October and December 1974, in the Gulf of Mexico. Based on the reported success of these tests, a second disposal operation of 8400 metric tons of chemical waste was carried out in the Gulf (December 1974–January 1975) under an EPA Interim Permit. The cumulative data led to further at-sea incineration activities by the U.S., namely another 16 000 metric tons of chemical waste for the Gulf of Mexico (March–April 1977), 10 400 metric tons of Herbicide Orange in the Pacific Ocean near the Johnston Atoll

(July–September 1977), and recently, back in the Gulf of Mexico again, disposal of nearly 1.5 million gallons of polychlorinated biphenyl (PCB) waste (December 1981–January 1982, and August 1982). All of these ocean incinerations were performed aboard the Vulcanus.

The validity of tests performed and the data accumulated, as well as the resulting chain of approval of U.S. ocean incineration applications (organochlorine wastes, leading to Herbicide Orange, leading to PCB wastes), do not rest on a firm, scientific basis. The unreliability of the initial assumptions made and the conclusions drawn at the outset of Vulcanus's applications to U.S. wastes have been and are being overlooked. The reported success of any previous burns seemed to provide authorization to perpetuate at-sea waste disposal by Vulcanus.

Wastes in the Gulf

Because U.S. emissions regulations for ocean incineration of chemical wastes had not been promulgated, the EPA issued a research permit in an exploratory move in 1974. To evaluate the effectiveness and desirability of Vulcanus being applied to that task in the Gulf of Mexico, a load of "4200 metric tons of organochlorine wastes" was fed to its incinerators (6, p. 1).

The research permit required "regular stack tests for emissions of total hydrocarbons," and that "the Permittees shall regularly monitor the combustion efficiency of the Vulcanus" (7, p. A5). Monitoring is reported to have taken place "for 119 hours of the total 190.5 hours required to incinerate the wastes." However, "seven samples were taken during Research Burn I" (6, p. 42). That "many experimental difficulties were encountered," that "oxygen and carbon dioxide values were erratic so were not used in the calculations," and that "problems were encountered in cleaning up the stack gas for presentation to the Beckman 109A Hydrocarbon Analyzer," (7, p. 17) are documented constraints to the acceptance of Research Burn I results.

Due to the sampling problems and readings that had not been taken, "on Nov. 17, 1974, EPA granted a second research permit to incinerate another shipload (4200 metric tons)" (6, p. 2). That permit led to modification of some of the monitoring. Due to the incineration hardware and system configuration of the Vulcanus, these adjustments still could not facilitate

measurement of a number of critical parameters. The criteria for evaluating the authenticity of the Research Burn were not changed.

Eight series of tests were taken over the 168 hours (from Dec. 2 to 9, 1974) on Research Burn II (6, p. 44). "Fewer problems were encountered on the second voyage than on the first. However, not everything went smoothly" (7, p. 27). The problems included probe distortions and failures, as well as failures of instruments for measurement and analysis (7, p. 28).

Shell Oil Co. scientists, themselves participants in both Research Burns, documented the unsound basis (for meaning) to be found in the measurements. "The permit required that the organic chloride waste be burned under conditions ensuring 99.9% combustion efficiency. It is clearly not possible to measure this efficiency directly by accounting for the amount of feed into the oven and the amount of HCl and CO₂ out, because none of the variables involved can be measured with the requisite 0.1% or better accuracy. For example, feed rates cannot be measured in real time at all and the volumes pumped from the tanks are not known to the required accuracy. Measurement of the mass of combustion products requires estimation of stack gas concentrations, velocity, and the diameter of the stack. Not even the diameter of the stack can be measured to 0.1% because the surface roughness of the fire bricks is greater than the 5 mm or so corresponding to the limit. Gas velocity measurements under much less difficult conditions seldom [have] better than 5% accuracy, and stack gas compositions data reliable to 0.1% are very difficult to obtain" (7, p. 5).

As if to guarantee the outcome under these conditions, the answers were assumed. "The feed analysis permits the calculation of the number of moles of stoichiometric products, that is, moles of stack gas formed by combustion with exactly enough air to react with a mole of carbon in the feed and its associated hydrogen. Then an analysis of the stack gas for oxygen permits the calculation of the amount of excess air" (7, p. 5). The emissions had to be evaluated from theory rather than being measured. The total flow of flue gas was not and could not be measured according to the EPA Method 2. Thus, with theoretical assumptions of ideal combustion, of waste and air feed rates, and of combustion product flow rate, as well as with particulates being ignored, and with partially combusted species not

being sought, the combustion efficiency became unrealistically inflated.

Research Burn II, with "modified monitoring requirements," had taken place Dec. 2-9, 1974. On Dec. 10, with deliberation based on the minimal amount of data then available from the second burn, the burn observation team concluded that "ocean incineration of remaining wastes is environmentally sound" (6, pp. 2, 11, 16). Despite the various experimental and systematic errors exemplified above, and the cumulative error approaching a substantial total—certainly of a different order from the 0.1% allowed under the permit—the test burns were declared to have been successful. The disposal of another two shiploads of organochlorine wastes (about 8400 metric tons) in the Gulf was authorized under an interim permit based on these test burn results. The write-up of these two cruises is barely documented; no combustion efficiency monitoring was demanded by the permit.

"The major reporting requirement of the interim permit was that the Master of the *Vulcanus* maintain log sheets on operating conditions" (6, p. 75). Incinerator temperatures were logged as read in the control room, as well as wind data and ship position—all at four-hour intervals. A daily log also was made of tank cleanings. It should be noted that the U.S. Coast Guard did conduct unannounced aerial surveillance for the existence of a stack plume. No data were gathered in those late-December 1974 to early-January 1975 burns relative to the effective destruction of the wastes.

More wastes for the Gulf

The report on the next U.S. disposal of chlorinated organic wastes by the *Vulcanus* opens with reference to the previous burn for support: "This effort [1974 at-sea burns], monitored by the U.S. Environmental Protection Agency, provided an initial technical basis for concluding that at-sea incineration was a viable alternative to other means of disposal using land-based facilities" (8, p. 1); it was further reported that "the *Vulcanus* incinerators were effective in destroying this organochlorine waste material" (8, p. 4).

Over the 186-h, 45-min burn in early March 1977, six tests, all on the starboard incinerator, were carried out on *Vulcanus* flue gas emissions (8, pp. 2, 16); three of these sets of data were said to be of limited value, and so were discarded (8, p. 52). Based on

the remaining data, the project was reported as successful; the data noted do not support the destruction effectiveness claimed.

The "Gas Composition Data Summary" (8, p. 41) shows combustion efficiencies to be derived from the averages of scattered readings. Relative to their respective average values, the ranges are as follows: for oxygen, -56% and +32%; for carbon monoxide -1233% and +176%; for hydrocarbons, minus an infinite % (zero reading) and +157%; for hydrochloric acid, a calculated value, incorporating the scattered carbon dioxide data; and for nitrogen, by difference. Combustion efficiencies were then reported to four significant figures. Excess air, unmeasured, was calculated to have varied between 70% and 135%.

Regarding the sampling train employed, the report admits that "although advantageous for acquiring large volume samples," an increase to 85 L/min from the 1 L/min of the 1974 apparatus (still to represent the nearly 10 million L/min stack emissions) "was of marginal utility," with "frequent calibration and maintenance required to keep the system on-line" (8, p. 4).

The incinerators, without physical modification or change in dimensions, experienced a volume expansion (for residence time calculation), from 88 to 120 m³. Particulates were not measured, despite the notes (8, pp. 11, 17, 65, 66, 82, 83) that periodically the burners did require cleaning, and that "a metal tool which is pushed through the burner" (4, p. 11) removes "black coke or tar" (8, p. 17).

Temperature measurement was also of questionable accuracy. "The thermocouples, used to feed the automatic waste shut-off system and the recording equipment have been quite reliable and durable, according to personnel of the [Motor Tanker] *M/T Vulcanus*. There were no known failures during the burn covered in this report" (8, p. 11). However, it is also recorded that "during the background test (fuel oil) the thermocouple readings became very erratic" (8, p. 33, also note Test VII, p. 18), raising the issue of how long the instrument had been unreliable. Further, it is admitted that "the controller is neither locked nor sealed and therefore it is possible to alter the temperature setting."

Herbicide Orange for the Pacific

A few months later in 1977 it was recorded that "thermal destruction of

combustible wastes at sea is recognized as an alternative to land-based incineration. In late 1974 and in March 1977, organochlorine wastes were incinerated in the Gulf of Mexico by the *M/T Vulcanus*. These efforts, evaluated by the U.S. EPA, provided a technical basis for concluding that at-sea incineration is a viable alternative to other means of disposal" (9, p. 1). So opens the report to the EPA on the disposal of Herbicide Orange by the *Vulcanus*. The bulk of this report is composed of safety plans for, toxicology and properties of, and analytical procedures for Herbicide Orange.

Efforts were made to improve attempts at monitoring, but the major issues still were not addressed. Reliance for essential data is freely admitted—in this burn report—to rest upon the estimating experience and instinct of the *Vulcanus* crew.

An attempt to measure the waste feed rate continuously proved inadequate. "The sealed waste gauging system installed for the Herbicide Orange burns was not satisfactory for measuring waste feed rates because it gauged only the top one-third of each tank" (9, p. 37). The manual measurement, which, due to "the ship's rolling," normally 20°, but sometimes 30°, also had to be discarded (9, pp. 32, 35, 37). "Waste feed rates were determined, therefore, by measuring the time to deplete each tank" (9, p. 37). That method cannot be considered precise for burns taking place over the 32 days of Herbicide Orange disposal (9, p. 48). And hazard was not avoided by this measurement: "During all three burns, the waste tanks were gauged manually with a coiled steel tape. Drips of herbicide occurred despite the use of a rag [disposal of which, as a solid, and not allowed under the permit, is undefined] to wipe the tape as it was removed from a tank" (9, p. 115).

Neither the sample method used nor the results obtained were questioned by the report writers; blame for problems encountered was attributed to various other causes, as exemplified below.

- "It is believed, however, that problems with the on-line instruments were caused by system design oversights rather than by any problems inherent in the instruments or by their use" (9, p. 100). "The only problems occurred because of design oversights" (9, p. 111).

- "TCDD was not detected in any of the benzene impinger samples . . . There was a large number of organic

compounds in the samples. Many of these compounds were similar to TCDD in molecular weight; consequently, the state-of-the-art methodology being employed was not capable of separating TCDD from these extraneous compounds" (9, p. 84).

- Concerning instances of calculated destruction efficiencies being found below the required 99.9% level: "It is considered, therefore, that the chemical interferences and not inadequate incinerator performance caused the marginal destruction efficiencies" (9, pp. 7, 8).

- "The flameouts [to which there were a notable number of allusions] were a source of contamination since vaporized Herbicide Orange left the stacks at a lower velocity and did not behave as a normal plume because of its lower density and lower temperature" (9, p. 116).

- "Because of inadvertent delays in transportation, the [gas bag] samples must be considered compromised" (9, p. 79).

Despite the shortcomings, the Pacific Ocean burns were declared successful with the efficiencies published to four or five significant figures; further, the destruction efficiency was recorded to seven or, in some cases, eight significant figures (9).

PCB waste in the Gulf

Again under the title "Research Burn," the Vulcanus discharged waste, this time with PCB content, into its incinerators. Between Dec. 22, 1981, and Jan. 2, 1983, about 3300 metric tons were fed. Not the least disconcerting feature in this research burn for disposal of PCBs is the confession that "there was no plan—either general or detailed—for monitoring, sampling, or analysis" (10). It should be noted that the permit for the cruise "does not mention polychlorinated biphenyls in the waste description" (10, p. 12).

According to a letter to the EPA from a burn observer, "there were several problems during incinerator operations" (10). As regards the sampling that was carried out, the "fixed-position probe in the port incinerator which supplied gas to the on-line monitoring instrumentation system became plugged. The combustion gas monitors were switched to TNO's probe [another sampling system], but it too became plugged. TNO [is] the Netherlands Organization for Applied Scientific Research (Delft, Holland). Thereafter, no combustion gas measurements were possible from the port incinerator" (11, p. 8). The data



Monitoring probe. This one is in the stack of the Vulcanus.

collection, thus overlooking particulates, could depend on a fixed-position, single entry, nonisokinetic probe only in the starboard incinerator's stack.

The particulate matter, although not collected or analyzed, could not be completely bypassed, however, because, "as noted above, TNO's probe in the port incinerator became plugged, presumably from particulate matter" (10, p. 10). In the 262 hours of PCB waste disposal, the testing was not error-free: "There were problems with the sampling activities. The first test (starboard incinerator) occurred on 24 December and apparently was completely successful. The second test (port incinerator) was made on 26 December and was not completely successful. The third test was essentially a total loss" (12).

The readings from the CO analyzer, leading to calculation of the permit's key criterion, the combustion efficiency, were not immune from interference. PCB waste feed rate and air feed rate still remained unmeasured and, hence, estimated. "Also during the test periods, TNO's CO analyzer was rendered inoperable by the vibration. The calibration of electronics of the ship's standard CO analyzer were likewise damaged, but otherwise this instrument seemed to remain functional" (11, p. 9). The facilities for complete service and standardizing the readings of the unit were not on-board; the uncalibrated readings were taken to be valid and were used to derive conclusions.

That substantial vibration of Vulcanus was brought on with the burning of the PCB wastes is reported. Rotary cup burners, as used in the Vulcanus system, are known to require fine tuning to operate, and vibration can greatly reduce their effec-

tiveness. The inadequacy of the burner's turn-down ratio is another point raised in the burn documents. Also, numerous violations of the at-sea incineration permit requirements are admitted (10-12). These items are but some of the many problems experienced when the Vulcanus burned PCB waste; the numerous and substantial quantity of details are not presented here, but can be found in the references cited.

The 365-page report on the PCB waste burn (11) notes numerous shortcomings of the reliability of sampling and analysis of that cruise; the conclusions reached favor ocean incineration, nevertheless. "The results of this burn demonstrate conclusively that these requirements [combustion efficiency and destruction efficiency values to be in excess of 99.9%] have been met and exceeded by a considerable amount. It is therefore the conclusion of the EPA that the Vulcanus has demonstrated its ability to destroy PCB wastes" (13, p. 71).

The Vulcanus sailed again from the Chickasaw (Mobile), Ala., harbor on Aug. 15, 1982, and disposed of another 3500 metric tons of PCB waste. Here, particular note is to be made only of the incinerator volume expanding, again, and this time from 120 m³ (14, p. 7) to 133 m³ (14, p. 35). Problems invalidating measurements, data, and conclusions, identical to the first PCB burn and little different from those of other cruises described above, plagued this burn as well. The relevant references cite shortcomings inherent to and incurred by that disposal.

Conclusions

This paper has identified some of the measurement and sampling shortcomings of the effectiveness of at-sea

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incineration of hazardous wastes, and has touched on the accuracy and error analysis of the results calculated that should be explored. Particularly, the following matters were flagged:

- The absence of any continuous or instantaneous measurement of the feed rate of the hazardous waste to the incinerators;
- The absence of any continuous or instantaneous measurement of the feed rate of combustion air to the incinerators;
- The absence of particulate measurement in the combustion gases;
- The impossibility of performance of isokinetic sampling of the Vulcanus's stacks, which perhaps led to the discard of consideration of particulate measurement;
- Questionable incinerator temperature measurement;
- Questionable selection of values of combustion gas component proportions used in calculations; and
- Invalid accuracy of the combustion and destruction efficiencies presented;

It is unlikely that the incineration system hardware on the Vulcanus would be found desirable (according to latest knowledge of incineration technology) for confident destruction of hazardous wastes.

Based on this analysis of the data accumulated, the method of data acquisition, the results derived, as well as the reference to the uncertainty of the effectiveness of the incineration equipment used, all of these matters should be closely reviewed and assessed for their true success to date, before another U.S. at-sea permit for the incineration of hazardous waste is approved.

Acknowledgment

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