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Risk Management in the United States: Three Case Studies Dioxin Emissions and Trash-To-Energy Plants in New York City

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RISK MANAGEMENT IN THE UNITED STATES: THREE CASE STUDIES

DIOXIN EMISSIONS AND TRASH-TO-ENERGY PLANTS IN NEW YORK CITY

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New York City, the largest US municipality with a population of 12 million, presently generates 28,000 tons of garbage per day.[1] Its main disposal facility—Fresh Kills—is expected to be the only one of four presently operating landfills still in use in 1987, and to be filled to capacity by 2001.[2] Institutional, economic, and environmental obstacles severely restrict landfill options within the city, and ocean disposal of municipal solid waste is not considered feasible.[3] In short, continued reliance on landfills to absorb the City's enormous volume of municipal waste is no longer considered viable.[4]

A joint New York City/New York State investigation of the city's solid waste disposal dilemma culminated in a 1977 comprehensive solid waste management plan. Among its recommendations, the plan proposed that sanitary landfills be gradually phased out as the City's primary means of solid waste disposal, and be replaced by seven to ten trash-to-energy processing plants, also referred to as resource recovery facilities (RRFs).[5] Legislation passed at the state level in 1979 enabled the city to contract with private vendors for construction and operation of the proposed RRFs. Following passage of this enabling legislation, the NYC Board of Estimate (BOE) directed the City's Department of Sanitation (DOS) to prepare an environmental impact statement (EIS) for a 3000–ton-per-day (tpd) RRF at the Brooklyn Navy Yard, the first of eight such facilities proposed for construction in New York City over the next 12 years.[6]

The EIS examined ambient air quality within a one-half mile radius of the site. Total air emissions of criteria air pollutants, such as total suspended particulates and sulfur dioxide, from the proposed facility were estimated to potentially comprise between .04 and 2.43 percent of all NYC emissions.[7] The DOS concluded that federal air quality standards for regulated "criteria" pollutants—sulfur dioxide, carbon monoxide, ozone, nitrogen dioxide, total suspended particulate matter, and lead—would not exceed the federal standards. The EIS preparers also concluded that emissions of dioxin and furans, classified as "non-criteria" pollutants, would fall within limits designated as acceptable by a New York State Department of Environmental Conservation guideline.[8] Based on the favorable overall assessment of health and environmental impacts, the DOS was prepared to commence with the Brooklyn plant, pending approval by the New York City Board of Estimate (BOE), the elective body responsible for deciding whether to proceed with the proposed RRFs.

The following case study presents (1) the decision by the BOE on the Brooklyn plant in particular, and on the series of proposed trash-to-energy plants in general; (2) the methodology and results of risk assessment of dioxin plant emissions and their potential impact on human health; (3) the risk management strategy adopted by BOE, (4) the risk assessment/risk management interface, which illustrates the prevalence of value judgments in selecting alternatives and risks for analysis, and the implications of choice of models and assumptions; and (5) an evaluation of the BOE decision. The risk assessment methodology is presented in detail because it is being used for adoption of a proposed dioxin guideline in Massachusetts and it is appropriate for application to many other proposed plants.

Background

Dioxin is a generic term for a group of isomers (chlorinated compounds differing from each other in the number and placement of their chlorine atoms) of dibenzo-p-dioxin; the term "furans" describes a similar group of chlorinated compounds, dibenzo-furans.[9] These toxic organic compounds derive from a number of sources, including the incineration of solid waste.[10] Research has identified dioxin as the cause of reproductive problems, cancer, and even death in animals exposed to it. Although parallel ill-effects have not yet been substantiated in humans, dioxin's potential carcinogenicity continues to be a source of concern.[11]

It was this concern that prompted the BOE to commission a study of potential health risks associated with dioxin emissions from the proposed Brooklyn Navy Yard facility. The health risk assessment, undertaken in 1984 by Fred C. Hart Associates, Inc.,[12] focused on cancer deaths likely to be caused by exposure to dioxin emissions. In their August, 1984 report (hereinafter referred to as the Hart Report), Hart Associates projected an additional six cancer deaths per million people exposed to plant emissions.

This estimate was substantially lower than one issued previously in a three-volume report produced in May, 1984 by Barry Commoner and associates at the Center for the Biology of Natural Systems in Flushing, New York.[13] The report (hereinafter referred to as the Commoner Report) projected an additional 1,430 cancers per million people exposed to plant emissions,[14] and was concerned as well with the cumulative impact of exposing New York City's 12 million residents to the emissions of the multiple plants envisioned by the BOE.[15]

Meanwhile, residents living near the proposed Brooklyn site were growing increasingly alarmed over the potential health risks of the facilities.[16] Their apprehension was exacerbated by the conflicting estimates of the number of cancer cases projected in the Hart and Commoner assessments.

Parties to the dispute were essentially deadlocked over whether to proceed with construction and operation of the proposed plant at the Brooklyn Navy Yard. Amidst this controversy, DOS asked the New York Academy of Sciences to coordinate a meeting of concerned parties. To its credit, the Academy decided not to try to set up an expert panel of scientists to determine the best alternative. Instead it sponsored a mediation of the dispute before the Board of Estimate.[17] (Susskind and Ozawa (1985) have described the use of third parties and the advantages and pitfalls that they face in science-intensive policy disputes.) In attendance at the December, 1984 mediation sessions were members of the BOE, representatives of various neighborhood and environmental groups, and national experts from the engineering and scientific community who were responsible for addressing a broad range of issues and answering questions related to technical aspects of the proposed facilities. A key role of the mediator in working with the various parties was to identify the source of disagreements and assure their clarification to the satisfaction of the decision maker, the BOE. For example, once identified as a source of disagreements, uncertainty arising from conflicting estimates of emissions and exposure—which might have proved a hurdle to productive negotiations—was addressed explicitly in the design of risk control measures that were subsequently incorporated in a draft agreement.

As a result of the mediation, the BOE decided to go ahead with the siting of the Brooklyn RRF and ordered environmental statements on four additional plants.

Dioxin Risk Assessment

Following enactment of the 1979 New York State enabling legislation, the DOS, by 1981, solicited and received four proposals for the design, construction and operation of a 3000-tpd resource recovery plant to be sited at the Brooklyn Navy Yard.[18] Before contracting for construction at the Brooklyn site, however, the DOS had to determine that the plant could be operated safely in terms of acceptable public health impacts.

The reason for commissioning a risk assessment by Hart Associates was twofold. First, an analysis of the health risks of dioxin was an essential component of the EIS required by federal legislation.[19] Second, the Hart Report was commissioned to quell environmentalist and other public reaction to a finding of unacceptably high dioxin health risk detailed in the Commoner Report. The Hart risk assessment satisfied the requirements of the EIS; however, it did not put to rest concern over the dioxin risk from resource recovery facilities.[20]

Dioxins, referred to here as PCDDs (polychlorinated dibenzo-dioxins) and

PCDFs (polychlorinated dibenzo-furans) are toxic organic compounds present in furnace emissions as gases or vapors. Analytic models were used to estimate the likelihood of human exposure to these compounds and the level of toxicity over a 70-year lifetime. Estimates were made of (1) the nature and quantity of PCDDs and PCDFs released into the environment, (2) their path through the environment, including transport and bioavailability, and (3) ingestion through inhalation and dermal exposure. "Worst-case" health risks were then estimated by multiplying exposure estimates by toxicity estimates (averaged over 70 years) to arrive at the number of additional cancer deaths per year attributable to dioxin emissions. Those readers desiring to know how the issue of the uncertainty in dioxin emissions was addressed by the New York City Board of Estimate may wish to move ahead to the section on the effectiveness of the risk management. What follows are descriptions of the way the Hart researchers arrived at their estimates of PCDD and PCDF formation, exposure of the population surrounding the plant, and health effects from the dioxin emissions.

PCDD and PCDF Estimates

The first task was to estimate the nature and amount of toxicity. Is dioxin a natural byproduct of the combustion process? PCDDs may be formed in two ways. First, the organic compounds containing chlorine may adhere to the surface of salt particles on the combustion grate, and then react to form PCDDs before reaching the stack. Alternatively, both PCDDs and PCDFs may be formed on or just above the burning grate owing to the combustion of other organic precursors contained in municipal solid waste (MSW) fed into the furnace.[21]

The concentration of PCDDs and PCDFs depends on the temperature at which the waste is burned: researchers have shown that over 99 percent of such isomers are destroyed at temperatures above 700 degrees C. The Hart Report notes that estimated destruction efficiencies (99.99 percent at 957 degrees C under reaction kinetics of a typical combustion system, with one second residence time) can vary substantially from laboratory studies. This is because it is impossible to control temperature, air supply, air/fuel mixing and residence time so that an incinerator burning heterogeneous waste yields results comparable to those obtained in laboratory tests. One can conclude that the combustion process can not always be controlled in a manner that gives minimal dioxin emissions, but that raising combustion temperature (perhaps through standby units) and residence time improves their destruction.

Estimates of PCDD and PCDF concentrations likely to be present in the Brooklyn plant emissions were simulated in the Hart Report using data from two other facilities: the Chicago Northwest facility, which burns MSW at only 650 degrees C., and the Zurich-Josefstrasse facility, for which burning temperatures were not noted. Both facilities use electrostatic precipitators for fly ash control. The Brooklyn Navy Yard facility, however, was expected to remove

more PCDDs and PCDFs than either of these facilities through the use of a fabric filter, rather than an electrostatic precipitator.[22]

Overall toxic emission estimates for gaseous forms of the two compounds (assuming all PCDDs and PCDFs are emitted in gaseous form) for the Brooklyn Navy Yard facility were 498 nanograms per normalized cubic meter (ng/Nm^3) of PCDF and 57.3 ng/Nm^3 of PCDD in the flue gas.[23] These estimates reflect the 650 degrees C. temperature at the Chicago facility rather than the design temperature of 980 degrees C. for the Brooklyn facility. The Hart report suggested that better results could be achieved by burning at the design temperature, but researchers were hesitant to adjust the ng/Nm^3 data downward because of the "design versus achieved" differences and measurement issues.[24]

The issue of how bad the effects of dioxin are if they do get out of the plant is complicated by a fundamental lack of knowledge about the state of the emissions: they could be in either gaseous or particulate form, or a combination. This complicates the task of controlling emission rates. Concentrations in the flue gas can be presented as a mass emission rate, in ug/sec (micrograms per second), at the outlet of the baghouse or fabric filter. Since PCDD and PCDF materials could be found either in a gaseous state or as particulate emissions, the range of estimates included both cases. The resulting estimates were 82.92 – 38.79 ug/sec for gaseous and particulate emissions of PCDF and 9.54 – 4.46 ug/sec for gaseous and particulate emissions of PCDD (Hart Report, p. 3–36). Simply put, the baghouse or fabric filter can capture the PCDD and PCDF compounds which are adsorbed on fly ash particles which enter the pollution control device. Both 100 percent gaseous emissions and 100 percent particulate emissions are evaluated in the remainder of the Hart report, since it was considered inadvisable to partition the data (Hart Report, p. 3–35).

Exposure Assessment

Two standard computer models of dispersion and deposition were used in the Hart Report. The dispersion model (the Multiple Point Source Gaussian Dispersion Algorithm with Optional Terrain Adjustment, or MPTER) was used to predict downwind concentrations of PCDDs and PCDFs in the ambient air, soil, dust, and dirt.[25] Similar dispersion models are used in estimating pollutant concentrations based on point source emission from tall power plant stacks. Pathways of exposure to humans included inhalation, ingestion, and dermal contact. The model results were calculated assuming, first, that all PCDF and PCDD emissions were gaseous and, second, that these PCDFs and PCDDs were adsorbed on fly ash particles.[26] Meterological data collected at LaGuardia Airport and Fort Totten was selected as the most representative source to estimate site conditions, and modifications were made to use the model in an urban environment (the existence of aerodynamic impacts for buildings was not evaluated; however, terrain adjustment for plume reflection was done for elevated receptor points).

The particulate case shows a much lower pg/m^3 maximum annual average concentration at ground level and elevated receptors. The emissions are reduced approximately one-half when a fabric filter or baghouse is used instead of an electrostatic precipitator.

The second computer model, the Industrial Source Complex model, or ISC, was used to predict deposition rates for ingestion and dermal exposure assessments.[27] Annual deposition rates were calculated at 612 receptor points addressed in the model which extended as far as 12 kilometers (km) from the proposed site. Meterological data, described above, for a five-year period was used in the model, and a map was presented, in milligrams per square meter per year (mg/m^2-yr) for four categories of deposition: concentration in ambient air, concentration in soil, concentration in street dirt, and concentration in house dust.

Deposition of fly ash particles is a function of the emitted particle size distribution. As mean particle size diameter decreased below 3.6 micrometers, for example, the fraction of particles deposited declined from five percent to none. The result of this analysis is a predicted maximum annual deposition rate, in nanograms per square meter. The maximum annual deposition rates are 7.759 ng/m^2 for Total- CDF and 0.895 ng/m^2 for total- CDD, with 0.0065 ng/m^2 for 2,3,7,8-Tetra-CDD.

Concentrations in the soil, street dirt, and house dust would increase with deposition over time, and would decrease over time as a result of degradation or volatilization. The environmental half-life of PCDDs has been estimated to range from one-half year to twelve years. Concentrations were presented for soil in femtograms per gram (fg/g or 10^{-15} g/g) and for dirt in picograms/gram (10^{-12} g/g). For soil, total CDF was 486 and total CDD was 56 fg/g after one year. Comparable 2,3,7,8 Tetra-CDD concentration was .41 fg/g. For street dirt (concentrations in settled particulates on outdoor surfaces), concentrations were 104 pg/g for total CDF and 12 pg for total CDD. Comparable 2,3,7,8 Tetra-CDD concentration was .087 pg/g. This data was further adjusted for accumulation on indoor surfaces. The adjustment used a factor of 0.12 to reduce outdoor deposition, assuming a 30-day accumulation time.[28]

The significance of showing these details is to demonstrate that 1) assumptions are made at every stage of the assessment of how deposition gets translated into ambient air concentrations (inhalation exposure) and particle deposition on horizontal surfaces (ingestion and/or dermal exposure), 2) the models themselves have significant limitations, such as the ability to explicitly consider adjustments for terrain or tall buildings, meterological conditions outside the five-year record, and changes in particle size distributions, and 3) the analysis is still based on the two scenarios, one reflecting all gaseous emission of PCDD and PCDF and the other as if all of these compounds were adsorbed on fly ash particles.

Maximum impacts of gaseous PCDF and PCDD emissions would occur at ground level approximately one km southeast of the plant site. At rooftop level, they would occur about 2.27 km southwest of the site. The gaseous theory of

TABLE 1. Summary of Maximum Impacts from Brooklyn Navy Yard Emissions

	Ambient Air pg/m^3[a]	Soil pg/g[b]	Street and Household Dirt, pg/g[c]
Case 1: Gaseous PCDF and PCDD			
PCDF	1.9900	—	—
PCDD	0.2290	—	—
2,3,7,8-TCDD	0.00168	—	—
Case 2: Particulate PCDF and PCDD			
PCDF	0.9309	0.486	104
PCDD	0.0882	0.560	12
2,3,7,8-TCDD	0.000782	0.00041	0.087

[a]Annual average concentration at point of maximum impact.
[b]After accumulation of one year at point of maximum impact.
[c]Annual average deposition concentration at point of maximum impact.
From Hart Report (1984).

emissions gives the largest impacts since the baghouse or fabric filter captures a significant portion of the PCDDs and PCDFs adsorbed on fly ash in the particulate scenario. In this "worst case," inhalation exposure is the major concern. Both the gaseous and the particulate theories were evaluated throughout the Hart Report. The summary is reproduced in Table 1.

Health Effects: Part 1, Scenario One Versus Scenario Two

If the PCDFs and PCDDs are instead formed as particulates, the health risk is substantially reduced. Emissions, and therefore ambient or particulate concentrations, would be roughly halved by the fabric filter or baghouse. Some particulates are captured by the fabric filter. Others settle out quickly because of their relatively large size, making them unavailable for inhalation. Still other particles may not be inhalable and/or respirable because their size would exceed that possible for pulmonary deposition. Health concerns do exist, however, since respirable small diameter particles end up in the environment near the plant. Some models have lower capture rates for gases than for small particles, so there are additional areas warranting scientific attention.

Health Effects: Part 2, Acceptable Daily Intake of TCDD

The Hart report also contained an extensive analysis of the Acceptable Daily Intake (ADI) of TCDD. This analysis contained many quite controversial assumptions, the most debatable being that ADI studies can be used for assessing carcinogenic as well as noncarcinogenic effects.[29]

Tumor counts are the essence of dose-response laboratory tests. The extrapolation to low or very low dosages is absolutely necessary because of the enormously large number of animals that would be required for a series of costly experiments. Conversion factors are applied to the extrapolations to "convert" animal dosage to human dosage, often on the basis of differences in weights or surface areas. Given the fact that different animal studies do not always count tumors in the same way (e.g., some just count liver tumors) and that different species, including humans, metabolize chemicals in various ways, much uncertainty exists in these extrapolations.

Use of a linear extrapolation of animal dose-response data may be conservative for TCDD if TCDD acts as promoter, rather than an initiator, of cancer. The most conservative assumption is that it is both, although the Hart Report authors present evidence indicating it might only be a cancer promoter. Rat and mice studies on the toxicity of 2,3,7,8-TCDD yield carcinogenic estimates that "vary over three orders of magnitude."[30] The results are presented in terms of the estimated quantity of dioxin (2,3,7,8-TCDD or HCDD) in femtograms per kilogram of body weight, which, if consumed each day over a 70-year lifetime, would cause one increased case of cancer for every one million people exposed to that concentration. The 10^{-6} cancer risk is given in fg/kg/day; it varies from 6.4 to 1428 fg/kg/day. Conversion factors also varied from dose to surface area compared to dose to body weight, which accounts for some of this wide variation. This range illustrates that we are dealing with the "art" of technical judgment, not scientific evidence based on reproducible experiments.

Other isomers of the dioxin 2,3,7,8-TCDD may have a less toxic effect, which results in a toxic equivalency factor of 0.1 for isomers having three and four chlorine atoms in the lateral positions. Olie (1980) estimated that the gas and fly ash from a municipal incinerator tested in the Netherlands contained 2,3,7,8-TCDD equivalents equal to 50 and 80 times, respectively, the analyzed amounts of 2,3,7,8-TCDD. This tends to support the use of a multiple components factor of 59 by the Hart researchers.

The Hart Report used a three-pronged approach to assess the "worst case" daily intake for humans. First, data from the previously cited summary table was used to estimate the worst-case daily intake for residents located in the areas of highest potential impacts. Second, the team compared the predicted maximum ground level ambient air concentrations of PCDDs and PCDFs to US EPA standards (and to those from abroad). Third, risk levels were estimated comparing predicted worst-case daily PCDD and PCDF intake levels to concentrations of these chemicals known or suspected to have a toxic effect on people.

To assess the worst-case daily dose, the Hart researchers relied on both Acceptable Daily Intake (ADI) and laboratory animal studies. ADI studies are typically used for non-carcinogenic toxic effects, while animal exposure studies using high dosage levels have generally been extrapolated to estimate low-dose human carcinogenic effects. Despite the controversy over the use of ADI studies for very toxic dioxins, the Hart Report retained this as well as the animal-to-

human dose response approach. In particular, the Hart Report focused on 2,3,7,8-TCDD. While the issue is what is the carcinogenicity of this toxic isomer to humans, there is no doubt that it has severe toxic effects in animals. It causes embryo toxicity and teratogenicity (birth defects) in laboratory test animals, particularly in the guinea pig. The ADI based on a no-observed-effects-level or NOEL of one nanogram per kilogram of body weight per day (1×10^{-9} g/kg/day) in rats has been multiplied by safety factors of 100, 250 and 1,000 by different researchers.

The final calculations of ADI were based on the daily intake (pg per day) for 2,3,7,8-TCDD and another dioxin isomer, Hexa-CDD, in a 70 kg person. These amounts were compared to the dose (pg/day) required to produce an increase of one case of cancer per million people over a 70 year lifetime. The U.S. EPA dose/response extrapolation for 2,3,7,8-TCDD projects a 1×10^{-6} excess cancer risk if 0.0064 pg per kg of body weight is ingested each day over this period. This is equivalent to one increased case of cancer for every one million people exposed to 0.0064 pg/kg/day over a 70 year lifetime. The overall result was an upper bound of less than 6 cases per million people exposed to the maximum concentration over a 70-year lifetime.

This worst-case estimate was made in the following way. A Swiss EPA approach was used that involves multiplying the predicted toxicity of 2,3,7,8-TCDD times a multiple components equivalency factor of 59. This multiplier is "somewhat arbitrary." A three-part sensitivity analysis assumes that 2,3,7,8-TCDD constituted the only significant PCDD-related risk, and that all TCDDs are as toxic as 2,3,7,8-TCDD.

Health Effects: Part 3, Inhalation Exposure Using the Gaseous Emissions Worst Case

The inhalation exposure was calculated by multiplying the average maximum annual ambient air concentration of 2,3,7,8-TCDD by three factors. These factors were: (1) the average amount of air exchanged per day, (2) the particulate retention rate, and (3) the bioavailability of the inhaled material. Further assumptions were made about contaminant concentrations of indoor versus outdoor air.

The result of this calculation was a daily intake from inhalation of 1.9×10^{-14} grams per day for the gaseous deposition scenario and 8.8×10^{-15} grams per day for the particulate deposition scenario.[31] These amounts were compared to ADI standards set by regulatory bodies in Canada, the Netherlands, and the US. The highest ADI for the Brooklyn facility was still less than 1.0 percent of the lowest of these countries' allowable intakes—that of Canada at 10 pg/kg/day.[32]

In sum, the Hart researchers calculated exposure using the MPTER dispersion model to predict downwind concentrations of PCDDs and PCDFs in the ambient air, soil, street dust, and house dirt; then they predicted deposition rates for ingestion and dermal exposure using the ISC model.[33] Finally, the "worst-case" daily intake was used to predict the number of additional cases of cancer attributable to plant emissions from operation over a 70-year period. The Hart researchers concluded their findings in the risk assessment Executive Summary:

> In our opinion, within the context of the assumptions used in the risk assessment, and the conservative methods used to estimate risk, and considering current regulatory practice regarding acceptable versus unacceptable health risks, a worst-case upper bound excess cancer risk less than 5.9×10^{-6} is below levels found by many regulatory agencies to require additional review and probable action to reduce risk.[34]

Effectiveness of Risk Management for Reducing Dioxin Emissions

The risk assessment was performed prior to the approval of the construction and operation of the Brooklyn Navy Yard facility. At this stage in the decision making, risk management alternatives to the project site or design modifications could be considered and implemented. The Brooklyn Navy Yard RRF site was chosen over other potential sites on the basis of the cost of development and environmental constraints at other locations.[35]

To facilitate communication, the DOS allocated funds for extensive public participation and set aside funding for consultants to advise a panel of neighborhood representatives from areas likely to be affected by the proposed facility. This reflects the efforts of DOS to be fair in obtaining citizen input in the face of significant controversy.

Technologies examined for risk reduction included an electrostatic precipitator, fabric filter or baghouse, and a dry scrubber for acid and gas control. Cost and reliability were key issues. Mass burn technology was chosen over alternatives because the technology is fairly well-known and considered to be quite reliable.

A mediation was held to demystify and clarify the scientific and technical issues involved in solid waste management. It was sponsored by the New York Academy of Sciences. The mediation efforts produced a proposal for managing the risks and scientific uncertainties identified during the mediation process.[36] Prescriptions were suggested and taken together they form a risk management strategy for coping with uncertainty. They went beyond a "technological fix" to the dioxin emission issue. Approval of the following measures links the decision to build the facility to an ongoing risk management strategy[37]:

1. A formal monitoring program, connected to targeted performance standards, was proposed to allow assessment of operating conditions at the Brooklyn facility. The facility may be automatically closed down in the event it exceeds pre-set performance standards. Performance contracting will ensure that the monitoring equipment is included as an integral part of the plant design, rather than as an add-on following construction.
2. Insurance options will be explored to determine whether risk for presently unforeseen events can be shared, with liability remaining with plant operators, but by which residents of affected areas are protected by an insurance bond.

3. Improvement and implementation of policies are sequenced so that there is an opportunity to adjust policy as indicated by experience acquired in the course of operating the plant. This suggested a rigorous monitoring and feedback program. At issue are the additional plants proposed by the Department of Sanitation. If the first plant does not have a good operating record, it will probably impede efforts to site additional plants.
4. Significant controversy remains over the potential contribution of a waste recycling and separation strategy to NYC's overall waste management strategy. It is important, however, to avoid policies that prematurely foreclose these options until the health risks of dioxin emissions and the effectiveness of risk reduction techniques are better understood.

Relationship of the Risk Assessment and the Risk Management

The decision to proceed with construction and operation was based on clarifying several aspects of the risk assessment that revealed substantial scientific uncertainty. For example, in specifying the independent variables in the predictive models used to estimate maximum annual downwind concentrations of PCDFs and PCDDs in the ambient air, soil, street dust, and house dirt, the Hart Report had to make multiple assumptions regarding dispersion and deposition rates. Little is known about the actual fate of dioxins in the environment. The risk assessment methodology in and of itself does nothing to guarantee residents exposed to plant emissions that the plant would meet a given standard for criteria or noncriteria pollutants. This would require a contractual agreement with the firm that builds the resource recovery plant. This has been done before (Michaels and Goldstein 1985).

Furthermore, several scholars have expressed doubt about the legitimacy of estimating human health risks based on surface area or per kilogram of body weight exposure of laboratory animals to 2,3,7,8-TCDD or other toxic dioxin isomers.[38] The 2,3,7,8-TCDD compound, in fact, shows considerable variation in toxicity among species.[39] The acute toxicity of different PCDDs also varies widely, based on the location and number of chlorine atoms in the isomer.[40] Most importantly, as noted in the Hart Report, it is not clear at this time whether PCDDs act as promoters or initiators of carcinogenesis.[41]

Scientific uncertainties such as those detailed above and the public unwillingness to risk the unknown health hazards of dioxin exacerbated the controversy over the siting of a series of proposed resource recovery facilities in New York. When public outcries over dioxin emission risks worsened, rather than subsided, following publication of the Hart Report, the DOS sought assistance from the New York Academy of Sciences in investigating and clarifying the uncertainties. The mediation led to proposed options that were adopted by the BOE and which would give all parties a wider range of options in the future. A New York Academy of Science analyst argues that tying the construction of future plants to the performance of the Brooklyn facility will provide incentives for a good operating performance at the Brooklyn trash-to-energy plant (Block 1985).

Evaluation of the Decision

Several lessons may be drawn from the mediation of the Brooklyn Navy Yard RRF siting controversy. These lessons may also have applicability to Europe, where PCDD and PCDF emissions have been recorded that are an order of magnitude higher than that documented in North American RRFs, or in siting RRFs in American cities and towns where similar disputes arise.[42]

First, the use of mediation in this case aided decision makers by allowing them to better comprehend the methodology, results, and limitations of the risk assessment. In addition, the mediation was the primary vehicle for developing an understanding of scientific uncertainty, technical parameters, and perceived risks to local populations. It facilitated the development of possible risk control strategies—an important adjunct to traditional decision making based on one-time approval of facility construction. By directly involving neighborhood associations and other interested parties in the mediation, decision makers took advantage of the opportunity to incorporate additional perspectives on, and solutions to, the problem. Solutions addressed a range of issues, including technological options, operating characteristics, performance contracts, and insurance options.

Second, clarification of the scientific uncertainty contained in the two risk assessments allowed decision makers to proceed even though they were not able to calculate the "true" overall cancer risk. Setting up a panel of scientific experts to decide the issue would have been unwise in the author's opinion, based on the wide range of issues raised by previous scientific work on the emission, transport, and human health effects of dioxin. Assumptions on how the resource recovery facility is expected to work must be explicitly covered, as well as the technological options for control of the plant emissions. The dramatic difference between projected cancer deaths per million people in the Hart and Commoner Reports became the focal point for discussion of the level of confidence one should have in the risk assessment and in the risk management based on those studies.

The third lesson extracted from this case is that mediation has limitations, even though it resulted in proposals for mitigation and operational agreements that will lower both the perceived and the actual risks from dioxin emissions from the plant. The proposals include insurance provisions (a plan for compensation of residents in the event of presently unforeseen events), formal monitoring based on preset standards, and performance contracts. The decision appears to incorporate a broader range of design, operation, and contingency facets than do previously approved incinerator proposals. However, there are challenging problems in implementing an effective monitoring and control strategy, and in developing effective state guidelines or standards for noncriteria pollutants like dioxins. History may show that the criteria pollutants from incinerators deserve more attention than they are presently receiving, and the dioxin issue less attention. Trace metals and ash disposal are additional environmental concerns.

In addition to approving the Brooklyn Navy Yard RRF, the BOE has ordered DOS to produce four additional environmental statements for plants similar to the one proposed in Brooklyn. Decision makers were satisfied that predicted dioxin emissions from the facility do not pose an unacceptable risk to the surrounding community. However, proposed strategies to lessen that risk were adopted by the Board of Estimate, so that mitigation of risk will be an essential condition of the siting.

The decision to proceed with conditions on operation should make the decision more stable, and more likely to be accepted by those who want to ensure that citizen concerns receive a fair hearing.[43] It is expected that litigation will still take place because a neighborhood near the plant feels it is unacceptable that whatever cancers might occur would occur in their neighborhood—indicating that there are local distributions of benefits, costs, and relative risk that cannot be assumed away though an apparently effective risk control strategy is to be put in place. The mediated result provided options which expanded the conclusion, laden with value judgment, drawn in the risk assessment that:

> In our opinion, within the context of the assumptions used in the risk assessment, and the conservative methods used to estimate risk, and considering current regulatory practice regarding acceptable versus unacceptable health risks, a worst-case upper bound cancer risk less than 5.9×10^{-6} is below levels found by many regulatory agencies to require additional and probable action to reduce risk."[44]

In summary, this case illustrates that scientific models for assessing health risks can be useful in risk assessments, but the results are contingent on assumptions and values. It also shows how technological and socioeconomic modifications in facility design, operation, and contingency plans can help mitigate negative environmental impacts. Finally, the case demonstrates how mediation can be an effective means of resolving disputes over facility siting and moving toward acceptance of public health risk.

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Notes

1. City of New York, Department of Sanitation (1984). See p. 1-4 of the *DEIS* and p. 30 of the *DEIS Executive Summary* for discussion of the characteristics of the NYC municipal solid waste (MSW) problem (Hereinafter, these reports are cited as DOS and DOS *Executive Summary*, respectively).
2. DOS (1984), p. 1-4. The DOS also noted the problems of transportation in addition to permitting for remote landfill sites. See p. 3-1 and 3-2. New Jersey is expected to stop allowing acceptance of 2,000 tons per day of MSW within a few years (p. 1-5).
3. DOS (1984), pp. 3-3, 3-4. Building up artificial islands or reefs was considered in 1974, but was abandoned as a permanent solution to the waste disposal problem. The 11,000–ton–per–day capacity resource recovery facility required construction of a 250-acre island and was abandoned for environmental, economic, and practical reasons.
4. DOS (1984), p. 1-5. Since passage of the Clean Water Act of 1970 and the Resource Conservation and Recovery Act in 1976, the City has closed 14 landfill operations due to depleted capacity, hazards to public health and the environment, and public opposition. Many landfills are leaking pollutants into the groundwater.
5. DOS (1984), p. 1-6. Also see City of New York and Environmental Protection Agency (1977).
6. DOS (1984), p. 1-6.
7. DOS *Executive Summary* (1984), p. 13.
8. DOS *Executive Summary* (1984), p. 22. Contact the NYS DEC for the lastest proposed guidelines for garbage incinerator operation.

   The federal government has not set standards for these noncriteria pollutants: it is in the process of defining the extent of dioxin contamination, implementing a cleanup program, and evaluating regulatory mechanisms to prevent future contamination. Significant measurement problems exist for dioxins and furans, and there is a lack of agreement on setting standards.

   See *Chemical and Engineering News*. (1983 p. 23) and Bureau of National Affairs (1984).
9. DOS *Executive Summary* (1984), p. 20.
10. DOS *Executive Summary* (1984), p. 21.
11. There are many forms of dioxin, which describes a class of organic compounds. Furans are a similar class of compounds and have been shown to have very similar toxic properties. Animal studies have shown dioxin to be the cause of reproductive problems, cancer, and death. A noted genetic toxicologist, William Thilly, and others have noted that no human deaths have ever been attributed to dioxin exposure. The Seveso chemical plant accident in Italy released large amounts of dioxin, which caused severe cases of chloracne (dermatological lesions) in some residents. Because of its potential human carcinogenicity, however, dioxin has received an enormous amount of attention.
12. Fred C. Hart Associates, Inc. (1984). Hereinafter, this report is referred to as Hart Report.
13. Barry Commoner and Associates (1984); Volumes I through IV.
14. Barry Commoner and Associates (1984), Vol. IV, p. 21.
15. Barry Commoner and Associates (1984), Vol. IV, p. 27.
16. Susskind and Ozawa (1985), p. 35.

17. Susskind and Ozawa (1985), pp. 35–36.
18. DOS (1984), p. 1-7.
19. National Environmental Policy Act (NEPA) is the federal law that established the role of environmental reviews in federal decision making: EPA permitting activities under the Clean Air Act can use the EIS, although EPA does not presently regulate emissions from solid waste incinerators as "hazardous air pollutants" (New York, Connecticut and Rhode Island have petitioned EPA to do so). The EIS was structured to meet federal requirements, and those of the state, which requires permits to protect air and water quality, and to set conditions for operation of solid waste facilities. See DOS *Executive Summary* (1984), pp. 1 and 2.
20. A member of the New York Academy of Sciences (Marc Block testimony, before the Legislative Commission on Solid Waste, Albany, NY, Feb. 13, 1985, p. 2) has noted that "Although science can be used to assess risk, decisions about 'acceptable risk' levels are largely ethical, social, and political rather than scientific."

    Articles have appeared throughout the debate on dioxin risks in the *New York Times*. One editorial questioned not only whether the dioxin emissions from the plant were acceptable, but also the integrity of the scientists involved in arguing various positions on dioxin emission and control.
21. MSW is fed into a furnace at a constant rate via a conveyer. It is then deposited on a grate (Martin, Passage or other) where it is burned. The heat generated in this process is used to produce steam, which powers turbines to generate electricity. Effluent gases, consisting of sulfur dioxide, hydrogen chloride and other gases then pass through a cooling convector. Lime spray may be used in the pollution control devices to neutralize acidic gases, forming small salt particles. These particles, along with products of incomplete combustion, are then captured by particulate control devices; in particular, an electrostatic precipitator or a baghouse. Organic materials may be present in the furnace effluent as gases. These materials may adhere to the surface of particles during combustion on the grate, then later react with chlorine between the grate and the stack. PCDDs are formed from the combustion of organic matter containing chlorine. Alternatively, as the most generally accepted theory holds, PCDDs and PCDFs may be formed on or just above the burning grate from compounds that are totally unrelated to the products. Chlorine is picked up from gaseous products around the organic precursors of the PCDDs and PCDFs.
22. The lack of consistency in sampling techniques was important in interpreting this data. Emission rates have been shown to vary up to ten times within a plant and up to 50 times between plants (Hart Report, p. 3-16). The Hart Report noted the wide range of concentrations of PCDF and PCDD in an actual test of six Italian incinerator plants: ". . . [these] ranged several orders of magnitude, from moderate (10 ng/Nm^3 TCDD) to very high levels (38,635 ng/Nm^3 Hexa-CDD)" (Hart Report, p. 3-16). Measurements are made in nanograms per normalized cubic meter, which reflects temperature at 0 degrees C and pressure at 1 atmosphere. This evidence suggests that the factors influencing emissions of PCDD and PCDF are very complex, and not well understood.

    The Hart Report's use of data from the Chicago facility is significant because that data gives a low estimate of exposure rates. PCDD and PCDF exposure rates are significantly lower than those estimated for the Virginia RRF, which has similar operating and pollution control characteristics but does not have a Martin grate.
23. *Hart Report* (1984). p. 3-22.
24. *Hart Report* (1984). p. 3-29, 3-32.
25. *Hart Report* (1984). p. 4-2.

26. Concentrations in the two cases were calculated using the mass emission rates (Table 3-8, Hart Report). Concentrations were normalized to a gram per second emission rate, and the model was first used to calculate concentrations of 2,3,7,8-Tetra-CDD. These were estimated at .00168 picograms per cubic meter in the gaseous emission state case and at 0.000782 picograms per cubic meter in the particulate theory case—obviously the latter is smaller because the fly ash particles are captured by the fabric filter. Overall maximum concentrations, again in picograms per cubic meter, were 1.9900 total CDF in the gaseous case and 0.9309 total CDF in the particulate emission case. For CDD, the respective numbers are 0.2290 pg/m^3 (gaseous state) and 0.0882 pg/m^3 (particulate state). See Hart Report, Tables 4-1 and 4-2.
27. *Hart Report* (1984), p. 4-6. The reader interested in the mechanics of estimating ingestion and dermal exposure for particles emitted from the Brooklyn Navy Yard facility stack, originating from solid particulates that settle to the ground and that are mixed with ambient dust, soil, and street dirt is referred to pp. 4-6 through 4-18.
28. *Hart Report* (1984), p. 4-16.
29. *Hart Report* (1984), p. 5-4.
30. *Hart Report* (1984), p. 5-8.
31. *Hart Report* (1984), p. 5-29.
32. *Hart Report* (1984), p. 5-30.
33. *Hart Report* (1984), pp. 4-2 and 4-6.
34. *Hart Report* (1984), p. 17.
35. DOS *Executive Summary* (1984), p. 33.
36. New York Academy of Sciences (1984).
37. New York Academy of Sciences (1984), p. 7-9. The mediator was instrumental in getting the parties to understand the areas of scientific disagreement and to consider means of addressing uncertainty that is a result of such disagreement.
38. New York Academy of Sciences (1984), p. 12.
39. New York Academy of Sciences (1984), p. 5.
40. New York Academy of Sciences (1984), p. 5.
41. New York Academy of Sciences (1984), p. 5.
42. New York Academy of Sciences (1984), p. 5-13.
43. Elliott has referred to these people as the "guardians." See Susskind, Elliott, et al. (1983).
44. *Hart Report* (1984), p. 17.

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