

Research on the thermal destruction of wastes

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Abstract

In general, toxic combustion byproducts (TCBs) are the unwanted residues remaining in flue gases, combustion ashes, and wastewaters from the operation of an incineration or combustion facility. If a combustor is not well designed and operated, it may emit too high a level of TCBs. Categories of TCBs and some example constituents are as follows:

1. Acid gases: HCl, NO_x and SO₂;
2. Organics: hydrocarbons such as dioxins and furans (PCDDs and PCDFs);
3. Particulates: trace metals (conventional metals and radioactive metals) and soots;
4. Contaminants in ash; and
5. Contaminants in spent wastewater.

Pollutants in Category (2) above are generally considered to be the products of incomplete combustion (PICs) in the field of hazardous waste incineration.

The issue of TCBs has been one of the major technical and sociological issues surrounding the implementation of incineration as a waste treatment alternative. Because of the complexity and controversy, EPA technologists conceived of and initiated the International Congress on Toxic Combustion Byproducts (ICTCB) to provide a forum for scientists to discuss the issues of and controls for TCBs in 1989. This paper focuses on the review of the 1989 ICTCB (the First ICTCB) activities. The 1991 (the Second), the 1993 (the Third), and the 1995 (the Fourth) ICTCB activities will be reviewed at other times. The objective of these reviews is to discuss:

1. What have we learned from the ICTCB conferences?
2. What can we use from what we have learned?
3. What improvement in the ICTCBs is needed?

Keywords: Thermal destruction; Toxic combustion byproduct

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1. Introduction

The control of emissions of toxic combustion byproducts (TCBs) is one of the major technical and sociological issues surrounding the implementation of incineration as a waste treatment alternative.

National organizations have been established to campaign against incineration. Local communities often mobilize against it. It is ironic that incineration has often been selected to be the most effective technology to treat toxic waste, yet it probably has maximum opposition from the public compared with alternative technologies. Although pollution prevention approaches have the potential to reduce substantially the quantity of hazardous waste generated, hazardous waste cannot be totally eliminated. That is, some hazardous waste will continue to be generated as long as industry is continuously manufacturing products for human consumption. The question then becomes: “Why not use one of the most effective and environmentally protective technologies (incineration) to dispose of these toxic wastes?”

One obstacle to the widespread adoption of incineration has been the issue of toxic combustion byproducts (TCBs). Categories of TCBs and some example constituents are as follows [Categories (2) and (3) contain the most critical components of concern]:

1. Acid gases: HCl, NO_x and SO₂;
2. Organics: hydrocarbons such as dioxins and furans (PCDDs and PCDFs) [this Category is generally referred to as the products of incomplete combustion (PICs)];
3. Particulates: trace metals (conventional metals and radioactive metals) and soots;
4. Contaminants in ash; and
5. Contaminants in spent wastewater.

The present authors began to write a series of TCB-related papers in 1988 to search for TCB solutions [1–8]. Then, the International Congress on Toxic Combustion Byproducts (ICTCB) was convened in 1989 to provide a forum for scientists to discuss TCB issues.

2. The theme of the ICTCB

The theme of the First ICTCB and all those to follow is:

- *Need*: To address the TCB issues. They cover the whole spectrum of issues ranging from TCB formation to controls, from regulation development to compliance and enforcement, from technology development to performance assurance, from the community right-to-know to public participation, etc.

- *Scope*: To encompass all waste incineration and fossil fuel combustion-related subjects. Both waste incineration and fossil fuel combustion have the same metals problems, similar chlorine-in-feed problems, etc.

- *Approach*: To provide a forum for all concerned parties to discuss issues and to develop answers.

- *Output*: To advance the understanding, development, and application of combustion/incineration and pollution control technologies for the reduction of risks from waste incineration and fossil fuel combustion operations.

3. Chronicle of events

• The First ICTCB was held at the University of California at Los Angeles (UCLA), on August 2–4, 1989. Twenty four (24) researchers presented papers which were later selected, peer-reviewed and published in a special edition of *Combustion Science and Technology* (CST) [9].

• The Second ICTCB was held at the University of Utah, Salt Lake City, on March 26–29, 1991. Twenty eight (28) presented papers were later selected, peer-reviewed and published in a special edition of CST [10].

• The Third ICTCB was held at the Massachusetts Institute of Technology (MIT), Cambridge, MA on June 14–16, 1993. As for the First and the Second ICTCB, selected papers were published in a special edition of the CST journal.

• The Fourth ICTCB was held at the University of California at Berkeley on June 5–7, 1995. Selected papers from this ICTCB will also be published.

4. Sponsoring organizations

The sponsoring organizations for the various ICTCBs are shown in Table 1.

5. Summary of the first congress

This paper summarizes information presented at the 1989 ICTCB, the First International Congress. It provides the highlights of major areas/papers presented. The major

Table 1
Sponsoring organizations (alphabetical order)

	ICTCB			
	1989	1991	1993	1995
Coalition For Responsible Waste Incineration, Washington DC		x	x	x
EPA, Risk Reduction Engineering Laboratory (now the National Risk Management Research Laboratory), Cincinnati, OH	x	x	x	x
Gas Research Institute, Chicago, IL		x	x	x
Industrial Technology Research Institute, Hsin Chu, Taiwan			x	
National Institute of Environmental Health Sciences, Research Triangle Park, NC		x	x	x
National Science Foundation/Advanced Combustion Engineering Research Center, University of Utah		x	x	x
National Science Foundation/Engineering Research Center for Hazardous Substances Control, UCLA	x			
Northeast Hazardous Substance Research Center, Newark, NJ			x	
Sandia National Laboratory, Livermore, CA		x	x	x
School of Public Health, University of California Berkeley, CA				x
Southern California Edison, Los Angeles, CA		x	x	x

areas are grouped under the following headings: (1) Overview; (2) Regulations; (3) Combustion systems; (4) Liquid combustion; (5) Solid combustion; (6) Metals emissions; (7) Organic emissions; (8) PAH and soot emissions; (9) Acid gas emissions; (10) Simulations and transport; (11) TCB control; (12) Monitoring, sampling and analysis; and (13) Risk assessment.

5.1. Overview

J. Skinner, then Acting Deputy Assistant Administrator of the EPA's Office of Research and Development, provided the Congress with a description of EPA's research and development direction. He indicated that the primary responsibility for technology innovation and development resides in the private sector. EPA's role is to stimulate and guide private sector development by identifying needs and by providing technical and logistical support where possible [11].

T. Oppelt, Director of EPA's Risk Reduction Engineering Laboratory, then provided EPA's mission. He said that EPA's mission must embody the concepts of risk prevention and reduction. These concepts involve a hierarchy of policy and technical tools that support national efforts to: (1) minimize the amounts of pollutants generated; (2) recycle or reuse pollutants; (3) control the materials or wastes that cannot be recycled or reused; and (4) minimize human and environmental exposures to any remaining wastes or pollutants. For many materials or wastes that cannot be prevented or recycled, he indicated that incineration will be the control technology of choice. He also indicated that substantial, continued research in improving the effectiveness of hazardous waste incineration, especially with regard to the importance of PICs and metals emissions, is required of EPA, academia, and industry to resolve the paradox which has arisen from the public's objection to the use of incineration technology—in that the technology which often provides the greatest level of control (destruction) of toxic materials, viz. incineration, often has the least amount of public support [11].

5.2. Regulations

Environmental regulations are the driving forces for the protection of the environment. R. Holloway of EPA's Office of Solid Waste discussed their regulatory work aimed at the "Burning of Hazardous Waste in Boilers and Industrial Furnaces (BIF)" so that the emissions of TCBS can be controlled. The BIF rules were later published in the *Federal Register*, Vol. 56, No. 35, Thursday, 21 February 1991 and were codified in 40 CFR Parts 260, and elsewhere. In brief, the BIF rules set standards to control the emissions of the following species from the operation of hazardous waste-burning BIFs [11]:

1. hydrogen chloride (HCl);
2. carbon monoxide (CO), which is used as the surrogate to control PIC emissions; and
3. metals, including: (A) four (4) carcinogenic elements [arsenic (As); beryllium (Be); chromium (Cr); and cadmium (Cd)]; and (B) six (6) toxic metals [antimony (Sb); barium (Ba); lead (Pb); mercury (Hg); silver (Ag); and thallium (Tl)].

Almost parallel to the development of the BIF rules, the U.S. Congress passed the Clean Air Act Amendments in 1991. One of the key elements in the Amendments is the control of the 190 hazardous air pollutants (HAPs) from major sources.

5.3. Combustion systems

O. Smith et al. of UCLA presented their work on the incineration of a surrogate (sulfur hexafluoride, SF₆) in a low speed “dump” combustor. The paper shows that good SF₆ destruction and removal efficiencies, or DREs, in some cases exceeding the detection limit of nearly six 9’s, can be achieved. SF₆ provides a severe test of one possible incinerator failure mode, i.e., thermal bypassing. The researchers then tested both SF₆ and acetonitrile in a larger-scale device, using laser diagnostics to observe directly the integrity of the recirculation zone, and also the hydroxyl radical and temperature fields [9].

Most presenters in this session did not seek to have their papers submitted for CST peer-review publication. R. Seeker and C. Koshland, editors of this CST edition [9], summarized their (the presenters) efforts as follows:

Mike Heap from the Energy and Environmental Research Corporation provided an overview of combustion systems and byproduct emissions. Robert Adrian from the California Air Resources Board presented results of extensive emissions testing from medical waste incinerators, while Ed Lawless of the Midwest Research Institute provided an overview of EPA studies on hazardous waste incinerator emissions. Finally, Victor Engleman of the Science Applications International Corporation provided an overview of innovative incineration systems. Rubin of Carnegie Mellon University discussed evaluation models that allow an assessment of emissions of chemical substances.

5.4. Liquid combustion

J. Dalplanque et al., of the University of California at Irvine, presented the issues surrounding the numerical modeling of multicomponent droplets vaporization and combustion of hazardous liquid wastes [11].

J. Kramlich of the Energy and Environmental Research Corporation discussed bench-scale testing of a turbulent spray flame reactor. Compounds studied included No. 2 fuel oil doped with an equimolar mixture of various compounds, such as chloroform, chlorobenzene, acrylonitrile, benzene, and 1,1,1-trichloroethane. His work provided further understanding of characteristics such as spray quality, the impact of stoichiometry on DRE, the use of CO as an indicator of destruction efficiency, etc. His study concluded that: (1) multicomponent droplets were not found to correlate with the waste compound rankings in the exhaust; (2) no correlation was observed between CO and waste emission; and (3) total hydrocarbon emissions were much more linearly correlated with waste emissions [9].

C. Law of the Princeton University presented an overview of liquid incineration phenomena and summarized important parameters which impact on the performance of liquid-injection incinerators. The parameters discussed were: droplets (20–2000 μm),

sprays, and the blending of wastes with different physical and chemical properties. Factors which affect droplet combustion include: (1) initial droplet size and droplet coalescence; (2) flame holding; (3) droplet gasification rate; (4) ignition and extinction phenomena; and (5) soot formation. The study concluded that: (1) fundamental understanding of waste destruction kinetics is severely lacking, especially those related to the pyrolysis and oxidation of halogenated compounds; and (2) the wide variability of component volatility, reactivity, miscibility, and phase change is important to the design of a mixture composition for optimum waste incineration and possibly energy extraction [9].

V. McDonell of the University of California at Irvine described the application of laser interferometry (optical scattering techniques) to the study of droplet/gas-phase interaction and behavior in liquid spray combustion systems. Three applications were presented: (1) the effect of swirl on the dispersion of droplets; (2) an assessment of spray symmetry; and (3) measurements in a reacting environment [9].

5.5. Solids combustion

G. Darivakis et al. of MIT presented the pyrolysis and combustion behavior of polyethylene (PE) and polystyrene (PS). In the first stage of solids combustion, thermal decomposition transforms the starting material into two products that fuel oxidation: a solid (char) and volatiles. The latter have sufficient mobility and/or vapor pressure to separate from the decomposing substrate. The detailed dynamics of this separation process (devolatilization) determine the release rates, yields, compositions and heating values of volatiles, and thus impact on ignition, flame duration, heterogeneous versus homogeneous combustion intensity, and emissions loadings, compositions, and toxicity. This paper quantified basic features of PE and PS devolatilization including the yields of total volatiles (total weight loss) and of condensibles (tars + higher molecular weight volatilizable material that solidifies at room temperature). Measurements were performed at temperatures and heating rates pertinent to solid waste incineration and to fires [9].

P. Lemieux et al. of EPA discussed the effect of oxygen augmentation on transient behavior in a rotary kiln. The study showed that physical processes controlling the release of waste from the sorbent material are greatly affected by the rotation speed of the kiln and the kiln temperature [9].

T. Lester et al. of the Louisiana State University described the repeatability of the dynamic fluctuations and transients resulting from the one-pack insertion of toluene/sorbent on the next insertion. The test was conducted on a Dow facility with the rotary kiln having dimensions of 3.2 m in diameter and 10.7 m long. The firing rate for the combined rotary kiln and afterburner was 24 300 kW, and the design outlet temperature of the kiln was maintained at 800°C. Their study objective was to provide, for the first time, detailed information on the physical and chemical environments inside the high-temperature zones of an operating industrial incinerator [9].

J. Lighty et al. of the University of Utah presented a study of transport processes in a rotary kiln during the desorption of organic and metallic contaminants from solids (contaminated soils). The “organic” research was based on two fundamental experi-

ments aimed at examining transport: (1) from a particle of soil; and (2) from a bed of soil. Contaminated and treated soils were analyzed by GC/MS for 15 polynuclear aromatic (PNA) compounds including naphthalene, acenaphthylene, etc. Temperatures were on the order of 350°C. The “metal” research was based on glass beads coated with PbO. Temperatures up to 540°C were tested. As far as metals are concerned, the lead was significantly more volatile in the presence of HCl [9].

5.6. Metals emissions

R. Barton et al. of the Energy and Environmental Research Corporation presented their computer model which can reportedly correlate the trace metal emission mechanisms of waste combustors. The mechanisms include particle entrainment, chemical speciation, chemical integrations, vaporization, condensation, particle coagulation and particle collection by flue gas cleaning equipment. The objective of the study was to assess the ability of waste combustion devices to control the emission of toxic metals [9].

R. Flagan et al. of the California Institute of Technology discussed the nature of pyrogenous fumes (fumes formed due to heat). The paper indicated that fume particles produced from vapors in high-temperature systems are remarkably similar in structure, regardless of their composition or the details of the system in which they were formed [11].

S. Friedlander et al. of UCLA discussed the needs for better understanding of aerosol formation, the chemistry of organic emissions, the processing of solid and liquid incinerator feeds, the modeling and control of combustion systems, gas mixing and turbulence and novel and advanced systems. Friedlander and his coworkers also presented their work on the control of fine aerosols in incineration processes [11].

N. Gallagher et al. of the University of Arizona presented their work on the alkali metal (sodium and potassium) partitioning from pulverized coal combustion in a down-fired coal combustor. In all cases, sodium was enriched in the small particle size range, and was shown to form both a sodium-rich fume and an enriched surface layer around existing particles [9].

R. Quann et al. of MIT presented their studies on the submicrometer particle formation as a function of coal types in a laboratory combustion furnace. When pulverized coal is burned, particles ranging in size from about 100 μm down to sub- μm sizes may form, and are composed primarily of oxides (and sulfates) of Si, Al, Fe, Ca, Mg, K and Na. The sub- μm particles, which may comprise only about 1% of the total particle mass, are of the greatest concern, because they are of respirable size, are surface-enriched in toxic trace metals and are the least effectively captured by conventional electrostatic precipitators [9].

5.7. Organic emissions

R. Barat et al. of MIT and J. Bozzelli of the New Jersey Institute of Technology (NJIT) presented their work in which they used a turbulent, jet-stirred, toroidal combus-

tor to study the inhibition of hydrocarbon oxidation by chlorine. This work provided an understanding of how this inhibition leads to flame instability and to PIC formation. The paper concluded that in the presence of chlorine, blowout of the flame occurs sooner (i.e., at a lower mass rate) after the onset of instabilities than in a comparable combustion environment without chlorine. The primary cause of this enhanced instability was an inhibition of CO burnout due to the consumption of OH radicals by product HCl. In addition, chain-terminating consumption of HO₂ radicals by Cl further inhibited CO burnout, as HO₂ was a major source of OH in their testing system [9].

H. Hagenmaier of the University of Tübingen in Germany presented the mechanisms of formation and decomposition of polychlorinated dibenzo-dioxins (PCDD) and -furans (PCDF) in incineration processes. The mechanisms include the following: (1) PCDD/PCDF are already present in the waste and are incompletely destroyed or transformed during combustion; (2) PCDD/PCDF are formed from structurally related compounds such as PCBs, chlorobenzenes, etc.; and (3) PCDD/PCDF are formed by de novo syntheses. This means that they are formed either from organochlorine compounds structurally not related to PCDD/PCDF, such as polyvinyl chloride (PVC), or by incomplete combustion of organic matter in the presence of a chlorine source such as metal chlorides [9].

E. Ritter et al. of NJIT discussed their work on the thermal reactions of chloro- and dichlorobenzene in H₂ and chlorobenzene in H₂/O₂ mixtures in a tubular flow reactor between 835 and 1275 K. The study successfully illustrated the elementary reaction pathways leading to the formation of polychlorinated dibenzofurans (PCDFs) and dibenzodioxins (PCDDs) by adding oxygen atoms to a chlorinated biphenyl and a chlorinated dibenzofuran respectively. Their paper suggested that there are two regimes in incineration or high-temperature reaction systems where homogeneous dioxin formation may occur. The first is a fuel-rich (pyrolysis) region where polyphenyls and aromatics may be present with oxygen and oxygen radicals at temperatures which favor addition reactions over oxidation-of-the-ring reactions [11].

D. Tirey et al. of the University of Dayton Research Institute (UDRI) introduced their work on the thermal degradation of tetrachloroethylene (C₂Cl₄) and ethylene (C₂H₄) using a high-temperature flow reactor system. The study showed that C₂Cl₄ has a propensity for formation of higher molecular weight aromatic species that is similar to that of its non-chlorinated analogue C₂H₄. Acetylene (C₂H₂) is the major product from C₂H₄ degradation, whereas hexachlorobenzene (C₆Cl₆) is the major product from C₂Cl₄ decomposition [9].

W. Tsang of the National Institute of Standards and Technology introduced a single-step reaction rate constant to aid in the understanding of the formation and destruction of chlorinated organic compounds. However, he noted that rechlorination is possible in the post-combustion region when the surface temperature is low [9].

R. Van Dell of the Dow Chemical Company presented a simplified computer flame model to predict the formation and destruction of soots and PICs in a laboratory thermal oxidizer (LTOX). Although the simple model adequately predicted flame temperature, diffusion velocity, soot yields and soot concentrations, the author indicated that refinement of the model was needed [9].

5.8. PAH and soot emissions

R. Barbella et al. of the University of Naples in Italy presented the optical and chemical characterization of carbon polymorphs formed during the spray combustion of hydrocarbons. Carbon polymorphs comprise a large variety of carbon structures resulting from the spray combustion of mixed saturated, unsaturated and aromatic hydrocarbons. The carbon polymorphs (which contain a larger number of carbon atoms than those contained in the original fuel) could represent toxic air pollutants, as they include compounds such as substituted and unsubstituted polycyclic aromatic compounds (PACs) and larger aggregates of carbon atoms such as tar and soot [9].

M. Frenklach of Pennsylvania State University presented his study on the formation of polycyclic aromatic hydrocarbons (PAHs) in chlorine-containing environments. PAHs are the precursors of soot and have been identified as carcinogenic and mutagenic. His study, which showed that the presence of chlorine in hydrocarbon systems strongly promotes the formation of PAHs, has concluded that: (1) the enhanced, chlorine-catalyzed degradation of POHC molecules promotes the formation of aromatic ring compounds; and (2) the large concentration of Cl atoms accelerates the abstraction of aromatic H from stable PAH molecules and activates them for further growth [9].

J. McKinnon et al. of MIT presented the soot formation mechanisms and the effects of chlorine. Chlorine is a known inhibitor of combustion and promoter of soot formation. The paper concluded that soot formation involves the growth of high molecular weight PAHs, the reactive coagulation of these heavy molecules, and mass addition from PAH and acetylene. These processes are opposed by oxidative and pyrolytic degradation, thus resulting in a competition which determines whether and to what extent any soot emission occurs [9].

J. Mitchell et al. of the University of Western Ontario presented the results of using additives to control soot formation. This study tested several additives including cesium salts, potassium salts, barium salts, and ferrocene. Additives can either enhance soot oxidation or inhibit soot agglomeration so that the soot particles remain small and thus are easily oxidized. Metallic additives, when they work as smoke inhibitors, appear to operate via mechanisms involving enhanced soot burnout rather than by reducing actual soot formation [9].

5.9. Acid gas emissions

M. Ravichandran et al. of Cornell University discussed the chemical kinetic constraints placed on NO_x reduction by ammonia injection in both a perfectly stirred reactor and a plug flow reactor. The results indicated that NO_x reduction by ammonia injection in the case of incinerators would require more stringent process control and is likely to require higher amounts of NH_3 and H_2 to achieve NO_x reduction efficiencies comparable with those achieved in the case of utility boiler furnaces. One of the reasons for this is that waste incinerators use more excess air than do utility boilers [11].

5.10. Simulations and transport

G. Silcox et al. of the University of Utah presented their study on the mathematical and physical modeling of rotary kilns with applications to scaling and design. The model

study examined heat and mass transfer in an indirectly fired rotary kiln and mixing times in a slumping kiln bed. The design and operating study examined kiln length, solids residence time, solids feed rate, and feed moisture content. The effects of moisture were particularly important to both heat and mass transfer [11].

P. Smith et al. of Brigham Young University presented their application of computational combustion simulations to full-scale pulverized-coal industrial furnaces and utility boilers. Heterogeneous and turbulent heat transfer aspects strongly influence the formation and decay of byproducts in practical coal combustion systems because many of the sub-processes resulting in combustion byproducts are highly temperature-sensitive and because the purpose of most furnaces is to extract energy from the flame [11].

5.11. TCB control

T. Brna of the U.S. EPA presented an overview of TCB control options which included (1) in-furnace methods, and (2) post-combustion methods [9].

M. Ho of Union Carbide Industrial Gases, Inc. presented a method of oxygen enrichment to control the transient emissions from a rotary kiln; the method described was an in-furnace method [11].

J. Kilgroe et al. of the U.S. EPA described the use of combustion control for limiting organic emissions (mainly chlorinated dibenzo-*p*-dioxins and -furans) from municipal waste combustors. The paper defined the concept of “good combustion practices (GCP)” as the set of conditions that minimizes the emission of organic compounds. GCPs at that time included: (1) uniformity of waste feed; (2) adequate combustion temperature; (3) amount and distribution of combustion air; (4) mixing; (5) minimization of particulate matter carryover; (6) control of downstream temperature; and (7) combustion monitoring and control [9].

R. Wood et al. of the ASME Research Committee on Industrial and Municipal Waste presented methods to minimize combustion excursions from rotary kiln incinerators. The paper reported that an operating kiln produces no significant combustion excursions from batch feeds when the minimum oxygen level at the outlet of the combustor is above 1% [11].

5.12. Monitoring, sampling and analysis

W. McClennen et al. of the University of Utah presented a system for the on-line analysis of organic vapors by short-column (1 m) gas chromatography/mass spectrometry (GC/MS) to monitor products from a thermal soil desorption reactor. The broad range of boiling points and polarities of the organic compounds in wastes mandates the use of sophisticated instrumentation for monitoring their production, evolution, and destruction. The short-column GC/MS can accurately measure the transient concentrations (30–60 s intervals) of a broad range of aromatic compounds. It can separate the organic vapors away from the major ambient atmospheric constituents and also provide some separation of isomers otherwise indistinguishable by MS. The mass spectrometer provides a rapid and sensitive method of compound identification [9].

5.13. Risk assessment

In the past, EPA's incineration standards such as the destruction and removal efficiency (DRE), HCl and particulate requirements have been technology-based standards. The BIF rule incorporates risk assessment calculations into the requirements of the standard.

A. Smith et al. of The University of California at Berkeley discussed the health risk assessment of incinerator air emissions incorporating background ambient air data. The emissions data used were supplied by Ogden Martin Systems, Inc. and were derived from stack sampling at a municipal waste incinerator located at West Babylon on Long Island, New York. Key substances used for the risk assessment were PCDDs, PCDFs, lead and mercury. Human exposure was estimated for a lifetime average exposure of a hypothetical person living for 70 years, 24 hours per day, at the point of maximum annual average ground level concentration of emissions. The study concluded that the cancer risks attributable to air pollution emissions from a municipal waste incineration facility with modern air pollution equipment are below 1 in 100 000 [9].

6. What have we learned from the ICTCB?

“A lot” is probably the most simple way to describe what was learned from the information presented at the First ICTCB. The thirteen areas identified in the above-mentioned groups/summary are but a sampling. Each area has so much more information to offer. Using the area of metals emissions as an example, metals speciation research requires specialized knowledge to understand fully the mechanisms that influence which metals species go to which effluent stream when metals are in the incineration/combustion environments.

7. What can we use from what we have learned?

The technical community has been searching for answers to the following questions:

1. Are significant TCBs actually being emitted from waste incinerators from an environmental risk standpoint and how much, quantitatively and qualitatively?
2. Why is the issue of TCBs still the focus of the public's concern, after so many years of research and after so many risk assessments have shown TCBs to be relatively benign (as long as appropriate pollution controls are incorporated into the incinerator design)?
3. Do other treatment technologies emit any unwanted reaction by-products (RBPs) and how much?
4. Is there any comparison between TCBs and RBPs? Which are more harmful to human health and the environment?
5. Can scientists provide any data to allay the public's fears or to overcome their “NIMBY” (“not in my backyard”) attitude?

Perhaps the ICTCBs may be able to provide answers to the above questions.

8. What improvement is needed?

Based upon the research topics/areas reviewed herein, the authors believe that the ICTCBs of the future need to emphasize such additional topics as:

- performance assurance (to assure that a permitted system will perform to the degree required);
- ash quality and its reuse or its ultimate disposal;
- the ultimate disposal of spent wastewaters from any air pollution control operations associated with incineration/combustion;
- fugitive emissions;
- the public's involvement; and
- health effects from environmental contaminations (this subject was included in the Second, Third and Fourth ICTBPs).

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