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Thailand

Dioxin Sampling and Analysis Program



Report

Prepared by
UNEP Chemicals



Deutsche Gesellschaft für
Technische Zusammenarbeit (GTZ) GmbH



EURO CHLOR
REPRESENTING THE CHLOR-ALKALI INDUSTRY

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IOMC

INTER-ORGANIZATION PROGRAMME FOR THE SOUND MANAGEMENT OF CHEMICALS
A cooperative agreement among UNEP, ILO, FAO, WHO, UNIDO, UNITAR and OECD

Thailand Dioxin Sampling and Analysis Program

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Prepared by

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In cooperation with
PCD, GTZ, Euro Chlor

September 2001

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Preface

Thailand has recognized chemical hazards as a priority problem particularly the management of chemicals management under Chapter 19 Agenda 21. With the Stockholm Convention on Persistent Organic Pollutants in place, the Royal Thai government decided to address dioxin and furan sources and releases. In order to do so, the Thai government has requested assistance from the German Technical Cooperation (GTZ) and UNEP Chemicals. In addition, Euro Chlor provided financial assistance.

This joint dioxin project in Thailand is a key element of UNEP's capacity building programme assisting countries in identifying their dioxin and furan sources and releases. It supports the Stockholm Convention on Persistent Organic Pollutants where in Article 5 Parties to the Convention are requested to identify and quantify the release of byproducts.

To assist the country in better defining its sources of dioxins and furans and to verify emission factors in UNEP's Toolkit to identify and quantify releases of PCDD/PCDF, a this sampling and analysis program was initiated and the results of this activity are being published as a stand-alone document for information to other countries and the Intergovernmental Negotiating Committee of the Stockholm Convention on POPs.

Geneva, September 2001



James B. Willis
Director, UNEP Chemicals

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List of Acronyms

APC	Air pollution control
d.m.	Dry mass
EAF	Electric arc furnace
EN	Euro Norm
Euro Chlor	Federation representing the European Chlor/Alkali Industry
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit GmbH
HCl	Hydrochloric acid
Hg	Mercury
ISO	International Standards Organization
MSWI	Municipal Solid Waste Incinerator
NATO/CCMS	North Atlantic Treaty Organization/Committee on Challenges in Modern Society
NO _x	Nitrogen oxides
Pb	Lead
PCD	Pollution Control Department
PCDD/PCDF	Polychlorinated dibenzo- <i>p</i> -dioxins and polychlorinated dibenzofurans
POPs	Persistent Organic Pollutants
QA/QC	Quality assurance / quality control
SO ₂	Sulfur dioxide
TA Luft 86	German Guideline for air emissions from industrial facilities effective 1986
TEF	Toxic equivalency factor
TEQ	Toxic equivalent
TRK	German technical orientation concentration
UNEP	United Nations Environment Programme
VDI	Society of German Engineers
WHO	World Health Organization

1 PROJECT OUTLINE

1.1 Objectives

In 1997 the Pollution Control Department (PCD) of the Ministry of Science, Technology, and Environment of the Government of Thailand in Bangkok initiated a dioxin program, which with the financial support of GTZ, UNEP Chemicals, and Euro Chlor included an emission inventory for polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (PCDD/PCDF). In order to establish a better basis for this inventory a sampling campaign was proposed to sample and analyze dioxin emissions from sources that were known to be potential emitters of PCDD/PCDF. Finally, seven facilities representative for their respective industries were selected by PCD for stack gas emission and residue (liquid, sludge, and solid) sampling, and PCDD/PCDF analysis to be performed.

The facilities chosen for sampling in the following consecutive order were:

- 1) Solid Waste Incinerator (one unit)
- 2) Cement Plant (cement kilns A and B) with and without co-combustion of liquid hazardous waste and/or tires
- 3) Secondary Lead Smelter (two units)
- 4) Steel Plant (2 electric arc furnaces)
- 5) Secondary Brass Smelter (one unit)
- 6) Crematory (one unit)
- 7) Hospital Waste Incinerator (two units).

The aim of this program is to identify the major PCDD/PCDF sources in the country, to serve as basis for measures to reduce dioxin releases. The reduction of releases will consequently reduce the risks resulting from dioxin emissions in Thailand.

1.2 Methods and Evaluation

The sampling and analysis was performed by GfA of Münster-Roxel, a laboratory which has accreditation according to EURO NORM 45001 and it performed the PCDD/PCDF sampling and analysis in full compliance with EN 1948. To a large extent, the work was monitored by either GTZ, UNEP Chemicals, and/or E&EC of Waldbröl, an independent international consultant to ensure compliance with the respective QA/QC protocols.

Sampling was performed with the cooled probe method, one of the three approved in the European Standard EN 1948. Typically, the sampling times were 6 hours per sample.

All PCDD/PCDF concentrations given in this report are based on TEQ (toxic equivalents).

For weighing the concentrations of the 17 2,3,7,8-substituted congeners with its toxicity, both, the toxicity equivalent factors (TEFs) as established by the NATO/CCMS group (= I-TEFs) as well as the values established by a WHO expert group (WHO-TEFs, however for PCDD/PCDF only) are reported. When calculating the TEQ, congeners that were below the detection limit were assigned a concentration of zero in agreement with the European standard where at a detection limit of 0.005 ng per congener, the non detectable congeners are being ignored when calculating the TEQ. This requirement was fulfilled for all stack samples. It should be noted, however, that due to the sensitivity and selectivity of the methods chosen, almost all 2,3,7,8-substituted congeners could be quantified. In the solid residues, all 2,3,7,8-substituted congeners were quantified.

The concentrations of PCDD/PCDF and other pollutants were normalized to standard conditions, which are 273 K, 101.3 kPa, dry gas, and the operating concentration of the plant. For all waste incinerators, the concentrations have been recalculated to 11 % O₂, the European standard for waste incinerators; the same reference value has also been applied for crematoria. For cement plants the reference O₂-concentration is 10 %. All data can be compared with the European emission limit value for waste incinerators of 0.1 ng I-TEQ/m³. This value is also an orientation and target value for PCDD/PCDF emissions from other combustion sources and industrial installations, although the conditions in these plants differ from those of waste incinerators. However, neither in Europe, North America, nor in Thailand industries such as steel, lead or brass smelters and cement kilns are regulated with respect to PCDD/PCDF emissions. Other measured emission values such as lead, mercury, HCl, and SO₂ are compared with the respective European or German values, *e.g.*, derived from the German TA Luft 86.

To make the results independent of the operating conditions, fluxes of PCDD/PCDF in mg TEQ per hour and emission factors in µg TEQ per ton of product or per ton of feed material processed were calculated as well.

2 RESULTS AND DISCUSSION

The PCDD/PCDF concentrations in the stack gases of all plants are summarized in Table 1. A summary of the PCDD/PCDF concentrations in the solid residues and in the indoor samples is given on page 15 in Table 3 and Table 4, respectively. The following sections give a brief presentation of results and put them into context. The main results of the discussions of the National Workshop on the Implementation of the Stockholm Convention, held in Bangkok, June 13—14, 2001, and recommendations for next actions are summarized in chapter 4.

2.1 Municipal Solid Waste Incinerator (MSWI)

The plant consists of one 250 t/d unit. Technologically, it has an inclined, reciprocating grate, a dual drum heat recovery steam boiler (14.8 t/h, 30 bar, 300 °C), a quench cooler, a dry lime injection system and a pulse jet baghouse.

Stack gas samples were taken in full accordance with EN 1948 as well as VDI 2066. During sampling all available on-line data measurements from the central control systems was monitored. Additionally to PCDD/PCDF, the flue gas was analyzed for SO₂, Hg, and Pb to evaluate the overall performance of the APC equipment. Additionally, bottom ash samples and APC residue samples were taken.

The flue gas concentrations @11 % O₂ ranged from 0.65 to 3.10 ng I-TEQ/Nm³ with an average of 1.71 ng I-TEQ/Nm³. The concentrations of total PCDD/PCDF (Cl₄-Cl₈) were between 41.3 and 239 with a mean of 122 ng/m³. Although the Thai standard – like the U.S. standard - sets a limit value for the total of the PCDD/PCDF (Cl₁-Cl₈) of 30 ng/m³, the here measured average concentration of 122 ng PCDD/PCDF/m³ is above the Thai standard for municipal waste incinerators. So is the mean of 1.7 ng I-TEQ/m³ above the European standard of 0.1 ng I-TEQ/m³.

The results are not surprising since conditioned dry absorption systems with a baghouse and without additional adsorbent injection typically yield stack emissions between 0.5 and 5 ng I-TEQ/Nm³ if designed and operated properly. The PCDD/PCDF emissions from this MSWI would have been typical for any municipal waste incinerator in Germany in the early/mid 1990s and in many European countries at the turn of the century. The overall patterns for the PCDD/PCDF congeners and homologue profiles are also typical of those from municipal solid waste incinerators.

The fluctuation in the PCDD/PCDF concentrations can be explained by the temperature (between 750 °C and 950 °C) and oxygen fluctuations (between 7 % and 15 %).

The mercury concentrations were 0.01 and 0.02 mg/Nm³ and would fully comply with the European current standard of 0.05 mg/Nm³ as well as with the more stringent German standard of 0.03 mg/Nm³. The lead emissions were 0.03 and 0.04 mg/Nm³; the European standard does not set a limit value for Pb alone but sets a standard of 0.5 mg/Nm³ for the sum

of ten heavy metals including lead. The here measured concentrations are less than 10 % of this limit concentration and thus would allow the conclusion that the emission limit would be met. The SO₂ concentration between 3.4 and 4.9 mg/m³ were very low whereas the HCl concentrations of 30-57 mg/Nm³ (18-35 ppm) were much higher than expected.

The PCDD/PCDF concentrations in the fly ashes were low with 228, 380, and 686 ng I-TEQ/kg. Concentrations below 1,000 ng I-TEQ/kg are considered typical for pure flyash from modern municipal waste incinerators. It should be remembered that the fly ashes from this MSWI are somewhat diluted with the salts from the acid gas removal and the lime injected. The results for the bottom ashes are also well within the expected range and gave concentrations of 10, 6, and 5 ng I-TEQ/kg. Most comparable European and North American MSWIs also report values around 10 ng I-TEQ/kg. The concentrations found in the solid residues of this plant were comparable to those from other modern facilities of that type, which leads to the conclusion that the plant performs adequately. The use of the existing equipment can be easily improved to meet a PCDD/PCDF emission limit of 0.1 ng I-TEQ/Nm³ at all times (see chapter 4.1).

2.2 Cement Plant

The technology of the cement plant is state-of-the-art utilizing the dry process, the equipment is well designed, maintained, and operated. Kiln A ran at a capacity of about 270 t/h of raw material and Kiln B ran at 330 t/h of raw material. Dioxin measurements at both kilns were performed under normal operation at full load when fueled with a blend of lignite and petroleum coke as primary and secondary fuel and with waste tires (Kiln A) or liquid hazardous waste (waste oils, contaminated solvents; kiln B) to replace a certain percentage of the secondary fuel at the calciner in the high temperature zone. The plants do not produce any solid residues since all the flyash collected is reintroduced into the cement production process.

All stack sampling could be performed in full compliance with EN 1948 and VDI 2066. The stack concentrations were all below 0.02 ng I-TEQ/m³ and as low as 0.0001 ng I-TEQ/m³; the means were 0.0105 ng I-TEQ/m³ and 0.0008 ng I-TEQ/m³ for the normal operation conditions and 0.003 ng I-TEQ/m³ and 0.0002 ng I-TEQ/m³ for the test performed with substitute secondary fuels, respectively. Thus, all test results are far below the orientation value of 0.1 ng I-TEQ/m³. In no case 2,3,7,8-Cl₄DD was detected. The results also clearly reveal that the addition of tires and/or liquid hazardous waste had no effect on the emission results keeping in mind that the dry cement kiln process employed in the cement plant is best state-of-the-art technology.

The SO₂ and Hg concentrations were also very low with SO₂ <0.9 mg/m³ and Hg of 0.011 and 0.012 mg/m³, respectively.

2.3 Secondary Lead Smelter

The company operates two rotary kiln secondary lead smelters for the recovery of approximately 7,500-8,000 tons of secondary lead per year and line. The capacity of each furnace is about 3.5-5 t of lead per batch and each batch takes about 2-3 hours. With a sampling time of 6 hours, each sampling covered 2-3 batches each. Each line has an after-

burning chamber behind the rotary kiln, a cooling tower, a cyclone separator and a baghouse. In case of line 1 the flue gas stream from the smelter is combined with numerous other off gases and large quantities of ventilation air from the work-floor, e.g. furnace feed door ventilation hood, slag tap kettle ventilation hood, refinery kettles for casting the final product, raw scrap material processing ventilation hood, ash agglomeration and melting furnace, and the ash melting slag tap kettle.

The PCDD/PCDF concentrations ranged from 0.021 to 0.032 ng I-TEQ/m³ with a mean of 0.027 ng I-TEQ/m³ for line 1 and from 0.06 to 0.11 ng I-TEQ/m³ with a mean of 0.089 ng I-TEQ/m³ for line 2 at the operational O₂ content of about 19 %.

The lead concentrations at line 1 were 0.64 and 0.74 mg/m³ and thus slightly above the European emission limit value of 0.5 mg/Nm³ based on the German TA Luft 86 for the sum of five heavy metals including lead. The SO₂ emissions were 40.8 and 41.0 mg/m³ for line 1 and 21.8 and 22.5 mg/m³ for line 2, respectively.

2.4 Secondary Steel Plant

The secondary steel plants consists of two electric arc furnaces (EAF) at 35 t per batch each to produce mostly concrete reinforcement steel bars for use in structural construction works. All feed material is scrap metal. Both EAFs operate with graphite electrodes to produce a minimum operating temperature of 1,550 °C. The flue gases from each EAF are vented to a post combustion chamber, then pass through a water cooled duct, pass through two parallel gas-gas heat exchangers, and finally are cleaned in a baghouse. A secondary duct leads all the air vented from the work-floor *via* a huge canopy hood above the EAFs through the baghouse as well. The collected dust is pelletized and reintroduced into the melting process.

Three sampling points were selected to measure PCDD/PCDF emissions of the steel plant; two flue gas samples, one in the stack and one in the primary duct, as well as one indoor ambient air sample in the hall above work-floor and the EAFs.

The emission samples from the EAF in the primary duct before the baghouse characterizes the PCDD/PCDF emissions released from the EAFs directly. These concentrations were between 3.4 and 11.8 ng I-TEQ/m³ with an average of 7.2 ng I-TEQ/m³ at the operational O₂ content of around 19 %. The stack emissions ranged from 0.32 to 0.61 ng I-TEQ/m³ with an average of 0.50 ng I-TEQ/m³.

The work hall concentrations were 13.3, 15.1, and 25.2 pg I-TEQ/m³, respectively (Table 4), and thus up to about half of the German technical orientation concentration (German TRK value) for permissible maximum work place exposure of 50 pg I-TEQ/m³.

The fly ash concentration was 1,899 ng I-TEQ/kg. From a German EAF process, filter dust concentrations of 700 ng I-TEQ/kg were reported.

2.5 Secondary Brass Smelter

The plant operates a small, batch-type smelter for primary and secondary brass production. The brass from the smelter is casted manually into bars, which are then rolled into coils for the electric/electronic industry, automobile radiators, ornaments, watches, and other high quality products. The furnace is heated with about 30 L/h low sulfur, heavy fuel oil. The set-up, configuration, and operation of the system are fully manual including loading the furnace, feeding additional material and extracting the molten brass. The furnace is operated on a 250 kg/batch discontinuous mode during one day shift between 8 a.m. and 5 p.m. The flue gases from the furnace and several surrounding areas pass a wet scrubber and are then discharged through the roof *via* a steel stack.

The stack concentrations ranged between 0.13 and 0.21 ng I-TEQ/m³ with an average of 0.15 ng I-TEQ/m³ at the actual operating O₂ concentration of 19 %. The work-floor concentrations were between 12.1 and 17.4 pg I-TEQ/m³ with an average of 14.2 pg I-TEQ/m³.

The PCDD/PCDF concentrations in the sludge samples taken from the clarifier of the water treatment system of the wet scrubbers had rather high concentrations of 8,683 and 8,567 ng I-TEQ/kg d.m.; in most countries, residues from such processes or with such concentrations would be classified as hazardous waste. As expected, the slag sample from the furnace exhibited a low concentration of 13.6 ng I-TEQ/kg.

2.6 Crematory

The crematorium consisted of a refractory lined primary combustion chamber, which is heated by a light fuel-oil fired burner. The secondary combustion chamber houses an afterburner, which is also fired by light fuel-oil. Subsequent follows a refractory lined flue gas duct, which discharges through an underground brick flue gas duct into a brick lined stack, which is about 15 meters away from the furnace. The furnace loading door is a slide door, which opens vertically to access the primary combustion chamber for placement of the coffin; the door is ventilated independently of the combustion system by an access door ventilation duct. Since each cremation takes only about 1.5 hours, it was decided to adjust the sampling time to the duration of one cremation.

The PCDD/PCDF concentrations at the two sampling points gave – as expected - higher concentrations at the stack than at the furnace door. Normalized to 11 % O₂ the PCDD/PCDF concentrations at the stack ranged from 6.3 to 14.8 ng I-TEQ/m³ with an average of 9.4 ng I-TEQ/m³ at the actual O₂ concentration of around 15 %. Normalized 10.5 to 28.6 ng I-TEQ/Nm³ with an average of 17.6 ng I-TEQ/Nm³. At the furnace door between 0.02 and 0.08 ng I-TEQ/m³ have been determined. The latter results should be taken with caution as the sampling conditions were not in accordance with the requirements of EN 1948 and there is some uncertainty with the determination of the flow rate.

The composite ash sample showed a concentration of 44 ng I-TEQ/kg and thus is higher than the bottom ash from the municipal solid waste incinerator.

2.7 Hospital Waste Incinerator

The hospital waste incinerator consists of two identical units built in the mid 1990s. The incinerator is started-up every morning around 6 a.m. and operated until all the hospital waste delivered is incinerated. The first batch of waste is introduced about 30 minutes after start-up of the burners. Immediately after the last batch of waste is introduced into the furnace, the burners are turned off, and the ashes are left in the combustion chamber over-night. This mode of operation favors the generation of PCDD/PCDF for at least two reasons: 1) the furnace is not sufficiently hot before the first waste is burned and the burners are shut down before the combustion is completed; and 2) the remaining ash provides ideal conditions for the synthesis of PCDD/PCDF as it stays for long times in the critical temperature range (200-450 °C). Further, the furnace has a static grate, which does not provide any mixing of the incoming waste; of the 4 burners designed, only two are installed and operated. The facility is also equipped with a secondary combustion chamber and two afterburners mounted on each sidewall. As could be seen from the temperature reading, the temperature in the first combustion chamber was as low as 637 °C and in the second combustion chamber occasionally dropped to 730 °C! The flue gases are passed through an alkaline water bath before being discharged through a non-insulated stainless steel, single flue stack per line.

Overall, the plant is rather poorly designed. Additionally, the plant is extremely poorly maintained with several essential pieces of equipment are either out of service or missing entirely.

Flue gas samples from the stack was taken from both incinerator units in accordance with EN 1948 and VDI 2066. However, due to numerous power and/or cooling water supply failures, continuous, uninterrupted sampling for 6 hours as required by EN 1948 could not be performed. The actual operating oxygen concentrations were between 14 % and 15.5 %. The PCDD/PCDF concentrations were – adjusted to 11 % O₂ – between 21.8 and 43 ng I-TEQ/Nm³ for line 1 and 10.7-45.0 ng I-TEQ/Nm³ for line 2; the averages were 33.8 and 28.6 ng I-TEQ/Nm³, respectively.

Samples of the sludge from the wastewater treatment system of the quench bath gave concentrations between 517 and 708 ng I-TQ/kg d.m. and the bottom ashes were between 1,410 and 2,300 ng I-TEQ/kg. The extremely high concentrations in the bottom ashes reflect the inefficient combustion in the furnace and the synthesis of PCDD/PCDF overnight. At an absolute scale and when compared to results obtained at the municipal solid waste incinerator, the concentrations found in the bottom ashes of this hospital waste incinerator are about the highest ever reported in the literature.

3 CONCLUSIONS AND RECOMMENDATIONS

3.1 Results in Comparison

The plants analyzed for PCDD/PCDF exhibit a broad spectrum of different activities and the PCDD/PCDF concentrations range over six order of magnitude (lowest at cement kiln with 0.0003 ng I-TEQ/m³ and highest at hospital waste incinerator with 33.8 ng I-TEQ/m³).

A common measure to compare emissions of PCDD/PCDF is to calculate emission factors, which give the mass of PCDD/PCDF to be produced or released when one (1) ton of product is produced or one ton of feed material is processed. These emission factors are shown in Table 2. As can be seen, the values cover a very broad range with the lowest emission factors for the cement kilns (0.02 µg I-TEQ/t of clinker and below) and the highest for the hospital waste incinerator (greater than 1,200 µg I-TEQ/t of hospital waste burned).

Another method to compare the emissions uses the emission per year emitted to air. The results are shown in Figure 1. The data in Figure 1 are obtained when the hourly releases (concentration per cubic meter x flue gas volume) are multiplied with the operational hours per year. To calculate these annual releases per furnace, it was assumed that the continuously operated plants (= municipal waste incinerator, cement kilns, lead smelters) are operated 8,600 hours per year, the brass plant and the hospital waste incinerators are operated 5 days a week for 8 hours, and the steel plant for 16 hours on 5 days per week. For the crematory the average number of cremations per year (40 bodies per months) was used. Per plant, the highest release into the atmosphere is from the two EAFs of the steel plant 2,841 mg I-TEQ/a), whereas the hospital waste incinerator with its two furnaces releases 1,436 mg I-TEQ/a).

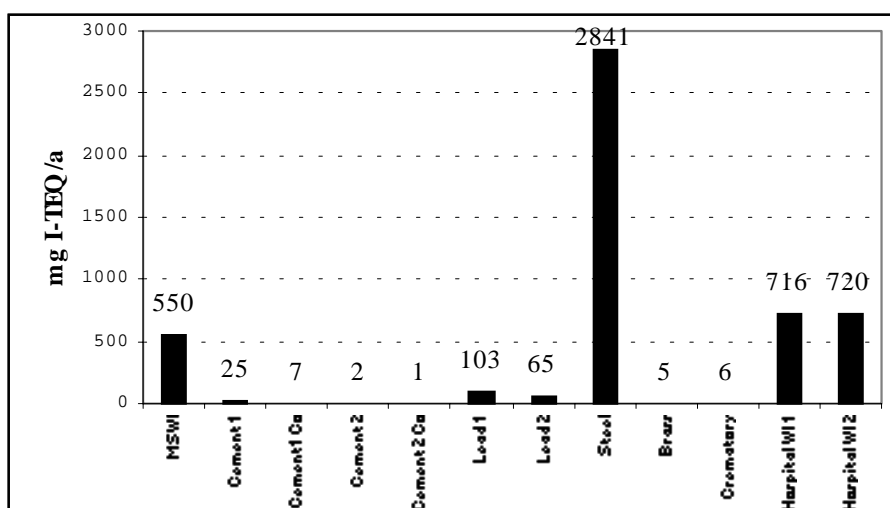


Figure 1: Annual releases per furnace (mg I-TEQ/a)

3.2 Results in International Perspective

From an overall point of view the results are within the expected range; most of them are similar to the situation in industrialized countries about 10–15 years ago. An exception at the positive site is the cement plant where the kilns represent best international state-of-the-art technology and operation. As was shown at many European plants that utilize the dry process, the PCDD/PCDF emissions were very low and the co-combustion – well dosed and carefully fed – did not increase the dioxin emissions at all.

Although some of the results, especially those from the hospital waste incinerator, are very high it should be remembered that in the early 1990s, in Germany municipal solid waste incinerators were shut down when the emissions exceeded 50 ng I-TEQ/Nm³ and today in Japan, MSWIs are closed down when the limit of 80 ng TEQ/m³ is exceeded. With these two numbers in mind, the results obtained in Thailand do not seem to be extraordinarily high as much higher emissions have been found elsewhere.

4 NEXT STEPS

The seminar on the “Implementation of the Stockholm Convention on POPs” held in Bangkok on June 13-14, 2001, discussed the results of this sampling campaign and the first estimates made for a Thai Dioxin Release Inventory. In the light of these results, the following recommendations were made and actions concluded. These activities include both general actions on dioxin releasing sectors and individual plants. Whereas most of the industrial plants would not need any or only very limited upgrading, some sectors need special consideration and the conclusions and recommendations for these are summarized below.

4.1 Municipal Solid Waste Incineration

Although the overall performance of the MSWI is satisfactory, the use of the existing equipment could be easily improved to meet a PCDD/PCDF emission limit of 0.1 ng I-TEQ/Nm³ at all times. Already in spring 2001, a consultant has visited the plant and made a proposal to upgrade the existing facility to meet the European standard of 0.1 ng I-TEQ/Nm³. The upgrade consists in the addition of active carbon injection to absorb/adsorb PCDD/PCDF and a monitoring system to control the performance of the baghouse filter. In addition – and outside the dioxin problem – the plant should obtain a NO_x reduction system (SNCR by injection of urea into the furnace). These measures will allow the plant to comply with the most stringent limit values for these two pollutants. The plant owner and operator have accepted the retrofitting proposal and work is in progress to upgrade the facility.

4.2 Hospital Waste Incinerator

The disposal of hospital waste is a big problem in Thailand. The experts at the workshop estimated that there are about 1,500 hospital waste incinerators nationwide. Most of these are very small plants, with a daily capacity between 50 and a few hundred kg. They are operated a few hours per day and only for a very limited number of days per week. Due to the problematic waste and the poor combustion conditions, PCDD/PCDF emissions of several hundred grams I-TEQ per year can be assumed. This would be more than the total emission inventory for countries such as Great Britain, Germany, Sweden, Austria, Switzerland, *etc.*

Whereas the fact that there is only one large plant to incinerate the hospital waste of Bangkok is a reasonable approach, the fact that all waste from the hospitals are incinerated without any presorting, that waste avoidance plans have not been developed, and the very poor circumstances at the plant in Bangkok makes it necessary to take measures to reduce dioxin emissions.

The first step is a feasibility study to identify waste reduction potentials at the hospitals in Thailand. Next is to identify the waste streams that could be detoxified or disposed of without incineration, *e.g.*, by utilizing reusable materials/equipment/tools, by autoclaving, *etc.* A respective feasibility study is already under development.

The remainder wastes must be considered for thermal treatment and options for the technology to be chosen (incineration *vs.* pyrolysis *vs.* co-combustion, *etc.*) will be evaluated. It may be necessary to develop different scenarios for the provinces and for the city of Bangkok. Staff and experts from the central government and the Bangkok Metropolitan Administration visited some installations abroad for information and orientation. The different aspects mentioned will be considered as the basis for further handling of hospital waste disposal in Thailand. The large hospital waste incinerator plant in Bangkok has to be significantly changed to meet international emission standards. The central government together with the Bangkok Metropolitan Administration is developing a strategy to solve this problem.

4.3 Crematoria

Cremation is an important factor in a Buddhist country like Thailand. It takes place all over the country and is associated with daily life. Unfortunately, cremation is also an activity that generates and releases dioxins and furans. Any action taken to reduce the releases of these pollutants have to be weighed against the cultural heritage of the country. From a technical point of view cremation, as a batch process with introduction of the burning material at once and due to the chemical composition of the feed that is combusted (organic matter, plastics, wood, is favorable to generate PCDD/PCDF *per se*. Nevertheless there are some parameters to be considered to improve the present situation. The Bangkok Metropolitan Administration already has taken action in the right direction by ordering 2-chamber furnaces. These furnaces would allow for a better burn-out of the flue gases and thus release less PCDD/PCDF than single chamber crematoria (Note: there are no measured data available for single chamber crematoria!). The high emissions from the 2-chamber crematorium measured in the Thailand program are due to the long flue gas duct where re-synthesis of PCDD/PCDF takes place. In cases where the stack is directly connected to the afterburner chamber, the critical temperature range of 200-450 °C can be avoided and lower PCDD/PCDF emission concentrations can be expected. However, it must be mentioned that the limit value of 0.1 ng I-TEQ/Nm³ also cannot be met at a 2-chamber crematorium. To comply with such a limit value, flue gas cleaning equipment needs to be installed. For example a small baghouse with adsorbent injection can be installed in order to achieve PCDD/PCDF flue gas emissions below 0.1 ng I-TEQ/Nm³.

From an operational point of view, an evaluation will be performed to consider if a more aggregated way of operation with several cremations in a row would reduce PCDD/PCDF emissions as compared with single cremations per day. Also the creation of a centralized cremation house is being considered. Actions in these directions have started immediately after the conclusion of the June seminar.

4.4 Secondary Steel Plant

All steel produced in Thailand is secondary. The emission factor determined at the EAF in Thailand is somewhat higher than expected. Multiplied with the national production rate of steel, Thailand very much may reflect the situation in Europe where the ferrous (and the non-ferrous) metal sector is a major emitter of PCDD/PCDF. The plant owner and plant manager have initiated contacts with international experts to evaluate options for improvement and reducing the PCDD/PCDF emissions.

5 CONCLUSIONS

The Thai-German-UNEP-Euro Chlor Dioxin Sampling and Analysis Project was considered to be a great success by all partners. All activities performed in this program have been carefully planned well ahead and have been agreed upon between all partners including the plant owners or managers. A special success of the project was that at the first attempt, high quality PCDD/PCDF data could be obtained from a variety of sectors, which has been hardly found before in any other developing country.

The results of this sampling and analysis program assist Thailand to better characterize its PCDD/PCDF releases. Thailand now is in the position to identify the major PCDD/PCDF emission sources in the country. Most important, the results of this program serve as the basis for focussing on the most efficient risk reduction measures in Thailand. First steps towards this direction have already been done during the Bangkok seminar, 13-14 June 2001. They will continue for more years to come and result in the implementation of dioxin-reducing actions and finally provide Thailand to fulfil its obligations for unintentionally produced substances (= by-products) under the Stockholm Convention on POPs.

Further, this program as carried out in Thailand assists the international community to learn about PCDD/PCDF emissions in developing countries. The results of this sampling and analysis program will be included when UNEP's Toolkit to make complete and harmonized dioxin and furan release inventories will be updated.

Table 1: Summary of the flue gas concentrations

	%O ₂ act.	Concentration at Actual O ₂		Concentration at 11 % O ₂	
		ng I-TEQ/m ³	ng WHO-TEQ/m ³	ng I-TEQ/m ³	ng WHO-TEQ/m ³
MSWI	<i>Mean</i>	<i>1.59</i>	<i>1.76</i>	<i>1.71</i>	<i>1.90</i>
1	11.38	1.33	1.44	1.38	1.50
2	11.41	0.62	0.68	0.65	0.71
3	11.93	2.81	3.17	3.10	3.50
Cement	<i>Mean</i>	<i>0.014</i>	<i>0.015</i>	<i>0.0105 *</i>	<i>0.0114 *</i>
3-1	6.46	0.0265	0.0290	0.018 *	0.0199 *
3-2	10.11	0.0094	0.0102	0.009 *	0.0094 *
3-3	9.85	0.0051	0.0054	0.005 *	0.0048 *
Co-comb. tires	<i>Mean</i>	<i>0.003</i>	<i>0.004</i>	<i>0.0029 *</i>	<i>0.003 *1</i>
3-1	9.60	0.0047	0.0052	0.004 *	0.0046 *
3-2	8.22	0.0040	0.0043	0.003 *	0.0034 *
3-3	9.56	0.0017	0.0017	0.001 *	0.0015 *
Cement	<i>Mean</i>	<i>0.0009</i>	<i>0.0008</i>	<i>0.0008 *</i>	<i>0.0007 *</i>
5-1	10.02	0.0020	0.0019	0.0018 *	0.0017 *
5-2	7.92	0.0005	0.0005	0.0004 *	0.0004 *
5-3	8.35	0.0001	0.0001	0.0001 *	0.0001 *
Co-comb waste oil	<i>Mean</i>	<i>0.0003</i>	<i>0.0003</i>	<i>0.0002 *</i>	<i>0.0002 *</i>
5-1	7.72	0.0001	0.0001	0.0001 *	0.0001 *
5-2	9.12	0.0001	0.0001	0.0001 *	0.0001 *
5-3	7.39	0.0008	0.0008	0.0006 *	0.0006 *
Lead	<i>Mean</i>	<i>0.027</i>	<i>0.031</i>		
1-1	19.91	0.0321	0.0364		
1-2	20.21	0.0205	0.0238		
1-3	20.19	0.0277	0.0319		
Lead	<i>Mean</i>	<i>0.089</i>	<i>0.100</i>		
2-1	19.01	0.0604	0.0675		
2-2	18.26	0.1063	0.1198		
2-3	18.53	0.0993	0.1132		
Steel	<i>Mean</i>	<i>0.50</i>	<i>0.57</i>		
1	20.04	0.586	0.667		
2	18.58	0.605	0.685		
3	19.38	0.317	0.356		
Steel Prim. Duct	<i>Mean</i>	<i>7.16</i>	<i>8.30</i>		
1	19.10	6.261	7.159		
2	18.96	11.834	13.829		
3	19.45	3.387	3.912		
Brass Plant	<i>Mean</i>	<i>0.15</i>	<i>0.16</i>		
1	18.70	0.125	0.133		
2	18.54	0.127	0.136		
3	19.26	0.206	0.220		
Crematory	<i>Mean</i>	<i>9.35</i>	<i>10.5</i>	<i>17.6</i>	<i>19.7</i>
1	15.77	14.84	16.74	28.64	32.31
2	14.98	6.25	6.90	10.45	11.54
3	15.87	6.96	7.71	13.70	15.17
Furnace door	<i>Mean</i>	<i>0.04</i>	<i>0.04</i>	<i>6.02</i>	<i>6.50</i>
1	20.85	0.08	0.086	15.84	17.03
2	20.69	0.026	0.029	1.23	1.37
3	20.73	0.017	0.019	0.99	1.11

	%O ₂ act.	Concentration at Actual O ₂		Concentration at 11 % O ₂	
		ng I-TEQ/m ³	ng WHO-TEQ/m ³	ng I-TEQ/m ³	ng WHO-TEQ/m ³
Hospital WI 2	<i>Mean</i>	23.2	25.4	33.8	37.1
1-1	14.00	29.97	33.07	43.00	47.45
1-2	14.79	22.59	24.79	36.60	40.17
1-3	13.16	17.01	18.46	21.76	23.61
Hospital WI 2	<i>Mean</i>	16.3	18.6	28.6	32.5
2-1	15.56	5.79	6.61	10.73	12.25
2-2	15.30	17.04	19.44	30.12	34.37
2-3	15.14	26.15	29.60	44.95	50.88

Table 2: Average PCDD/PCDF fluxes and emission factors

	Flux/h	EF	EF	
	µg I-TEQ/h	µg I-TEQ/t	µg WHO-TEQ/t	
MSWI	64	6.1	6.8	of waste burned
Cement 1	2.9	0.017	0.019	of clinker
Cement1 Co-combustion	0.81	0.005	0.005	of clinker
Cement 2	0.2	0.0010	0.0010	of clinker
Cement 2 Co-combustion	0.08	0.0003	0.0003	of clinker
Lead 1	12	15	18	of lead
Lead 2	7.6	10	11	of lead
Steel	807	12	13	of liquid steel
Brass	2.8	11	11	of brass
Crematory	12	18	20	per cremation
Hospital WI 1	407	1,272	1,396	of waste burned
Hospital WI 2	409	1,277	1,451	of waste burned

Table 3: Summary of the PCDD/PCDF concentrations in the solid residues

Facility	Type of Residue	Concentration	
		ng I-TEQ/kg	ng WHO-TEQ/kg
Municipal Solid Waste Incinerator	Bottom Ash	7	8
	Flyash	431	468
Steel Plant	Flyash	1,899	2,151
Brass Smelter	Wastewater Treatment Sludge	8,625	9,168
	Furnace Slag	14	14
Crematory	Cremation Ash	44	48
Hospital Waste Incinerator	Mixed Bottom Ash	1,390	1,980
	Mixed Flyash Sludge	629	703

Table 4: Summary of the PCDD/PCDF concentrations in the indoor samples

Working Hall	Concentration			German TRK pg I-TEQ/m ³
	pg I-TEQ/m ³ / pg WHO-TEQ/m ³			
Steel/EAF	13.30 / 14.37	15.10 / 16.49	25.17 / 27.19	50
Brass Plant	12.98 / 14.25	12.11 / 13.01	17.39 / 18.56	50