Summary

of the Swedish report “Förbränning av avfall – en kunskapssammanställning om dioxiner” (Waste–to-energy, an inventory and review about dioxins)

Continuous efforts are being made to further improve waste incineration as a means of dealing with household waste and other combustible material, while also producing valuable energy. The main aims are to further reduce the already low emissions to air, and to ensure effective long-term deposition of ashes and other residues from the flue-gas treatment of the waste incineration process.

In order to increase knowledge in this area, the Swedish Association of Waste Management (RVF) has taken the initiative for the biggest study to date into dioxins and waste incineration in Sweden. RVF is a trade association working within the areas of waste management and recycling. The owners of Sweden’s 22 waste incineration plants are all members of RVF. The study has been carried out by engineer Nils Ahlgren, an independent consultant in energy and the environment, and Professor Stellan Marklund of the University of Umeå, who has a doctorate in dioxins and conducts research into incineration technology and environmental effects.

A summary of the report of this study is presented here. The order of the text in this summary follows the order of the respective sections in the main report, see below for further explanation.

The report – outline and content

The main aim of this report is to provide and distribute information about the current situation and developments within the field of waste incineration with particular focus on dioxins. We have endeavoured to structure the way we provide knowledge to ensure it fulfils requirements on clarity and general information, as well as demands on factual reports and other more detailed information. We have therefore chosen to divide the report into a main report and two sub-reports.

The main report begins with a summary in which we recount the most important results of the study and charting work on dioxins and waste incineration, and give a general outline of developments and the current situation in the field of waste incineration. Taking into account the central role of dioxin-related issues in this work and the great interest in these issues, we have highlighted the results in brief in the first section of this summary. The results are then presented in more detail in the following sections together with various background information as is described below.

The main text in the report begins with a retrospective look at developments within the field of waste, and the role of waste incineration in waste processing and energy generation. This first section also details the current situation at the 22 incineration plants in Sweden that are authorised to incinerate household waste. The second section provides a broad analysis and description of the issues surrounding chlorinated dioxins.
in society and our surroundings – properties, structure, exposure, formation, incidence etc.

Issues regarding waste incineration and dioxins are brought together and discussed in the following two sections. The third section contains an overview of what has happened since the end of the 1970s when dioxins were discovered in ash from waste incineration, up until the present day situation. In the fourth section we review the degradation, formation and separation of dioxins which occur in waste incineration plants, and discuss the conditions and consequences.

One central task of the investigative work has been to clarify the contents and quantities of dioxins in residues from waste incineration. The fifth section reports the results and conclusions from the studies carried out at the plants during 1999 and 2000. More detailed information can be found in the sub-report entitled ‘Dioxins in residues from waste incineration. Results from studies in 1999/2000 by Swedish waste incineration plants.’

The main report concludes with a review of and comments on current knowledge levels regarding leaching and degradation of dioxins in ashes. For more detailed information, please refer to the sub-report entitled ‘Dioxins in ashes from waste-fuelled plants. A review and report of current knowledge levels regarding leaching and degradation.’

Since some of the issues treated in the main report and both of the sub-reports are complex in nature, we have, as far as possible, endeavoured to integrate explanations of various conditions into the running text. This is particularly relevant in section 2 (main report) which deals with issues relating to dioxins in society and our surroundings. As a complement, appendix A contains a glossary of measures, units, abbreviations and chemical denominations.

In the case of dioxins, particular attention should be paid to the fact that there are different ways of assessing poisonousness or toxicity to produce a measure of TCDD equivalents. The most commonly applied and generally accepted method today is the international I-TEQ system, in which the 17 toxic dioxins are assigned a factor indicating their relative toxicity. ‘Eadon’ is an older method that has been in use for a long time, and is still used quite often in, for example, permits in line with environmental legislation. We have therefore been obliged to use both systems in parallel in our reports.

Briefly, the difference between both methods is that Eadon is based on an assessment of the acute toxicity, while I-TEQ also takes into account other effects of dioxins. The measured values for dioxin content according to Eadon are, as a rule, lower than I-TEQ values, although the differences in figures for flue gases from normal waste incineration, for instance, are not normally particularly great. The differences between Eadon and I-TEQ values are a result of the target object in question and prevailing conditions. There is therefore no universal conversion factor that can be applied to convert figures from one method to the other. Unless otherwise stated, our dioxin quantities refer to Eadon measurements.
The results in brief

Waste incineration and dioxins - the current situation and development tendencies

The waste treated and used as fuel at the Swedish waste incineration plants in 1999 contained dioxins of varying quantities, depending on the origin and composition of the waste. The information available, however, has not been sufficient for any reliable assessments to be made about the amounts of dioxins involved.

At the high temperatures involved in waste incineration in the plants, 90-95% of the dioxins in the waste are broken down into carbon dioxide, water and hydrogen chloride. A small quantity (5-10 g in 1999) of these dioxins in incoming waste are borne with particles and found in slag and bottom ash (FB plants), which are used as a filler or sent to landfill.

When the flue gases were cooled 115-125 g of dioxin were formed, and this went with the raw gases to the flue-gas treatment system. Flue-gas cleaning separated 110-120 g of dioxin and stored it in fly ash, sludge, etc., which was then sent to long-term landfill. Total emissions of dioxins into the air from waste incineration plants in Sweden amounted to just under 3 g.

A major advantage of waste incineration when dealing with the dioxins in society, is that the vast majority of the dioxins separated after incineration through flue-gas cleaning are collected and deposited in ash and other residual waste from the flue-gas treatment system. Dioxins in these residues, and to an even higher degree in slag and bottom ash, are solidly fixed to particles, and many studies have shown that separate handling gives rise to practically no leaching at all.

The risk of dioxins in residues from waste incineration leaching out and polluting the environment is therefore very low, provided that the residues from flue-gas cleaning are deposited without coming into contact with other waste, at landfill sites which are designed and dimensioned for long-term disposal of hazardous waste, see following section and section 6 (main report). The question of what would happen to the waste and its dioxin content if it were not incinerated is therefore of interest when discussing the role of waste incineration as a dioxin source, and selecting a method of treating household waste.

Efforts to further improve waste incineration as a method of treating household waste and other waste, and to increase energy production, is now continuing as plants expand and modernise. Of course environmental protection is a central aspect in this work, and continued initiatives within the field of dioxins play an important role. The main aims are to reduce the formation of dioxins, to further reduce the already low emissions to air, and to ensure effective long-term deposition of ashes and other flue-gas treatment residues from the waste incineration process.

In our opinion, conditions are also favourable for waste incineration to be made even more effective in reducing the flow of dioxins through society and reducing the health-
related and environmental problems this can cause. This applies to all stages of the process, from degradation of dioxins in the waste, reduction of formation, and separation of dioxins, to long-term deposition of waste from flue-gas cleaning.

*Leaching and degradation of dioxins in ashes*

The aim of the inventory and review carried out has been to chart and report current knowledge levels regarding the degradation and leaching properties of dioxins in ash and other residues from flue-gas cleaning from the waste incineration plants.

The work has encompassed and been based on documentary research, interviews with experts, and reviews of reports and studies etc. It soon became clear that only a few studies and investigations on leaching of dioxins and other persistent organic pollutants have been carried out. To all intents and purposes, there are no proper studies on ashes related to the degradation of dioxins, and we have therefore been referred to investigations into soil types.

The most important conclusions from this charting and review work on the leaching of dioxins from ashes can briefly be summarised in the following points:

- Dioxins and other organic environmental toxins are solidly fixed to particles and it is primarily the small particles in the leachate that carry these pollutants.
- Dioxin in fly ash does not leach at all, or to a very small extent (0.004%) when using distilled water or unaffected natural water as a leaching agent.
- Tests have shown that using different types of solvent as leaching agents results in considerably larger quantities of dioxin leaching.
- Leaching tests have shown that an increased concentration of e.g. detergent or other substances which reduce surface tension in the leaching agent result in increased leaching – tests show that the increase can be 100 times or even more compared to pure water.
- The leaching tests also showed that acidic solutions have a similar effect to solvents, although they involve lower levels of dioxin leaching.
- The higher chlorinated dioxins, which are present in the highest quantities, leach to a greater extent than the low chlorinated toxic dioxins, which are found in lower quantities, despite the latter being more water soluble.
- Background values for dioxins in rainwater and fall-out are at the same level as the dioxin contents in leachate.

These conclusions concur with experiences from previous research and studies. The results both on the dioxins’ leaching properties and the factors which affect leaching are also concordant with earlier findings. The quantities and contents measured in tests using different leaching agents also tally well with previous findings.

The following conclusions can be drawn with regard to the degradation of dioxins in ashes.
• Dioxins in ashes are characterised by high stability and low mobility, provided that the ashes are handled separately and isolated from the surroundings.
• Under these conditions, the dioxins in ashes degrade very slowly and the half-life can be several decades.
• Dioxins in contaminated soil can degrade significantly faster than dioxins in ashes, depending on the different composition, the soil’s structure, water flow and other factors which facilitate degradation.
• Dioxins in ashes which are handled separately and isolated from external influence maintain their stability and degrade very slowly – particularly ashes containing unincinerated material.

Waste incineration

Incineration has a long history as a method of disposing of waste from households, industries and other activities in society. Special plants for incinerating household waste started being developed in Europe at the end of the 19th century. The first waste incineration plant in Sweden started up in 1901 in Lövsta outside Stockholm. However, it would be a long time before incineration plants started being expanded in earnest. Any incineration that did occur took place in open fires on rubbish tips or in simple furnaces.

At the end of the 1960s environmental issues came to the fore, while waste quantities increased and municipalities had more and more trouble disposing of their waste. In the city regions in particular, investments were made in expanding large waste incineration plants that could process the waste from wide catchment areas. These kinds of plant with a capacity of 150,000 – 200,000 tons/year were developed in Stockholm, Göteborg, Malmö and Uppsala.

In the mid-1970s there were 13 waste incineration plants in Sweden, which dealt with a total of 0.8 million tons of waste. The following years saw rapid expansion and by 1985 there were 27 plants in operation. Collectively they handled just over 1.4 million tons, of which 1.3 million was household waste. By this time waste incineration had become the most common method of handling and treating household waste, see figure 1.

Strict requirements regarding environmental measures soon started being placed on the waste incineration plants, partly as a result of the moratorium in spring 1985 and the ENA inquiry (see main report), and due to subsequent related decisions by the Swedish Franchise Board for Environmental Protection and the Swedish government. This applied to both existing and future plants. The requirements were primarily focused on restricting emissions and other negative effects of heavy metals and dioxins.

One result of the requirements was that in the late 1980s and early 1990s, 20 of the 27 existing plants were rebuilt to improve incineration, and fitted with what were then highly advanced flue-gas treatment systems. The other seven plants were closed for environmental and economic reasons. These reconstructions and the opening of two new plants also increased the incineration capacity to approximately two million tons a year.
The total volume of household waste in Sweden amounted to 3.8 million tons in 1999. As shown in figure 1, 1.1 million tons or approximately 30% of this was waste collected separately for material recovery in accordance with the producer responsibility charter. The remaining 2.7 million tons or 70% was collected under the direction of the local authorities and passed on for biological treatment, incineration or landfill.

Since 1975, the volume of household waste in Sweden has increased by a total of 1.2 million tons, an average of 50,000 tons a year. It has been possible, for the most part, to handle these increased amounts of waste over this 25-year period by increasing material recovery from 0.15 to 1.1 million tons a year. As regards the treatment of other household waste, incineration has doubled from 0.77 to 1.44 million tons a year, and biological treatment has increased from 0.06 to 0.32 million tons. At the same time, landfill has decreased from 1.62 to 0.92 million tons.

**The waste incineration plants**

In 1999, the existing 22 waste incineration plants in Sweden dealt with and incinerated a total of 1.9 million tons of waste. Of this, 1.3 million tons was household waste, 0.5 million tons industrial waste and 0.1 million tons waste wood etc.

The different plants vary a great deal in terms of size and capacity, see figure 2. In 1999, the largest plant incinerated almost 400,000 tons, while the smallest plant handled only 5,000 tons. The five largest plants – Göteborg, Stockholm, Uppsala, Linköping and Malmö – incinerated just over 1.3 million tons, almost 70% of the total waste incineration in Sweden.
Improved incineration with more efficient energy recovery, along with flue-gas condensation at some plants, has led to a twofold increase in energy production from 2.8 TWh in 1985 to 5.6 TWh in 1999, see figure 3. This entails an energy exchange of 2.9 MWh per ton of waste, which is comparable with the energy obtained using peat and damp wood fuel. The majority (5.3 TWh) comprised district heating. Waste incineration therefore accounted for 10% of the district heating requirement in Sweden. The remaining 0.3 TWh comprised electricity.

Moving grates dominate incineration technology in the waste incineration plants. The sixteen grate-fired plants also accounted for 90% of waste incineration in Sweden. The other six are fitted with FB boilers for fluidised combustion.
All Swedish waste incineration plants are fitted with equipment for dry cleaning of flue gases and efficient separation of dust into different electrostatic and/or barrier filters. Half of the plants are equipped with wet cleaning with flue-gas condensation, and several more are being extended or are planned for extension. Equipment to reduce nitrogen oxides is also installed at all plants.

Thanks to the comprehensive environmental protection efforts made at the plants, emissions of pollutants into the air have been dramatically reduced. Discharges of mercury and cadmium decreased by approximately 99% between 1985 and 1999, see figure 4. During the same period, emissions of lead to air fell from 25,000 kg a year to 35 kg a year, and zinc from 54,000 kg to 90 kg a year. Emissions of dioxins were reduced during the same period from 90 g a year to just under 3 g a year.

**Figure 4  Discharges of mercury and cadmium from waste incineration in Sweden 1985-1999, kg per year.**

Incinerating waste at the plants in 1999 resulted in 370,000 tons of slag and bottom ash being formed, equivalent to 19% by weight of the original amount of waste. At the grate-fired plants, slag and bottom ash comprised 20% of the additional amount of waste. The corresponding figure for FB plants was 6%.

During flue-gas cleaning, a total of 75,000 tons of ash and other residues from flue-gas treatment was separated, equivalent to 4% by weight of the original amount of waste. These residues consist of electrostatic filter ash, bag filter ash, sludge from water treatment, and lime and activated carbon additives. When FB boilers are used, some bed materials are borne with the flue gases and separated together with the ash. The proportion of flue-gas residues in the grate-fired plants was 3.5% of the original amount of waste. At the plants with FB boilers, the amount of residual waste separated during flue-gas cleaning was considerably higher, amounting to 8.5%.

**Chlorinated and brominated dioxins**

Chlorinated dioxins and other substances within the group known as persistent (stable) organic pollutants (POPs) occur and are formed in many different activities and
processes, and in many different places within the industrialised countries. Due to emissions and other activities, these substances, which by nature are stable and are enriched in the food chains, have built up in the ecosystems where they cause serious disturbances. Dioxins include the most toxic substances known to mankind. The dioxins have therefore come into focus, and now form the template for dealing with chlorinated organic substances.

‘Dioxins’ is a collective name for 210 different chlorinated dibenzo-p-dioxins and dibenzofurans. Some of these compounds are extremely toxic, while others are practically harmless. In total, 17 of these dioxins are toxic to some degree, and of these 2,3,7,8-TCDD is the most toxic.

The dioxins’ toxicity is given in TCDD equivalents, which are a measure of how the 17 toxic dioxins are distributed in a sample from a flue gas, an ash or another material. Today toxicity is usually reported in the international I-TEQ system, although the older ‘Eadon’ method is still extensively used in parallel.

Brominated dioxins and dibenzofurans form a group of substances with similar properties to the chlorinated analogues (equivalents). The composition, structure and toxicity of both groups are comparable. One crucial difference, however, is that the brominated dioxins and dibenzofurans are not as stable in sunlight as their chlorinated counterparts. Tests have also shown that the rate of degradation of the brominated compounds in nature is significantly faster.

However, only a few studies into brominated dioxins and mixed chlorinated-brominated dioxins have been carried out, and the information basis for assessing incidence, formation, effects etc. is therefore extremely limited and unreliable. In this study on waste incineration and dioxins, we have therefore had to concentrate on issues surrounding chlorinated dioxins and dibenzofurans. It may, however, also be noted that during the investigations carried out, no brominated dioxins were observed in flue gases and ashes. Taking into account the risk of, for example, brominated flameproofing agents appearing to a greater extent in household and other waste, it is important that the issue of brominated dioxins be studied and investigated.

Enrichment and exposure of dioxins

The main problem with dioxins and other stable organic environmental toxins – apart from their toxicity – is the fact that they are enriched in the food chains (biomagnification). Organisms in sea and lake beds form the first step in this enrichment chain, as the dioxins remain in the organisms. The enrichment process then continues in fish, and the highest contents are found primarily in predatory fish, birds of prey and seals, all of which consume large quantities of fish. High dioxin contents have been measured in wild salmon from the Baltic Sea, for example, while Baltic herring and other fish products from this inland sea also contain dioxins.
As humans we are principally exposed to environmental toxins through what we eat. The size of an individual person’s dioxin intake depends both on the content in the food which that person eats, and the actual amount of food the person consumes. Taking into consideration the high content in fish caught in the Baltic Sea, the National Swedish Food Administration has recommended that particularly vulnerable groups, such as pregnant women, limit their consumption of these species of fish. However, by far the largest source of exposure to dioxins for humans is – despite the relatively low dioxin contents – dairy products, for the reason that these products form such a large part of our diet. The dioxin content in air, water and vegetables on the other hand is so low in Sweden that they are not significant sources of direct exposure for humans.

Bearing in mind that some of the dioxins are exceptionally harmful, stringent demands are in place to ensure that people are only exposed to extremely small doses of dioxin. The starting point for these assessments is the highest level at which the dioxins do not affect the organism (NOEL – no observed effect level). The NOEL value obtained is divided by a safety factor of 200, and based on this level, an assessment is made of how much dioxin a human can take in without being affected. World Health Organisation, WHO, recommendations state that an intake of 1-4 picograms (pg) per kilogram of body weight per day is tolerable.

The National Swedish Food Administration has set a limit of 5 picograms per kilogram of body weight per day for dioxin intake. This means that a person who weighs 70 kg should not be exposed to more than 350 pg (1 pg = 0.000 000 000 001 g) of dioxins a day.

**Formation of dioxins**

Dioxins have never been produced commercially in the same way as polychlorinated biphenyls (PCBs) and polychlorinated naphthalenes (PCNs). Distribution in the environment has only happened via products which have been contaminated with dioxins or through emissions from thermal and chemical/biological processes.

Dioxins can be formed in a number of different ways. A distinction is usually drawn between two main types of formation: formation in thermal processes and formation in chemical/biological processes.

During thermal processes, dioxins of the elements carbon, hydrogen, oxygen and chlorine are newly formed by the effect of a catalyst, such as copper. Alternatively, dioxins can be formed from precursors (the forerunners of dioxins) in the form of chlorinated organic compounds, such as chlorophenols. This too requires access to a catalyst. A third method of formation entails chlorination from non-chlorinated or low-chlorinated dioxins.

As regards chemical and biological formation at lower temperatures, this can take place in a number of different ways: chemical reactions based on specific chemical compounds, photochemical reactions when using UV light, or exposure of organic material to activated chlorine are just some examples.
It has emerged that conditions for dioxin formation can be found in many different activities and processes in society, and even in nature under both natural and influenced conditions. For example, dioxins can be formed during all types of incineration based on organic material. This is a result of chlorine and catalytically active substances such as copper commonly occurring in all forms of organic material. Precursors can also be found in many materials, which means the conditions are there for dioxin formation.

Sources of dioxins

Research and studies have shown that there are a great many dioxin sources in the modern industrial society, and new sources are emerging all the time. Dioxin sources are usually divided into three groups according to their formation: handling chemical residues, thermal treatment and natural formation.

An alternative basis for division, which may be easier to link with the development in society, is a division into primary and secondary sources. Primary sources refers to sources where dioxins are formed through chemical/biological and thermal processes. Secondary sources are products and materials contaminated with dioxins, and which may cause health and environmental problems when used or destroyed.

Our reviews and studies have enabled us to establish that the occurrence of dioxin sources in society and their properties are relatively well-charted. However, there is great, and in some cases very great, uncertainty concerning the size of these sources and their significance from a health and environmental perspective. In particular, this applies to the many minor sources within the energy and traffic sectors, and the diffuse emissions from house fires, forest fires and landfill sites etc. Drawing comparisons between different sources mainly relies on information about emissions of dioxins to air from various activities and otherwise on general valuations and assessments.

According to a charting carried out within a research project entitled “The Swedish Dioxin Survey”, emissions of dioxins to air from different activities and areas in Sweden amounted to 20-90 g in 1993. The uncertainty of these assessments is, as shown in figure 5, quite significant due to large gaps in the foundation material. Waste incineration is an exception here, as a high number of samples have been taken from outgoing flue gases at the plants as part of research work and environmental controls, and these samples have then formed the basis for determining dioxin contents.
Figure 5  

**Emissions of dioxins to air from different areas of activity in Sweden in 1993, g.**

According to this charting of emissions to air, industry was a major source of dioxins, emitting between 10 and 31 g of dioxins in 1993. The industries in question are forest industries, iron and steelworks, aluminium and copperworks, foundries, the cement industry and lime-burning. It should be noted in this context that emissions of dioxins are higher at plants that work with recycled metals and other recovered materials than at plants which base their production on virgin raw materials.

Energy production – excluding waste incineration plants’ energy production – is another major source of dioxins, with emissions of dioxin to air amounting to 4-23 g in 1993. According to estimates, the highest emissions are from small boilers, wood-fuelled furnaces etc., totalling 2-10 g.

There is of course a great amount of uncertainty regarding the magnitude of these dioxin emissions from at least a couple of hundred thousand furnaces, as the estimates are based on only a limited number of studies. The studies conducted, however, indicate that small boilers and other small furnaces are important sources of dioxins, since incineration can be uneven and the flue gases are not treated. These problems also apply to small biofuel-powered heating plants without more advanced cleaning. Emissions of dioxins to air from what the study terms ‘other biofuel incineration’ are estimated to have totalled between 1.5 g and 8 g in 1993.

Emissions of dioxins to air from traffic are considered relatively low, which is probably a result of the introduction of catalytic exhaust cleaning and unleaded petrol, among other things. In total, it was estimated that this sector of society accounted for 1-3 g of dioxin emissions into the air in 1993.
The great uncertainty surrounding emissions of dioxins springs from different forms of fire. In the Swedish study, emissions from fires at landfill sites have been estimated at between 3 and 30 g per year. Forest and land fires were previously considered a significant source of dioxin formation and distribution. Nowadays, however, it is thought that fires in buildings, cars and other objects that contain PVC and other chlorine-containing materials, are a larger source of dioxins.

The role of waste incineration as a source of dioxin has therefore decreased sharply as annual emissions to air have been brought down from 90-100 g in the mid-1980s to 3 g in 1993. Assuming that total emissions in Sweden averaged 50-60 g, waste incineration would therefore have accounted for 5-6% of emissions of dioxins to air.

Household waste contains dioxins to a varying degree, depending on the origin and composition of the waste. Surveys indicate that no degradation of dioxins takes place during composting, but rather that the waste’s dioxin content remains and is transferred to and included in the resulting product – compost. When it comes to issues surrounding dioxin formation the situation is less clear, although it has been observed in studies that biological formation of dioxins from chlorophenols has occurred during composting processes.

**Dioxins in materials and products**

The formation and distribution of dioxins mainly during the latter half of the 20th century, means that dioxins are now found in many materials, products, buildings and plants, as well as in the air, water, land, plants and animals.

Chlorophenols and their derivatives were the first products to be identified as containing dioxins as pollutants. Chlorophenol in the form of pentachlorophenol was used, for example, to protect timber against dry-rot. In Sweden, chlorophenols and PCBs were banned as far back as the 1970s, while stringent demands were placed on chlorophenol derivatives. However, there still remains a great deal of chlorophenol-treated timber in buildings and constructions, which could cause problems in demolition and reconstruction work if this waste is not dealt with in an environmentally friendly way.

The rate of turnover for many products and materials in society is often slow, and sometimes very slow. This is particularly true for buildings and plants which can have an economic life of 50-100 years or more. Consequently – despite dioxins being eliminated from various products and materials in Sweden as long ago as the 1970s – the ‘dioxin contamination’ of waste continues while these long-life products and materials become waste.

Another problem related to dioxin was the hormoslyr used frequently during the 1960s and into the 1970s to clear leafy brushwood along embankments and clear-felled areas. The herbicide contained a substance called 2.4.5-T which was manufactured from chlorophenol and, depending on the production method, could contain the toxic dioxin analogues. The use of hormoslyr was prohibited in Sweden at the end of the 1970s.
Household waste contains varying levels of dioxins, depending on the origin and composition of the waste. Studies carried out in countries such as Germany have shown that the variations can be great, and measurements of content have ranged from a few micrograms per ton to several hundred micrograms per ton. There is not sufficient data on Swedish household waste to make possible any reliable assessments of the dioxin content in the waste dealt with for incineration or other treatment. Bearing in mind the importance dioxin contents in waste can have in the choice of treatment method, for example, we consider it essential that these issues are closely analysed.

**Dioxins in nature and the environment**

Small quantities of chlorinated dioxins are present in the air around us. The concentrations are usually higher in towns and industrial areas than in areas of undisturbed nature.

Dioxins emitted into the air are, however, transported long distances by the air streams before they sediment on land or in water. As a result dioxins can now be found all over the globe – in the polar bears of the Arctic and the penguins of the Antarctic.

The groundwater and drinking water in Sweden contain very low quantities of chlorinated dioxins. Water is therefore not a major contributor to human exposure to dioxins.

The majority of the dioxins that reach the earth’s surface come from the air through sedimentation or with rainwater. The dioxin contents in soils which have not been contaminated are, as a rule, very low. Studies in the UK have shown contents of 1-5 ng per kg of soil in the countryside and 10-50 ng per kg in industrialised areas.

Plants do not usually absorb dioxins, rather these are adsorbed onto the root-fibres or leaves when they fall. Therefore the dioxin contents in plants are, as a rule, very low. The dioxin contents we reported earlier, however, can be high in animals found high up the food chain.

**Degradation, formation and separation of dioxins during waste incineration**

Household waste and other waste generated by modern society are a reflection of production and consumption. These kinds of waste will therefore contain all the types of material and chemicals used in society and the pollutants that form. In particular, this applies to household waste which comprises a heterogeneous material and which contains small amounts of mercury, cadmium, dioxins or other pollutants.

Household and other waste must therefore be treated carefully and dealt with safely to ensure the pollutants do not spread and cause harm to humans and the environment. The
aim of waste incineration, however, is not only to break the harmful ecocycle of heavy metals, dioxins etc., but also to close beneficial material and energy ecocycles. Waste incineration with energy recovery, separation of pollutants and handling of residual waste – which is the most common method of treating household and other similar waste – satisfies both these requirements.

A modern waste plant is organised with the following main functions:

- Reception, including separation, storage and feed system
- Incineration including furnace, boiler and energy recovery
- Flue-gas cleaning with dust separation and dry, and at some plants wet, cleaning with flue-gas condensation.
- Water treatment (with wet flue-gas cleaning)
- Production of district heating and in some cases also electricity
- Treatment and handling of slag, ash and other flue-gas treatment residues

Consequently, the incoming waste contains varying amounts of dioxins, depending on the origin and composition. By far the largest proportion of these dioxins are broken down into carbon dioxide, water and hydrogen chloride during incineration at temperatures above 850°C. The small quantities of dioxins that have not been broken down are borne with particles into slag and bottom ash. The dioxins are solidly fixed in these materials and there is no risk of leaching. It is estimated that there were 5-10 g of dioxin in the 370,000 tons of slag and bottom ash separated at the waste incineration plants in 1999.

As the hot flue gases are cooled, there is a degree of dioxin formation provided that three conditions are fulfilled. There must be sufficient chlorine in the flue gas for the carbon skeleton to be chlorinated. A catalyst in the form of copper, for instance, must be available in the flue gas. The temperature of the gas must be at least 200°C and no more than 600°C. These conditions are usually fulfilled in the convection part where the flue gases are cooled and emit heat which is used in district heat production or as steam in electricity generation.

Dioxins are therefore formed during waste incineration, although there are large variations between different plants, due to differences in factors such as technical design and the composition of the waste. Results from the investigations carried out show that 115-125 g of dioxin may have been formed at the waste incineration plants in Sweden in 1999.

The efficient flue-gas treatment systems at the Swedish plants today have in several cases already reduced the dioxin content in outgoing flue gases to below the EU’s limit value of 0.1 ng/m³, and in some cases well below this limit. It should be noted that this limit value will apply for new plants as of the day the EU Directive is implemented in Swedish legislation (December 2002 at the latest) and for existing plants three years after this date. At the majority of the waste incineration plants, over 99% of the dioxins which have been formed and borne with the flue gases from the incineration are separated. Total dioxin emissions from the waste incineration plants in Sweden over the
past five-year period have amounted to just under 3 g per year, which means the rate of separation is 98% on average.

Ash and other residues from flue-gas treatment, with their content of dioxins and other pollutants, are classified as hazardous waste and may therefore only be deposited at landfill sites approved for hazardous waste. This means for example that these residues must be deposited separately from other types of waste, and that special protective measures must be taken to prevent the leaching of dioxins, heavy metals and other pollutants. At several plants, there is also some degree of stabilisation of these residues, through mixing different materials and adding stabilising agents. The total quantity of residues from flue-gas cleaning at the Swedish waste incineration plants amounted to 75,000 tons in 1999. These residues contained a total of 110-120 g of dioxin (Eadon).

**Dioxins in residues from waste incineration**

Of course, developments in waste incineration have led to considerable reductions in emissions of dioxins, heavy metals and other pollutants into the air, mainly through the expansion of highly effective flue-gas cleaning. The pollutants that were previously emitted out through the factory chimneys with the flue gases are – to the extent that they are not broken down – stored in ash and other residues from flue-gas cleaning. The focus in the dioxin issues, for instance, has therefore shifted to issues on dealing with and treating these residues. This applies in the industry and among experts, as well as among the general public and in the general debate on environmental issues.

In recent years, the Swedish Association of Waste Management (RVF) has therefore taken the initiative in establishing a series of measures to improve knowledge within these areas, and the information basis for decisions on measures. As part of this work, RVF and the waste incineration companies carried out the presented extensive investigation into dioxins in residues from waste incineration in autumn 1999 and spring 2000. As mentioned above, the main aim of this investigative work was to establish the contents and quantities of dioxins in ashes and other residues from flue-gas treatment.

Samples were taken at 21 of the 22 plants in operation during 1999/2000. The dioxin contents were found to vary within relatively wide limits, with a lowest value of 0.10 ng/g and a highest of 10 ng/g according to Eadon, see figure 6. The corresponding values according to I-TEQ were, as expected, slightly higher with 0.14 ng/g as the lowest value measured and 18 ng/g as the highest.

To some extent, these relatively large variations between plants can probably be explained by differences in technical design, operating conditions, waste composition and other conditions specific to each plant. However, the uncertainty in the individual samples has also played a crucial role. An accuracy of ± 50% in an individual sample can be expected under optimal conditions.

The crucial question, however, is whether the sample taken is representative of the operating conditions over a longer period. Since the samples were taken over one or a
few days, there is of course a risk that they continuously ‘missed the mark’, and ended up reflecting periods that were not representative of the operation during an annual cycle.

**Figure 6**  Dioxin contents in residues from flue-gas cleaning at waste incineration plants in Sweden in 1999, ng/g.

However, the majority of samples fall quite nicely within a more restricted window. Half of the values within the second and third quartiles lie between 0.35 and 2.0 ng/g according to Eadon and between 0.45 and 2.5 ng/g according to I-TEQ. The median value for both methods is 0.7 ng/g. Based on the total quantities of residues from flue-gas cleaning collected from all plants, the mean value is 2.0 ng/g (Eadon) and 2.8 ng/g (I-TEQ).

In light of these findings and after reviewing documented information, we concluded that an average figure of 2-3 ng/g of dioxin content in residues from flue-gas cleaning for waste incineration in Sweden appeared to be the norm.

The total quantity of dioxins in residues from flue-gas cleaning at the plants in 1999 amounted to approximately 110 g according to Eadon and approximately 160 g according to I-TEQ. A few of the plants account for the great majority of these quantities of dioxin, as shown in figure 7. It should be observed that when calculating quantities of dioxins for the individual plants there were, in addition to the significant differences in dioxin contents, large variations in the quantities of residues. The largest plant generated 15,000 tons of ash and other flue-gas treatment residues, while the smallest produced just 250 tons.
As a basis for continued discussions on dioxin-related issues, we have produced two ‘key ratios’ for dioxin content in residues from waste incineration. The first specifies micrograms of dioxin per ton of incinerated waste, and the second micrograms of dioxin per MWh of energy produced.

In approximate terms, an average of 40-60 μg/ton of incinerated waste during waste incineration can be viewed as the norm for the key ratios linked to the quantity of incinerated waste over a longer period, see figure 8. The corresponding key ratios linked to energy production can be estimated to amount to 15-20 μg/MWh of energy produced.
In short the results can be summarized as:

*The study shows that dioxins found in the residual waste from incineration are solidly fixed. This breaks the ecocycle of the dioxins in the waste. Incineration and energy production using waste as the fuel is a good way of dealing with combustible waste.*