Risk quantification for industrial facilities as input to decision making

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Abstract

This paper describes a research project to develop and test tools that could improve the authorization procedure for controversial installations such as chemical plants and waste incinerators that are feared for their potential health risks. The approach is based on case studies in six countries of Europe. The case studies (seven waste incinerators, two landfills and a power plant) have been selected at an early stage of the authorization procedure in order to permit real time input into the decision process. The first tool extends the scope of a traditional impact study by quantifying the health risks and the associated costs that would be imposed on the general public; they are estimated by an impact pathway analysis, tracing the fate of a pollutant from source to receptors. The resulting risk estimates are used as input to surveys of the population and of the key actors in the authorization procedure (proposers, opponents and decision makers). A questionnaire for the survey of the key actors constitutes the second tool developed in this research project; it has been used as guideline for in-depth interviews at all case study sites. The third tool is a contingent valuation survey of the population to assess their preferences; questionnaires for this have been developed and applied the general population. Finally tools for the communication of risks to proposers, to decision makers and to the general public have been studied. Risk comparisons demonstrate the wide divergence between the small objective risks of new incineration technologies and the exaggerated perception of these risks by the public. Another tool for the communication of risks is the comparison of costs and benefits.

Key Words: risk analysis, risk communication, risk perception, incinerators, waste management, air pollution, environmental impact study, authorization procedure

1. Introduction

The fear of health hazards due to pollution is one of the main reasons why the authorization of installations such as chemical plants and waste incinerators has often been hotly contested. In principle such fears should be allayed by the environmental impact statement[1]. However, in current practice most impact studies limit themselves, more or less, to saying "... will satisfy all applicable regulations" as far as pollutant emissions are concerned; despite the name "impact study" the actual impacts are rarely quantified.

The goal of this research project, carried out between July 1996 and June 1999, is to help improve the quality and transparency of decision making for controversial installations by extending the scope of a traditional impact study and including the quantification of health risks and costs that would be imposed on the general public. The key idea is to link the objective quantification of impacts and risks with the subjective perception of these risks by the population.

Tools for this purpose have been developed and tested by case studies in six countries of Europe. The case studies have been selected at an early stage of the authorization procedure in order to permit real time input into the decision process. A brief description of the sites/installations chosen for the case studies is given in Section 2 (see summary in Table 1). Most of them concern waste management, especially incineration of MSW (municipal solid waste).

The first tool is the quantification of risks and costs; it is based on the impact pathway analysis of the ExternE Project [1995, 1998] of the EC. A summary of methodology and key results is presented in Section 3. The principal steps of the impact pathway analysis are the following:

- specification of the relevant technologies and the environmental burdens they impose (e. g. kg/s of particles emitted by an incinerator);
- calculation of increased pollutant concentration in all affected regions (e. g. $\mu g/m^3$ of particles, using models of atmospheric dispersion and chemistry);
- calculation of the resulting dose and the physical impacts (e. g. number of cases of asthma due to these particles, using a dose-response function);
- economic valuation of these impacts (e. g. multiplication by the cost of a case of asthma).

The second tool is a survey of the key individuals involved in the authorization procedure: proposers, opponents and decision makers. A questionnaire for the survey of the key actors has been developed and has been used as guideline for in-depth interviews at all sites. The key findings are shown in Section 4.1 below.

The third tool is a contingent valuation survey of the population to assess their preferences. Questionnaires have been developed and, after extensive testing in focus groups, they have been applied to the general population at three sites. Two of these sites (Barcelona and Lausanne) concern proposed incinerators for municipal solid waste (MSW). The population is asked to value the air pollution health risks associated with different technological options.

[1] The environmental authorization procedure for major installations in the EU is based on the Directive 85/337/EEC (European Communities Council of Ministers, 1985) on environmental impact assessment (EIA). A new Directive was issued in 1997 (European Union Council of Ministers, 1997) amending the previous one.

The third questionnaire, applied in the region of Paris, puts the interviewee in the position of a decision maker, by asking which of several technologies with different levels of pollution control he/she would prefer, given specific information about the costs and the benefits.

The fourth tool concerns the communication of risks to decision makers and to the general public. One of the elements involves the comparison of risks, costs and benefits. As an example we have examined the costs and benefits of the proposed new EC [1994] regulations for MSW incineration.

The ultimate goal is to help bring about a more rational and efficient allocation of societal resources for the protection from environmental risks. Here we provide only a brief summary of the project; for more detail the reader is referred to the full report [Rabl et al 1999] or to the web site [http://www-cenerg.ensmp.fr/~rabl/].

2. The Case Studies

In this Section we provide a very brief description of the sites that have been studied. Needless to say, the issues are far more complex than could be presented in such a brief summary; the reader is therefore referred to the full report. An overview of the case studies can be found in Table 1. In addition to the sites in the partner countries, we have decided to take a close look at the MSW incinerator of Vienna, Austria, because it provides a very interesting and instructive example of how a community can successfully resolve a problem of environmental risk.

It is interesting to note that the search for sites to study turned out to be difficult and frustrating, because for most of the suitable projects the proposers were afraid our study might somehow interfere with their goals. This fear was common both on the private (industry) and on the public side (local and regional government). Above all, there was extreme reluctance to allow an opinion survey of the public.

The timing of the authorization procedure for the various installations did not always coincide with the timeframe of our research project. Some of the proposed installations have been abandoned since the time we decided to study them, while others are still undecided.

Of the ten sites/installations, seven deal with waste incineration, two with landfills and one with a power plant. The emphasis on waste disposal emerged naturally during our search for suitable sites. It is a subject of increasing concern, especially over health impacts from incinerators and land filling of hazardous waste. Thermal waste treatment (incineration, pyrolysis or gasification) is especially interesting to study because it greatly reduces the space requirement of landfills (the only major alternative after all possibilities of source reduction and recycling have been exhausted), yet evokes intense fears of perceived health risks from air pollution, especially dioxins. Whereas such concerns are natural after the bad practices of the past, the decisions to be considered now deal with new technologies, subject to stringent regulations. Their emission of pollutants is orders of magnitude lower than with the old unregulated incinerators that had little or no flue gas clean up.

Table 1. The case studies (sites/installations) of this research project.

Country **Site**	**Characteristics, Key issues**
Austria MSW incinerator of Vienna	Fear of toxic air pollutants after fire 1986 in older version of this incinerator, new installation (1988-1992) is showcase for clean technology and open communication.
Belgium Proposed enlargement of existing Landfill	The additional landfill is to be used for ultimate waste. Some local residents are opposed. Public inquiry 1998. May 1999 decision to refuse authorization. Proposer filed appeal but lost. Project abandoned.
Denmark Proposed addition to existing power plant	Unlike the concerns with local health impacts at the other sites, the key concerns here are regional and global energy policy, especially global warming. After much public debate and modification of original design (from mainly coal to mainly gas), construction is proceeding.
France MSW incinerator for Bordeaux	After authorization to build was granted June 1996, environmentalists filed an appeal on the grounds that risks from dioxins have not been addressed and that incinerator is oversized. However, the incinerator has been built anyway and has been operating since 1998.
France MSW incinerator proposed for Lille	Good preparation by publicity campaign emphasizing recycling and clean technologies (even though the proposed installation is not significantly better than current regulations). Construction started 1998.
France Industrial waste incinerator Northern France	Strong opposition by environmentalists because of dioxins, leading the proposer to abandon this project in 1998.
France hazardous waste landfill proposed for Aquitaine region at Lucmau	Strong opposition by local population because of feared health impacts. Project abandoned.
Spain MSW incinerator proposed for Barcelona	The proposed incinerator is to replace two older ones. After the opposition from environmentalists, it was decided that the new incinerator will only be built if the ambitious recycling target (60%) of the regional waste management plan is not met by 2006. Instead, the older ones are being modernized, although opponents would like them to be closed.
Switzerland MSW incinerator proposed for Lausanne	Opposition by local residents for being over-sized and because of destruction of forest at the proposed site. So far the proposers of the incinerator have convinced neither the population nor the Federal authorities (whose agreement is required when federal subsidies are at stake). The Federal Court has decided that the need for the project has not been demonstrated.
UK MSW pyrolysis unit proposed for a Borough of London	While there is general widespread opposition to waste incineration in the UK, this is a different technology (first commercial demonstration of a novel waste pyrolysis plant). After much debate project finally is proceeding, Public inquiry expected in 2000.

3. Real Risks: Quantification and Comparisons

3.1 Impact Pathway Analysis

To quantify the health risks due to a source of pollution, one needs to carry out an impact pathway analysis (environmental fate analysis) whose principal steps have been listed above in the Introduction ("first tool"). For this, we draw on the major studies of external costs of pollution in the USA [ORNL/RFF 1994, Rowe et al 1995] and Europe [EC 1995]; the latter, known as the ExternE Program of the European Commission, is continuing and some authors are participants. A more detailed documentation of the impact pathway methodology and of the typical results for incinerators has been published by Rabl, Spadaro & McGavran [1998].

We have carried out such an analysis for each of the sites and installations under consideration in this research project. However, for landfills we do not present a detailed analysis, for the following reason. The only landfills studied in this research project are for ultimate waste, i.e. what remains after all reasonable efforts have been made to recycle and/or extract materials and energy. New landfills for ultimate waste are subject to stringent regulations, in particular for the impermeability of the containment, and the waste is stabilized to be practically inert (no liquids, powders, or decaying organic matter). They are built on a layer of clay, with multiple waterproof barriers and a drainage system to capture leachates. Thus essentially no pollutants are released to the environment during the period of active management, typically 20 to 30 years. Accidental risks are not significant either, for stabilized waste - always assuming good management, of course.

Thus there is essentially no health risk from a modern landfill as long as the facility is maintained and managed correctly. What happens after the landfill is closed is, however, an unresolved question. Current plans usually call for a return of the land to other uses, once the landfill has been filled to capacity and sealed. Over the long term the barriers and seals can leak. Whether leaks from landfills will cause appreciable risks it very difficult to predict. Thus, there could be small local risks, but only for future generations, and they are unpredictable because they depend on how the site will be managed after closure.

We have reported the site specific results for the individual installations in Annex 2b-g of the full report. Since the damage depends on the site where a pollutant is emitted, there is the question how to generalize site-specific results to typical numbers that may be needed for many policy questions. Spadaro & Rabl [1999] have studied the variability of damage with emission site. Based on ExternE [1998] results for over fifty sites in all countries of the EU, they have shown that the results are sufficiently representative to permit general conclusions to be drawn about combustion installations with tall stacks such as waste incinerators and power plants. Here we present typical results, with focus on incinerators.

Going down the steps of an impact pathway analysis, the results come progressively closer to criteria of direct concern, but involve progressively more assumptions and uncertainties. In view of the large uncertainties of health risk estimates, it is advisable to put the results in perspective by making a number of comparisons, in terms of emissions, concentrations, damages and damage costs. A comparison of emissions and concentrations is instructive because it shows the significance of MSW relative to other pollution sources that we may or may not be able or willing to reduce. It also has the great advantage of being unaffected by the dominant source of uncertainty, namely epidemiology. We therefore offer the following comparisons:

- incremental emission compared to other emissions;
- incremental concentration compared to background concentration;
- incremental concentration compared to health guidelines (EC or WHO);
- health risks from different pollutants compared to each other;
- incremental years of life lost compared to other risks of everyday life;
- incremental damage cost compared to the cost of incineration itself.

For this purpose we consider the incineration of municipal solid waste (MSW) with emissions equal to the regulations proposed by the EC [1994], for typical per capita MSW production. The results can be adapted to the emissions of a specific site, by simply adjusting the numbers in proportion to the emission rates of the EC [1994] regulation; this is justified in

view of current epidemiological evidence that health damages for the total population are approximately proportional to incremental exposure.

3.2. Emissions

3.2.1. Measured Data and Regulations

Emissions depend on the equipment used to treat the waste, especially the flue gas clean up, and for a given installation the emissions vary with varying operating conditions and composition of the waste. Fig.1 shows the concentration of pollutants in the flue gas, as measured for older plants, and compares them with regulations in the US and Europe. In the European Union the EC regulations of 1989 have been incorporated in the legislation of the member countries and apply to new incinerators; a further tightening was proposed in 1994. Since this latter regulation [EC1994] will become law in due course in all member countries of the EU, we use it as standard of comparison in Fig.1. Because of the wide range of values, the data are shown with logarithmic scale.

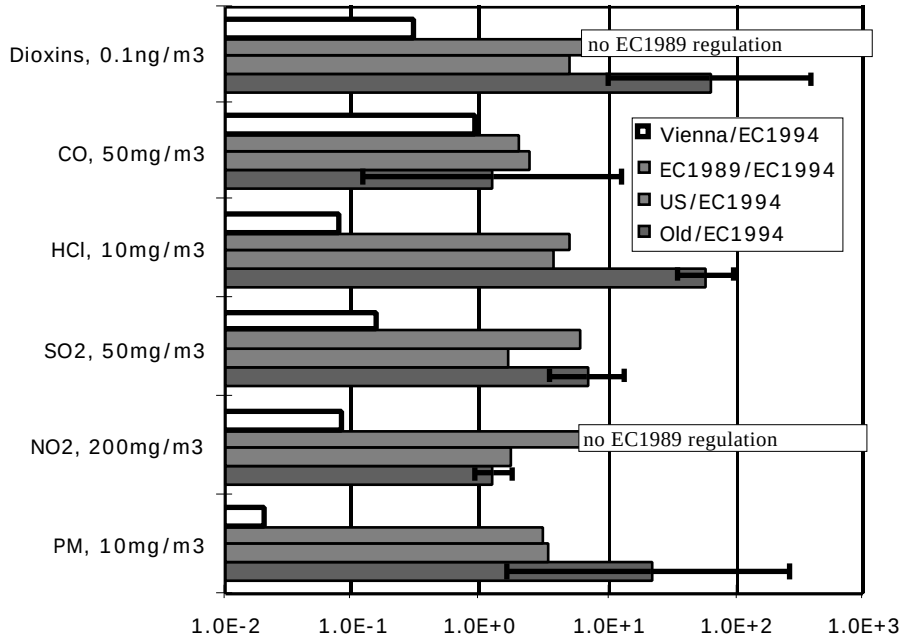

Fig.1. Regulations and measured data for pollutant concentrations in flue gas of MSW incinerators. Presentation is dimensionless with logarithmic scale in units of EC [1994]; the absolute values of the latter are shown in the pollutant labels. Vienna = Measured emissions of incinerator of the city of Vienna, Austria [Wien 1995].

Notes for Fig.1:

gas volumes are normalized to standard conditions;
error bars show range of measured data for older plants, mostly for UK data [Table 1 of Williams 1994];
US regulations are New Source Performance Standard, in effect since 1991, as cited in Steverson [1994];
measured data for dioxins in UK and US based on Williams [1994], and EPA [1994A vol.I, p.23];
for further details see Rabl, Spadaro & McGavran [1998].

We do not show toxic metals in Fig.1 because different regulations are stated in terms of different combinations of metals and cannot be compared directly. For example EC [1994] imposes the following limits:

- for Hg 0.05 mg/m^3;
- for the sum of Cd and Tl 0.05 mg/m^3;
- for the sum of As, Co, Cr, Cu, Mn, Ni, Pb, Sn, Sb and V 0.5 mg/m^3.

We will report some results for individual metals by assuming typical compositions.

There are technologies that easily meet the proposed new EC [1994] regulations. A good example is the MSW incinerator in Vienna which has been operating in its present version since 1992 [Wien 1995]. It is a showcase, with sophisticated clean up equipment, good communication (emissions monitored and publicly displayed in real time), and a beautiful exterior (designed by the painter and architect Hundertwasser). Most of its emissions are a small fraction of EC [1994]. Very low emissions have also been achieved with pyrolysis.

3.2.2. Emissions per Capita

For a comparison of per capita emissions it is instructive to assume that all MSW would be incinerated in plants that satisfy the EC [1994] regulations, taking a MSW production of 500 kg_{waste}/yr per capita as typical round number. Multiplying the regulatory values by a typical flue gas volume of 5.15 m^3 per kg of waste, one finds the per capita emissions.

Rabl, Spadaro & McGavran [1998] have presented comparisons (not shown here) with data for natural and anthropogenic emissions. For example, the per capita emissions and impacts from MSW incineration, even with this maximal scenario, are small compared to those of cars. A very firm conclusion from these comparisons is that even if the entire MSW were incinerated, subject to EC [1994], the burden would be small compared to current per capita emissions in industrialized countries. These conclusions hold also for dioxins.

3.3. Comparison with Typical Ambient Concentrations

Using the ISC model [Wackter & Foster 1987], a gaussian plume model approved by EPA, we have calculated the highest annual average concentration c_{max} in the vicinity of an MSW incinerator appropriate for a city of half a million, with emissions equal to the EC [1994] regulations. Table 2 compares c_{max} with typical concentrations that have been measured in urban environments. We also show the WHO [1987] health guidelines for Europe. If these guidelines were no-effect thresholds, the ratio of health guidelines and c_{max} could be considered a margin of safety. The peak concentration c_{max} is two or more orders of magnitude smaller than Urban or WHO, with the exception of Hg for which c_{max} is a quarter of urban (although still tiny compared to WHO). Thus one can conclude that the increment due to such an incinerator is very small and insignificant compared to health guidelines.

3.4. Key Assumptions for Calculation of Health Risks and Costs

3.4.1. Dispersion modeling

For most air pollutants from incinerators atmospheric dispersion is significant over hundreds to thousands of km [Seinfeld & Pandis 1998, Curtiss & Rabl 1996]. We have therefore used a combination of local and regional dispersion models to account for all significant damages: the gaussian plume model ISC [Wackter & Foster 1987] for the short range, and at the regional scale the Harwell Trajectory model. The dispersion calculations are coupled with an integration over population data, using the ECOSENSE software package [ExternE 1998].

Table 2. Maximum incremental concentration c_{max} (annual average, a few km from source) due to MSW incinerators, and comparison with typical urban concentrations and with World Health Organization guidelines for Europe [WHO 1987]. MSW incinerator has throughput of 250000 t_{waste}/yr, stack height 100 m, and the emissions are equal to EC [1994]. Adapted from Rabl, Spadaro & McGavran [1998].

Pollutant	**c_{max}** ng/m^3	***Urban*** ng/m^3	**Urban/c_{max}**	***WHO*** ng/m^3	**WHO/c_{max}**
PM	39	3.40E+04	**870**	5.00E+04	**1280**
NO2	773	4.60E+04	**60**	1.50E+05	**190**
SO2	193	2.50E+04	**130**	5.00E+04	**260**
CO	193	2.23E+06	**11500**	1.00E+07	**51800**
Hg	0.19	0.7	**4**	300	**1580**
Pb	0.42	566	**1330**	1.00E+03	**2350**
Dioxins	3.86E-07	1.00E-04	**260**	4.40E-04	**1300**

3.4.2. Monetary Valuation

The goal of the monetary valuation of damages is to account for all costs, market and non-market. For example, the valuation of a hospitalization should include not only the cost of the medical treatment but also the willingness-to-pay (WTP) to avoid the suffering. If the WTP for a non-market good has been determined correctly, it is like a price, consistent with prices paid for market goods. Economists have developed several methods for determining the price of non-market goods, especially the contingent valuation method which has enjoyed increasing popularity in recent years [Mitchell and Carson 1989, Arrow et al 1993]. The results of good studies are considered sufficiently reliable for policy applications.

It turns out that damage costs of air pollution are dominated by non-market goods, especially the valuation of mortality. For this the single most important parameter is the so-called “value of statistical life” (VSL) – an unfortunate term that often evokes hostile reactions from people who feel that a life cannot be measured in terms of money and who misunderstand the purpose of VSL. A clearer and more neutral term would be “collective willingness to pay for avoiding the risk of an anonymous premature death”. Here we follow ExternE [1998] in using a European-wide value of 3.1 MEuro ($ 3.4 million) for VSL, close to similar studies in the USA.

A crucial question for the valuation of air pollution mortality is whether one should simply multiply the number of premature deaths by VSL, or whether one should take into account the years of life lost (YOLL) per death. The difference is very important because premature deaths from air pollution tend to involve a smaller number of YOLL per death than accidents (on which VSL is based). The ExternE [1998] numbers, cited here, are based on YOLL and thus significantly lower (for the same dose-response function) than the simple VSL valuation assumed in most previous external cost studies. For the value of a YOLL we have assumed 0.08 to 0.15 M€, depending on the lag between exposure and death. This value of a YOLL has been derived on theoretical grounds as the prorated annual equivalent of the VSL of 3.1 M€ [ExternE 1998]. For the cost of a cancer we have assumed 1.5 MEuro, averaged over fatal and nonfatal cases and taking into account latency and discounting.

3.4.3. Health Impacts of Air Pollution

Of special importance are health impacts because, according to ExternE [1998], they account for more than 95% of the damage costs of particles, NO_x and SO_2. A consensus has been emerging among public health experts that air pollution, even at current ambient levels, causes a variety of significant health problems, especially respiratory diseases and mortality [Lipfert 1994, Wilson & Spengler 1996]. There is less certainty about specific causes, but most recent studies have identified fine particles as a prime culprit; ozone has also been implicated directly. In addition there may be significant direct health impacts of SO_2, but for direct impacts of NO_x the evidence is less convincing.

In ExternE [1995, 1998] the working hypothesis has been to use the dose-response functions for particles and for ozone as basis. Effects of NO_x and SO_2 are assumed to arise indirectly from the particulate nature of nitrate and sulfate aerosols, and they are calculated by applying the particle dose-response functions to these aerosol concentrations. With this assumption the impacts of NO_2 and SO_2 become very large, but this is uncertain because there is insufficient evidence for the health impacts of the individual components of particulate air pollution, especially for nitrates. The reason for the lack of epidemiological studies of nitrate aerosols is that until recently this pollutant has not been monitored by air pollution monitoring stations.

For cancers we have used the dose-response functions published by the EPA; they are linear and stated as slope factors. For the carcinogenic metals (As, Cd, Cr and Ni) we have used the values in the HEAST [1995] tables of EPA, and for dioxins the value in EPA [1994B]. For dioxins we have taken non-inhalation pathways into account by assuming that the total dose is 54 times the inhalation dose [EPA 1994A].

3.5. Damage Costs

With the assumptions of ExternE [1995, 1998] it turns out that the damage of NO_x and SO_2 as primary pollutants is negligible compared to their damage as precursors of secondary pollutants. For the pollutants evaluated in this paper, only the damage due to particle emissions and due to the carcinogenic metals is strongly site dependent. For dioxins the damage varies only weakly with site because it is dominated by non-inhalation pathways involving transport over long distances. In Table 3 we summarize our estimates of the damage costs, and we indicate how the cost can vary with site and stack conditions. The numbers in this table have been calculated for a population density of 105 persons/km^2, typical of European conditions when averaged over land and adjacent water surfaces. For other regions, the numbers have to be scaled in proportion to population density.

Multiplying the cost per ton of pollutant by the emissions per ton of waste, one finds the damage cost per ton of waste in Fig.2. Dioxins do not make a significant contribution, despite their high specific toxicity, because the emission limits of EC [1994] are so low. For a comparison of health risks from such incinerators, see Fig.3 in Section 5.

To conclude this section we note that by any of our comparisons the health impacts of MSW incineration appear insignificant, if the emissions respect the proposed EC 1994 regulations. In particular, the incremental concentration of pollutants from such incinerators is far below

the WHO guidelines for ambient air quality. Since current background concentrations in the EU are usually also well below such guidelines, so is the total. Thus there would be no damage if these guidelines were no-effect thresholds. That does not guarantee the complete absence of harmful effects, but whatever they may be, air quality guidelines do not suffice to quantify them.

Table 3. Typical values of health damage costs per t of air pollutant emitted in Europe. Multipliers indicate how much the €/t numbers can change with site and stack conditions (stack height h, temperature T, exhaust velocity v). SO_2 damage is mostly via sulfates. From Rabl, Spadaro & McGavran [1998].

	Cost €/t_{poll}	**Multiplier for site** (rural ↔ urban)	**Multiplier for stack conditions** (height [a], T, v)
PM_{10}	1.36E+04	≈ 0.3 ↔ 3	≈ 0.6 ↔ 2.0
SO_2	1.22E+04	≈ 0.7 ↔ 1.5	≈ 1.0
NO_2 (via nitrates)	1.69E+04	≈ 0.7 ↔ 1.5	≈ 1.0
NO_2 (via ozone) [b]	1.15E+03	?	?
CO	2.07E+00	?	?
As	1.50E+05	≈ 0.3 ↔ 3	≈ 0.6 ↔ 2.0
Cd	1.83E+04	≈ 0.3 ↔ 3	≈ 0.6 ↔ 2.0
Cr	1.23E+05	≈ 0.3 ↔ 3	≈ 0.6 ↔ 2.0
Ni	2.53E+03	≈ 0.3 ↔ 3	≈ 0.6 ↔ 2.0
Dioxins, TEQ	1.63E+10	≈ 0.7 ↔ 1.5	≈ 1.0

[a] stack height range 250 ↔ 0m (damage decreases with stack height)

[b] Rabl & Eyre [1998]

The cancer impacts of micropollutants, in particular of dioxins, are small compared to the mortality due to ordinary particulate matter from MSW incinerators which in turn is insignificant compared to the contribution of other sources of particulate matter or compared to other risks of everyday life. These findings are in stark contrast to the perception of incinerators by the general public.

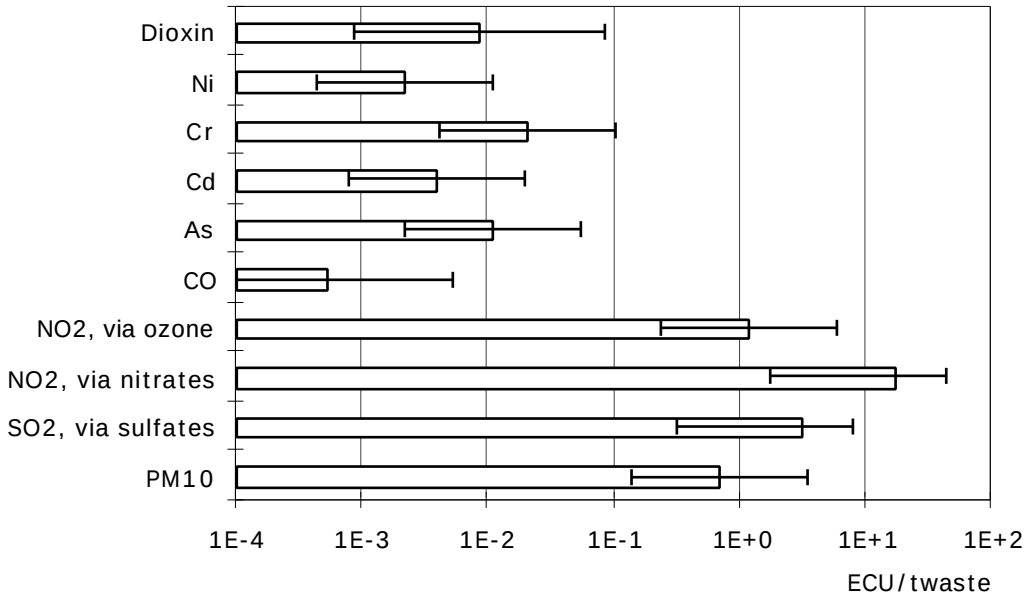

Fig.2. Cost of health damage per ton of waste, for the €/t_{poll} values in Table 3 with the emission rates of proposed EC regulation, Fig.1. Scale is logarithmic and error bars express uncertainty. ECU = €.

4. Tools for eliciting preferences

4.1. Survey of decision makers

The experience of participants in the decision-making process for the authorization of major installations was evaluated by interviewing participants in such a process in each of six countries: Belgium, Denmark, France, Spain, Switzerland and the United Kingdom. A standardized interview protocol was developed for this purpose and translated as appropriate; the text of this protocol can be found in Annex 3 of the full report.

At each site, between four and eight informants were selected in order to represent the views of all the major stakeholders involved. These included the proposers, the local planning authorities, and the objectors (including environmental pressure groups). Tape-recorded interviews lasting between 40 and 180 minutes were held with the informants and were transcribed. The same basic questionnaire was followed in each interview, but with slight variations for each case, allowing for the different circumstances. Topics covered were:

- Initial opinion of the proposal
- Rationale for the proposal
- Choice of technology
- Choice of site
- Opinion of the decision-making process
- Opinion of the public inquiry system
- Opinion of the Environmental Impact Assessment process
- Concern about environmental and health impacts.

A summary of the results of this survey, based on the reports by the individual teams, is presented in Annex 3; a shortened version has been published by Dresner & Gilbert [1999]. We find that the following criticisms of the present authorization processes have wide support:

1. There is a common complaint from all sides that the decision-making process does not genuinely involve the public.
2. Public inquiries are widely perceived in all countries as taking place too late in the process, when all the decisions have already been taken.
3. Environmental Impact Assessments are widely regarded as lacking credibility because they are commissioned and paid for by the proposer.
4. Environmental Impact Assessments are widely regarded as taking place too late to have any influence on the project.
5. Environmental Impact Assessments are often criticized for failing to properly consider alternatives to the proposed project.
6. Environmental Impact Assessments are sometimes criticized for being too narrow and failing to take into account social and economic issues.
7. Environmental Impact Statements are often criticized for being incomprehensible to the public.

Lack of trust is inevitable when there are disagreements. But the lack of openness from the start of the decision-making process exacerbates the problem. The following general observations can be made about the opposition:

1. Opponents almost invariably question the size of the facility, claiming that it is too large and will discourage efficient use of resources.
2. Opponents sometimes question the very need for the facility as there is already enough capacity.
3. Opponents usually treat the choice of technology as subsidiary to issues of size and need. But they are critical of the technologies chosen as wasteful of resources and polluting.
4. Opponents almost invariably criticize the choice of siting. Sometimes that is a major criticism; more usually it is a secondary criticism.

Based on the criticisms made by the interviewees, a number of suggestions can be made about how to improve satisfaction with the procedures:

(i) Public consultation could begin much earlier. Local residents and environmental groups could be included in a panel assessing the options.

(ii) The Environmental Impact Assessment could be conducted much earlier in the process, contain more detailed assessments of the alternatives to the proposed project, and always have a summary written in language that lay-people can understand.

(iii) For improved credibility the Environmental Impact Assessment (EIA) could be commissioned from consultants by a body independent of the proposer, such as the national environmental protection agency.

(iv) An analogous Social Impact Assessment could be conducted, as in the United States.

The new Directive on Environmental Impact Assessment [EU 1997] will require some assessment of alternatives and hopefully prevent the short-circuiting of any public consultation that has taken place sometimes. However, it does not address the main sources of dissatisfaction with EIA procedures identified by the interviewees in this study: it still does not require a proactive consultation of the public at an early planning stage; it still does not require a serious assessment of the alternatives, just a mention of them; and there is no test that the summary is actually understandable for lay-people. One would require another directive or significant changes in national laws to greatly increase the transparency of the decision-making processes.

We are aware that there are differing views on the practicality of such reforms as greater public involvement in project design and independently-commissioned EIAs. However, we do believe that they would be necessary if the aim was to gain trust in the fairness of decision-making processes.

4.2. Survey of Population

4.2.1. General Remarks

Preferences of the population can be assessed by means of a contingent valuation (CV) [Mitchell & Carson 1989, Arrow et al 1993]. Contingent valuation is like a vote, by contrast to a public inquiry which is not representative because only the people most concerned participate. A contingent valuation reflects the perception of the population and allows to express personal preferences in monetary terms. The monetary values determined by a CV survey should not be taken too literally; rather they are a general indication of how willing the public is to accept a proposed installation.

A CV survey can be especially instructive if it is designed to determine the ranking of alternative options. For example, in Barcelona the decision makers have used the results of the contingent evaluation to take into account the preferences that the population expresses for different for waste management options.

4.2.2. Contingent valuation in Lausanne

The Questionnaire

A contingent valuation survey was carried out in Lausanne to measure the benefits that the population associates with the air quality improvement that would be achieved if the current incinerator at Vallon were replaced by the new incinerator proposed for the Tridel site. However, in view of the controversies surrounding the choice of the site for the new incinerator, the site of Tridel is not mentioned in this survey. Instead two decontextualized scenarios have been evaluated:

i) the improvement in air quality due to the replacement of the old incinerator at Vallon by a new incinerator at Tridel;
ii) an improvement that is only half as large as in i).

Scenario (i) takes into account the reduction in total emissions when the incinerator is at the Tridel site where it can be connected to the district heating system of Lausanne; scenario (ii) corresponds to an installation outside the city where connection to the district heating system is not possible.

Meetings with three groups of residents (March-May 1998) allowed to take into account the manner how the population perceives the situation. On this basis a preliminary questionnaire was conceived (May-September 1998) and tested during seven verbal protocols (September 98). Using the revised questionnaire, 200 persons in Lausanne were interviewed.

Results

Of the 199 validated questionnaires, 65 correspond to the case where the interviewee refused to declare a willingness to pay (WTP) or indicated a WTP of zero. Thanks to questions designed for this purpose, it has been possible to distinguish 20 cases of "true WTP = 0" among these 65 observations. These 20 cases correspond to individuals who are too poor (budgetary constraint too tight) or who are indifferent to an improvement in air quality. Therefore the econometric analysis has been realized with 199 – (65 – 20) = 154 observations.

Instead of using the WTP data directly, we calculate the collective benefit by means of a modified Box-Cox model; this has the advantage of reducing the hypothetical bias by discounting the influence of extreme values. As further precautionary measures we choose the median WTP rather than the mean which would be 50% higher. These precautionary measures follow the recommendations of the NOAA Panel on contingent valuation [Arrow et al 1993]: when different interpretations of a CV study are possible, the one yielding the lowest WTP should be chosen.

When one compares the WTP for a 50% reduction of the health risks to the WTP for a 100% reduction, several different behaviors are seen: constant marginal utility (14% of the 154 individuals), growing marginal utility (14%), decreasing marginal utility (12%), lump sum behavior (38% of which lump sum > 0: 25% and lump sum = 0: 13%), risk aversion (22%).

For the totality of 154 observations, the WTP announced for the 50% reduction of the risk corresponds 51% of the WTP announced for the total suppression of the risk. This proportion is also seen for the calculation of the total benefit for the population.

The total benefit for Lausanne of the reduction of health risks due to the replacement of the old Vallon incinerator by the one proposed at Tridel amounts to 2 million € per year (31 €/year per household) for scenario i. The benefit of a 50% reduction of the risk is estimated at half, i.e. 1 million € per year for scenario ii. This latter corresponds to replacing the incinerator of Vallon by one like TRIDEL but without connection to the district heating system, as would be done if the incinerator were to be put outside the city. The difference, 1 million of € per year, is therefore the benefit of locating the incinerator in the city so it can be connected to the district heating system.

4.2.3. Contingent valuation in Barcelona

The main goal of the Spanish exercise was to value the externalities involved with the incineration and landfilling of municipal solid waste in that country. The contingent valuation method (CVM) was applied to estimate people's maximum willingness to pay (WTP) for a change from the current situation to a proposed one where such externalities, and the risks associated to them, would be reduced significantly. The survey, undertaken in Spring 1999, involved 1500 telephone interviews in the Metropolitan Area of Barcelona, subject to a new waste management program that contemplates the above changes. The area encompasses 33 municipalities, with about 3 million people over 17 yeas of age. The survey consists of three parts, the first concerns the incinerator, the second the landfill and the third the entire proposed program for MSW management, called Programa Metropolitano de Gestión de Residuos Sólidos Municipales (PMGRM) del Área Metropolitana de Barcelona, each applied to a sample of 500 people.

Incinerator

For incineration, the simulated change was to develop a new incinerator, with better technology than the two current and obsolete incinerators, resulting in a 50 per cent reduction of the health damages. The reduction of emissions for some of the pollutants was estimated to be equivalent to eliminating the emissions of one out of four cars in the city of Barcelona.

The mean maximum willingness to pay (WTP) was of 39.18 euros (95% confidence interval 36.08 to 42.20 euros) per person and year, for reducing the air pollution from the current incinerators by 50%.

Landfill

For landfilling, the proposed change was to close down the current main landfill of the region, and replace it by another one with better insulation and management, which would receive much less waste due to a planned increase in recycling. This would obviously have a positive impact on the risks for health and the environment, even though no quantitative estimate was provided.

According to the results of the survey, the average respondent would be willing to pay a maximum of 29.40 euros (95% confidence interval 27.20 to 31.60 euros) per year, additional to current payments.

PMGRM

For the third valuation, the proposed change was from the absence of the PMGRM Program (maintaining the status quo) to its full implementation, which implies the ambitious objective of increasing the fraction recycled from 5% in 1997 to 60% in 2006, maintaining the incineration share (but with improved technology) and sharply decreasing the portion of landfilled waste from 67% to 7%.

The overall mean of the individual maximum willingness to pay for implementing the PMGRM is 43.93 euros (95% confidence interval 40.79 to 47.07 euros) per year, additional to what people are already paying.

Results for Payment Schemes

The way Spanish municipalities charge citizens for waste management varies from one place to another. Mostly, the cost is covered through a municipal tax, which can be fixed or vary according to the size of the house or the amount of water consumed. The results of the survey indicated that 60% of respondents thought the current way of charging for waste costs is inadequate. When faced with different payment options, 86% of people found most adequate to pay according to the amount (weight or volume) produced, and 64% would agree with paying according to income. The options with the lowest agreement rates were the current ones, paying according to house size or water consumption. If a pay-as-you-throw scheme was to be implemented, the preferred vehicle of payment would be through special bags (83% agreement), followed by labels (70%), containers of different sizes or the size of the household (66%).

4.2.4. Contingent Valuation of Different Levels of Pollution Control

A third CV study, complementary to the very site specific surveys in Barcelona and Lausanne, was carried out in a part of Paris and a nearby suburb, communities chosen because they are either close to an existing incinerator or close to an existing landfill but where no specific new installation has been proposed. In essence we put the interviewee in the position of a decision maker who has to choose between different levels of pollution control, weighing the costs and benefits of each option.

While a full paper is being prepared for publication, we present here the key elements. The interview begins by providing information about the problems of MSW disposal in France and about possible solutions. Then the interviewee is asked what he/she knows about the waste management system of the local community, including recycling programs, and what he/she thinks of the nuisances and health risks of landfills and incinerators. After these introductory questions the interviewee is asked whether he/she is willing to pay the stated extra cost (see Table 4) for several options that reduce health risks; the costs and benefits of each of these options was explained. This questionnaire was administered in 403 interviews face-to-face at home.

The distribution of answers to the question of technology choice is shown in Table 4. Note that votes for Options 1 to 4 were counted only if the interviewee explicitly agreed with the resulting increase in taxes, as asked in the last question; otherwise the vote was considered to be for the status quo. The results show that most people are willing to pay extra for stricter control technologies if they believe that the health benefits outweigh the costs.

Table 4. The distribution of answers to the question of technology choice. The current cost is 1000 F per household per year for waste collection and treatment. Incremental costs and benefits are in F per household per year. Individuals were asked to vote after being told the incremental costs and benefits for each option. 6.56 F = 1 €.

	Incremental **cost**, above status quo F/yr [a]	Incremental **benefit**, above status quo F/yr	**% of population voting for each option**
Status quo	0	0	25%
Option 1 An incinerator that meets the new European regulation concerning dust and sulfur oxides.	111	136	5%
Option 2 An incinerator that offers the advantages of Option 1 and in addition emits less dioxins.	124	145	6%
Option 3 An incinerator that offers the advantages of Option 2 and in addition emits less nitrogen oxides.	204	201	15%
Option 4 An incinerator that offers the advantages of Option 3 but emits even less nitrogen oxides.	272	272	49%

[a] data provided by the incinerator industry in France [Peyrelongue 1997]

5. Use of Information for Environmental Decision Making

In this Section we comment on the use of these tools and their practical application. We also propose some examples of suitable strategies for the communication of environmental risks. We begin with some general observations about the use of information for environmental decisions.

5.1. General Observations

5.1.1. Spatial allocation of costs and benefits

An irony of the authorization procedure is that the decision is made locally whereas the costs and benefits are incurred over a much wider region. The spatial distribution of health risks due to an installation is readily obtained during the quantification of impacts, and for air pollution one finds [ExternE 1995, Curtiss & Rabl 1996] that most of the risk is imposed on the population living beyond a radius of 25 km, i.e. on the nonparticipants in the decision.

Usually the benefits are also distributed over a wide area: the local benefit of increased employment and business activity is only part of the total, since there will be induced benefits due to increased economic activity elsewhere, often much more important than the local ones.

It is, of course, practically impossible to consult everybody who might be affected. The decision will necessarily be local, influenced mostly by local considerations. The question is whether a decision would change if total costs and benefits where considered rather than just the ones in the local area. There would be no serious distortion of the decisions if on average the local criteria are fairly consistent with those of people elsewhere in the affected region.

5.1.2. Binary Thinking about Risks

One of the difficulties lies in the complexity of the information that needs to be considered. There is a large variety of health risks, each requiring statements such as “the installation emits x tons per year of pollutant A which is estimated to cause y DOLL (days of life lost), with confidence interval z”. Furthermore, one needs to consider this information not just for the proposed installation but also for the most likely alternative(s).

One of the obstacles to a successful communication of risk estimates lies in the innumeracy, so pervasive among the general population and even among some decision makers. Few people have a good sense for quantitative information, and even less are willing to make the effort to understand what the numbers mean in a given context.

Communicating uncertainties is even more difficult than communicating the risk estimates themselves. It would be helpful if the teaching of uncertainty were included in the high school curriculum as is the case in Denmark.

However, the difficulties go beyond innumeracy. Since the human mind is too limited to treat a large amount of quantitative information in full detail, simplified intuitive images are substituted, especially when the subject in question is only of peripheral importance. Faced with a myriad of decisions to be made in everyday life, we do not have the time to analyze each one in full quantitative detail. That is why most people think about risks in simple binary terms: “there is a risk” or “there is no risk”. Only a limited number of risks can be taken seriously at a time; they become a hot topic in the media, to the exclusion of other risks that may be far more important.

5.1.3. Which type of decision at which level?

The decision process involves several administrative levels. In addition to the local government that takes specific decisions whether or not to authorize a proposed project, there are decisions by regional or national government and by the EC that can play an important role. Therefore the question arises: which information should be communicated to whom? The content and style should be adapted accordingly.

The importance of regulations and risk estimates provided by the European Commission is highlighted by the phenomenon of binary thinking. In our case studies we found that many people tend to accept the claim by proposers that if the emission of pollutants respects the regulations of the EC, there is "no significant risk"; the authority of the EC is crucial. Since

very few people understand the nature of small risks, the argument between proposer and opponents usually boils down to "what are the regulations?". If no other country has stricter limits, the opponents have difficulty being taken seriously.

5.1.4. Consultative and deliberative modes of decision-making.

An important distinction must be recognised between the consultative and deliberative modes of decision-making. In a consultation process it is assumed that the stakeholders are known in advance, and that their preferences are pre-formed so that they can be "assessed" via public surveys (including contingent valuation). Consultation exercises are usually based on some form of consultation document or proposal, presented to the known stakeholders or a sample of them, perhaps along with information which is selected and structured by the decision-makers as being relevant to the decision. Most of the work in the present paper is relevant to the consultative model.

However, it is increasingly being recognised that this model may not be appropriate for decisions in the public sector [e.g. Foster 1997, Petts 1997, RCEP 1998, Pinkau & Renn 1998]. Criticisms of the consultation mode of decision-making are that it can exclude important stakeholders from the process and possible options from consideration by prescribing the way the problem is framed, that it can exacerbate existing or potential conflicts, and - perhaps most fundamentally - that the assumption that views and preferences are pre-formed is unsound. An alternative approach, deliberation, engages the stakeholders in a mutual learning process designed and facilitated to develop and elicit their values, and to achieve sufficient mutual understanding to reach agreement on resolving the problem which initiated the process.

5.2. Communication strategies

Communication strategies can facilitate the decision-making at several levels: first by improving directly the information provided to decision-makers, second by improving the climate in which a public inquiry unfolds. Some communication activities are appropriate before or at the start of a public inquiry, others during the inquiry to facilitate a smooth unfolding. Finally, some communication activities are necessary after an installation has obtained authorization.

5.2.1. Outside the public inquiry

It is essential to prepare the population to take a constructive and active share in the public consultation process. Activities of education and information are necessary. They concern notably the environment, the technologies, the authorization procedures and the public inquiry. To be effective, all these activities will have to be coordinated, and adequate financial and human resources have to be made available for the purpose.

5.2.2. Before the public inquiry

At the start of the authorization procedure, before the public inquiry, an opinion poll would be very useful to decision makers, to the promoter of the project and to the author of the

environmental impact study. This poll would allow to identify the state of knowledge among the concerned population and the nature of its concerns about the project.

5.2.3. During the public inquiry

Two missions could contribute to improving a public inquiry: a “guarantor of the public inquiry” and a “counselor to the participation”. These missions could be filled by the same physical person. The guarantor would observe the public inquiry and assure its good execution.

The counselor to the participation could facilitate encounters between opposing actors and help the flow of information between them. He/she should have sufficient scientific competence to understand the technical aspects of the project and of the impact study, in addition to possessing good communication skills, being able to answer questions and facilitate the flow of information between the actors. This could help overcome a deadlock due to mutual incomprehension and distrust.

5.2.4. After the authorization

Communication activities begun during the authorization procedure should not stop when the authorization has been obtained. The different actors will have to continue getting along with each other. The operating permit will have to be renewed periodically. And sometimes the installation will require an extension or modification. Examples of communication strategies after the authorization are the signing of a “charter of good neighborhood”, the specification of a set of commitments, and the creation of a monitoring committee. The monitoring committee should unite the main actors to exchange information on the operation of the installation and its impacts. Beyond purely informational aspects, such a committee would help the different actors understand each others concerns and views.

5.3. Risk Comparisons

Comparisons can be helpful for setting priorities for the protection from risks. But risk comparisons require a fair amount of training and sophistication, and the general public may not understand them. To make the comparisons meaningful, it is important to choose the appropriate metric for quantifying risks. When the field of risk analysis started, life saving measures were quantified in terms of lives saved. In recent years people have increasingly recognized that such an approach is inappropriate: it is life years we can save, not lives since the probability of dying remains unity no matter what we do. Therefore in this research project, all mortality risks have been quantified in terms of life shortening (years of life lost YOLL) rather than simply the number of premature deaths, so as to allow meaningful comparisons between risks that entail very different loss of life, such as car accidents, which can affect people of any age, and mortality due to air pollution, which tend to affect older people or people in poor health.

A complication for the communication of health risks lies in the multiplicity of endpoints, ranging from doctor visits and asthma attacks, to cancers and premature deaths. The presentation of results would be greatly simplified if instead of separate numbers for each endpoint one could show a single equivalent number that expresses the total. Monetary

valuation is an obvious way of doing that, but it is not the only one. In recent years the medical profession has developed a nonmonetary weighting scheme for ranking different morbidity and mortality end points. In fact there are two variants, the QALY (quality adjusted life years) [Weinstein et al 1996] and the DALY (disability adjusted life years) [Murray & Lopez 1996] indicators; they are very similar, the main difference being a greater weighting of the income producing years for DALY.

In view of the controversies regarding the monetary valuation of a premature death, these nonmonetary indicators appear very attractive. We have compared the health damages from air pollution if weighted in monetary terms or according to DALY, and we have found that the rankings are not markedly different [Spadaro 1999]. And in any case, most of the damage is due to mortality. Therefore we consider only mortality (stated in terms of YOLL) in the following comparison of health risks due to incinerators, based on the assumptions and results in Section 3.

The most relevant comparison for incinerators would be with health damages from landfills and other waste management options, but unfortunately we do not have sufficient data (except for the observation of essentially no risk for the present generation from new well managed landfills, see Section 3.1). In fact, the difficulties are more general since most risks are not directly comparable. Mortality risks can differ in the nature of the death (e.g. by accident, by cancer, or by other illness) as well as in attributes that affect the perception of a risk, such as:

- is the risk voluntary or involuntary?
- is the risk natural or manmade?
- to what extent is it associated with an activity that is considered socially desirable?
- how much control does an individual have over the exposure or consequences?

The classification of risks according to these attributes is not always clear. For instance, while radon is a natural substance, the exposure to radon depends on the design and construction of the residence where an individual lives; the individual can control the exposure to radon by making appropriate repairs.

Risks from exposure to air pollutants are involuntary and an individual has little or no control over the exposure, short of moving far away or filtering the air. Although society may benefit from waste incineration, there is little perceived benefit to an individual, unlike driving a car or smoking, which are voluntary risks. The risk is also clearly manmade.

The best format for the presentation of a risk comparison is not obvious. For example, risks could be expressed as life time total for the entire population or as risks during an activity, e.g. actual time of driving a car. Here we show days of life lost for an average person in France, for lifetime exposure at current rates of accident probability and pollutant concentration. Of course, a simple comparison such as in Fig.3 does not distinguish individual differences, for instance between reckless drivers and people who rarely venture into the street. Since the risks of car accidents are usually considered voluntary, we also include in Fig.3 the risk of pedestrians getting killed by cars.

After all these precautionary remarks, the risk estimates in Fig.3 are presented to help put different risks in perspective. They indicate that health risks from MSW incineration are insignificant, if the emissions respect the new regulations proposed by the EC [1994]. These emissions limits are so strict that the contribution of MSW incineration becomes very small

compared to the total current air pollution burden. The latter is not negligible in terms of health risks as the entry for a hypothetical 10% increase in Paris shows.

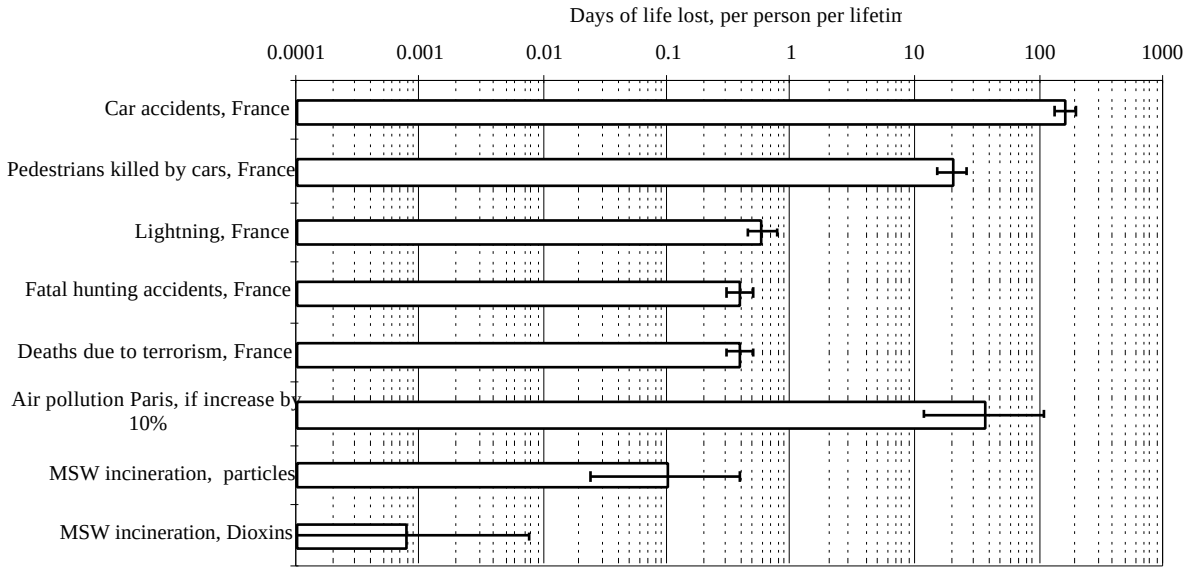

Fig.3. Comparisons of some risks, expressed as days of life lost per person if lifetime exposure at current rate. Risks from air pollution due to MSW incineration assume 500 kg of waste per year per person for average conditions of Europe subject to regulations of EC [1994]. Error bars indicate confidence intervals. Risks other than air pollution from Frémy & Frémy [1996].

Most of the technologies considered in this research project, in particular the incinerators, suffer from a bad image. Of course, once people have been scared by events such as the dioxins emitted at Seveso, it is difficult to "unscare" them. Only gradually and after a long time can the fear of a risk be overcome if the scientific evidence is consistently reassuring, and if risk managers act wisely and industry responsibly. A publication, such as the paper by Rabl et al [1998] on health risks of incinerators, will not single-handedly turn around the general opinion of this technology, but it will be a contribution to the process, especially since it is consistent with the emerging consensus of scientific opinion [Eduljee & Gair 1997, Boudet et al 1999, SFSP 1999, ExternE 1998].

5.4. Cost-Benefit Analysis of Regulations for Incinerators

A very important type of central decision concerns the regulations for emission limits of pollutants. In many countries there has been a movement towards stricter regulations for the emission of pollutants, with the goal of reducing the damage to environment and health. Unfortunately the cost pollution control increases steeply the further one tries to reduce the emissions. Thus the question whether the benefits justify the costs becomes increasingly more important [Arrow et al 1996].

Our quantification of damage costs can be used for a cost-benefit analysis of measures to reduce health risks due to pollution. That has been illustrated in this research project by comparing health damage costs due to waste incinerators with various technological options to reduce the emission of pollution [Rabl, Spadaro & Desaigues 1998]. Despite the large uncertainty of risk estimates, the results show that the new regulations for MSW incineration

proposed by the EC in 1994 appear well justified, in the sense that the net benefit for society is most probably positive.

5.5. Test

In this research project our focus has been on health risks because they tend to be the most hotly contested. In some situations health risks may not really be the primary concern, but they may be used as a powerful argument by people who are opposed to a new installation on other grounds. Such use of health risks as proxy argument can occur because protection of health tends to demand greater respect than protection from increased traffic, visual intrusion and the like.

All installations studied in this research project have been the source of conflicts. In four cases, a solution has been found: in France, the incinerators for Bordeaux and for Lille have been authorized; in Denmark, the power plant Avedøre has been authorized after modification of the initial version; in Spain, the proposed incinerator of Barcelona will be built only if the waste reduction goals are not reached. Two other cases, (in Switzerland and in Belgium), are still blocked; the cases are in court and the outcome is uncertain. The industrial incinerator proposed for a site in the North of France has been abandoned. In Table 5 we describe briefly to what extent the information provided by our research did help or could have contributed toward a resolution.

Our efforts to communicate our estimates of the health risks to decision makers have encountered varying degrees of success, as summarized in Table 5. Generally they have been quite interested in our results, except in situations of controversy. The interest has been especially strong on the part of industry, because they will propose additional installations and so our results are useful for their general planning and communication strategy.

6. Conclusions and Recommendations

Using the impact pathway methodology of the ExternE Project of the EC, we have carried out an assessment of the objective health risks. Our risk comparisons (see Sections 3 and 5.3) demonstrate the wide divergence between objective risks of incineration and the well known perception of these risks by the lay public. This divergence is especially striking with regard to dioxin emissions from clean new incinerators: whereas the fear of these emissions has become a rallying cry of the opposition to incineration in many places, objectively this risk is negligible compared to more familiar sources of air pollution, in particular cars.

Of course, once people have been scared by events such as Seveso, it is difficult to “unscare” them. It is part of human nature to pay more attention to bad news than to good news. Only gradually and after a long time can the fear of a risk be overcome if the technologies are improved, if the scientific evidence is consistently reassuring, and if risk managers act wisely and industry responsibly. The risk comparisons in Sections 3 and 5.3 are offered as one element on the side of scientific evidence; they are consistent with other studies that have been published recently.

In view of this situation it is not surprising that the communication of our results has not been uniformly easy. Generally we found the receptiveness to be inversely related to the degree of controversy in which our contact persons were involved. Public officials in communities with a controversial project tended to be skeptical or even hostile: typically they were afraid that our findings might complicate their conflict.

Table 5. Reactions of key players.

Country **Site**	**Reaction**
Belgium Proposed enlargement of existing Landfill	Close cooperation between proposer and our research team.
Denmark Proposed addition to existing power plant	The Avedøre 2 project was formulated in 1994 and received its final approval in 1998. Our research [a] thus could not directly influence the decision procedures but was seen as a welcome clarification of the issues by several of the players, as they expressed it at the seminar we organized in June 1998. Several of the issues we raised are taken into consideration in the deliberations on possible updates of the formalities regarding environmental impact assessments.
France MSW incinerator for Bordeaux	Industry has been very interested in our results. Local government appreciated our results for the health impacts of dioxins.
France MSW incinerator proposed for Lille	Local government was very cooperative in providing information and data, and was interested in our results.
France Industrial waste incinerator Northern France	Initially we encountered a great deal of resistance, understandable in view of the intense public debate about this project. But eventually the proposing industry became very interested in our results which showed that the most controversial impacts of the installation (health effects of dioxins) would be negligible; they provided much information and urged us to publish our results.
France Waste management for Le Havre	The director of waste management of Le Havre was very interested in our research and we had several meetings with him and his staff to provide input to the planning of the waste management for the city. However, the mayor did not allow this contact to continue, for fear of controversies about waste incineration.
Spain MSW incinerator proposed for Barcelona	Close co-operation with EMMA (Entitat Metropolitana del Medi Ambient) evolved during this research, in both directions. EMMA provided detailed information about PMGRM, and became sufficiently interested to co-sponsor our contingent valuation survey and use our results.
Switzerland MSW incinerator proposed for Lausanne	In view of the tense judicial context of confrontation between communal and cantonal administrations and opponents of the proposed incinerator, we decided not to become directly involved; however, the city of Lausanne has expressed interest in our research.
UK MSW pyrolysis unit proposed for a Borough of London	Both the Borough's officials and Compact Power (the proposer) were very interested in our research. We suggested to add a de-NOx unit to the plant to reduce health damage; this would make it one of the cleanest technologies for MSW. Compact Power agreed, saying that they found the results of the impact pathways analysis very useful as it enabled them to be proactive rather than reactive relative to the best technology. The significance of NOx emissions was something they had not fully appreciated before. They also found the results of the survey of decision-makers very instructive.

[a] Kuemmel, Krüger Nielsen & Sørensen [1997]

By contrast, we encountered great interest among people who were not too directly involved in a particular conflict, for example among industries that expect to sell waste incineration equipment for future installations. The administration of Barcelona was especially receptive: here the decision to build an incinerator had been postponed for several years until the results of a recycling program could be evaluated; the administration interacted closely with our

research project because it found our results very helpful for the formulation of their waste management plan.

At three sites we have carried out a contingent valuation (CV) survey to assess the perception of the risks by the population and to express personal preferences in monetary terms. Each of these CV questionnaires was based explicitly on the site-specific health risk estimates calculated with the impact pathway methodology outlined in Section 3. The CV results indicate a large willingness to pay for reducing health risks due to air pollution. In particular, one of the surveys placed the interviewee in the position of a decision maker who has to choose among different technologies; the result shows that the majority of the population is willing to pay for cleaner technologies if the benefits are expected to outweigh the costs, even though they will have to pay higher taxes.

Finally tools for the communication of risks to decision makers and to the general public have been studied. For graphical forms of risk comparison we have modified the traditional (and controversial) risk ladder format by showing risks in terms of days of life lost rather than number of deaths; also we choose risks that are as comparable as possible. Another type of tool for the communication of risks is the comparison of costs and benefits. As an example we have examined the costs and benefits of the proposed new EC [1994] regulations for MSW incineration. We have found that these regulations appear to be well justified.

This result and the findings of the contingent valuation indicate that continuing efforts, by the EU as well as by national, regional and local governments, to reduce environmental risks even further, are generally (though not always) justified despite the high cost. Such efforts are also an important means of reassuring the population that environmental risks are being managed responsibly.

Acknowledgments

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Glossary

EC = European Commission

ECU = European currency unit = Euro = € (1 € = 6.60 FF ≈ $ 1.00 to 1.25)

M€ = million €

MSW = municipal solid waste

NOx = unspecified mixture of nitrogen oxides, especially NO and NO2

PMd = particulate matter with aerodynamic diameter smaller than d _m (1 _m = 10-6 m).

t = ton = 1000 kg (with subscripts poll for ton of pollutant and waste for ton of waste)

VSL = value of statistical life (also called reference value of life)

WTP = willingness to pay

YOLL = years of life lost (reduction of life expectancy)

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