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Technical Report on Nuclear Accidents and other Major Accidents in Europe: an integrated economic and environmental assessment

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This Report has been prepared by RIVM, EFTEC, NTUA and IIASA in association with TME and TNO under contract with the Environment Directorate-General of the European Commission.

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Abstract

The economic assessment of priorities for a European environmental policy plan focuses on twelve identified Prominent European Environmental Problems such as climate change, chemical risks and biodiversity. The study, commissioned by the European Commission (DG Environment) to a European consortium led by RIVM, provides a basis for priority setting for European environmental policy planning in support of the sixth Environmental Action Programme as follow-up of the current fifth Environmental Action Plan called 'Towards Sustainability'. The analysis is based on an examination of the cost of avoided damage, environmental expenditures, risk assessment, public opinion, social incidence and sustainability. The study incorporates information on targets, scenario results, and policy options and measures including their costs and benefits.

Main findings of the study are the following. Current trends show that if all existing policies are fully implemented and enforced, the European Union will be successful in reducing pressures on the environment. However, damage to human health and ecosystems can be substantially reduced with accelerated policies. The implementation costs of these additional policies will not exceed the environmental benefits and the impact on the economy is manageable. This requires future policies to focus on least-cost solutions and follow an integrated approach. Nevertheless, these policies will not be adequate for achieving all policy objectives. Remaining major problems are the excess load of nitrogen in the ecosystem, exceedance of air quality guidelines (especially particulate matter), noise nuisance and biodiversity loss.

This report is one of a series supporting the main report: *European Environmental Priorities: an Integrated Economic and Environmental Assessment*. The areas discussed in the main report are fully documented in the various *Technical reports*. A background report is presented for each environmental issue giving an outline of the problem and its relationship to economic sectors and other issues; the benefits and the cost-benefit analysis; and the policy responses. Additional reports outline the benefits methodology, the EU enlargement issue and the macro-economic consequences of the scenarios.

Technical Report on Nuclear Accidents and other Major Accidents

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Reports in this series have been subject to limited peer review.

The report consists of three parts:

Section 1:
Environmental assessment
Prepared by J. Lembrechts (RIVM), H. Slaper (RIVM)

Section 2:
Benefit assessment
Prepared by D.W. Pearce, A. Howarth (EFTEC)

Section 3:
Policy assessment
Prepared by D.W. Pearce, A. Howarth (EFTEC)

References
All references made in the sections on benefit and policy assessment have been brought together in the Technical Report on Benefit Assessment Methodology. The references made in the section on environmental assessment follows at the end of section 1.

The findings, conclusions, recommendations and views expressed in this report represent those of the authors and do not necessarily coincide with those of the European Commission services.

Contents

1. Environmental assessment

1.1 Introduction

In this study, the issue ‘major accidents’ (which was the original scope of the environmental problem under concern) has been restricted to nuclear accidents. Oil spills and chemical accidents are excluded from the study because it is hard to extrapolate accidents frequencies for the years to come from accident registries, such as the MARS-database (Kirchsteiger, 1997). In order to properly predict a trend in technological hazards information is needed on (a) location-specific developments in the chemical industry, (b) developments in transport of chemicals and (c) whether these activities will take place close to residential areas.

1.1.1 DPSIR-chain

The safety of nuclear power plants (NPPs) is an important issue in the discussion regarding future scenarios for power generation. The major questions focus on risks regarding the disposal of radioactive waste and the risk of severe accidents with the reactor core. The number of reactors operating below acceptable standards can be considered as the most straightforward *pressure indicator*, which, however, does not allow a quantitative assessment of impacts. That is why this study is aimed at an integrated risk assessment for possible accidental releases from NPPs in Europe. We developed and applied a method which provides a probabilistic evaluation of the chain: sources-dispersion-exposure-risk (see Slaper and Blaauboer, 1995; Slaper et al., 1994; Slaper et al., 1993 for details). The results of the evaluation are risk maps, providing an estimated location-dependent probabilistic death-risk (*impact*) due to accidents with NPPs. The risk maps do in no way reflect the situation following a specific accident. They provide a probabilistic view of the risks involved, and the major areas at risk. The uncertainties associated with this approach will be discussed in paragraph 1.2.4.

1.1.2 Current status of policies

The Commission of the European Communities, CEC, has formulated its Basic Safety Standards for radiological protection (CEC, 1996) in which limits on exposure for members of the public are formulated. Safety criteria for the risk from accidental releases from a nuclear installation and limits on the probability of occurrence of large releases of radionuclides, however, have not been formulated at the European level. With respect to nuclear safety in Eastern Europe, the CEC stresses the importance of resolving safety issues in the context of the EU accession process.

The International Atomic Energy Agency, IAEA, in its Basic Safety Standards describes basic principles of radiation protection for ‘normal’ and ‘potential’ exposures (IAEA, 1996). Normal exposures are defined as predictable exposures, whereas potential exposures are defined as unexpected but feasible exposure scenarios, i.e. when there is no certainty that an exposure will in fact occur. They occur for example as a consequence of equipment failure, design or operating errors or unforeseen changes in environmental conditions. In the Standards the restriction of the dose delivered is given as the means for controlling normal exposures. The primary means for controlling potential exposures is by good design of installations, equipment and operating procedures intended to restrict the probability and magnitude of unplanned exposures. Nuclear installations are furthermore typically subject to more specific technical and other requirements such as those issued under the IAEA Nuclear Safety Standards (IAEA, 1988).

The IAEA Standards comprise the basic requirements to be fulfilled in all activities involving radiation exposure. They do not entail any obligation for States to bring their legislation into conformity with them, nor are they intended to replace the provisions of national laws or regulations. They are aimed rather to serve as a practical guide.

The Operational Safety Review Team (OSART) programme is an IAEA service meant to conduct in-depth reviews of operational safety performance at individual nuclear power plants at the request of the government of the host country. The provision of nuclear safety assistance and the progress of the nuclear safety efforts is regularly evaluated (e.g. IAEA, 1999).

1.2 Methods

1.2.1 Estimating impacts

The estimation of accidental releases requires an evaluation of accident probabilities and subsequent release scenarios for all NPPs. A number of studies have assessed the potential risk of a nuclear accident for individual reactor types. The method used most widely to determine risk is the Probabilistic Safety Assessment (PSA) which identifies and quantifies accident sequences leading to a core damage accident. Clearly risk probabilities will vary between different reactor designs and ages. Detailed safety analyses are not available for many of the 213 European power plants, that were operational in 1992 (Atomwirtschaft, 1992). Therefore, a generalisation was made to estimate accident probabilities and probabilistic releases. Reactor design and redundancy of safety features led to estimated probabilities of severe damage to the reactor core (Eendebak et al., 1992). The nuclear power reactors were classified in four accident probability classes: 10^{-3}, 10^{-4}, 10^{-5} and 10^{-6} per year (see Table 1.2.1). The 213 include Eastern European reactors that make up the majority of higher risk facilities. By 1996 the total had changed to 210.

Table 1.2.1 European Nuclear Reactors categorised by risk probability

Risk category (per reactor per reactor year)	Number of reactors 1992	Number of reactors 1996
10^{-3}	25	25
10^{-4}	146	142
10^{-5}	39	40
10^{-6}	3	3
Total	**213**	**210**

Source : Slaper et al., (1994), Slaper and Blaauboer (1995)

The risk categories and probabilities used by Slaper and Blaauboer are supported by other studies on individual European reactor risk probabilities. A study on two French reactors, a 900 MW Pressurised Water Reactor (PWR) and a 1300 MW PWR, indicated the following risk probability of a major core meltdown (World Bank, 1991):

900 MW	4.95×10^{-5} per reactor per reactor year
1300 MW (newer)	1.08×10^{-5} per reactor per reactor year

A German study into a Biblis-B PWR reactor found the risk probability of severe core damage to be as large as 3 10^{-5} per reactor per reactor year (World Bank, 1991). In addition Haywood et al (1991) state that the design specification for new UK reactors includes a risk probability of 10^{-6} per reactor per reactor year.

Core damage does not necessarily lead to large releases from the plants. This is taken into account by considering four different release scenarios in relation to the concept of the reactor design. Eendebak et al. 1992 provided various release scenarios, in line with NUREG-1150 studies. As an example: a core damage accident for the western type reactors of the LWR-type leads to different release probabilities for different accident scenarios and for different nuclides: 2% probability that 5% of all Cs is released, 2% probability that 20% of it is released, 20% probability that 1% is released, and 76% that 0.001% is released. For the LWGR ('Chernobyl') reactor types a large release is expected in 100% of the core damage accidents in view of the lack of containment. By May 1998, Eendebak indicated that these release scenarios are still usefull estimates.

A source-dispersion-exposure-risk model, called RISKA, is used to estimate the excess cancer mortality from accidental releases. Atmospheric dispersion and deposition is calculated applying a probabilistic air dispersion model. Radiation exposure of the population can occur through inhalation, external exposure and ingestion of contaminated food products. A full description of the model is given in Slaper and Blaauboer (1998).

The exposure is calculated for a lifetime follow up period of 70 years and excess risks are expressed in terms of excess cancer mortality due to excess radiation doses received. Short-term deaths in the direct vicinity of the power plants are not included. Baseline risk estimates are provided for an adult rural population, eating fresh products with a food consumption, which is regarded at the high end of the consumption range. The group considered is assumed to spend 30% of the time outdoors. Countermeasures such as sheltering, evacuation or food bans are not considered. The conversion coefficient used to translate the dose estimate into death risk is 2.5% per Sievert.

For 8000 receptor locations in Europe, the excess cancer death risks due to possible accidental releases from the operational nuclear power reactors are calculated.

1.2.2 Scenarios

For the present study four situations have been modelled. The first two represent the situation in 1992 and 1996. Compared to earlier studies (Slaper and Blaauboer, 1995), the coordinates of a number of sites, most notably Ignalina, Lithuania, have been corrected. The now used coordinates are derived from the PRIS-database of the IAEA.

The third situation, the BaseLine scenario, for the year 2010 was made assuming (1) all NPPs will be closed after a commercial lifespan of 35 years, (2) all NPPs that were ordered or under construction in April 1998 will be operational in 2010, and (3) present long term national policies will not change. The Baseline scenario assumes a decrease in the number of high risk category reactors (10^{-3}, i.e. with an average of 1 major accident in 1000 years) from 25 to 21, and a decrease (was increase) of 146 to 134 in the number of mid-risk (Table 1.2.2). Since the change in number of reactors per risk category in 2010 is small compared to the situation in 1992 no risk values have been computed for the 2010 BaseLine scenario.

For the fourth scenario, the TD scenario, it is assumed that there is a gradual reduction in the number of high risk category reactors (10^{-3}) from 25 to 2 by 2010 (see Table 1.2.2). This reduction is partly due to the fact that 4 power plants will be closed after a commercial lifespan of 35 years. Two reactors in the 10^{-3} probability class are supposed to be upgraded before 2000 (Bohunice-1 and 2 in Slovakia) and 15 others by the year 2010. Kozloduy-2 in Hungary and Kola-2 in Russia, will be closed down in 2010 or shortly thereafter.

The 15 most hazardous NPPs to be upgraded between 2000 and 2010 are: Kozloduy 3 and 4 in Bulgaria, Ignalina 1 and 2 in Lithuania, and Sosnovi Bor 2–4, Kursk 1–4, Smolensk 1–3 and Chernobyl 3 in the Ukraine. In the TD scenario they will be in the probability class 10^{-4} a^{-1} by the year 2010. The overall result is an increase in the number of mid risk category reactors (10^{-4}) from 146 to 153. NPPs in the high risk category do not exist in the EU15. A full list of all NPPs in Europe and their associated accident risks can be found in Slaper (1994).

Table 1.2.2: TD and Baseline scenarios

Risk category	Number of reactors		
	1992	2010	
		Baseline	TD
10^{-3}	25	21	2
10^{-4}	146	134	153
10^{-5}	39	36	36
10^{-6}	3	3	3
Total	**213**	**194**	**194**

Although legislation exists with respect to safety, no sustainability or policy targets exist that can be evaluated by our models. With respect to NTPS no additional computations were performed. It is by no means clear how an NTPS should look like, nor is it possible to perform a satisfactory cost-benefit analysis.

1.2.3 TD policy package

The TD-measure applied is given in Table 1.2.3. Closing NPPs is not considered as an option. The reactors involved are specified in section 1.2.2.

Table 1.2.3 Extend Community Safety culture to former Soviet Union and Central and Eastern European Countries (CEECs)

Costs	(a) € 4.7 to 9.4 million per NPP to compose a Probabilistic Safety Assessment (PSA). (b) Implementation costs of safety study will vary widely per NPP from tens to hundreds of millions of €s. However, the priority study will be based on the PSA for the Ignalina NPPs, in which costs are estimated to be € 57.3 million per NPP.
Press. red.	Risk of accidents
Resolution	NPP
Remark	The PSA for Ignalina does not mention safety levels explicitly, but it suggests that current safety levels could well be below 10^{-3}. Nevertheless, in the priority study it is assumed that PWR-V230 and LWGR reactors are upgraded to a security level of an PWR-V213, i.e. the probability of a severe damage to the reactor is reduced from 10^{-3} to 10^{-4} per year and a limited containment is build reducing the accidental release of radioactivity.

1.2.4 Uncertainties and caveats

An indication of the overall uncertainty involved, is obtained by assuming that various errors in the chain are independent, and lognormally distributed (Slaper et al., 1994). Largest uncertainties are due to the estimation of accident probabilities, accident scenarios and nuclide releases. The overall risk is composed of a multiplication of the various components in the chain. The overall estimate of the uncertainty factor (at 95% significance) is 15 in Western Europe and 20 to 25 in Eastern Europe (up as well as down).

Accident probabilities and release scenarios were obtained from nuclear safety specialists at KEMA, the Netherlands (Eendebak et al., 1992). In view of our study, Eendebak was asked to report in May 1998 on expected changes compared with his 1992 report. He expected improvements in the core damage frequencies for the WWER 440/V230 reactor type, which were originally in the highest risk group: 0.001 per year. According to his report an upgrade to 0.0001 should be possible in the near future, following improvements to these reactors. An overview of presently available PSA-studies for Eastern European reactors has recently been reported (Enconet, 1999):

	Enconet estimate	Estimate used in this study
WWER440/V230	five PSA's mean 0.0013, median 0.00089 per year	0.001 per year
WWER440/V213	seven PSA's mean 0.000294, median 0.00018 per year	0.0001 per year
WWER 1000	five PSA's mean 0.000279, median 0.000076 per year	0.0001 per year

The Core Damage Frequencies assumed in this study for the above reactors are on average in full agreement with the findings in a recent overview of PSA-studies for Eastern European reactors (ENCONET, 1999). Limited new information is available for the LWGR/RBMK reactors (the Chernobyl type of reactor). The overall probability of core damage for the European reactors is in line with the observed core damage incidents observed in the reactor history (Slaper and Blaauboer 1995).

When completely accounting for the ICRP-60 (ICRP, 1991) changes overall risk is increased with a factor of 2.5. Another source of variation in the risk assessment can be due to the definition of the risk-group under consideration. Small children at the time of an accident are estimated to have 3 to 4 fold higher risks than the risk-group considered here.

As indicated before, the analysis is limited to risks of severe accidents with the reactor core. It, however, does not include acute victims, which can occur in the close vicinity of the reactor (closer than 5 to 10 km).

The costs for upgrading unsafe reactors are highly dependent on the type and characteristics of the reactor and its operation. WISE (1998) gives cost estimates varying between DM 500 to 2000 million. Furthermore, the VOSL and the effort required to neutralize the unacceptable environmental effects of an accident is much more difficult to quantify. The latter not only depends on reactor and release characteristics, but, for example, also on the (agricultural) economics of the area affected. As has been said previously, this study furthermore has been limited to mortality estimates and related costs and not to morbidity, costs related to evacuation and decontamination, etc.

Though very uncertain the estimates are a good starting point for a first comparison of accident costs and costs for upgrading power plant safety. When doing so, one especially has to keep in mind that adverse effects have been underrated.

1.3 Results

1.3.1 Baseline

Ingestion is the major dose-contributing pathway (± 50% of the total dose). External exposure contributes around 33% (primarily due to Cs-137), inhalation around 10% and external exposure from the cloud 3% or less. Thus, deposition related contributions amount to around 85% of the total dose. For the adult population 70% of the 70-years follow-up dose will be received in the first year. The two major dose contributing nuclides in the various source terms are I-131 and Cs-137. Together they are responsible for 60–75% of the total dose. In addition Cs-134 contributes approximately 15%, and the 54 other nuclides less than 5% each, and no more than 25% in total.

The risk estimates are plotted on a map of Europe. Two risk maps are obtained: the first one (Figure 1.3.1) representing the situation of 1996, which is assumed to apply for the whole period 1990 to 2010 in the baseline scenario, and a second one (Figure 1.3.2) presenting the 2010 situation assuming that Eastern European reactor types have a safety level which is comparable to that of Western European reactors. (see section 1.3.2).

The estimated excess death risk provided for Europe shows a large variation. This risk is less than $1\ 10^{-8}$ per year in Iceland and south-western parts of Spain and Portugal. It increases from west to east: $2\ 10^{-8}$ per year in Ireland, $3\ 10^{-8}$ to $10\ 10^{-8}$ per year in England and large parts of France, Italy and Norway, around $10\ 10^{-8}$ to $30\ 10^{-8}$ per year in the Netherlands, Belgium, Germany and large parts of central Europe. A risk over

100 10^{-8} per year is found in large areas of the former Soviet Union, including the Baltic states, Belarus, Russia and Ukraine. In these countries a risk of 1000 10^{-8} per year is exceeded in the smaller regions around the nuclear reactors.

Nuclear power reactors in the Eastern European countries dominate the estimated risk pattern and contribute at least 40 to 50% to the average risk in the Western European countries. Because very little information is available on the safety of NPPs in Eastern Europe, risks could easily be (much) higher or lower.

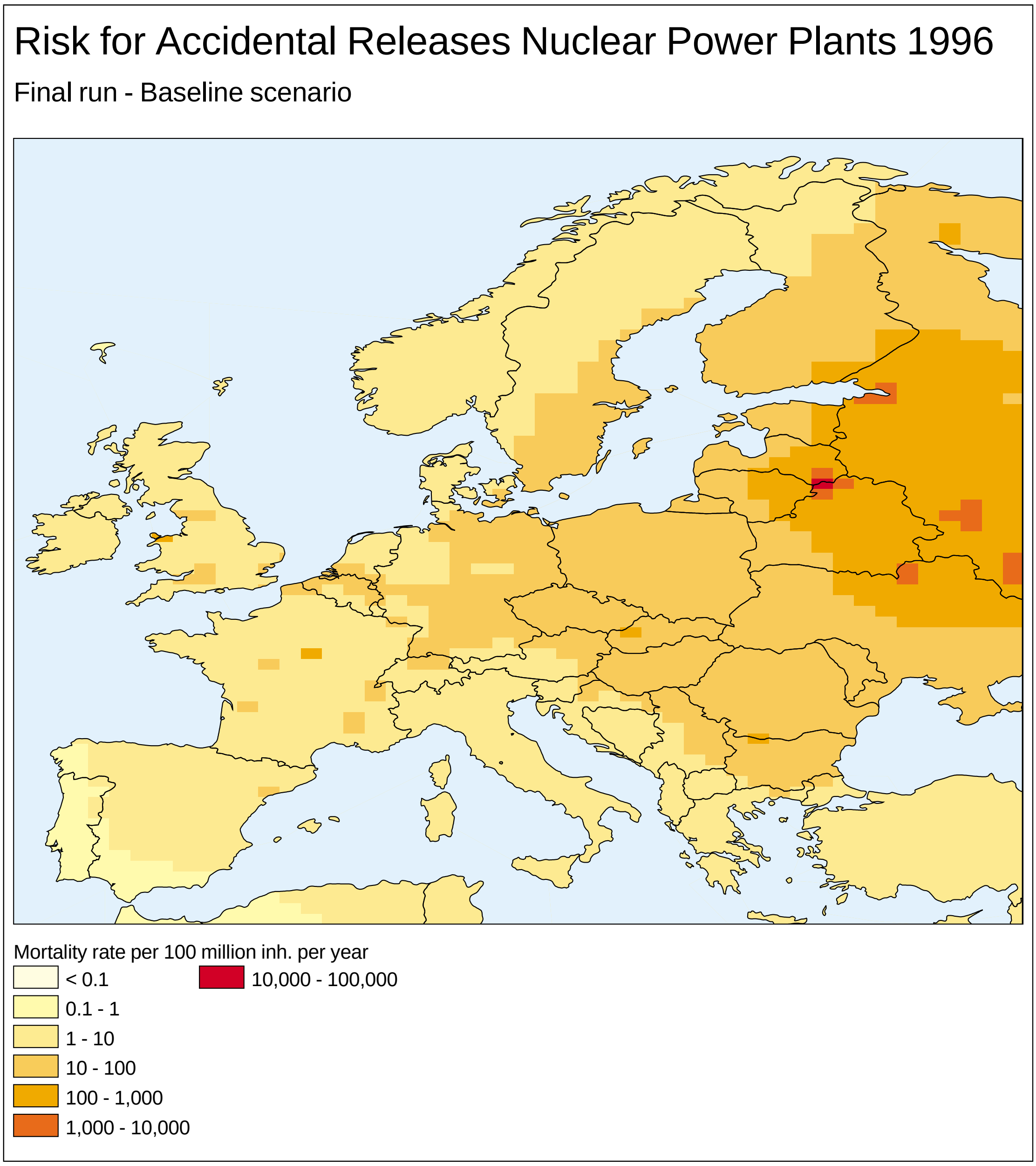

Figure 1.3.1 Excess mortality rate in the baseline, based on the situation in 1996.

1.3.2 TD-scenario

The Technology Driven (TD) scenario shows how overall risks will be reduced if all but two high risk NPPs were upgraded to a lower risk category. Whether this is actually possible, is not easy to determine.

Improving the reactor safety in Eastern European countries leads to considerable reductions in the estimated risk (see Figure 1.3.2). The average mortality risk in the EU is expected to decline to 3.2 cancer deaths per 100 million people per year in 2010, compared to the 10.2 in 1990. These numbers are low but, as indicated above, it should be realised that deaths in the short term are excluded. Large variations exist throughout Europe too, with the largest reductions in cancer deaths found in Central and Eastern Europe. In fact, for all European countries combined, the average risk is decreasing from 50 deaths per year per 100 million to 5.5; a difference of almost 90%.

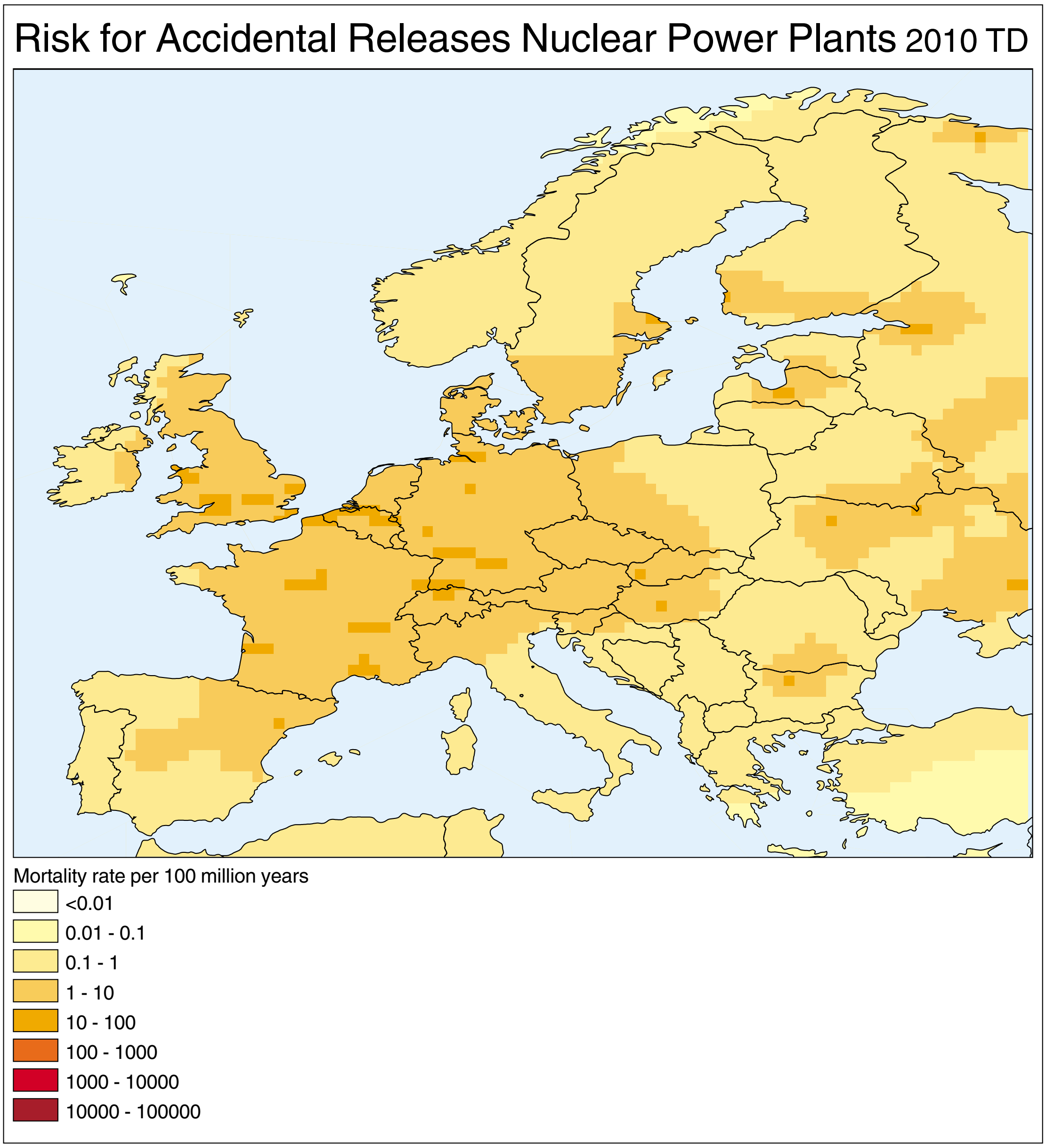

Figure 1.3.2 Excess mortality rate in 2010 in TD-scenario.

1.3.3 Costs

The analysis of nuclear power risks suggests strongly that policy should focus on reducing risks in Central and Eastern Europe. Various policy measures are possible (see Table 1.3.1).

The Baseline scenario assumes that reactors over 35 years of age will be closed by 2010, resulting in 19 fewer reactors (see Table 1.3.2). Some of these closures would occur without explicit policy measures, but some closures would occur because of deliberate policy. Those closed deliberately because of policy will have to be replaced. Those closed 'naturally' will have replacement sources already accounted for. If, say, half the reactors are closed prematurely, then the relevant cost of the baseline scenario would be some € 5600 million over 20 years, allowing € 700 million to close each plant and produce replacement fuel sources.

Table 1.3.3. Costs of measures per plant to reduce risks in NPPs of CEECs.

Measure	Cost € million	Risk reduction of core meltdown
Improved management and safety measures	4 to 8	Up to a factor of 10 (ENCONET, 1999)
Plant modification	10 to 200	By a factor of 10
Emission control in the event of meltdown	More than 200	n.a.
Decommissioning	150 to 700 plus cost of replacement supply	

The TD scenario requires that, in addition to the Baseline plant closures, 19 reactors be taken out of the highest risk category (10^{-3}) and put into the next risk category. We have taken € 62.5 million per reactor as the cost of making the necessary modifications (see table 1.3.3). These costs are applied to 17 NPPs only, because it is assumed that the two oldest NPPs, Kozloduy-2 in Hungary and Kola-2 in Russia, will be closed down in 2010 or shortly thereafter. Also, it is known that before 2000 only 2 NPPs, Bohunice 1 and 2 in Slovakia, were upgraded, which costed € 130 million [EIS, 1999]. Therefore, in the period 2000 to 2010, 15 NPPs will have to be upgraded in the TD scenario, which costs about € 940 million. Assuming these costs are distributed equally over the 10 years period it would amount to some € 94 million per annum, which compares to the € 44-115 million annual benefits (see table 8), i.e. benefits and costs are about equal for the TD scenario compared to the Baseline scenario. More problematic is the Baseline scenario itself since this costs some € 280 million per annum (€ 5600 million over 20 years as an annuity). It seems unlikely that benefits will exceed this sum. Stanners and Bordeau (1995, p.540) note that between 1990 and 1994 the EU contributed over € 400 million to a special fund designed to assist Central and East European countries with safety measures in high risk reactors. Given the high risk reductions obtainable from modest measures, this particular expenditure would appear to have a high benefit-cost ratio. The costs of extensive closure do, however, appear to be larger than the benefits. Once disaster-aversion is included, however, benefits would greatly exceed costs.

1.4 Conclusions

The aim of environmental policies is the reduction of man-made environmental risk, both for regular releases and for accidental releases. This study provides a probabilistic evaluation of individual death risks due to possible accidents with NPPs in Europe. The risks evaluated in this study are restricted to radiation induced cancer deaths, thus acute radiation victims, which can occur in the close vicinity of the reactor (closer than 5 to 10 km), costs for evacuation and decontamination, etc. are not included. An other aspect not covered in the present evaluation is the fact that a large-scale accident, when occurring, could lead to a disruption of the society.

Although the risk evaluation does not cover all aspects of risks involved in accidental situations, it serves the purpose that risks can be put in perspective and made comparable to risks from regular emissions. The overall average uncertainty is considerable. The main contributor to the uncertainty is the lack of knowledge on accidental probabilities and releases, especially for the Eastern European reactors.

The Eastern European reactors are presently dominating the calculated risks in Europe, and substantial lowering of the overall risks could be achieved if the safety measures and procedures which apply to Western European reactors are also implemented for Eastern European reactors. In that case the average risk in Western Europe is reduced nearly twofold, and in Eastern Europe the risk reduction can amount to more than a factor of 100. Thus quality of safety design can reduce risks considerably.

The safety of NPPs is said to be an important issue in the discussion regarding future scenarios for power generation. Accidents with NPPs, however, are just one element in the judgement of nuclear power generation and in balancing its pros and cons. Problems associated with other areas of the nuclear fuel cycle should be considered as well and compared to those of other fuel cycles. Examples are the production of waste and the emission of greenhouse gases and acidifying substances. The European ‘ExternE’-study (CEC, 1995b) is an example of a project in which costs and benefits of various energy options have been compared more extensively in order to stimulate the comparison of damages to a wide range of receptors and the discussion on optimising the abatement of important environmental problems related to energy production.

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2. Benefit assessment

2.1 Introduction

To a limited extend, both this section and the next discuss not only nuclear accidents, but also other major accidents, like oil spills. For convenience of the reader, all references made have been brought together in the Technical Report on Benefit Assessment Methodology.

2.1.1 Public opinion

Eurobarometer (1995) ranks 'major accidents' (which also includes nuclear accidents) as the seventh most serious environmental problem. This ranking is fairly consistent with the results from other surveys, in which accidents are considered an issue of intermediate importance. This ranking is also is accordance with expert opinion (see below).

2.1.2 Expert opinion

GEP et al., (1997) include accidents under a general category which includes both nuclear risk world-wide and nuclear risk from Eastern Europe and Russian nuclear plants. The category is quite broad, since it also includes nuclear and industrial waste management. Nuclear accidents are ranked fourth as a priority issue world-wide, with 21% of respondents ranking it as the first or second most important issue. However, the ranking by European respondents was sixth, much lower than the global average. All respondents show a decreasing concern for this environmental issue as the time horizon extends to the year 2050.

2.2 Benefit estimation

The main findings of the analysis are summarised in Table 2.2.1.

Table 2.2.1 Summary of benefit estimates

Benefit of TD scenario over Baseline in 2010 € million		Confidence
Mortality only: Mortality and morbidity	135 - 362 225 - 603	Moderate: VOSL figure valid due to age distribution of mortality due to a nuclear accident
Including disaster aversion Mortality only: Mortality and morbidity	 6750 - 18100 11250 - 30150	Underestimate: non-health effects excluded

Suitable indicators for future research in this area would be, cancers by type and per time period.

Methodology: valuation of health impacts to human health

The approach adopted to value the environmental costs of nuclear accidents involves a three stage process.

1) risk probabilities of a major nuclear accident, involving reactor core damage, are assessed.

   Clearly risk probability varies between reactors of different design and age. Therefore, the 217 European reactors are categorised using four risk probabilities ranging from 10^{-3} to 10^{-6}.

2) costs of damage due to the accident are estimated; (human mortality only).

The "value of a statistical life" (VOSL) is used in conjunction with the number of deaths due to a simulated nuclear accident involving the release of 10% of the reactor core inventory.

3) the first two stages are combined to provide a total probabilistic cost of nuclear accidents in Europe.

The following formula is used for each reactor risk category with each sub-total then being summed to provide the total European probabilistic cost of a nuclear accident for the year 2010.

‘risk probability’ *x* ‘number of reactors in risk category’ *x* ‘estimated accident cost’

Risk Probabilities

A number of studies have assessed the potential risk of a nuclear accident for individual reactor types. The method used most widely to determine risk is the Probabilistic Safety Assessment (PSA) which identifies and quantifies accident sequences leading to a core damage accident. Clearly risk probabilities will vary between different reactor designs and ages. We group European reactors into broad risk probability categories.

RIVM, developing the earlier analysis of Slaper and Blaauboer (1995) categorise the 213 European reactors operating in 1992 as shown in Table 2.2.2. The 213 include Eastern European reactors that make up the majority of higher risk facilities. By 1996 the total had fallen to 210.

Table 2.2.2 European nuclear reactors categorised by risk probabilities

Risk category (per reactor per reactor year)	Number of reactors 1992	Number of reactors 1996
10^{-3}	25	25
10^{-4}	146	142
10^{-5}	39	40
10^{-6}	3	3
Total no of reactors	**213**	**210**

Source : RIVM

The risk categories and probabilities used by Slaper and Blaauboer are supported by other studies of individual European reactor risk probabilities. A study of two French reactors, a 900 MW Pressurised Water Reactor (PWR) and a 1300 MW PWR, indicated the following risk probability of a major core meltdown (World Bank, 1991):

900 MW	$4.95 * 10^{-5}$ per reactor per reactor year
1300 MW (newer)	$1.08 * 10^{-5}$ per reactor per reactor year

A German study into a Biblis-B PWR reactor found the risk probability of severe core damage to be 3 10^{-5} per reactor per reactor year (World Bank, 1991). In addition Haywood et al., (1991) state that the design specification for new UK reactors includes a risk probability of 10^{-6} per reactor per reactor year.

Estimating accident costs

The study conducted by the Centre d'Etude sur l'Evaluation de la Protection dans le Domaine Nucleaire (CEPN, 1992) provides the most extensive research into the impacts of a major nuclear accident. The study simulates an accident in a French 900 MW CP1/CP2 series reactor. It assumes the equivalent of 10% of the core inventory is released. To estimate the dose-response function and valuation components the study divides the accident effects into three geographic / time categories:

Near Early (NE):	short term doses and early effects close to site
Near Late (NL):	lifetime doses and late effects close to site
Far Late (FL):	lifetime doses and late effects away from site

Within each category a number of sensitivity scenarios are constructed. This provides a wide variation in the estimated accident effects. For this study the mean and the 95% fraction estimated accident effects are used for sensitivity.

CEPN (1992) address three main impacts these are: human health, human health treatment and evacuation / decontamination. For the purpose of this study of the environmental costs of nuclear accidents only the human health impacts are considered. The CEPN study estimates the number of human mortality and morbidity cases for a 200 year period after the accident. The CEPN human mortality estimates are used in conjunction with the estimated VOSL to provide the estimated cost of a nuclear accident. The CEPN mortality estimates are shown in Table 2.2.3. Morbidity costs are not included in this study as no breakdown of time scale for cases is available and discounting over the 200 year period is therefore not possible. This omission means the health cost estimate is an underestimate.

Table 2.2.3 Mortality estimates over a 200 year period for a major nuclear accident

Geographic / time category	Number of mortality cases	
	Mean	95% Fraction
Near Early	9	32
Near Late	3, 424	7, 779
Far Late	11, 376	30, 944
Total	**14, 809**	**38, 755**

Source : CEPN (1992)

The estimated VOSL used is € 3.31 million per life (1997 prices). It is assumed that Willingness To Pay (WTP) values have a rising relative price through time that is linked to per capita income. The VOSL is adjusted by 0.5% per annum, over the 200 year period that mortality cases occur.

Scenario analysis

The Baseline and TD scenarios are determined using the following assumptions.

In the Baseline scenario it is assumed that there is a small decrease in the risk configuration of reactors between 1992 and 2010: a decrease in the number of high risk category reactors (10^{-3}) from 25 to 21, a decrease of 146 to 134 in the number of mid-risk reactors (10^{-4}) and a decrease in the number of low risk category reactors (10^{-5}), from 39 to 36. In the TD scenario it is assumed there is a gradual reduction in the number of high risk category reactors (10^{-3}) from 25 to 2 by 2010. Over the same period it assumes there is an increase in the number of mid risk category reactors (10^{-4}) from 146 to 153, whilst the total number of reactors decreases as it is assumed that all plants will be closed after a commercial life-span of 35 years. As a result, the overall European risk level falls. Table 2.2.4 illustrates the two scenarios.

Table 2.2.4 Baseline and Technology Driven scenarios

Risk category	Number of reactors		
	1992	2010	
		Baseline	TD
10^{-3}	25	21	2
10^{-4}	146	134	153
10^{-5}	39	36	36
10^{-6}	3	3	3
Total reactors	213	194	194

A monetary estimate of mortality due to a nuclear accident happening, with certainty, in each year between 2000 and 2010 is estimated. The change in probabilistic risk of a nuclear accident happening in each year is found by subtracting the risks of an accident in the TD less the Baseline. The monetary benefit of the TD is found by multiplying this change in probabilistic risk by the value of a nuclear accident for each year between 2000 - 2010. Each is discounted (base year 1999) using the 4% discount factors to match that used to discount the mortality costs over the 200 year period. They are then aggregated to give a present value of benefits of TD over Baseline in 2010.

Results

The benefit of the TD scenario over the Baseline scenario in 2010 is given in Table 2.2.5. This is the avoided probabilistic cost, in terms of human mortality, of a major nuclear accident happening in Europe between the years 2000 - 2010. The results use the mean fraction estimates of mortality in the CEPN simulation, the discount rate is 4% over the 200 year period and the results do not include a disaster aversion factor for the VOSL.

The sensitivity analysis reports results using the 95% fraction estimates of mortality in the CEPN simulation. It also gives valuations of mortality costs discounted using discount rates of 2% and 6% over the 200 year period.

Table 2.2.5 Benefit of TD: € million

	Benefit of TD scenario
Mean 4% discount rate	135

Note: this is a present value of avoided probabilistic mortality cost of nuclear accident happening in each year 2000 - 2010. Discount rate 4%, base year 1999.

The TD scenario has significant benefits over the Baseline scenario. As would be expected these benefits are increased to € 362 million, as the mortality impacts become more severe, as in the 95% fraction (see Sensitivity analysis).

'Disaster aversion' in accident damage estimates

It is well known that people are more averse to accidents in which a significant number of people die, or are injured, compared to a series of accidents each of which has a few fatalities but where the total fatalities are the same. This is known as ‘disaster aversion’. It is less obvious how this aversion should be accounted for. One issue is whether public risk aversion should be accounted for at all – perhaps expert opinion should suffice. Using expert opinion alone would be inconsistent with the tenets of cost-benefit analysis. On the other hand, it is suggested that public risk assessments could imply nuclear risk damages 100 times or more those implied by expert assessments (Krupnick et al., 1993). Krupnick et al., also suggest that disaster aversion might result in damages 50 times the value of expected damages (i.e. actual damage multiplied by the probability of that damage occurring).

The formula used to estimate the monetary benefit of moving from the Baseline to the TD scenario is based on an *expected value* (EV) approach to representing risk: i.e.

$$EV.€ = p.D.VOSL$$

Where p is the probability of a nuclear accident, D is the number of human mortality cases and VOSL is the 'value of statistical life'. There are several problems with such an approach, these are;

- it is ‘ex post’ in that it assumes an accident happens with certainty, works out the damage, and then multiplies the damage by the probability of it happening. Whereas, an ‘ex ante’ approach would look at people’s WTP to avoid an accident and this may not give the same result (dread, fear etc. would be relevant in the ex ante approach);

- it considers only mortality and ignores morbidity, land sterilisation and ecological damage;

- the probabilities tend to be expert based, i.e. they are not the probabilities perceived by those at risk. This is a complex problem because we know lay people exaggerate actual risks. But there is evidence that experts may similarly be biased (Galy, 1998). It is not therefore clear which assessment of probabilities we should use;

- it ignores risk aversion. It is well known that EV approaches imply risk neutrality.

Disasters are better represented by risk-aversion and the standard risk aversion model is the expected utility model (EU). The EU model is basically:

$$EU = p.U(A) + (1-p)U(NA)$$

Where A is 'accident' and NA is 'no accident' and U(A) would be negative. Which ‘p’ is used, remains undetermined so we can adopt the probabilities we have since it is not clear how they should be modified.

There is a debate over how to deal with accidents in which many people are at risk, and how to account for the fear and anxiety of certain risks. Early work by Jones-Lee (1985) suggests that context matters (underground, train, road) but scale might not (i.e. numbers of people dying). Other literature tends not to distinguish between scale and context, conflating the two. In the context of nuclear risks, however, it is hard to believe that scale does not matter – 100s or maybe 1000s of people are at risk, not the tens or so in transport accidents. Several recent studies explore the relationship between disaster aversion and expected values:

Eeckhoudt et al., (1997) use an expected utility model to get the result that damage with disaster aversion is 20 times damage based on expected values.

Ascari and Bernasconi (1997) adopt different functional forms and obtain multiplication factors of 1 to 2.4 in one case, and substantially greater numbers for another case: 140-300 for risks with probability of 10^{-5} and 660-1430 for a probability of 10^{-6}.

Approaches based on risk aversion ‘rules of thumb’ produce multiplication factors of 300-2300 (Pearce et al. 1993) and 22-367 (Infras / Prognos, as reported in ExternE, 1999).

ExternE (1999) is of the view that the larger estimates in the Ascari-Bernasconi study are to be preferred (i.e. 140 -1430). If so, they accord well with the rules of thumb surveyed in Pearce et al., (1993). The effect of using such multipliers for the present assessment of benefits would be dramatic, turning expected values of benefits € 135 million in 2010 into € 19 to 193 billion.

In this analysis we suggest adopting 50 as a conservative multiplier. This would increase the expected benefits of moving from the Baseline to the TD to € 6.7 billion (mortality only).

Morbidity

Galy (1998) suggests that fatal cancers account for around 60% of all health impacts in monetary terms. Therefore to account for morbidity effects the benefit estimate should be raised by a further 1.67 times to € 225 million. Combining this estimate for avoided mortality and morbidity with the disaster aversion factor discussed above gives a benefit estimate of € 11.2 billion.

We conclude, that when the mortality and morbidity effects of a nuclear accident are combined with a 'disaster aversion' factor, the social costs of a nuclear accident in Europe would be highly significant.

Other major accidents

Nuclear accidents are but one type of major hazard. Apart from 'natural' disasters, there are inevitable risks attached to economic activity. The two most notable are chemical risks and oil spills. Table 2.2.6 shows estimates of damage from selected major accidents in Europe but also including the *Exxon Valdez* incident in Alaska. Clean up costs can be added to the damage costs, although in some circumstances it is clear that clean-up costs have been incurred for no particular benefit - 'natural' cleansing mechanisms have also been at work. Table 2.2.6 suggests that a single accident may cost some € 200 to 400 million in damage and clean-up costs.

The relevant cost-benefit comparison is between preventative measures and the total damage and clean-up costs. The benefit would be the expected value of the avoided damage and clean-up costs since not all preventative costs would necessarily result in avoided accidents. But rapid response arrangements would also help to reduce the severity of incidents even if they cannot be prevented. The UK Coastguard Agency has estimated that the costs of stationing year-round salvage tugs to respond to such emergencies would be outweighed by the avoided damages in the event of an accident. Net benefits from winter-only stationing occurred even if recreational benefits from beaches were ignored. If recreational benefits were included, then year-round stationing is justified.

From the limited evidence available, then, there are likely to be net benefits from the stationing of rapid-respond vessels around Europe's coastline.

Table 2.2.6 Selected major accidents in Europe and their costs

Type of accident	Year	Casualties (deaths)	Damage costs $€_{97}$ million	Clean-up costs $€_{97}$ million
Amoco Cadiz oil spill, France	1978		71-122*	200
Exxon Valdez, oil spill, Alaska	1989		2700-8800	2700
Le Haven oil spill, Italy	1991			69
Tanio incident, France	1980			47
Sandoz chemical accident, Basle	1986			7
Livorno tanker explosion, Italy	1991	140	305**	
Oil platform explosion, UK	1988	167	334	
Vessel fire, sodium cargo. La Coruna, Spain	1987	23	45	
Sea Empress oil spill, UK	1996		159-309	35 million

Sources: Stanners and Bordeau, 1995, p537; OECD, *Environmental Data, 1993*, OECD, Paris; Bonnieux and Rainelli, 1994; *Sea Empress* Environmental Evaluation Committee, 1998; Carson et al., 1994.

Notes:
* based on Bonnieux and Rainelli, 1994, using economic valuation approaches for tourism loss, open sea fisheries loss and oyster fisheries losses, and adjusted from 1978 francs to $€_{97}$.
** valuing deaths at the VOSL that would be relevant to the year in question.

Sensitivity analysis

Based on the analysis of reduced probabilistic risk of a nuclear accident, Table 2.2.7 reports the results of changing some of the key assumptions.

Table 2.2.7 Key assumptions and the estimated results of changing these assumptions

Current Assumption	Current estimate € million	Revised Assumption	Revised estimate € million
4% discount rate	135	2% discount rate 6% discount rate	354 61.1
Mean fraction estimates of mortality from CEPN simulation 4% discount rate	135	95% fraction estimates of mortality from CEPN simulation 4% discount rate	362
No disaster aversion factor	135 - 362	With disaster aversion factor Multiplier 50 Multiplier 140 Multiplier 1430	 6,750 - 18100 18,900 193,050
Mortality effects only	135 - 362	Morbidity and mortality (Galy 1998)	225 - 603

Present value (discount rate = 4%)

From the results of the sensitivity analysis we conclude that;

- The sensitivity to the discount rate used is due to the relatively large portion of medium and long-term impacts associated with nuclear accidents.

- Using the 95% fraction estimates of mortality in the CEPN (1992) simulation would increase avoided damages by 2.6.

- Inclusion of disaster aversion factors means the avoided damages would increase by 50 - 1400 times the expected avoided damages.

- Inclusion of morbidity effects will increase benefits by 1.67 to € 225 million.

3. Policy assessment

To a limited extend, both this section and the previous discuss not only nuclear accidents, but also other major accidents, like oil spills. For convenience of the reader, all references have been brought together in the Technical Report on Benefit Assessment Methodology.

3.1 Policy package

3.1.1 Recommended policy initiatives: Nuclear accidents

Avoidance of nuclear accidents in Central and Eastern Europe

Since the highest risk reactors are located in Central and Eastern Europe it is unlikely that the costs of these measures will be met, at least not fully, by the countries in question. Thus EU-15 plus associated countries will have to pay for the costs of the mitigation. This context is important since it rules out some of the policy measures that might apply in the EU itself, e.g.:

- a tax on nuclear power, with proceeds being earmarked for plant improvement or even closure, and
- liability legislation, probably associated with mandatory insurance cover, as in Germany, Japan and Switzerland.

The liability insurance option may well result in the private insurance sector not covering all damages, as is the case with existing schemes. Where there is only a rudimentary insurance sector, or where that sector will not assume risks, then governments typically assume the risks. However, in the case of some Central and East European countries this may not result in actual compensation being paid. More importantly, if the industry does not bear the cost of liability, it is unlikely that such legislation will alter the risk levels. Hence any policy measure has to be tested against the likelihood that it will reduce risks. As is well known, insurance may have little effect on the actual risks, and could even increase them (‘moral hazard’). Liability legislation, on the other hand, should give incentives to reduce risks if the industry itself knows it has to meet at least some of the damage claims. Finally, many reactors in the high risk areas are state-owned, thus again reducing the potential for the introduction of any of the conventional measures.

One possibility is the use of *environmental funds* in EITs, where the funds are generated through charges and taxes on existing pollution unrelated to the nuclear sector. Such funds are now commonplace in several EITs. However, none has earmarking for reducing nuclear risks and the scale of the Funds would have to increase substantially and almost certainly to unrealistic levels, before they could be used to reduce risks significantly.

Because of the problems outlined above, the polluter-pays principle has to be rejected in favour of a partial *victim pays principle*, i.e. where the potential sufferers of the damage pay the source of the risk to reduce risks. Despite the polluter pays principle being embodied in the Treaty of Union, this is very much how the European Union approaches the issue, with the EC TACIS and PHARE Programmes contributing to a broader fund aimed at improved safety in Central and East European states. To a considerable extent, therefore, the appropriate policy instrument is already in place. The outstanding issue is whether the finance going into such funds reflects the scale of the problem. From the analysis of the likely costs of decommissioning and other serious risk reduction measures, this seems unlikely.

In the event that an emergency does occur, the EC and the IAEA have the ‘Emercom’ and ‘ECURIE’ communications systems to facilitate rapid dissemination of radiological information which itself would assist evacuation, and food and water safety measures.

3.1.2 Recommended policy initiatives: Chemical risks

'Owner liability' and 'performance bonds'

Where tanker and installation owners are clearly identifiable, and cause and effect can be established, there is scope for the use of *liability* mechanisms, and *performance bonds*.

Liability mechanisms establish the legal obligation to pay damages in the event of an accident. As such they assess and recover damages *ex post*. Liability may be fault-based, such that the agent must be shown to be at fault in creating the accident, or strict, in which case fault does not have to be demonstrated. The trend is away from fault-based liability to strict liability. To be effective, the expected value of any damages must be larger than the benefits of not complying, and there must be a well developed legal system such that damages can be assessed in court. While liability is a potentially effective instrument, it has the disadvantage that settlement can be costly and very time-consuming, cause and effect may be difficult to prove, and what constitutes 'damage' may vary according to court judgements. Even stringent liability regulations, such as the joint and several liability regulation in the USA relating to hazardous waste sites ('Superfund'), and which make any one agent responsible for the total costs of clean-up even if others are involved, have proved to be extremely cost-inefficient (Dower, 1990). Joint and several liability was designed to overcome judicial barriers to the settlement of compensation since it avoids all parties having to be identified and 'processed'. In some cases, litigation costs have exceeded the cost of clean up (Dower, 1990). Liability may also have unintended consequences. Thus, increased damage liability for oil spills in the USA has led to various 'evasion' measures by tanker owners, including dividing tanker fleets into minimum-asset companies which therefore have limited liability; and avoidance of ports where liability regulations are strict (Dunford, 1992).

More seriously, within Europe there appears to be a growing consensus that civil liability is 'out of step' with the likely size of future environmental damages. This does not reflect increasing accident risks (both quantities spilled and the number of incidents have declined, see Stanners and Bordeau, 1995, p.387), so much as a rising 'price' of damage. This may explain the reluctance of some EU countries to sign the *Council of Europe Convention on Civil Liability for Damage Resulting from Activities Dangerous to the Environment* - the 'Lugano' Convention (Tromans, 1993). The policy option of the EU signing this Convention remains open.

The 1969 *International Convention on Civil Liability for Oil Pollution Damage* establishes strict liability on ship owners and requires compulsory insurance (a discussion about compensation funds is provided below).

The liability picture is complicated by 'flags of convenience'. OECD (1993) reports that tankers under the Liberian flag of convenience have had the single largest number of accidents, making pursuit of claims difficult if not impossible.

Environmental bonds: Environmental bonds differ from liability systems in that the potential polluter pays for a bond in advance of the relevant economic activity (e.g. a shipping journey) and collects the refund on completion of the activity. The bond is therefore an *ex ante* instrument. Where the activity is continuous in the sense of being repeated, then the bond can stay in force at all times. Determining the size of the bond can be complex since, as has been seen in the cost-benefit study, the costs of oil spills vary substantially with local ecological conditions. Many 'major' spills have produced negligible damage, whilst some small spills have created substantial damage. However, one advantage of the bond system is that it avoids the often lengthy and costly process of court proceedings (in the *Amoco Cadiz* case, for example, damages were still not paid 15 years after the spill occurred). Either the tanker owner undertakes the clean up or the state can effect restoration using the bond funds. Finally, bonds funds can be invested so that interest accrues to the tanker owner, thus avoiding a dead-weight cost on the owner. One disadvantage is that, unless bonds are set in such a way that funds exceed the expected value of damages, there is no real incentive for tanker owners to improve tanker design over time. Put another way, the size of the bond does not vary with the chance of an accident. In the USA, the Oil Pollution Act of 1990 requires that ocean vessels carrying oil be improved to have double hulls. But this is a legislative requirement that will take a long time to implement.

Insurance: Insurance systems operate like environmental bonds except that the tanker owner pays an insurance premium rather than the larger sum required for a bond that must have a value equal to the expected value of damage. Since all owners pay the insurance premium, risks are effectively pooled. Insurance systems have the strong advantage that clean-up costs and damages can, in principle, be met and settled quickly, something that is unlikely with liability systems. Moreover, premia can be varied according to the risk rating of the tanker owner. A disadvantage arises if the insurers are uncertain of the likely damages. This may deter them from providing insurance altogether, something that happened under the Resource Recovery and Conservation Act and 'Superfund' in the USA, relating to hazardous land sites. This may be particularly relevant if damage claims are based on monetary valuation of damages, including 'non-use' damages (i.e. damages to individuals who are not directly affected by an accident but who experience a loss of wellbeing due to the fact of the accident). The *Exxon Valdez* case illustrates the potential for damages to be many times larger than clean-up costs. Tanker insurance did in fact increase for visits to US ports after the US introduced various pieces of damage liability legislation (Dunford, 1992).

Compensation Funds: The advantage of insurance, that it shares the burden of damage costs across the industry in question and in proportion to risk ratings, is partly shared by the concept of a compensation fund. This is a fund financed by a charge or tax on the industry as a whole and which is then used to meet claims and finance clean-up. This is the principle behind the *International Fund for Compensation of Oil Pollution Damage* (IFCOPD) established in 1971 under the Convention of the same name. It also underlies the Swedish fund introduced in the Environmental damage Act of 1986, and the ‘Superfund’ legislation in the USA. The problem with such funds is that they tend to penalise good operators who, effectively, end up subsidising bad operators. This is likely to be a serious problem in an enlarged Europe if the concept was applied Europe-wide. IFCOPD is linked to the 1969 *International Convention on Civil Liability for Oil Pollution Damage* which establishes strict liability on ship owners and requires compulsory insurance. Essentially, IFCOPD is designed to help in cases where redress cannot be sought under the 1969 Convention. These cases relate to contexts where the owner has inadequate resources and/or insurance to meet claims, and where the claims exceed the upper limit set for liability in the 1969 agreement. Note that the use of the Fund in this way removes some of the power of liability legislation to ‘internalise’ the risk of accidents: the tanker owner knows he can claim inadequate finance as a reason for not meeting claims, and hence can take out less insurance than is needed. This conjunction of a liability law and a joint compensation fund has much in common with the suggestion made in the European Commission’s Green Paper *Remedying Environmental Damage* (1993) which called for a strict liability regime, polluter responsibility for restoration of damage, and a compensation fund[1].

The Commission’s White Paper on environmental liability based on the Green Paper mentioned above is still being prepared at the time of writing this paper. However, it seems to apply only to future damage, leaving the rules for dealing with the backlog of historic pollution and hence the financing of it to Member States, although with some doubts as to how to draw the line between past and future (ENDS Report No. 280, May 1998).

An even broader interpretation of a compensation fund simply requires that any charge be levied on all ‘polluters’ regardless of their links to the particular agent concerned in an accident. This is unlikely to be realistic.

Effectiveness of liability: There already exists a liability regime under the 1969 oil pollution damage Convention. The issue, again, is whether the Convention establishes liability limits that are consistent with the probable increasing scale of damages for future accidents. The rising scale is likely to be due to the broadening of the scope of the term ‘damage’ to include not just loss of livelihood and property but also disamenity and, ultimately, non-use values, as in the USA. If this scenario is correct, either the liability ‘cap’ has to be changed or the joint compensation fund has to be increased. As noted above, neither option is without serious problems. This suggests a further approach based on a broader EU-wide general strict liability Directive, as suggested already by the EC as one option, or consideration of a system of performance bonds for tankers entering EU ports or using European waters.

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[1] The Green Paper rejected retrospective liability, joint and several liability, and lender liability.

3.2 Policy assessment

The main policy initiatives are;

Nuclear accidents: the substitution of nuclear technology in order to reduce the probability of nuclear accidents in Central and Eastern Europe;

Chemical accidents: such as oil spills: 'Owner liability', where the scope of 'damage' extends beyond property and direct economic losses to disamenity and ecological damage and even to non-use values.

3.2.1 Causal criterion

Table 3.2.1 presents the driving forces and the underlying causes behind the problem of major accidents.

Table 3.2.1 Driving forces and underlying causes of nuclar accidents

	Driving forces	Underlying causes		
		MF	IntF	ImpF
D1	Industrial growth (particularly petroleum refineries and petroleum industry)			
D2	Deficient maintenance of nuclear plants			X
D3	Human errors during operation			X
D4	Toxicity, degradability, flammability and explosivemess of chemical substances			X
D5	Transport growth (road, air and sea) of radio-active and hazardous materials			

X = main underlying cause, MF = market failure, IntF = intervention failure, ImpF = implementation failure.
Note that for driving forces D1 and D5 the main causes are due to growth in real income and population.

Nuclear accidents: The highest risk of a nuclear accident is from Central and Eastern European reactors. The policy initiative is specifically targeted at the highest risk reactors.

Oil spills: owner liability provides incentives to operators to invest in pollution mitigating technology.

3.2.2 Efficiency criterion

Benefit-cost ratio for Technology Driven scenario

The cost benefit analysis of the TD scenario gives the following range of B/C ratios:

- expected value mortality only:	0.15 - 0.41
- expected value mortality and morbidity:	0.25 - 0.68
- mortality only including disaster aversion:	7.7 - 20.7
- mortality and morbidity including disaster aversion:	12.8 - 34.5

A key issue in the analysis of nuclear accidents is the use of a disaster aversion factor. In this study we adopt 50 as a conservative multiplier of expected damages. This has the effect of changing the B/C ratio from below unity to greater than unity. Assuming the use of DAF is acceptable, then, even omitting all non-health effects[2] which Galy (1998) suggest may in fact dominate, we see that investments in nuclear risk factor reductions in Central and Eastern Europe have substantial benefit-cost ratios.

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[2] Non-health effects include: costs of food bans and relocation of population

Benefit assessment of Technology Driven scenario

The benefits of TD scenario over the baseline are given in Table 3.2.2.

Table 3.2.2 Benefits of TD

present value of total avoided damage discount rate = 4%	€ million
Mortality only	135 - 362
Mortality and morbidity	225 - 603
Mortality only, including disaster aversion factor	6750 - 18100
Mortality and morbidity including disaster aversion factor	11250 - 30150

Costs of Technology Driven scenario

Table 3.2.3 presents the welfare costs and direct costs for upgrading nuclear power stations.

Table 3.2.3 Welfare costs and direct costs for upgrading nuclear power stations

Additional costs (costs TD 2010 - Baseline costs 2010)	€ million
nuclear power upgrading costs in 2010	95
present value of costs[3]	874
EBRD (1999): $1 billion	880

Cost-effectiveness

Nuclear accidents: despite the polluter pays principle being embodied in the Treaty of Union, it is a partial *victim pays principle*[4] that guides the European Union approach to the issue, with the EC TACIS and PHARE Programmes contributing to a broader fund aimed at improved safety in Central and East European states. To a considerable extent, therefore, the appropriate policy instrument is already in place. The outstanding issue is whether the finance going into such funds reflects the scale of the problem. From the analysis of the likely costs of decommissioning and other serious risk reduction measures, this seems unlikely.

In the event that an emergency does occur, the EC and the IAEA have the ‘Emercom’ and ‘ECURIE’ communications systems to facilitate rapid dissemination of radiological information which itself would assist evacuation, and food and water safety measures.

Oil spills: owner liability is a potentially effective instrument but it has the disadvantage that settlement can be costly and very time-consuming. Cause and effect may be difficult to prove, and what constitutes ‘damage’ may vary according to court judgements. Even stringent liability regulations, such as the joint and several liability regulation in the USA relating to hazardous waste sites (‘Superfund’), and which make any one agent responsible for the total costs of clean-up even if others are involved, have proved to be extremely cost-inefficient (Dower, 1990).

Public opinion

Eurobarometer (1995) ranks ‘major accidents’ as the seventh most serious environmental problem. This ranking is fairly consistent with the results from other surveys, in which accidents are considered an issue of intermediate importance. This ranking is also is accordance with expert opinion (see below).

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[3] Assumes measures taken take place in the year 2000 and beyond, and cost € 95 million per annum

[4] *victim pays principle*, i.e. where the potential sufferers of the damage pay the source of the risk to reduce risks

3.2.3 Administrative complexity

Nuclear accidents: Administratively very simple to operate due to existence of markets for nuclear power and EBRD. Implementability is high. The main issue is 'political will' of contributing countries.

One of the factors which limits technical assistance to EITs in respect of nuclear accident risk reduction is the limited coverage of liability regulations in these countries. It is well known that liability is ‘capped’ in most countries with nuclear installations but, as Chernobyl showed, liability in a number of potentially high risk countries is non-existent. Therefore it is important to encourage liability regulations in the EITs and Former Soviet Union, as the Nuclear Energy Agency is currently doing.

Oil spills: the relevant international legislation is in place. This establishes a strict liability regime for ship owners and a fund to meet claims in excess of the ‘cap’ set under the liability regime. We speculate that claims will increase as the scope of ‘damage’ is widened in a manner similar to what has happened in the USA, i.e. extending beyond property and direct economic losses to disamenity and ecological damage and even to non-use values. This would require a, well developed legal system such that damages can be assessed in court.

3.2.4 Equity criterion

Nuclear accidents: the policy initiative to reduce high risk nuclear reactors in Central and Eastern Europe meets the equity criterion. This is because nuclear damage affects all socio-economic groups i.e. the benefits are neutrally distributed. The costs are small but taxes may be used to finance the reduction in nuclear risk. Thus, the distributional incidence of the clean up program is fair. However, damage could well be distributed unequally, i.e. Accession countries are more at risk. Unfortunately, resources have not permitted a full analysis of the distributional incidence. The ‘Victim Pays Principle’ in effect means benefits to Eastern Europe.

Oil spills: owner liability will only have a distributional incidence once a company has been found responsible for an oil spill. Until this occurs, the distributional incidence of owner liability is zero. When an accident occurs and companies are required to pay the expected price of damage, these costs have the potential of being passed on to the consumer. However, due to the diversity of oil based products and products that require oil as an input it is not possible to determine the degree of distributional incidence. Oil spills affect all socio-economic groups, thus the benefits of avoided oil spills are neutrally distributed.

3.2.5 Jurisdictional criterion

Nuclear accidents: are a trans-national externality, therefore the policy initiative must be centralised and become an EU policy.

Oil spills: are a local issue in general, but they can also be trans-national. There are potential cost savings from co-ordinated action plans and when co-ordinated action plans are needed, credibility of centralisation is high.

Macroeconomic effect

Details are provided in Technical Report Socio-Economic Trends, Macro-Economic Impacts and Cost Interface.