Nuclear Development
and Radiation Protection

OECD

Methodologies for Assessing the Economic Consequences of Nuclear Reactor Accidents

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and Radiation Protection

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NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996) and the Republic of Korea (12th December 1996). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of 27 OECD Member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its Member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

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MÉTHODES D'ÉVALUATION DES CONSÉQUENCES ÉCONOMIQUES DES ACCIDENTS NUCLÉAIRES

FOREWORD

A comparative study of accident consequence assessment codes, completed jointly by the NEA and the EC in 1993, concluded that the prediction of economic consequences was one of the least mature areas of such computer modelling, and should be studied further. Accordingly, the NEA Committee on Radiation Protection and Public Health (CRPPH) and the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) created a joint expert group in 1994 to investigate the methodologies used in calculating the economic consequences of accidents, and the bases for such methodologies.

Calculation methods were assessed according to three end uses: for compensation and liability purposes; for accident preparedness and management purposes; and for making electricity-generation choices. The group concluded that comparing numerical results is very difficult, even for estimates made from the same perspective, as more detailed “boundary” conditions (such as the accident scenarios used, plant characteristics and source terms) also affect results.

This report provides a summary of the expert group’s findings. It reflects the collective views of the participating experts though not necessarily those of their parent organisations or Member governments. This report is published under the responsibility of the Secretary-General of the OECD.

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EXECUTIVE SUMMARY

The interest of its Member countries in the assessment of the consequences of nuclear accidents led the OECD/NEA to conduct two international probabilistic consequence assessment (PCA) code comparison exercises, the first during the early 1980s and the second, jointly with the European Commission, during the early 1990s. One of the key recommendations resulting from the second exercise suggested that further work should be done to better estimate the economic consequences of nuclear accidents.

Also during the early 1990s, a large number of estimates of the costs of hypothetical nuclear accidents were published, often in a widely publicised fashion, which were used in accounting for the externalities of nuclear energy generation, namely, the costs not included in the price of electricity. The numerical results of these studies tended to diverge by several orders of magnitude. Experts within the NEA programme felt that the bases for these estimates were unclear and that they were, perhaps, not well founded.

In response to these developments, the NEA Committee on Radiation Protection and Public Health (CRPPH), jointly with the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC), created in 1994 the Expert group on the Methodologies for Assessing the Economic Consequences of Nuclear Reactor Accidents. The Group was asked to carry out an in-depth study of the methodologies for assessing the economic consequences of nuclear reactor accidents. Specific areas for attention would be:

- The methodologies and techniques used to quantify economic impacts of nuclear reactor accidents.
- The applications of economic impact assessments.
- The uncertainties in current assessment models and the quality of input data.
- The identification of those areas where improvement would be valuable.

The Expert group agreed that the scope of its studies should only include:

- The off-site radiological consequences of nuclear reactor accidents, i.e., health effects on the exposed population and its descendants.
- Direct and indirect effects on the environment and on the economy of the affected area (which may include areas not directly touched by contamination).
- The social disruptions and repercussions which would inevitably follow such an event and the associated implementation of protective countermeasures.

The Expert group reviewed in some detail the elements to be considered in estimating the total off-site costs caused by a severe nuclear accident, as well as the boundaries and limitations which constrain this kind of assessment. The Group reached very early a consensus on the conclusion that there is no single “cost of an accident”. It was, in fact, realised that the cost elements considered and the methodology used to combine those cost elements depend greatly upon the objective of the cost study and the intended use of the resulting “accident cost”. The Group chose, therefore, to investigate methodologies for calculating costs from three perspectives:

- Accident preparedness and management.
- Compensation for the affected parties.
- Power generation choices.

According to the Group’s view, the objective of calculating the cost from the accident preparedness and management perspective was to optimise the planning and implementation of countermeasures to be taken to mitigate the detrimental consequences of a major accident, in both the short and the long term. Because the optimisation of countermeasures had been one of the prime objectives since the early days of this type of accident consequence assessment, the cost elements associated with this perspective were fairly well understood. In terms of results, however, costs varied considerably depending upon local details.

Another important perspective addressed by the Expert group was the compensation of those affected by an accident. It was suggested that the general public expects existing liability regimes and other systems of financial security provided for this purpose should ensure that the operator who had caused the damages would compensate all consequences of a nuclear accident. However, it was observed that the compensation systems set up under the existing international conventions and national legislation did not fulfil completely this expectation and this issue.

The third perspective explored was that of power generation choices. When assessing the various options for electricity generation, a key factor is the cost. External costs are the economic consequences of an activity that accrue to society, but which are not explicitly recognised in the decision-making process. In the case of electricity production, external costs are those which are not included in the price of electricity. The Group suggested that state-of-the-art, rational and defensible methodological approaches should be used to quantify these costs, and should be based on full-scope, site-specific probabilistic safety assessment (PSA) studies. Such an approach would account for the relative costs of all accidents, which can be modelled using PSA studies for the specific plant in question. Obvious shortcomings of this approach included: the burden of producing very detailed PSA studies, the inherent uncertainties of these PSA studies, and inherent uncertainties in the micro- and macro-economic effects of wide-scale contamination and societal disruption.

The Group also noted that the statistical techniques necessary to characterise radioactive releases and depositions were relatively new and were being continuously improved; current developments of computing techniques were contributing to this improvement. In terms of micro-economic aspects, the Group discussed in great detail the various modelling elements necessary to accurately predict the costs of environmental and health damage. The availability of data and its accuracy were addressed qualitatively. These were seen as being important aspects with regard to the relative and absolute confidence attached to the numerical values which were generated.

In terms of macro-economic aspects, the Group suggested that “input-output” methods should be used. This approach considered the interchanges between the different economic sectors of a region or a country as a factor in the analysis of impacts of population movement or countermeasures in agriculture. The difficulties with these methods were associated with the compilation of suitable input-output tables, with the calculational effort required, and with the definition of non-directly affected areas, (some effects may extend over an entire country).

The Group proposed several conclusions and recommendations as to how additional work could reasonably take these considerations further. In particular, the following points were stressed:

- Future efforts should focus on the detailed assessment of cost elements, especially in the area of health effects, where the alternative costing approaches (human capital approach and willingness to pay approach) should be better understood and justified.

- A more consistent definition of the cost elements which are relevant to each consequence assessment perspective should be sought, with their perspective-specific characterisation and relative order of importance, and with particular attention to the assessment of externalities.

- Existing accident consequence assessment codes should be further developed to better integrate medium- and long-term impacts at the macro-economic level.

- Decision making on the management of post accident situations will need in the future to be supported by the development of models more accurately reflecting the post-accident economic impacts, especially in terms of consequences of reorganising the conditions of living, farming and production in the affected communities.

Chapter 1

INTRODUCTION

Nuclear emergency planning, preparedness and management have been for many years one of the main areas of interest for the Member countries of the OECD Nuclear Energy Agency (NEA). They have consistently supported, and continue to support, an active programme of work by the Agency on these matters (see, for example, a recent report on the International Nuclear Emergency Exercise Programme).[1] One of the aspects of this multifaceted area is that of accident consequence assessment. In this context, the number of published estimates of the costs of hypothetical nuclear accidents has grown in recent years and this has led to a debate on the matter of accident costs within the NEA frame. This report is the summary of work carried out so far on this very important topic.

Background

One major part of accident planning, preparedness and management is the evaluation of the off-site consequences of nuclear accidents. One of the tools used to perform such kind of evaluations is Probabilistic Safety Assessment (PSA). Since its introduction, numerous Probabilistic Consequence Assessment (PCA) models and codes have been developed, beginning with a 1975 study by the US Nuclear Regulatory Commission (more details concerning this background are presented in Chapter 2). As the science of accident planning, preparedness and management advanced, and PCA models became more and more complicated, it became important to develop techniques to evaluate the performance of the various computer models. To this end, in the early 1980s, the OECD/NEA organised an international PCA code comparison exercise which provided a valuable check as to the quality of the various participating codes, as well as a benchmark against which subsequent developments could be judged.

Since that time, a significant number of new models and codes have been developed and it was felt by the Member countries of the NEA that it was time for another benchmark exercise to be performed. To this end, beginning in 1991, the NEA organised a second exercise, titled *Probabilistic Accident Consequence Assessment Codes: Second International Comparison*. This work, performed jointly with the European Commission, was completed in 1993 and the results were published by the OECD/NEA,[2] and by the Commission of the European Communities[3] in 1994. One of the recommendations of this report was as follows:

> "Notwithstanding the reasonable agreement between the economic consequences predicted by the codes, this area is the least mature part of PCA modelling and warrants further investigation. In particular, the potential importance of indirect costs which are not currently modelled (e.g. the more general effects on trade, tourism, etc., in affected countries) requires some study."

This recommendation was taken up by the NEA Committee on Radiation Protection and Public Health (CRPPH).

At the same time, the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) was becoming aware of a number of published estimates of the costs of hypothetical nuclear accidents. These had been widely publicised and had been used in accounting for the externalities of generation of electricity from nuclear energy (i.e. those costs not included in the price charged for the electricity). The basis for these estimates was not clear and there were suspicions that they were not well founded. The NDC, therefore, felt that some analysis of the applicable methods of estimating costs would be warranted.

The converging interests of the two Committees led to the setting-up of a joint Expert group to study these questions.

Joint NDC/CRPPH Expert group on the methodologies for assessing the economic consequences of nuclear reactor accidents

Based on recommendations from the two parent Committees, the above-mentioned Expert group was formed and held its first meeting at the OECD Headquarters, in Paris, in May 1994. The members of the Expert group are listed in Annex VII. The following Terms of Reference were agreed upon by the Expert group and approved by the NDC and the CRPPH:

- To carry out an in-depth study of the methods for the assessment of the economic consequences of nuclear reactor accidents, including:
  - The methodology and techniques used to quantify economic impacts of nuclear reactor accidents.
  - The applications for economic impact assessment.
  - The associated uncertainties, both, in terms of current assessment capabilities, and the quality requirements for input data.
  - The identification of those areas where improvement would be valuable.
- To prepare a report for approval by the NDC and the CRPPH.
- To report periodically to the CRPPH and to the NDC on the progress of the programme.

Scope of the report

In the case of a reactor accident, the first consequences are those affecting the operators and the accident site. In the case of a radioactive release to the environment, the spectrum of consequences is considerably enlarged. In this report, only the economic aspects of off-site consequences which may result from a reactor accident, are considered. These consequences include mainly: the health effects on the exposed population and its descendants; direct and indirect effects on the environment and on the economy of the affected area (which may include areas not directly touched by contamination); the social disruptions and repercussions which inevitably follow such an event; the associated implementation of protective countermeasures.

The amount of radioactive material potentially released may range from trivial quantities up to a significant fraction of the radionuclide inventory of the facility. The off-site economic consequences of such a release are dependent on the quantity of radioactive material released but may also vary considerably for a given source term depending upon other factors (e.g. the demographic features of the area surrounding the reactor, the prevailing meteorological conditions at the time of the release). In this document, only large reactor accidents, resulting in wide spatial and temporal distributions of radioactive material, are considered.

The experience with actual reactor accidents is, fortunately, extremely limited. Only the Three Mile Island (TMI) accident in 1979, and the Chernobyl accident in 1986 can be considered as large. Only the Chernobyl accident, however, resulted in significant off-site consequences. Many studies have been published on these events, and attempts are still going on, in the case of Chernobyl, to evaluate the economic impacts of the accident. Many different figures have been proposed as "the cost" of the TMI and Chernobyl accidents, which vary depending upon the cost components included. As such, it is difficult to determine any final authoritative numbers.

Another source of economic assessments is the use of predictive models, which have been developed for the purpose of probabilistic safety assessment and emergency planning and preparedness. Costs resulting from these models directly reflect the assumed scenarios. For this reason, as well as the fact mentioned above – that economic effects greatly depend on the demographic characteristics of the area surrounding the accident site – it is difficult for these models to provide any figures which could be considered as representative of large nuclear accidents.

After some discussion on these and other issues, the Expert group agreed that this report should be of a generic nature, not being specific to the circumstances in any one or group of countries. Further, and this was considered to be a very important caveat by the Expert group, it was decided that this work would focus on the development of economic consequence assessment methods and methodologies and that, although specific cost figures may be used to illustrate specific points or provided as historical reference, no attempt would be made to quantify accident economic effects.

It was felt by the Expert group that this report represents the current state-of-the-art thinking in the area of economic consequence assessment methodologies, and that it should be used as guidance for further work in this area.

Report organisation and structure

As discussed in the body of this Report, the Expert group felt that the most important aspect to be elaborated was that of economic consequence assessment methodologies. Chapter 2, as well as Annexes V and VI, discuss these methodologies in detail.

However, after much discussion of these issues, the Expert group also felt that the methodology chosen for cost assessment would depend greatly upon the intended use of the resulting cost figures, i.e. on the perspective from which the costs were viewed. This general notion of different perspectives is thus discussed in detail in Chapter 3. In addition, the Expert group also spent much time and effort discussing the concepts of external costs and compensation and felt that these topics were also very important. The methodological approach to these perspectives is thus also presented in Chapters 3 and 4, and in Annexes I, II and IV.

Finally, based on the discussions of the Expert group, several conclusions and recommendations for additional work in the area of assessment methodologies are presented in Chapter 5. It is hoped that these recommendations will be addressed either by subsequent groups at the NEA, or by other international organisations.

Chapter 2

COST ELEMENTS FOR CONSEQUENCE ASSESSMENT MODELS

Particularly since the Chernobyl accident, the economic and social consequences of a potential large reactor accident have become a matter of sometimes difficult debate, outside as well as inside the nuclear community. Because of the extent of the damage in space and time, this accident has revealed some limitations in the existing systems and structures for the social management of post-accident situations. From the economic point of view, several issues have emerged which were not considered or were underestimated in the past. For example, what is the “true cost” of an accident? Beyond the direct and obvious effects, how can the global impact of a large accident be measured on a macro-economic level? Has an accident the potential to seriously affect the economic equilibrium of a country?

In the light of these new considerations, this chapter reviews the elements to be considered in estimating the total off-site cost caused by an accident, also focusing on their distribution in time (short and long term) and space (evacuation area and its surroundings, and local versus regional scale). Some costs are more or less directly valued and normally considered in the existing models. Other costs, like psychological effects or the impact on wildlife, can hardly be quantified in economic terms; nevertheless, their nature and relative importance are also discussed.

Definitions in the evaluation of economic consequences

In common usage, the term “cost” is used to define a quantity with a particular monetary value, which may be represented by a bill of sale or receipt. However, the economic definition of “cost” is broader, that is, as a benefit foregone. According to economic theory, this benefit foregone can be measured by the amount of money that would be required to restore the individuals concerned to their original level of well-being, i.e. their pre-accident state.

In a purely economic perspective, the total cost of the accident will be the sum of these individual benefits foregone, summed over all affected individuals, businesses and public bodies. It should be noted that, although this approach can be viewed as measuring the need for compensation, it does not assume that this compensation is actually paid, either in full or in part. It is, therefore, not necessarily a cost to the government, or to insurance companies, but it is simply a measure of the impact of the accident expressed as a cost to society as a whole, normally referred to as a “social cost”.

In the sense defined, most of the consequences of an accident can, at least theoretically, be associated with an economic cost. However, the global cost is not only the direct monetary impact, but includes personal and psychological aspects, such as pain and anxiety, which lead to a degradation of the quality of life and welfare. Therefore, the consequences as a whole may be broadly summarised as resulting from:

- The application of countermeasures to reduce doses.

- Radiation-induced health effects in the exposed population.
- Psychological effects.
- Impact on the activity with which the installation is associated, for example the power programme.
- Impact on economic factors: employment, revenues, losses of capital, etc.
- Long-term social and political impact.
- Environmental and ecological impact.

The economic effects associated with these consequences can be generally classified into two categories: direct and indirect. Direct economic consequences are normally described in terms of cost of the implementation of countermeasures. On the contrary, the indirect (or secondary) economic consequences would cover the effects which are produced out of the areas directly impacted by the contamination, as for instance the impact on non-contaminated food marketing, on tourism, or on the nation's nuclear programme. These are normally difficult to quantify a priori, but they are amenable to an a posteriori evaluation.

Also, very difficult to predict and to quantify in terms of cost are the economic effects which can result from ecological damage, i.e. the general and long-term effects of contamination of wildlife and vegetation (other than agricultural or forestry), or from the loss of the recreational use of contaminated environments. These can have an important economic impact, and may need to be considered separately. Such effects can arise not only in the contaminated areas, but also in non-contaminated areas, although normally in these areas with less effect.

Finally, there are other effects which, due to their nature, cannot be easily evaluated by accounting methods, such as the loss of image that the company, the region or even the country affected by an accident would experience, with the accompanying decrease in investments and loss of intrinsic wealth, which could be made apparent by a depreciation of the nation's currency, for instance. These costs can be called "unquantifiable".

Boundaries and limitations of the estimation of economic consequences

The evaluation of economic consequences of nuclear accidents is subject to a number of limiting conditions, in space and time, as well as to other limitations due to the nature of the specific items being evaluated.

While some of the cost elements introduced in the previous section will last for only a short time period, such as short-term countermeasures or early health effects, others, such as long-term countermeasures, can continue to be relevant for a long time period, or can emerge a long time after the accident, such as latent and hereditary health effects. The economic cost of the elements of the first type will be incurred typically in a period shorter than one year, and it is reasonable to assume their full cost as a measure of the economic impact caused. On the other hand, for effects delayed in time, a discounting is needed in order to obtain comparable costs. Normally, discounting is a technique used to assess the present value of an investment and can be thought of as representing the amount of money needed to be invested today in order to cover the full cost expected after a given number of years.

No unanimity exists between economists as to the validity of discounting environmental damage in risk assessments, but, if an accident is assumed to have taken place, it is evident that not all its consequences will occur soon after, and thus a more correct picture of the cost is obtained if delayed costs are discounted. In this sense, there is now an increasing consensus on using normal discount rates for marketable goods in general, whilst, for non-marketable goods, such as health effects or environmental damage, a much reduced discount rate is preferably used for the medium term and an even lower or no discount rate at all for effects appearing far in the future.[4]

Still with regard to the time span of accident consequences, another limitation for the evaluation is that the uncertainties in predictions of physical impacts, as well as of the economy growth, increase with time. This is due to an increasing number of uncertain effects, as well as to uncertainties in the hypotheses incorporated into the economic models.

Another boundary condition can be associated with the wide spatial extension that the consequences of a large accident can have, especially if different countries or regions are affected. This may lead to the necessity of combining data from different sources (not always based on the same type of statistics) and linked to different economic circumstances (currency exchange rates, interest and discount rates, income per capita, etc.). This complicates the assessment and introduces additional uncertainties. The larger the differences in the economic systems of the affected countries, the larger would be the differences in data. Past experience in the case of the TMI and the Chernobyl accidents shows that for small scale accidents, like the first, it is relatively easy to account for all the off-site costs caused by the accident, but for large scale accidents like the second, the only possibility is to assess country-by-country costs. An example of this is available for the Nordic countries[5] (see Annex V).

Additionally, some effects are more directly valued using micro-economic models, which essentially sum up all the individual items of which the cost is composed. A clear example is food disposal or decontamination, which essentially will depend on the amounts to dispose of, or to decontaminate, and on the techniques applied. On the other extreme, are effects more difficult to quantify, like secondary impacts of countermeasures, which would be more adequately evaluated using macro-economic methods, like those based on input-output tables. This will require the combination of results from separate assessments. However, special caution must be taken to avoid double counting the same effect when combining different assessments.

Finally, the “unquantifiable” effects are not easily accounted for, and usually impose a forced boundary on assessments. Alternative methods to those normally included in the existing models could be used to analyse some of these effects, such as the willingness-to-pay method in the case of losses of environment recreational uses. Substantial development would be needed, however, if it were desired to fully cope with such effects.

Cost of countermeasures

Countermeasures adopted to limit the individual and collective exposure to radioactive products released in case of an accident are an obvious source of economic costs, since such countermeasures will generally interfere with the normal living activities of the population, can involve destruction of contaminated products, or will require the use of special techniques and tools to return conditions to their pre-accident state as best possible. Indeed, all the existing models consider the costs associated with the implementation of these countermeasures.

This evaluation is often used as part of the decision-making process to reach optimal intervention levels for the application of alternative countermeasures. According to the international recommendations for intervention after a radiological accident,[6,7] the protective actions to avoid delayed health effects should be initiated when they produce more good than harm in the affected population, and should be introduced and withdrawn at levels that produce a maximum net benefit to the population. In applying these principles, the terms "good", "harm" and "benefit" should include, obviously, health and safety and the tangible costs of protective actions, as well as other unquantifiable factors such as reassurance, stress, and other societal values. It is to be noted that, besides their direct costs, the implementation of countermeasures can induce indirect costs in terms of secondary consequences on the welfare of society and the economy, which should also be taken into account by the decision maker.

Population movement

The countermeasures which affect an individual through restrictions on movement or compulsory movement are, in the short term, sheltering and evacuation and, in the longer term, relocation to an area of lower exposure rate. The most representative examples of minimum and maximum extension of this kind of protective actions are the accidents of Three Mile Island and Chernobyl: after the TMI accident, 144 000 people (i.e. 39% of the local population) spontaneously left the area for some days, and then moved back without additional problems; on the contrary, in the case of Chernobyl, approximately 135 000 persons were evacuated in 1986, soon after the accident,[8] and through 1990 approximately 73 000 more were relocated, leading to a total of almost 190 000 persons relocated for a very long period. Another significant example of countermeasures of this nature is the accident which occurred in 1957 in Kyshtym, in the Eastern Urals, which involved the definitive relocation of 1 100 persons after seven to ten days, plus another 9 600 people some 250-670 days after the accident.[9]

In addition to the countermeasures implemented by the authorities, there may be non-controlled behaviour, like the voluntary population movement**s** observed in the aftermath of the Chernobyl accident, including the abandoning of less contaminated areas (the size of populations who have voluntarily moved has been cited as between 100 000 and 300 000) or the return of previously relocated families.[10] These effects would be certainly very difficult to account for in any model, and should be borne in mind when dealing with the uncertainties in the assessments.

The costs arising from this type of countermeasure, without excluding other possible impacts, can be mainly associated with the following:

- Transport away from the affected area.
- Temporary accommodation and food.
- Supervision of the evacuated area and monitoring of people.
- Loss of income for people unable to reach the workplace.
- Lost capital value and investment on land and property.
- Psychological effects of worry and upheaval.

Costs relative to the short-term countermeasures belong to the micro-economics field. They generally remain marginal with regard to the global assessment, but they are mentioned here in order to be exhaustive, and because of the heavy psychological impact that these countermeasures can have on the affected populations.

Costs of transport away from the affected area

Transport costs arise if evacuation and/or relocation are implemented. It is likely that there will be differences in cost between evacuation, which is organised rapidly and involves transport of people rather than possessions, and relocation, for which there is more time available for planning and, possibly, the movement of belongings is required. A representative cost per journey (evacuation or relocation) can be estimated, assuming, both, organised transport, using military and public means, and private transport by cars, excluding mileage-independent costs (as depreciation, insurance or taxes).

Costs of temporary accommodation and food

In the event of an accident, people will be likely to stay either with friends or relatives, or in hotels, or in emergency reception centres. In the case of hotels, a proportion of the apparent cost of food and accommodation should not be seen as a true cost, but it would represent a profit for the hotel owners. In costing this aspect, the expenditure on food that would have been borne by the evacuated population if the countermeasures had not occurred should not be accounted for as part of the cost of the countermeasures.

Housing expenses are bound to be subject to compensation claims, and households will be reimbursed. But there is a distinction between calculating the cost of accommodation during evacuation or in the early stages of relocation, and that of accommodation for longer-term relocation. Housing solutions during the initial phase are usually not acceptable in the long run, and people will likely search for more permanent solutions. For long-term relocation, new permanent accommodation will replace that which has been lost, and so this does not constitute an on-going cost.

In costing accommodation during evacuation and relocation, the following three factors are applicable: the cost of the lost benefit of the old (and temporarily lost) accommodation, the cost of the new emergency accommodation, and the benefit gained from the new accommodation. To avoid double counting, the cost of the new accommodation should not be considered to be part of the cost of the accident, because a benefit is being derived from it. A simple approach is to estimate only the cost of the lost accommodation. This can be useful for calculating the compensation to be paid by the insurance. But, from a social point of view, if housing is included as a part of the losses of capital and losses of income, the best is simply not to consider it separately, in order to avoid a double counting: households are indemnified for their losses in income and capital and will finance their new housing themselves.

From the practical point of view, it is certain that if, in the case of a major accident, thousands of relocated people entered the rental market overnight, they would face a shortage of housing and an inflationary pressure. One may suppose that, in view of the sudden rush of demand, the government would judiciously impose a price freeze. At the same time, the sudden influx of a large number of relocated people might affect the construction market, and this effect should be modelled.

Costs related to loss of income

Whether or not people affected by evacuation or relocation are able to continue to work at their usual place of work depends to a large extent on the scale of the accident. In the case of a large accident, normally people will loose home and workplace at the same time, so it is unlikely that a person will be moved from his home while still being able to access his place of work; this would only occur on the edge of the evacuation or relocation area, or in areas where people travel significant distances between home and the workplace, or in the case of industries which would need special conditions to be safely shutdown. However, for accidents of a smaller scale, it is possible that for a significant percentage of the population only the home would be affected by restrictions and work could theoretically continue, especially in the industrial sector.

If the evacuated or relocated populations are unable to reach their workplaces, the contribution they would have made to the economy will be lost. This may also happen in the case of sheltering. A measure for this, which has been used in several models, is the contribution made to the Gross Domestic Product (GDP), which quantifies the value of goods and services produced within a country in a particular period, usually one year. GDP may simplistically be regarded as the sum of the following categories:

- Wages and salaries ("personal or household" income).
- Profits and interest payments ("corporate" income).
- Rent on land and housing.

Whether an economic model uses GDP as its measure of lost income or not, these three categories are components of cost that need to be considered. An alternative and frequently used measure to GDP is GVA (Gross Value Added) at factor costs, since taxes and subsidies are simple transfers. Both concepts are very close and the choice between them should not affect the assessments more than the uncertainties in evaluating the impact of the countermeasures.

During a lengthy period of relocation, it is likely that there will be a gradual reduction in costs associated with loss of income, due to individuals finding re-employment outside the affected area. This effect can be modelled by stopping the loss of income costs at some point in time, or over a period of time. In finding employment outside the affected area, some of the relocated people will find jobs similar to their previous ones, but others may have to change occupations or find temporary employment. However, for practical reasons, the models normally assume that the replacement jobs will have the same contribution to GDP as the previous ones.

To estimate the contribution of an area of land to GDP, specific data on the utilisation of that land may be used. Another technique is to assume that the value of the affected region can be represented by the average national value per unit area of land. Alternatively, the national average value of the contribution to GDP per head can be applied to the population of the affected area. There are advantages and disadvantages associated with each of these approaches. In particular, lack of data may be an overriding consideration.

Costs of lost capital

During long-term relocation, individuals may find re-employment and the costs from loss of income will end. After this recovery process has occurred, the only cost remaining is that representing the lost services of the capital value of land and assets. There are two aspects to this loss of capital services: a loss of interest on the original investment and depreciation for different reasons.

The owner of a property made an investment, from which he receives a rent. The price of his asset can be estimated by the sum of the discounted future revenues. Thus, if the property cannot be used for a period of time, its market value is reduced by the amount of the discounted revenues over that period. And this is equal to the loss of capital due to the accident.

Normal or "natural" depreciation of capital is included in GDP, and it should not be accounted for during the transition period in which GDP losses are considered. However, an additional depreciation will occur in the area from which people are relocated, due to lack of maintenance and use of installations and, possibly, to vandalism and looting. In the extreme case, for certain industries, a stop can represent a total loss of the industry. Finally, a third loss can come in addition, corresponding to the reduction in the market value of the fixed capital which suffers environment degradation. This is an example of indirect cost. So, two zones could therefore be distinguished: the prohibited zone with losses due to restriction of use of the capital, and a more diffuse zone with losses due to the degradation of the environment.

These costs are clearly dependent on the original value of the land and its assets and the period for which the area is unused. The estimation of that value at the time of the accident is usually subdivided into different categories depending on the availability of statistical data. An example of categorisation is that included in Haywood,[11] which comprises four classes:

- Non-residential capital stock (excluding housing and consumer durable).
- Housing (only considered if not included in GDP).
- Consumer durable.
- Land.

For areas from which populations have been removed, some period of time will be necessary to allow for rebuilding and repairing it, and for its gradual resettlement. During this time a proportion of the capital service costs may well continue, and this should be considered.

Agricultural restrictions and countermeasures

The costs here are those arising from the placing of restrictions on the production or consumption of foodstuffs, because the levels of radioactivity in the food exceed given criteria, or those arising from other food countermeasures which are implemented to reduce the levels of contamination in agricultural products. These criteria, which should be fixed by the authorities, are in fact the driving parameters for these costs, and are generally fixed bearing in mind the cost of their implementation.

There have been some significant events in the past involving agricultural countermeasures, of which the most severe example is the Chernobyl accident, with very large amounts of food discarded and vast expanses of land affected by agricultural restrictions in several European countries. However other accidents can also serve as a reference, like those of Kyshtym (Eastern Urals, 1957), with 106 000 ha with agricultural production blocked for a minimum of 4 years, or Windscale (United Kingdom, 1957), with milk disposal in 520 km^2 for 6 weeks.[12]

The costs which arise from restrictions being placed on the production or consumption of foodstuffs are the cost of the lost food itself, the cost of lost capital value of land and stock during the period of restriction, the cost of disposal or processing or storage of the food and the cost of alternative supplies. These costs can be reduced if alternative less drastic countermeasures are implemented, such as diversion of some of the banned products to other uses, storage to allow for radioactive decay or modification of agricultural practices and crop patterns. The discussion below is about the costs appropriate for restrictions on terrestrial foods, but these do apply to some extent to restrictions on freshwater produce.

The usual units by which the consequences of food restrictions are expressed are the amounts of agricultural produce that are lost or restricted. These may, for instance, be the amount of milk lost in a period, the number of livestock restricted or the area of crop producing land that is restricted. Statistics exist in many countries by which costs (usually GDP-related) may be associated with these broad categories.

Such quantities represent the contribution made by the raw produce to the economy. It is likely that there will be additional costs, caused by the raw produce being unavailable to the food processing industry and the resulting need for alternative food supplies. This should be considered, but any possible double counting should be avoided if the cost of the lost production has already been included in the assessment. The extent to which food processing industries would be affected would depend on the form in which alternative food supplies are provided. Although it is likely that alternative supplies of these foods in the form of the raw product could be imported, it would take some time to re-establish supplies and so enable the processing industries to return to production.

An area affected by food restrictions may or may not also be subject to evacuation or relocation of the population. If there is evacuation or relocation in the area in addition to food restrictions, it is important to avoid double counting economic effects.

In the same way as for long-term relocation, there will gradually be a recovery of the economy if food restrictions continue for a prolonged period. The farmers and their workers will find alternative employments (not necessarily in agriculture). This recovery of the economy will need to be considered. As for loss of income-related costs, the only costs remaining after the cut-off period, when the members of the affected farming population have found re-employment, are those from the capital value of the farm, its land and its assets. Of these, the capital value of the land is likely to be the most significant. Figures for the value of agricultural land per unit area are readily available in many countries. The loss of capital services from this land are then those from the loss of interest on the original investment in the land, i.e. its lost utility; there is no depreciation component.

As in the case of relocation, it is likely that the re-use of the area will not occur instantaneously after a lengthy period of food restrictions. Some time will be necessary to allow for repairs, treatment of the land, restocking of livestock, etc. During this time, a proportion of the capital service costs will continue. Unfortunately, it is not easy to define, a priori, the expected duration of countermeasures with regard to agriculture.

Restrictions on the production or consumption of food will usually require action to be taken on the product which cannot be consumed. Possible actions include disposal, storage or processing of the contaminated food. In some cases, as mentioned earlier, these actions could allow some economic use of the affected food, thus reducing the actual cost of the countermeasure, and this should be taken into account.

There are difficulties in estimating the costs of food disposal, arising mainly from uncertainty about the processes that would actually be adopted in the event of an accident. These would, to some extent, be influenced by the scale of the accident. More expensive methods may be applied after a small-scale accident, with little agricultural produce affected, than it would be possible in the event of a large accident. This uncertainty particularly affects the disposal of livestock, as, in the event of comparatively low levels of contamination, affected animals may be kept as breeding stock even if produce obtained from the animals themselves cannot be consumed. The cost of disposing of food may be evaluated in terms of generalised values for the disposal cost of milk (per litre), crops (per kg), and livestock (per animal).

Decontamination

Decontamination allows a more rapid reduction of ambient radioactivity levels toward pre-accident levels. This countermeasure thus influences the duration of the ban on the evacuated area, but also the degree of radiation exposure of the population.

The costs of decontamination consist of:

- Cost of cleaning process, including the necessary equipment and materials, as well as the disposal and transportation of the generated waste.
- Cost of labour.
- Cost of health effects induced in the workforce.

Decontamination costs differ markedly, depending on the level of decontamination or dose rate reduction desired, and on the type of environment (for example, inner city, residential or rural environment) being decontaminated. Costs should be specified as a function of decontamination effectiveness and environment. Default data may be derived from a search of the available literature on the costs and effectiveness of common decontamination processes.[13,14,15]

It should be noted that default values for effectiveness and cost often assume that the decontamination process occurs in the first year. This is because the effects of natural processes, such as weathering and runoff, in decreasing the effectiveness of decontamination processes applied after this time, are not usually included. More complex models may be able to take such features into account, and in this case a series of costs and factors which varied with the assumed time of decontamination would be required.

Cost of radiation-induced health effects

There are three main categories of effects which may be directly caused by exposure to ionising radiation:

- Early effects.
- Latent effects.
- Hereditary effects.

Moreover, it is recognised that in case of a catastrophic accident, such as Chernobyl, the psychological distress with which a population would be faced is an important effect in itself, and can lead to an increase in the cases of health impairment. These are, however, much more difficult to assess a priori, since they will not directly depend on measurable magnitudes, like the extension of the contamination or the radiation dose received by the individuals. Furthermore, the sudden change in living conditions among those affected by the countermeasures can also lead to an increase in cases of stress related illness.

The estimation of the economic cost resulting from the predicted number of health effects is an important part of the assessment of the full economic consequences of an accident. However, the quantification of health detriment is a controversial subject, because, whilst in principle a monetary value of life is required, not all costs associated with health effects – shown in the following list – can be directly expressed in monetary terms:

- Direct health care costs.

- Indirect costs, due to the loss of earnings during treatment and convalescence or of the total expected future earnings in the case of death.
- Non-monetary costs, such as pain, grief and suffering associated with each effect.

A number of approaches have been developed, which essentially differ in the extent to which they quantify non-monetary factors. Baseline costs for health effects may be derived to assess the impact of a health effect on the economy. This involves the evaluation of the treatment cost of that effect, together with that from its indirect impact on the economy, resulting from the temporary or permanent removal of the individual from the workforce. This method is called the human capital approach. The inclusion of non-monetary factors is difficult and requires information on the relative amounts of pain, grief and distress associated with each effect, and would probably be better evaluated with subjective approaches, like the willingness-to-pay method.

Human capital approach

This method assesses those costs which have a directly measurable effect on the economy, and so define a useful baseline cost. The two first broad components of the cost of health effects (first two bullets above) are considered.

The derivation of the costs of treatment, hospitalisation and medicines is conceptually straightforward. It requires information on the type and duration of treatment for each type of health effect. A rigorous study has been performed by Nieves.[16]

In the human capital approach, the value of an individual is determined by his or her production potential, and the impact of a health effect is determined by its effect on this potential in terms of loss of contribution to the economy. The production potential is measured by the expected earnings of the individual and this approach does not directly address non-monetary effects, although some allowance for these effects may be included through the choice of appropriate earnings data.

This type of assessment requires information on the number of years of life either lost or impaired as a result of a health effect and the annual earnings of the individual. For many applications, it will be adequate to assign to each man year of illness or life lost a single value, representing the average annual potential earnings of the individual over his or her lifetime. However, care should be taken not to include the loss of earnings twice, since they were already accounted in the loss of income in the evacuated/relocation zones. Since it is in those zones where the exposure of the population is higher that the larger number of health effects can be expected, the probability of double counting the loss of income for the duration of the evacuation/relocation countermeasures is not negligible. Also, the foregone earnings should include only earnings derived from labour. The power of assets other than labour – such as bonds, stocks and savings certificates – to generate earnings is unaffected by adverse health or death.

For health effects which can appear delayed in time, appropriate discounting methods are very important to get reasonable estimates of their economic cost. It should be noted that it is not the number of health effects that is being discounted, but their respective costs in case the effects appear years after the accident. It is generally considered that, even if subjective valuation methods are used, an individual would assign a higher value to a damage occurring immediately than if the same effect would appear many years later. This is a reflection of some subjective discounting of the damage that a health effect can produce. However, a careful choice should be made of the discount rate to be used, which generally should be lower than that used in economic investment analysis to take a conservative option facing long-term impacts.

The criticisms of this method are based on the limited consideration given to non-monetary factors, and the fact that it could result in an uneven valuation of different population groups, by assigning a lower or a zero value to those not contributing actively to the economy. These problems could be overcome if average values were established for the whole population, irrespective of their economic situation, then including some increase to take into account non-monetary factors. In any case, this method can be useful for some regulatory activities (like, for instance, derivation of countermeasure criteria), as it allows a base comparison of objective quantifications of the value of a statistical life. It is recognised, however, that for other applications, such as for the evaluation of external costs of energy alternatives, the subjective valuation can offer more acceptable results.

The willingness to pay approach

This approach enables the non-pecuniary elements, like anxiety, pain, grief, distress and discomfort, of the cost of health effects to be evaluated where required. The simplest approach to evaluating these costs is to assign a single value to each health effect category. Various valuation methods have been established, in an effort to include these non-monetary impacts of ill-health and death more explicitly. Some models using this approach also allow the inclusion of risk aversion factors that reflect the higher subjective valuation that individuals put on the more severe health effects.

The cost for each health effect is determined by the amount which an individual would be willing to pay to decrease the risk of that health effect, or, alternatively, the amount which he or she is willing to accept to compensate for an increased risk. A number of different methods have been employed to derive these values, including survey techniques and revealed preference studies. Each of these methods may yield different results depending on the elements of cost which are taken into account in the derivation of the figures; care is necessary to ensure that the values used are consistent with the application sought. In any case, these methods have many limitations and can only be seen as a surrogate for the valuation of health effects.

Indirect or secondary effects

It is possible for an accident to have positive and negative economic impacts outside of the area directly affected by the countermeasures for the protection of the population. At the macro-economic level, impacts on employment, value added, government expenditures and receipts, tourism industry and balance of payments are interesting to measure. One problem when analysing indirect or secondary impacts is that their magnitude depends on the size of the area included in the analysis. Negative effects in one specific region can be balanced by positive effects in another area. In that case, it is important that the results of the analysis clearly show which kind of impact can be expected in which area.

In terms of negative indirect effects, most areas of significant size will produce certain goods (such as intermediate manufacturing components and electricity supply) which are important to the economy of other areas. Restrictions in an area which produced items or services required in production processes outside the affected area will disrupt production unless, or until an alternative source of supply can be established. In certain circumstances, disruption costs may be more long lasting because of the rarity of supply, for example in the mining of a rare substance. A similar, and more likely effect may occur if the affected area contained a major service, such as a principal transport facility, which it would take a considerable time to re-establish elsewhere. An example of this might be a major container port. The loss of such an area would have a greater impact on the nation's economy than would be indicated by its direct contribution to GDP. Similarly, the inability to use a mainline railway or motorway would cause costly diversions, and decontamination of these areas would be a priority.

An accident may have a marked impact on the tourist industry, which will not be necessarily confined to the area which is immediately affected by the accident. Moreover, restrictions imposed on the consumption of food may result in losses in the export of both contaminated and uncontaminated produce, and may affect the sale of foods totally unconnected with the accident. Also, even after the end of the countermeasures, the consumers may refuse to buy products from the contaminated region for some time.

Economic assessments should not ignore these various indirect factors. In fact, as the case of the Chernobyl accident has shown, for some countries indirect costs can amount to as much as the direct costs (see, for instance, Annex V).

On the other hand, although the global balance of an accident is undoubtedly negative, a view exists that for consistency of assessment methods, other effects such as the creation of new demands for goods and services should be accounted for. Thus, even though these effects are extremely difficult to predict, a comprehensive study should also take into account this type of impact, such as growth in demand and employment in the building industry and civil engineering.[17]

Also, as discussed above, the production loss of the region directly affected will be partly balanced by an increase in the production of neighbour regions. In this case, positive effects could be expressed by rises in demand for the relevant products in the adjacent unaffected areas. For this reason, calculations of indirect costs are limited in time and space. In conclusion, for a comprehensive assessment of the economic impact of an accident, these increases in demands for goods and services, in the areas not directly influenced by the countermeasures, should be considered in addition to the effects in the affected regions. However, it should be recognised that for some scenarios these effects can be only partially considered, given the limited capacity to model a priori some effects like the aforementioned on tourism or on food marketing.

An evaluation of indirect effects can be based, with some limitations, on the use of input-output methods, which represent the interchanges between the different economic sectors of a region or a country. These methods are useful to analyse amplified impacts derived from the loss of value added as a consequence of population movements or countermeasures in agriculture.

The difficulties with these methods are associated with the compilation of suitable input-output tables, with the calculational effort required, and with the definition of non-directly affected areas, (some effects may extend over the entire country). Given the interest and the increasing use of these kinds of methods, Annex VI describes the input-output approach more thoroughly, including some application examples.

Chapter 3

PERSPECTIVES OF COST ASSESSMENT

Introduction: cost assessment perspectives

In Chapter 2 a full review of the elements which comprise an assessment of the economic consequences of a nuclear accident was presented and the various types of costs to be considered in such an assessment were analysed.

Historically, the approach to this kind of assessment has evolved significantly. Before the TMI accident, most work in this area concentrated on the costs of short-term countermeasures, and this information was used as input to the decision-making process for the selection of appropriate responses. Thus, this was mostly an emergency management consideration. After TMI, the concept of a probabilistic approach, PSA, began to be applied in practice. This expanded the above approach somewhat to include emergency planning and preparedness, as well as accident management. Development along these lines continued until the Chernobyl accident. The post-Chernobyl approach then added the idea that emergency planning, preparedness, and management assessments should be expanded to include large-scale accident consequences. For this reason, the social aspects of emergency management took on much greater significance. Thus, questions as whether or not existing liability and compensation systems are appropriate to address the consequences of a large nuclear accident and how the possibility of a large accident would affect, a priori, the price of electricity, began to be addressed. Therefore, the concepts of dealing with the compensation of victims and with internalising accident costs have become an important component of the consequence assessments.

In the light of this evolution, from focusing on the short-term to focusing also on the long-term aspects of an emergency, it is now felt that there is no single “cost of an accident”. The cost, and the methodologies necessary to calculate that cost, will depend upon the perspective taken. That is to say, the cost elements to be considered, and the methodology used to combine those cost elements, will depend greatly upon the objective of the cost study, and the intended use of the resulting “accident cost”. For example, from the perspective of accident preparedness and management the choice of short-term countermeasures will be the primary focus. This perspective will define which cost elements should be taken into account. Viewed from the compensation perspective, the cost elements taken into account will be completely different, but although they will overlap somewhat with those necessary for the accident preparedness and management perspective. Finally, if viewing the cost from the perspective of power generation choices, different and again somewhat overlapping cost elements will have to be considered. Although there are other perspectives from which accident costs can be viewed, the Expert group felt that the three cited here are among the most important to current discussions in this area.

Each of these perspectives is valid in the sense that the resulting calculations are useful in a specifically defined application. However each perspective will most likely terminate in a different numerical result.

In addition to discussion of work in the area of cost assessment methodologies for accident preparedness and management purposes, the Expert group felt that the perspectives of external costs and compensation, although not in the original charter of the Group, were fairly important. As such, the following sections of this chapter provide a brief overview of compensation and external cost issues that have emerged from the ongoing debates in these areas.

The accident preparedness and management perspective

Before the Chernobyl accident, economic analysis was mainly used for the evaluation of countermeasures, especially within the process aiming at the determination of intervention levels. Emphasis was mainly on immediate response and short-term actions, while consideration of the long-term consequences of accidents was given a lower priority. After the Chernobyl accident, later countermeasures became an important issue. In this perspective, the economic analysis was also used for defining the level of implementation of the long-term intervention criteria, for example, for permanent relocation or food restriction.

Short-term countermeasures

The assessment of the effectiveness of short-term countermeasures in terms of dose reduction is now well established and can be performed with reasonable confidence. On this basis, in order to define an accident management policy in accordance with the ALARA principle, efforts are now made to evaluate and compare the economic consequences of alternative countermeasures.

These evaluations are generally performed in the framework of classical cost-benefit analysis which implies the definition of a system of monetary values of the person sievert. Although the understanding and the use of this concept still remain a matter of controversy, its adoption is, however, necessary in order to determine, within an a priori evaluation, the optimum extent of short-term countermeasures and to choose the accident management strategy according to the situation considered. Different methods, including the human capital approach and the willingness to pay approach, have been proposed to establish the monetary value of person sievert to be used in the cost-benefit analysis.

Examples of application of the cost-benefit approach include the evaluation of the benefit associated with the potassium iodide prophylaxis as well as the definition of the optimal use of sheltering and temporary relocation.

The potassium iodide prophylaxis case

When defining the best strategies for the distribution of potassium iodide tablets, two problems have to be addressed: the size of the area in which the distribution of potassium iodide tablets is necessary and which option (stockpiling or predistribution) is the more cost-effective. In this perspective, detailed analyses have been performed[18] considering the economic benefits as avoidance of potential thyroidal health effects and fatal and non fatal cancer effects. Accident consequence assessment codes are generally used to perform the calculations of the expected reduction of effects according to the distance from the plant and the size of the population.

The economic values associated with these health effects have been determined, including direct and indirect costs as well as a monetary value for the psychological consequences associated with these health effects. These costs were compared to the implementation cost of the potassium iodide tablets distribution (for the two options mentioned above). This comparison led to the determination of a "cost-benefit" ratio reflecting, for each part of the population (for example the population within a 5 miles radius of a nuclear installation), the amount of money which would be spent in order to avoid the economic equivalent cost of $1 in terms of health effects.

The cost-benefit ratios evaluated by this study were in the range of 2.26 for the population living in the first 5 miles and 216 for populations out to a distance of 100 miles. Although these values are affected by large uncertainties and are dependent on the monetary value associated with the health effects, they can be useful for the selection of the strategy concerning the distribution of potassium iodide tablets, even if the definition of an optimal strategy for short-term countermeasures is not limited to the cost-benefit analysis.

The sheltering versus evacuation case

For the economic analysis, it is easy to estimate the cost of the evacuation while the cost of sheltering is generally considered as very low. On the other hand, the effectiveness of the two countermeasures is different, sheltering being less effective. This evaluation of the two options has been largely used by the Nuclear Regulatory Commission in the United States for the establishment of guidance on emergency management, recognising the effectiveness of prompt evacuation of people residing close to the plant and downwind.[19] As a result, prompt evacuation in these situations was considered effective for a monetary equivalent of one person-sievert avoided ranging between $12 000 and $200 000, depending on the source-terms considered, while sheltering was deemed to be more appropriate for areas farther away from the plant.

Long-term countermeasures

Following the Chernobyl accident, more emphasis was devoted to the analysis of long-term consequences of the accident, which became an important component of the consequence assessments for accident preparedness and management purposes. The reflection was, thus, oriented towards the elaboration of a conceptual framework for the evaluation of intervention, which aims at reducing the exposures of the population by reference to the principles of justification and optimisation proposed by the ICRP.[6,20,21,22]

As far as the justification of intervention is concerned, the introduction of protective measures to deal with long term consequences of a nuclear accident should provide more good than harm. In this perspective, a cost-benefit analysis has been proposed in order to assist the selection of internationally applicable generic intervention levels.

Assessments based on this approach have been applied to the definition of relocation strategies and the time of return as well as for foodstuff restrictions. This conceptual framework has been used for the establishment of intervention levels by various national and international organisations.[23,24,25]

As an example, on the basis of an average cost for relocation of $200-600/person.month and assuming a monetary value of the person Sv ranging from $20 000 to $40 000, the cost-benefit analysis leads to recommend the implementation of the relocation in areas where the actual rate of individual effective dose accumulation would exceed: 5-30 mSv/month.

On the same basis, intervention levels for food restrictions can be derived, assuming a cost rate of $0.5-5 per kg for different foodstuffs. Thus, the cost-benefit analysis should lead to introduce food restrictions when the collective dose from consumption exceeds: 10-250 person.microSv/kg. In the case of ^{131}I and ^{137}Cs, these restrictions correspond to 1 000-25 000 Bq/kg.[26]

The compensation perspective

Historical context

From the beginning of the nuclear power industry, it was understood that the production and use of atomic energy created hazards which were different in nature and scope from those encountered in other industrial activities. It was also recognised that, while the probability of a nuclear accident is very low, the potential damage resulting from such an occurrence could be very severe and could extend beyond national boundaries. In addition, such damage could be relatively slow to appear.

In the 1950s, Governments, many of which were embarking upon nuclear power programmes or were expected to do so in the future, saw the need to ensure that, in the case of nuclear damage, victims would be compensated in an equitable manner. It was recognised early on, however, that ordinary tort law was not well suited to addressing the special kinds of problems that could emerge in the course of compensating victims of nuclear damage. Under such tort law, victims would likely encounter enormous difficulties trying to determine who was legally liable for causing the damage, be they the suppliers of goods or services, builders, owners, operators or any combination thereof.

At the same time, those same Governments wished to ensure that the growth of the nuclear industry, from which it was considered that the public would benefit, would not be hindered by an intolerable burden of liability for nuclear damage. It was generally accepted that those persons who could, in law, be liable for nuclear damage should not have to be exposed to an unlimited liability for which they could not obtain full insurance coverage.

Table 2.1 **Nuclear damage compensation amounts available in some OECD countries in "Special Drawing Rights (SDR)" as defined by the International Monetary Fund**

Country	Liability limits as set out in national legislation, in millions of SDRs	Comments	Total compensation available including public funds in millions of SDRs	Comments
Austria	35		35	
Belgium	90		300	And appropriate measures by the Government
Canada	35			To be decided by Government
Denmark	60		300	
Finland	150		300	
France	80		330	
Germany		Unlimited liability	450	
Italy	5		300	
Japan		Unlimited liability		To be decided by the Diet
Netherlands	310		2 070	
Norway	60		300	
Spain	125		300	Additional measures to be taken by the State
Sweden	175		300	
Switzerland		Unlimited liability	560	
United Kingdom	150		300	And appropriate measures by Parliament
United States	5 705			Any additional funds to be decided by the Congress

Note. The rates used in these calculations are based upon the 31 March 1995 exchange rate of national currency per SDR as taken from *International Financial Statistics*, May 1995, rounded to the nearest 5 million SDRs.

The two goals referred above have led to the development of special regimes at the international level to govern civil liability for nuclear damage incurred by third parties. These regimes are reflected in a number of international conventions, most notably the Paris, Brussels and Vienna Conventions, which are described in Annex III of this Report. Table 2.1 above illustrates the amounts of compensation that are available to compensate victims of nuclear damage in various OECD countries.

Not all countries which exploit nuclear energy for peaceful purposes have adhered to these Conventions, particularly if their relative geographical isolation makes such adherence seemingly less necessary. Such countries as the United States, Canada and Japan have chosen not to participate in these Conventions. However, the national legislations of these countries still reflect the principles upon which those Conventions are based.

Economic consequences and compensation systems

A nuclear accident may have negative impacts on many things. For example, plant investment and operation, public and worker health, environmental quality, social relations and acceptance of social/governmental institutions, and the stability of social structure itself may all suffer as the result of an accident.

It is not difficult to understand that the general public expects existing liability regimes and the systems of financial security provided for this purpose to ensure that all consequences of a nuclear accident are compensated by the operator who has caused the damage.

However, even focusing on the economic consequences resulting from an accident, the compensation systems do not fulfil this expectation, but there are substantial gaps between the total economic effects and the compensations which have to be provided. The most important gaps refer to the amounts of compensation, on the one hand, and to the types of compensation to which affected parties are entitled, on the other.

The reason for these gaps is that compensation systems follow different aims and, therefore, the methodology applied when assessing the amount of compensation due to affected parties is different from that used to calculate the total economic effects of a nuclear accident.

Calculation of the economic affect of a nuclear accident involves calculating all possible effects of a nuclear accident in a specific geographical area, to the extent that such effects can be described in economic terms. This approach is prospective, and makes use of probabilistic and macro-economic methodologies and standards. Rather than taking into account potential individual claims for compensation, the approach looks at the consequences for groups of people. This approach can be used for both emergency planning and post-accident management, as well as for investigating external costs.

Compensation, on the other hand, is based upon national legal regimes which have been established for the purpose of enabling victims of nuclear damage to receive monetary compensation for personal injury and property damage suffered as a result of a nuclear accident. Experts working in this field often try to adapt compensation to cover ever-increasing amounts of liability and an ever-broadening scope of damage. For example, it has been suggested that both environmental damage and the cost of implementing preventive measures are heads of damage which deserve compensation even though neither are currently included in the existing international liability regimes.

Some of the differences between these two approaches are illustrated in Table 2.2.

Table 2.2 **Economic and compensation cost analysis perspectives**

	Economic Analysis	Compensation
Purpose	Economic understanding and management	Compensating individual victims
Application	Before and/or during an accident (ex-ante)	After an accident (ex-post)
Framework	Defined scientifically but no general consensus	Defined legally
Approach	Probabilistic / Deterministic Macro-economic	Deterministic (causation) Micro-economic(individual claim)
Claimant	Groups of victims	Individual victims
Consequences	All direct and indirect consequences	Consequences as defined by "Nuclear Damage" (See paragraph on the definition of nuclear damage)
Geography	Off-site, state, trans-boundary	Off-site, state, trans-boundary for convention member states
Limitations on amounts	No limitation (goal is to be exhaustive)	Limited amounts of compensation available

The power generation choice perspective

Background and definitions

Cost is a very important element to be considered when making decisions concerning methods of electricity generation (oil, natural gas, nuclear, hydroelectric, wind, solar, etc.). Over time, the notion of what is or should be included in generation cost has, however, evolved. Whereas costs were once considered to be the "classic" engineering costs of plant construction, operation, dismantling and waste disposal, more and more the costs of environmental and social impacts are being considered. Efforts to fully characterise these costs, many of which are not currently included in the price of electricity to users, are underway in many electricity production sectors, with the ultimate goal of including these costs in the price of electricity. Costs which are not currently included in the price of electricity are generically referred to as "external costs", or "externalities", and their assessment is essential to valid comparison of generation options.

The concept of externalities has a long tradition in the economic literature.[27] This term is intended to represent the economic consequences of an activity (such as energy production) that accrue to society, but are not explicitly accounted for, by the activity participants, in their decision making. In economic terms, detrimental consequences are called "external costs", beneficial consequences are called "external benefits".[1]

1. Marshall[28] addressed exclusively the advantages (benefits) enjoyed by businessmen without payment and outside the market. Later, Pigou[29] pointed out that externalities could also be of negative character and lead to costs. Apart from the outside of the market influence on the production conditions of the third parties, also, the welfare of private persons can be seriously affected both in cost and benefit terms. Kapp[30] anticipated the far reaching consequences of economic growth on the environment and introduced the concept of "social cost", which is defined as all direct and indirect burdens imposed on third parties or the general public by the participants in economic activities. He explicitly mentions all costs emanating from production processes that are passed on to outsiders by way of air and water pollution.

Externalities arise due to the imperfections and/or non-existence of markets. For instance, there is no market for clean air and water. In a system of purely competitive markets, and in the absence of externalities, prices constitute the instrument for efficient resource allocation both on the production and consumption sides of the economy.

Two fundamental types of externalities can be distinguished: environmental and non-environmental. Examples of environmental externalities include impacts on public and occupational health (mortality, morbidity), impacts on agriculture and forests, bio-diversity effects, aquatic impacts (ground water, surface water), impacts on materials (such as buildings, cultural objects), and global impacts (greenhouse effect). Among non-environmental externalities are those concerning public infrastructure, security of supply of strategic goods, and government actions (such as R&D expenditures).

The impact of every industrial activity in a society includes external costs like pollution, and also external benefits like improvement of the standard of living, employment generation or economic development. From a society's point of view, the price of a product should reflect all the involved external costs and benefits. When this is the case, the costs and benefits are considered as "internalised". Much attention has been directed towards internalisation of external costs. With respect to external benefits, the major ones are usually considered as already internalised by the existing market processes. There is, however, no general consensus about this point of view.

The OECD has defined "the polluter pays principle" as a fundamental principle of cost allocation, according to which[31] the polluters should bear the expenses of preventing and controlling pollution to ensure that the environment is in an acceptable state. In particular, this certainly applies to electricity generation, which, like other industrial activities, is not free from health and environmental impacts. Several of these impacts are traditionally not accounted for in the price of electricity. It is only recently that the issue of internalisation of external impacts started to receive the attention it deserves towards creating conditions where the damages from energy production and consumption are taken into account by those who cause these effects. According to the current trend, externalities play an increasingly important role in decision-making and planning by utilities and other actors in the energy market.

It is worth noting that, prior to this development, a substantial number of potential external impacts have been effectively internalised through regulation and standards to which the power industry must comply.

Certain NEA publications are relevant to the subject of externalities, e.g. *Broad Economic Impacts of Nuclear Power*[32], and the Proceedings of the *International Symposium on Power Generation Choices: Cost, Risks and Externalities*.[33] In particular, in the former publication the main externality of nuclear energy was identified as the costs of very rare, large accidents.

External costs of nuclear reactor accidents

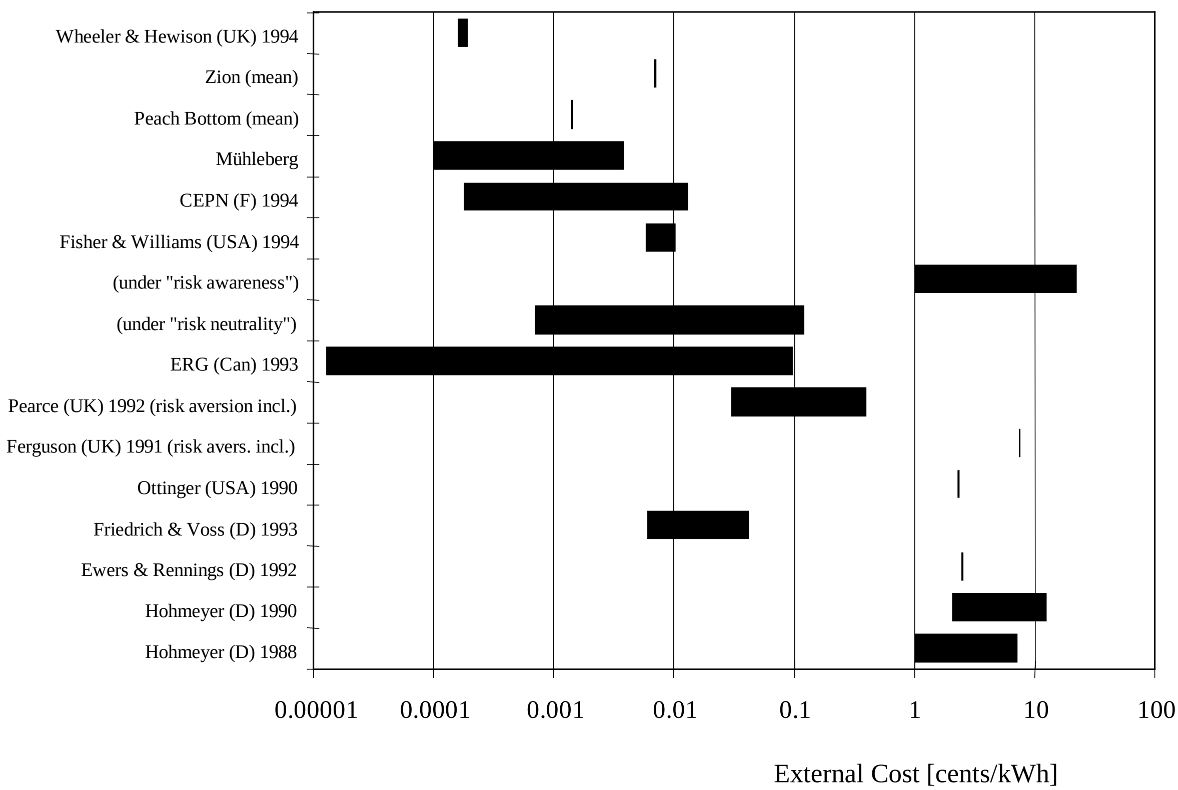
There is no disagreement that the external costs associated with normal operation of nuclear power plants are small, i.e. typically of the order of 0.1 cent per kWh.[34,35] With regard to nuclear accidents, the past external cost studies concentrate on hypothetical severe accidents. The Chernobyl accident has a special "prominence" in this context in view of the large number of estimated delayed fatalities and other serious health, environmental and social impacts.

Use of past experience to evaluate external costs of nuclear reactor accidents is limited to only two accidents, i.e. TMI in 1979 and Chernobyl in 1986. Komanoff Energy Associates[36] estimated the total cost of the TMI accident to be about US\$ 130×10^9.[2] The estimated costs for the Chernobyl accident cited in Nucleonics Week[37] range between 20 to US\$ 320×10^9 (the range depends on the assumed exchange rate for rubles). Sörensen[38] estimated the cost of TMI as 40×10^9 ECU and of Chernobyl as 600×10^9 ECU. It should be noted that these estimates represent accident costs which may include cost elements that have been internalised. Given this and considering that the total commercial nuclear experience until the end of 1994 corresponds to about 3 000 GWa, we obtain a normalised cost of past nuclear accidents to be in the range of 0.3 to 3.6 cents per kWh. These figures are provided here only as the background to the estimates based on the different approaches presented in the next section. They are not representative for current plants with good safety standards (from the design and operational point of view), since neither TMI nor Chernobyl in particular were designed to meet these standards.

Figure 2.1 shows the estimates of contributions of severe accidents to external costs of nuclear power, obtained in different studies in recent years. All costs are expressed in cents per kWh, based on exchange rates in March 1994. Annex I briefly presents some of these studies.

The values in the figure cover a range of some five orders of magnitude. No attempt to express the prices in terms of present values was made here; this would actually, in most cases, further increase the differences.

Figure 2.1 **Span of estimated external costs of severe reactor accidents**



Note: The Mühleberg estimate includes external events.[39]

2. The external costs of TMI have also been quoted as \$26 million, these being the costs of the fund set up after public negotiations and court action to provide compensation and pay for relevant research.

Methodologies for the assessment of the external costs of accidents

The calculation of external costs associated with rare severe accidents includes the same basic steps as the estimation of external costs in general.[40] There are, however, some specific characteristics related to the random nature of the events, which require special treatment. The main steps are:

1. Identification of types of accidents specific for the activity.

2. Evaluation of resulting physical impacts. This step involves the assessment of frequencies associated with accidental consequences of different magnitudes.

3. Financial assessment of damage.

As evident from point 2 above, any estimate of external costs will need to use some input from Probabilistic Safety Assessment (PSA). This is actually the case with all studies cited in this section. However, the extent to which the PSA results have been used and the consistency of application vary significantly. For this reason, the studies considered here have been grouped with respect to the weight given to PSA, on the one hand, and to past experience of severe nuclear accidents (equivalent to Chernobyl), on the other hand. In reality, they are some mixtures of the different approaches; in applicable cases the allocation is made on the basis of the dominance of one factor over the others:

- ***"Top down" approach***. This quite rough method, relies on previous estimates of total damage with an assessment of adequate fractions if adjustments seem necessary. Studies of this type are generally based on (and driven by) the Chernobyl estimated total dose to the population, used as a reference to derive the consequences related to a given specific plant.

- ***Limited "Bottom-up" approach***. The method relies heavily on the estimates from previous studies; thus, no data are collected on the primary level. Damage**s** are calculated by extrapolating PSA results obtained for a specific plant in a specific environment to the case of interest and/or using few PSA-based scenarios. However, site-specific effects are not considered.

- ***Full scope "Bottom-up" approach***. These studies are fully based on a plant-specific PSA or on an alternative, detailed, plant-specific probabilistic consequence analysis.

Some of the results are driven by risk aversion, independently of the type of approach listed above. The treatment of risk aversion is, from the methodological point of view, a central but simultaneously an open issue.

A number of difficulties and limitations are associated with the estimation of external costs.[39] In the following, they are described in generic terms for a variety of energy sources and associated fuel cycles, but they are, of course, fully applicable to external costs of nuclear reactor accidents:

- Estimation of physical impacts is a complicated and resource-demanding task. Among many factors affecting these estimations we may mention physical characteristics of the emissions (e.g. rate, duration, and location), meteorological and topographical conditions, pollutant interactions and transformations. Dose-response functions for estimation of health and environmental effects are known for only few major pollutants and are frequently subject to large uncertainties.

- Transferability of results obtained for a specific environment to a different environment may be questionable or invalid. Ideally the full scope “bottom-up” approach should not be subject to this limitation. However, from a practical point of view, it may not be feasible to simulate from scratch all environmental damage for all fuel cycles on a location-specific basis. Consequently, it is customary to use, to some extent, data from different studies, and attempt to correct for the differences between the source and application environments by introduction of systematic factors (scaling). Bearing in mind the complexity of the estimation (see the point above), this process is normally associated with large uncertainties.

- The effects of incremental loads may be non-linear, i.e. depending on the baseline level of environmental quality, and a small increment could lead to substantial damage or none at all.

- Establishment of boundary conditions, particularly time and space limits, for environmental damage estimation is not straightforward. Thus, the time scales for manifestation of environmental damage can vary; transboundary effects and contributions of parts of fuel cycles in foreign countries may be very important and it is an open question how deep in the structure of fuel cycles one should go in order to account for all significant contributions (e.g. material manufacturing). The effects can be local, regional or global. Usually, local and regional impacts can be assessed with more confidence than the global ones.

Explicit financial assessment of damage allows the expression of cost for a specific damage per unit of energy produced. Advantages of such representation are clear – the detrimental effects are expressed in a manner which allows direct and consistent comparisons between internal and external costs, between different contributors to external costs and between various fuel cycles. Financial assessment is carried out using different approaches, particularly since some of the commodities are marketable and others are not. The use of discounting, i.e. placing a lower value on damage that occur in the future as compared to the present ones, is a debatable issue with large potential impact on the numerical results.

Different studies are known to show numerical discrepancies in their results. It is worthwhile to consider which factors may have the primary influence on these discrepancies:[39]

Accident frequency: The frequencies used in the different studies are generally either plant-specific, or adopted from other plants, or assumed on a generic basis. There are cases where relatively high frequencies were allocated to specific very severe consequences (corresponding to the Chernobyl accident), possibly due to misunderstanding of the reference set of data used. Only this can explain differences of three orders of magnitude between some studies.

Magnitude of consequences: The amount of radioactivity released is generally either assumed, or estimated on a plant-specific basis or simply adopted from the Chernobyl accident. The extent of the consequences is then either calculated for the specific location or extrapolated using results obtained for other plants. Alternatively, Chernobyl-specific consequences are used with very limited adjustments for-site-specific characteristics. In some cases the implementation of extrapolations and adjustments is subject to errors.

Scope: The scope of the different studies ranges from consideration of one specific accident (typically Chernobyl) to systematic modelling of the full spectrum of hypothetical accidents; the latter approach, when properly implemented, provides a set of consequences with specific magnitudes and the associated frequencies. Some studies are limited to coverage of only one type of consequence, i.e. radiation-induced health effects, others also provide estimates of the costs of a wide spectrum of short- and long-term countermeasures (including related effects such as loss of land and property).

Calculation of risk: Risks are integrated by combining the consequences with specific magnitudes and the associated frequencies. In most cases the so called "product formula" is used, where the frequency of an accident is simply multiplied by the magnitude of its consequences. Some studies consider risk aversion by explicit or implicit allocation of extra weight to events with very large consequences. As an example, the results of Masuhr and Oczipka[41] show an increase by two to three orders of magnitude when such an approach is adopted.

Economic parameters: Depending on the scope and perspective (accident preparedness and management, or compensation, or external costs and power generation choices) of the economic analysis, the results are particularly sensitive to the monetary values assigned to loss of life, land and property. The degree of sensitivity may in turn be highly dependent on the plant-specific spectrum of accidents and on local conditions. In recent studies, however, quite similar values have been used for loss of life.

The estimation of external costs of nuclear accidents is clearly subject to large uncertainties; some of them are inherent and will stay with us, others are a matter of practice and are bound to be reduced with the increased state of knowledge and prospective agreements on procedures for carrying out balanced evaluations. Moreover, treatment and representation of uncertainties, which appear to be central in the support of decision-making, are other weak points of current studies.

In no way should the deficiencies and difficulties currently being experienced be viewed as disqualifying the efforts to estimate the costs of environmental damage. Firstly, the discipline is extremely young, and tries to penetrate partially unexplored terrain. Secondly, we know for certain that environmental damages occur, although we may have difficulties in estimating their magnitude with the desired precision. Assigning to them a value of zero, as was practised in the past, appears to be the worst possible solution.

Development continues in the area of characterisation of externalities, specifically, in the methodology for calculation. Annex II presents the basic steps of external cost calculation which would be involved in the full-scope "Bottom-up" approach.

Some concluding remarks on externalities

Past estimates of external costs of severe nuclear accidents show discrepancies which are larger than those from similar studies for other fuel cycles and are considered controversial. Independently of the numerical results, use of the Chernobyl accident as the only reference for the assessment of environmental consequences is more than questionable. Generally, state-of-the-art, rational and defensible methodological approaches, based on full scope PSAs, have not been used extensively in this context.

The results obtained for western plants using predominantly PSA-based approaches show low (quantifiable) contributions of severe accidents to external costs of nuclear power. This indication is applicable to plants with good safety standards and within the limited boundaries of the analyses performed, and generalisations should, therefore, be avoided. The relative differences between the different applications can still be large since the risks are expected to be strongly plant- and site-specific.

External costs associated with rare severe accidents are of interest primarily for comparisons, which are an important support to any decision-making process. However, there appears to be a disputable rationale behind internalisation of costs of events which, with a very high probability, will not occur during the lifetime of the plants being examined. In contrast, detrimental impacts associated with normal operation and with operational incidents, are not hypothetical but deterministic, and deserve appropriate consideration.

Chapter 4

CURRENT MODELS AND CODES FOR THE ASSESSMENT OF ECONOMIC CONSEQUENCES

It was in the context of risk assessment, and the comprehensive evaluation of the consequences of accidental releases of radioactive material, that early accident consequence assessment (ACA) computer programmes were first developed. Development has advanced greatly since early attempts, particularly with the introduction of probabilistic consequence assessment codes used for PSA Level 3 analysis. Now these programmes are capable of predicting the consequences of accidents in particular weather conditions, also taking into account the range of weather conditions which may occur. Such models may be useful in emergency planning, and in studies in connection with the siting, design and licensing of nuclear facilities.

Computer systems are also developed to aid the formulation of decisions on protective actions in the event of an actual accident, and assist in emergency planning. An example is the RODOS system,[42] currently being developed jointly by several European organisations under an European Commission funded programme of work.

As already explained in Chapter 2, the economic impact of protective countermeasures is a very important input factor for decision making about their implementation, and, therefore, several economic consequence models, which integrate many of the cost elements relevant in the event of a large nuclear accident, now exist and can be used as the basis of economic modules appropriate for application in programmes of both of the above types. The application of these models in the field of damage compensation or to determine the external costs of nuclear power is still to be fully developed, but some promising attempts have been already published.[43] The predictive nature of all these models is also the cause of many of their limitations, since they must be applied to a variety of scenarios, using generally applicable techniques, which cannot be as precise as the use of classical accounting methods applied to specific cases.

A comparative summary of the main characteristics of these models is presented and discussed in this chapter, preceded by a historical background, including references to the international intercomparison exercises performed in the last years.

In currently existing models, the approach adopted to the costing of each category of consequence is influenced by factors such as the availability and form of the necessary economic data, and the need to avoid high computational costs when the model is incorporated in an accident consequence assessment programme. These limiting factors, as well as the associated uncertainties, are discussed in the last section of this chapter.

Background

Consequence assessment is a very important step in PSA (Probabilistic Safety Assessment)[1] studies. This is the main task of PSA Level 3 analyses, which combine the output from the previous PSA Level 1 and 2 analyses (assessing respectively the frequencies of accidents leading to severe damage to the reactor core and possibly to a significant release of radioactive material, and the amounts of radioactive material released from the containment to atmosphere). The PSA Level 3 includes the integration of the variability of off-site weather conditions in a probabilistic environment, and results in an assessment of the risk associated with a given installation in its basic terms: damage and probability of damage to the public off-site.

The primary objective of early studies was, in most cases, the estimation of off-site financial consequences of nuclear reactor accidents, without consideration of the probability of occurrence of such accidents. The first very rough attempt in this direction was undertaken by the US Atomic Energy Commission.[44] *The Reactor Safety Study, RSS,*[45] on the other hand, was the first comprehensive application of Probabilistic Safety Assessment (PSA) techniques to estimate the risks to the public from the operation of a nuclear power plants. This included the assessment of economic risks using the Calculation of Reactor Accident Consequence (CRAC) model. Using an improved version of CRAC,[46] estimates of the off-site financial costs of five types of accidents for 91 nuclear power plant sites in the US were made. Economic effects labelled "property damage" included: lost wages, relocation expenses of the evacuated population, decontamination costs, loss of crops and milk, and interdicted land costs. In addition, three major types of public health effects were estimated, i.e. prompt fatalities, early injuries, and latent cancer fatalities; financial costs were attached to these effects using empirical values of society's willingness to expend resources to avert a death. Burke *et al*.[47] developed a new set of models based on the original CRAC model, which allowed for more flexibility in operation and accuracy in supplying input data for the off-site cost estimations. The models were applied to the Surry site in the United States.

Shortly after the publication of the draft RSS, the development of the first version of the Finnish ARANO code was begun, and the first results of its application for site evaluation were published in 1976.[48] Since this time, the initially quite simple calculational methods of ARANO have been further developed.

Later applications reflect the improvements in consequence modelling, as well as better knowledge of source terms. Thus, code systems such as UFOMOD,[49] MACCS,[50] COSYMA[51] and CONDOR[52] were developed.

In the United States, the MACCS code was developed in the late 1980s for the Nuclear Regulatory Commission to replace the previously used CRAC and CRAC2 codes, which contained the economic models used in the RSS. MACCS incorporates an economic model based on the work by Burke.[47] The new model which updated the micro-economic approach of the previous model, is more detailed and updates the basic data sets for the application in the United States.

In the late 1980s-early 1990s, the code MECA (Model for Economic Consequence Assessment) was developed by the Polytechnic University of Madrid as an alternative specific model, incorporating more detailed features in the quantification of the economic impact and a greater capability to use detailed data bases for the evaluation of the costs. Coupled initially to MACCS, and later to COSYMA,[53] in its last version (named MECA3,[54]), it also includes an input-output model to evaluate the direct and indirect costs caused by population movements.

1. A summary description of the full PSA methodology is included in Annex II.

Finally, in the United Kingdom, the NRPB developed the model COCO-1 (Cost Of Consequences Off-site), which has been incorporated as a standard model into COSYMA[55] and in the British code CONDOR.[52]

Among the precursor models, apart from the model contained in the RSS, it is worth mentioning the code developed by the US Bureau of Economic Analysis[56] and the ECONO-MARC model, of the NRPB.[57] The former, RIMS (Regional Industrial Multiplier System), was based on economic production and on the input-output methodology. It allowed estimating the effect on a regional economy of a change in demand for goods in one sector of the economy. For reactor accident impacts, the regions under consideration were divided into "physically affected" and "physically unaffected" areas. Estimates of the amount of output lost are needed for the analysis. The model can then calculate the effects of compensating adjustments within the economy. However, the economic effects were only calculated for the first year after the accident, and the model was considered unsuitable for direct use in probabilistic accident consequence assessment, because it required a very detailed data base and a great deal of computational effort. In the latter case, the basic assumption in ECONO-MARC was that the cost of countermeasures would be a function of the contribution to Gross Domestic Product (GDP) from the area prior to its contamination. Both concepts served as the germs of several of the models now in use.

Economic consequence models in all these codes were expanded and upgraded in relation to the earlier approaches. With respect to source terms calculations, major advancements were achieved and implemented in the latest severe accident risk study by USNRC,[58] leading to less conservative source terms than those used by Burke.[47] Economic accident consequence analyses were also carried out for non light water reactors (for example Canadian CANDU).[59] This was followed by numerous calculations of external costs associated with severe nuclear accidents.

Intercomparison exercises

Due to the increasing number of codes and models, intercomparison exercises have been considered necessary in order to compare capacities and identify weaknesses in the models, and to determine guidelines for future investigations. In this sense, in the early eighties the *First International Comparison Study on Reactor Accident Consequence Modelling*[60] was organised within the Nuclear Energy Agency of the OECD. The participating codes had very different characteristics, but were representative of the state of the art at that time. Among these codes, only a few were capable of producing results in economic terms. As a consequence, economic results were not compared on that occasion.

More recently, after the development of a completely new generation of ACA codes, the need for a new intercomparison was considered. In this way, some of the previously mentioned models and codes (ARANO, MACCS, MECA, COSYMA, OSCAAR and CONDOR) participated in the recent *NEA/EC Second International Comparison of Probabilistic Accident Consequence Assessment Codes*,[2] together with other ACA codes not specifically addressing the problem of economic consequences.

The outcome of that exercise showed not only the differences between the various economic models, but also those resulting from the previous steps of accident consequence assessment, especially in the calculation of the impact of countermeasures and the number of health effects. Additional differences came from certain assumptions the users made in adapting data from the specifications of the exercise to their own models. In general, the differences in the results obtained were within reasonable variation factors, and the exercise presented a lower dispersion in the results from modelling differences than previously expected.

For example, with regard to the cost of population movement, the differences between the predictions of the codes for this end point were relatively small, within a factor of 4 for a large magnitude release, and the Complementary Cumulative Distribution Function (CCDF)[2] curves were in reasonable agreement. The differences observed were largely due to differences in output from the countermeasures module, such as the extent and duration of relocation, and, for a low magnitude release, from the assumed duration of short-term evacuation, with a less significant contribution from differences in economic modelling.

Concerning the cost of food bans, the differences were also certainly small, within a factor of 5 for the two releases, also showing a reasonable agreement in the CCDF curves. The differences observed were due partly to differences in output from the food countermeasure modules, and partly to different assumptions made in adapting the data in the specification of the exercise for food.

The results for the cost of health effects were dominated by the predicted number of latent effects (fatal cancers). All the models basically used a similar method, considering the specified unitary costs for medical treatment and for time of life lost; but the time distributions considered for the appearance of cancers were different, and this was a source of difference in the costing of health effects.

With regard to the relative importance for the final cost of each of the basic cost elements, it was apparent that food ban costs were dominant for all the codes and calculations. Population movements were the next in importance for the large magnitude release, and health effects for the low magnitude release.[3] The total combined spread was by about a factor of two or three for the cases analysed. This explains the comment made above on the lower than expected differences that were observed in the exercise.

Model capabilities and limitations

In order to provide an orientation on the direction in which models should be developed to improve their capability for assessing the off-site economic impact of nuclear accidents, it is useful to summarise the capabilities and limitations of the existing models, comparing their basic features and noting for which aspects of the economic impact they are not suitable.

It is relatively straightforward to make a list of some common limitations contained in the models. They are generally intended for assessing direct economic impacts derived from the application of countermeasures, or from the health effects caused by the accidents. The ways in which they evaluate such impacts differ with regard to the conceptual definition of the costs considered, the level of detail in which they desaggregate the costs, and the detail of the data bases used. However, none of the models tries to assess indirect or secondary impacts as they were defined in Chapter 2, for example, those resulting outside the areas directly affected by the application of countermeasures.[4] Unquantifiable costs, such as image impact, the cost of ecological damage due to an accident, or the cost of psychological repercussions on the population are also not addressed at all by any of the models.

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2. CCDF: the curves which are normally used in ACA codes to represent the risk, showing the probability of having a consequence equal or higher than a given value.

3. Decontamination was not considered in the specifications of the exercise. Therefore, no conclusions about that restoration countermeasure were drawn from the exercise.

4. In a very recent version of the MECA code (*MECA3*[54]) a model is incorporated to evaluate the costs produced by population movements both in the affected and in the non-affected areas, using Input-Output methods.

To facilitate the comparison of the characteristics of each model, the enclosed set of tables (4.1 to 4.6) illustrate the basic features. The comments below provide some hints to the interpretation of the tables.

Costs of short-term countermeasures

Table 4.1 refers to the way in which the models evaluate the costs of short-term countermeasures, basically evacuation, short-term relocation and sheltering. Although prophylaxis with stable iodine is also normally considered in probabilistic consequence assessment codes, given the low economic impact associated with that protective action, the cost of this countermeasure is not evaluated by any of the codes mentioned here.

As it can be seen, the costs of evacuation are treated with different levels of detail. In most applications made by ARANO, the costs of short-term countermeasures, like evacuation, have not been accounted for separately, since these costs have been considered small compared to the longer-term relocation costs, especially in accidents involving quite large releases. In less severe accidents, where early countermeasures are implemented mainly as a precaution and later population relocation is not at all or to a minimal extent required, the relative share of short-term countermeasures is then, of course, larger. Only MECA considers specifically the cost of operating teams for management and monitoring of the population during the emergency, with a reduced cost for longer relocation periods (typically exceeding one week). Transport costs are explicitly taken into account by both COCO-1 and MECA, with consideration of different unit costs for people using public and private transport. This is, in any case, a detail of minor importance in the global cost of the emergency countermeasures. The costs of lodging and food during evacuation are considered in a similar way by MACCS and MECA, although the former includes them in a single unit cost together with loss of income, while MECA can use different unit costs for people using private or public lodgings, and reduced costs for longer periods of relocation. COCO-1 only considers the cost of the accommodation lost during the application of the countermeasures. Finally, the costs associated with the loss of income during the evacuation or relocation are treated in different ways: MACCS uses a single value per person and day that should represent the income lost by an individual; COCO-1 can use regional values (up to 15) of the *per capita* GDP; and MECA bases the evaluation on the Gross Value Added at factors cost, distributed in the grid and by economic sectors, excluding agriculture.

The differences above can be significant with regard to the total cost of an accident only if the magnitude of the accident is low. For large scale accidents, the costs of short-term countermeasures only represent a small fraction of total costs. Furthermore, these countermeasures are normally adopted to avoid serious deterministic health effects, as a consequence of the higher doses and dose rates at the beginning of a radioactive release, and as such, their potential for avoiding early health effects will be a factor more important than their economic cost.[10] In any case, this first comparison gives a general flavour of the kind of existing models: some quite simple and some more detailed and complicated. This can be verified in the following paragraphs.

Costs of long-term relocation of populations

In Chapter 2, the different cost elements in the case of a population movement for some time were discussed in some detail. Here, in Table 4.2, they are presented as they are dealt with in each model. Again, the management and monitoring costs are only explicitly considered by MECA, now with a reduced unit cost for longer periods, and only for the transitory period during which a population does not have permanent new accommodation. Given their relative minor importance, transport costs are not considered in MACCS, while ARANO simply includes them in a single value per person together with lodging and (extra) food, irrespective of the duration of the relocation. In COCO-1 and MECA these costs are treated similarly to the case of a short evacuation, but in the latter model, and using the livestock census, the hypothesis is made of livestock relocation and the transport cost of livestock is estimated. For lodging and food during relocation, the ARANO and MACCS models use a single per person value, associated with transport costs in the former, and with loss-of-income cost in the latter. COCO-1 accounts the accommodation lost up to a given recovery period, while MECA still considers different unit costs of lodging and food for private and public lodgings, now reduced with respect to evacuation, and only during a transition period after which it is assumed that relocated persons will have found new permanent accommodation. The accounting of food as a cost would be correct only if the new price of food is higher than the one before relocation. That is, normal expenses in accommodation and food should not be taken as a cost.

Losses of income during a long-term relocation are also treated with a different degree of detail. MACCS is the simplest model, using a single unit value, per day and person, for evaluation, together with the losses of accommodation and food. ARANO accounts for both loss of income by workers and losses of production, the former as a single unit value per worker, and the latter with four values per worker and day of production lost. If these are summed, a double counting could be produced since loss-of-income by workers is a part of production losses. In COCO-1 and MECA the basic measures for loss of income are GDP and GVA respectively. COCO-1 considers *per capita* GDP distributed in up to 15 regions, while MECA uses GVA distributions in the grid for the industry and service economic sectors. In both cases the losses are considered up to a recovery time, and the inherent uncertainties in other steps of the calculations result in no significant differences between models. As an option, MECA can use an input-output model for the estimation of production losses in case of population relocation: the full final demand of the affected areas will be lost, thus inducing an Output loss. For the surrounding regions, a loss will be induced by the loss of demand for products, normally going to the relocation area (no exports can be made during the relocation period to the affected area); but also positive effects are measured if private consumption of the relocated population is transferred to the non-relocation areas, thus originating an increase in their final demand, and an output increase at the end. MECA is, therefore, the only model which can fully estimate the indirect (negative and positive) effects in the non-relocation areas.

The second section of Table 4.2 gives a comparison of the way in which the models handle losses of capital services. Again, the simplest model is MACCS, which only considers two categories of property: farm and non-farm, with unit values per hectare and person respectively, including all the components, distributed in up to 99 regions. Depreciation of improvements (not land) gives the measure of the lost capital services during the relocation period. ARANO considers three categories of capital (agriculture and forestry, manufacturing and construction, and services) distributed as the number of workers in each sector, plus a housing component, distributed as a function of the population. Losses are assumed to increase linearly up to ten years, after which a total loss of the investments is considered. COCO-1 assess lost capital services based on four categories: non-residential, housing and buildings, consumer durable and land. Unit values per person can be used and distributed in up to 15 regions. Capital depreciation for consumer durable and land is considered for the full duration of the relocation period. Since capital depreciation is already included in GDP (as a part of the loss-of-income calculation) for the first two categories, which contribute to production, it is only taken into account when GDP losses stop, after the recovery period. Finally, still a different categorisation is considered in MECA which, as in MACCS, distinguishes between farm (rural) and non-farm (urban) property. In rural areas, the capital is associated with land, distributed in 15 types and up to 17 regions. Each land category has a unit cost, which reflects its potential for production. If relocation is temporary, it is assumed that GVA losses for agriculture will reflect the losses due to land interdiction. In the case of permanent relocation, the total value of the rural land is lost, with no need to account separately for agricultural production losses, except for the first crop if it was already growing. For urban areas, five categories of property are considered: dwellings, public buildings and public open areas are valued per person, with up to 17 regional values; industrial and commercial buildings and installations are valued per employee in industry and services, the number of employees being spatially distributed in the calculation grid. During relocation, before and after the recovery times, different depreciation rates can be considered to account not only for normal depreciation but also for the accelerated depreciation due to lack of use and maintenance.

Once more, one comment should be made in the sense that model differences cannot be very serious if appropriate data sets are put in the calculations for a given scenario. The a priori uncertainty in the definition of the areas to be relocated, and of the duration of relocation can be a stronger source of differences in the results of the economic assessments than the economic models themselves.

Costs of agricultural countermeasures

The comparison of the models for the evaluation of the costs associated with the adoption of food-bans is included in Table 4.3. A distinction is made between the first year, in which growing crops can become contaminated, and the following years, when restrictions on the normal use of agricultural land for food production would be imposed.

Apart from the agricultural capital losses already mentioned, ARANO considers the unit value of production losses, per agricultural worker and per day of banning, during the full period, differentiating three categories of products: milk, corn and the rest of agricultural products. MACCS values the farm production per unit area, distinguishing two types of products: milk and non-milk crops (for milk only three-month losses are accounted for). If farmland is condemned for long term, then losses of capital services are accounted for as in the case of long-term relocation, which also resulted in a loss of use of farmland. In COCO-1 the cost of lost food is valued at the gross output during the first year, while for the following years, up to recovery time, the contribution to GDP of each product is used. The costs of food disposal can be valued based on a unit cost per product. And the costs of lost value of agricultural capital are also considered in three categories (non-residential capital, buildings and land), which can include depreciation. In MECA no capital losses are considered for farmland if no relocation of the population is imposed, that is, the assumption is made that if the land is accessible, other uses could be found, or at least the improvements could be maintained with almost no depreciation. Thus, from the second year on the only losses considered are those of production (GVA) for agriculture, distributed in the grid. For the first year, the contaminated lost food is valued at the market price perceived by farmers, with a potential to consider up to 40 agricultural products and ten livestock species distributed in the grid.

As a conclusion, the different degrees of detail and the assumptions in each model, together with their limitations in considering alternative countermeasures for agriculture other than food disposal or restrictions in land use, can be a source of deviations in the assessments. However, these deviations may not be larger than the uncertainty existing in the definition of the impact of the countermeasures on agriculture. This is particularly true if the existing experience (post-Chernobyl, for instance, with modified agricultural practices, soil treatment, food processing, etc.) is compared with the alternatives offered by the existing PCA codes with regard to agricultural countermeasures. This was one of the limitations already identified in the last international comparison exercise.[2]

Costs of decontamination

Decontamination itself is a process not well defined, neither in its cost nor in its effectiveness for dose reduction, and it can be very scenario-specific, thus difficult to model accurately. As a consequence, the general tendency is to use simple approaches, or even not to take it into account, as it was in the case of the ARANO code for some of the earlier applications. In general, the models use unit costs per unit area for the decontamination of rural areas, and unit costs per person for urban decontamination. This is the case of MACCS and COCO-1, while MECA always uses unit costs per unit surface to be decontaminated, corresponding to the type of surface and the technique assumed to be applied, being capable of considering up to six types of surfaces and six different techniques, both for urban and rural areas. In rural areas, the distribution of land uses in the grid is used to derive a distribution of surfaces to decontaminate. In urban areas, conversion factors representing the areas of each type of surface per person are needed as input. MACCS can only use up to three values for rural and urban decontamination, and COCO-1 allows for time variation of the decontamination efficiency and cost.

In any case, for small scale accidents, decontamination efforts will be more important, and decontamination would probably dominate the overall cost, whilst, for large accidents, the effectiveness would decrease greatly, as was observed in the case of Chernobyl, and probably only in certain urban locations decontamination would be effectively applied, thus having only a minor importance in the total budget of the accident costs. The aspects included in the models for the costs of decontamination are summarised in Table 4.4.

Costs of health effects

The characteristics of each model for the valuation of the cost of health effects are reflected in Table 4.5. MACCS does not include such assessment. ARANO contains a simple model which assigns a single value to the cost of any radiation-induced illness or fatality, whether early or latent, introducing a risk aversion approach by the use of weighting factors which increase with the number of expected health effect cases. In COCO-1 two options are available: the human capital approach and the subjective valuation. In the first option, the calculation is based on unitary costs for medical treatment and loss of an individual’s contribution to economy, the last being multiplied by the number of years lost due to the health effect; for latent health effects, the time distribution of the expected cases is used to discount the costs of such effects emerging in the future. The second option consists of the use of single unit values which represent the subjective cost associated with a given case of health effect. Both approaches were described in Chapter 2. The model in MECA has two components for the cost of each effect: one objective component, the cost of medical treatment, and one subjective component representing the losses to the individual because of the health impairment. For latent health effects, the model can consider an increase rate in the cost of medical treatment, as well as a user input time frame for discounting the effects appearing in the future.

Since the estimated number of latent health effects is normally much higher than that of early health effects, their economic relevance can be also significantly higher. Thus, the way in which discounting is considered for the valuation of latent health effects is of prime importance for the resulting total cost of health effects. As it was observed in the last Benchmark Exercise,[2] not only the discount rates are important, but also the time frame considered, which should represent the time distribution for the latent health effects, is highly relevant. This is normally part of health effect models, and care must be taken to consider it appropriately if information is available. Otherwise, it is preferable to use a conservative discount rate, normally a few per cent, so as not to underestimate the actual economic importance of the health impact of an accident.

Data sets

To end this comparative description of the models, it may be useful to look at the gridded data sets[5] that every model uses for its calculations, since this will give an approximate impression of the resources needed to fully use the models, and of the precision that a model can achieve for a given site specific scenario. The comparison is included in Table 4.6.

Obviously, all the codes need the distribution of the population around the site as a first data set, not only for economic consequence but also for general consequence assessment. Additionally, ARANO uses the distributions of the number of workers in three basic economic sectors. MACCS site data file can contain up to 99 regional values of assets of non-farm and farm property, as well as the total farm productions, and the fraction corresponding to milk and dairy products. COCO-1 (as implemented in COSYMA or in CONDOR) includes in its calculations the distribution of milk, livestock and crop area (so-called agro-economic productions). And finally, MECA employs the most extensive data base, with distributions for the GVA and number of workers in the three basic economic sectors, agricultural production of up to 40 different products, livestock of up to 10 categories, and land use of up to 15 types.

The preparation of these data sets is a user's responsibility, except in the case of MACCS, which contains ready-to-use information for all the states of the United States, and COSYMA which includes a data base which basically covers all Europe, with different levels of detail for some countries. As can be imagined, the preparation of a full data base is not at all an easy task if the spatial range to be covered is large, as it can be the case for a severe accident.

Availability of data

Although it is true that a good description of every scenario can only be obtained if the calculations are supported by a proper data base, the need for data to feed the models can be a serious restriction if very limited resources are available for a given study. So, the choice between models will be many times constrained by the availability of data, although the user can always use a given model with uniform or semi-uniform distributions for some of the items. However, in developed countries, the statistical information needed for a model is commonly available in a suitable form. Also, models like MACCS or COSYMA already provide data bases adequate for their origin areas.

Problems can exist when the impact studied extends to more than one country, and statistical records are in a non-homogeneous form. This can happen, for instance, between several countries in Central and East Europe. More serious problems, like differences in the economic systems between bordering countries, are often difficult to resolve.

From the description of the models, a general comment can be made concerning their complexity from a user's point of view. Probably, the more complicated a model, the more hesitant will be a user to modify default parameter values, especially those not directly available from statistics. In this sense, it is of fundamental importance to have good advice and guidance in the user's guide, including examples on how to derive new data for a different country, or how to update old data.

5. As a basis for the calculations, in PCA (Probabilistic Consequence Assessment) codes, the space around a nuclear power plant is normally subdivided using polar grids, with circles and sectors centered at the plant, or geographical grids, with meridians and parallels. The impact of the accident is assumed to be uniform within a given grid element.

Uncertainties in the models

A quantification of the inherent uncertainty of the presented models is not available. However, there are some studies from which the reader can get a feeling about how large the uncertainties in the predictions of ACA codes can be. Maybe the most representative study is the recent Benchmark Exercise,[1] already mentioned, in which the four models were exercised for two hypothetical, though realistic, scenarios, beginning with source terms and covering all the steps in the accident consequence assessment up to the estimation of the economic consequences. The results, briefly discussed in Chapter 4, were encouraging, since the models showed deviations by only a factor of four to five, always less than one order of magnitude. Also within less than one order of magnitude were the economic costs quoted in the 1987 draft of NUREG-1150, where the calculations performed with the CRAC2 and the MACCS code for five US nuclear power plants were compared. Similar conclusions can be drawn from more recent studies performed in Spain, in a joint project between the Consejo de Seguridad Nuclear (CSN) and the Universidad Politécnica de Madrid (UPM), which has included probabilistic consequence assessments for five nuclear power plants, both with the MACCS and the COSYMA codes.

Although a formal uncertainty study has not yet been performed, the available evidence suggests that only small differences would be observed between models when applied to the same scenario, due to the uncertainties in the input parameters. User's assumptions, such as the subjective values assigned to the costing of health effects, or to the discount rates used for long delayed effects, would probably have more influence on the variations of the results than the modelling differences described in this chapter.

Table 4.1 **Aspects included in the models for the cost of short-term countermeasures**

<table>
<tr><th>Type of countermeasure</th><th>Economic impacts</th><th>ARANO</th></tr>
<tr><td rowspan="4">Evacuation –
short-term relocation</td><td>Management – monitoring</td><td rowspan="4">Costs not considered except for small scale accidents</td></tr>
<tr><td>Transport</td></tr>
<tr><td>Lodging and food</td></tr>
<tr><td>Loss-of-income</td></tr>
<tr><td>Sheltering</td><td>Loss-of-income</td><td>Not considered</td></tr>
</table>

Table 4.2 **Aspects included in the models for the cost of long-term relocation of population**

<table>
<tr><th>Economic Impacts</th><th>ARANO</th><th>MACCS</th></tr>
<tr><td>Management - monitoring</td><td>Not considered</td><td rowspan="2">Not considered</td></tr>
<tr><td>Transport</td><td rowspan="2">Single value per person</td></tr>
<tr><td>Lodging and food</td><td>Single unitary cost
(per day and person)</td></tr>
<tr><td>Loss-of-income</td><td>Single value per worker
(loss-of-income)
+
Losses of production in 4 sectors
(unit values per worker-day)</td><td></td></tr>
<tr><td rowspan="2">Lost capital services</td><td>4 categories:
• Agriculture and forestry
• Manufacturing and construction
• Services
(distributed as the number of workers in each sector)
• Housing
(distributed as population)</td><td>Non-farm property
(single value per person):
• residential, commercial and public land, improvements, equipment and possessions

Farm property
(single value per hectare)

In up to 99 regional values</td></tr>
<tr><td>Losses increase linearly
up to 10 years (total loss)</td><td>Depreciation of improvements
(not land) during loss of usage</td></tr>
</table>

Table 4.1 **Aspects included in the models for the cost of short-term countermeasures**

MACCS	COCO-1 – COSYMA & CONDOR	MECA
Not considered.	Not considered.	Unit cost (per person and day). Reduced for relocation.
	Different unit cost for private and public transport (per person).	Different unit cost for private and public transport (per person and km).
Single unitary cost (per day and person).	Unit cost of accommodation lost (per person and day).	Different unit cost of lodging and food for private and public lodgings (per person and day).
	GDP (per person and year). Up to 15 regional values.	GVA (gross value added, per person and day) by economic sectors except agriculture. Distributed in the grid.
Not considered.	GDP (per person and year). Up to 15 regional values.	Not considered.

Table 4.2 **Aspects included in the models for the cost of long-term relocation of population**

COCO-1 – COSYMA & CONDOR	MECA	
Not considered.	Reduced unit cost (per person-day) during transitory period.	
Different unit cost for private and public transport (per person).	Different unit cost for private and public transport (per person-km). Transport of livestock (per km-head).	
Unit cost of accommodation lost (per person-year). Considering the costs up to a recovery time. Including depreciation	Different unit cost of lodging and food for private and public lodgings (per person-day). Only during transitory period. Reduced for relocation.	
GDP (per person-year). 15 regional values max up to a mean recovery time. Region indices distributed in the grid.	GVA (gross value added, per person-day) by economic sectors except agriculture. Distributed in the grid. Sector specific recovery time. Optional input-output model for impact on production, in and out of the relocation area (including positive and negative effects).	
4 categories: • Non-residential. • Housing and buildings. • Consumer durable. • Land. (per person, up to 15 regional values)	5 categories in Urban areas: • Dwellings. • Public buildings. • Public open areas (per person in up to 17 regions). • Industrial installations. • Commercial and other buildings (per employee in industry & services). (number of employees by economic sectors distributed in the grid).	In Rural areas: • Land. Unit cost per unit area, up to 15 land uses and 17 region values. Areas of up to 15 types of land uses, distributed in the grid.
Capital depreciation from recovery time for 1 and 2, for 3 and 4 all the time.	Normal capital depreciation + accelerated depreciation due to lack of use and maintenance (different rates for each category and period, before and after recovery times).	Only if permanent relocation. No depreciation for rural land.

Table 4.3 **Aspects included in the models for the cost of food-bans**

Economic impacts	ARANO	MACCS
Cost of lost food (first year).	Unit value of production losses, per agricultural worker-day. 3 categories: milk, corn and all other products. Costs evaluated for the first year and for the rest of the ban period.	Unit value of farm production, per unit area-year. 2 categories: milk and non-milk production. Milk losses for 3 months.
Cost of food bans (following years).		Lost capital services for farm property (as for long-term relocation).

Table 4.4 **Aspects included in the models for the cost of decontamination**

Economic impacts	ARANO	MACCS
Cost of rural decontamination.	Not directly considered.	Unit costs for up to 3 decontamination levels (per unit area).
Cost of urban decontamination.		Unit costs for up to 3 decontamination levels (per person).

Table 4.3 **Aspects included in the models for the cost of food-bans**

COCO-1 – COSYMA and CONDOR	MECA
Lost food: gross output Lost agricultural capital: • Non-residential capital. • Buildings and land. • Including depreciation. Food disposal	Lost food: price perceived by farmers (representative of the cost of crop losses). Production of up to 40 agricultural products, and livestock census of up to 10 species distributed in the grid.
Lost food: GDP contribution by products – during recovery time. Lost agricultural capital. Food disposal.	GVA (gross value added, per person-day) for agriculture. Distributed in the grid.

Table 4.4 **Aspects included in the models for the cost of decontamination**

COCO-1 – COSYMA & CONDOR	MECA
Unit cost of decontamination (per unit area). Single value for each time period.	Unit costs for up to 6 types of surfaces and 6 decontamination levels (per unit area). Areas of up to 15 types of land uses, distributed in the grid. Assigned to decontamination categories.
Unit cost of decontamination (per person). Single value for each time period.	Unit costs for up to 6 types of surfaces and 6 decontamination levels (per unit area). Areas of each decontamination category per person.

Table 4.5 **Aspects included in the models for the cost of health effects**

Type of effect	Economic impacts	ARANO
Early health effects.	Medical treatment.	Single value per illness and fatality. Risk aversion considered with higher weighting factors for accidents causing large numbers of health effects.
	Loss of "human capital".	
Latent health effects.	Medical treatment.	
	Loss of "human capital".	

Table 4.6 **Gridded data sets in the models**

ARANO	MACCS
Population. Number of workers in: • Agriculture and forestry. • Manufacturing and construction. • Service.	Population. Regional values (up to 99) of: • Non-farm property. • Farm property. • Farm production. • Fraction of farm production for milk.

Table 4.5 **Aspects included in the models for the cost of health effects**

MACCS	COCO-1 – COSYMA & CONDOR	MECA
Not considered.	Unit cost per case of each type of health effect.	Unit cost per case of each type of health effect.
	Unit loss of an individual's contribution to economy (per year) times the number of years lost.	Unit loss per case input by the user (subjective valuation).
	Subjective valuation option: Single value per case	
Not considered.	Unit cost per case of each type of health effect. Time frame for discounting hardware.	Unit cost per case of each type of health effect. Increase in medical treatment costs.
	Unit loss of an individual's contribution to economy (per year) times the number of years lost. Number of years lost due to cancers. Time frame for discounting hardware.	Unit loss per case input by the user (subjective valuation). User input time frame for discounting.
	Subjective valuation option: Single value per case.	

Table 4.6 **Gridded data sets in the models**

COCO-1 – COSYMA & CONDOR	MECA
Population. Agricultural production for human consumption for 9 products (only for ingestion dose calculation). Agri-economic production for 3 categories: • Milk. • Livestock. • Crops.	Population. Gross value added & number of workers in: • Agriculture. • Industry. • Services. Agricultural production for up to 40 products. Livestock census for up to 10 species. Farmland use (area) for up to 15 types of rural surface.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Based on the study summarised in this report, the Expert group drew several conclusions, based upon which it was felt that certain recommendations would be of value.

The cost of an accident

- The Expert group felt strongly that there is no single "cost of an accident". Various perspectives exist from which accident costs are approached, each based on different goals, rationale and needs. Earlier studies had focused on the cost of countermeasures in the perspective of accident management. Since that time, the interest has shifted to the external and the compensation costs. Debate of these issues continues among both professionals and the public.

Recommendations

- Future efforts should focus on the detailed assessment of cost elements. This is particularly the case with health effects, the costs of which are dominant in the case of large accidents with long-term impacts. Two different approaches to the assessment of health-care costs are currently most popular: the human capital approach and the willingness to pay approach. The current use of these two approaches in codes may contribute to large discrepancies in the results. Better understanding, and justification of these two approaches should be studied in the future.

- Studies of the externalities of the long-term impacts from all electricity-generation industries, including nuclear, should be performed on a consistent basis.

- Along with the detailed assessment of individual cost elements should be an assessment of those which should be addressed as a function of the perspective taken, their relative order of importance, as well as their perspective-specific characterisation.

Accident consequence assessment studies

- Attempts to compare studies of the costs of different, hypothetical accidents, even when costs were viewed from the same perspective, are extremely difficult because the final values are very dependant on the scenario(s) selected and the specific characteristics of the plant; the source term is particularly important. The diversity of numerical results observed between various published studies attests to this difficulty.

Recommendation

- Great care should be taken when comparing the results of different cost studies. Numerical comparisons are particularly difficult.

Accident consequence assessment codes

- Comparisons of accident consequence assessment codes have shown that, in spite of many uncertainties, when a single case is analysed by several different codes, differences in resulting code outputs were not as significant as might have been expected. This reflects a coherence in the overall calculational approaches used in these codes.

- It should be noted, however, that in general the boundaries of the analyses performed can have significant effects on the results. This reflects the relative nature of numerical results.

- There is a conflict between improving the analytical capabilities of assessment codes and the difficulties encountered in supplying the resulting models with appropriately detailed and accurate data. This difficulty is accentuated in codes based on full-scope, site-specific, probabilistic safety assessments which integrate effects over a large number of scenarios.

- Those accident consequence assessment codes which address economic consequences generally take an accident-management perspective. In this regard, developments have been mainly focused on the costs of countermeasures. This approach is still reflected in current accident consequence assessment codes.

- First experiences with input-output models are promising, but further developments are nevertheless necessary.

Recommendations

- Efforts need to be made to further develop existing accident consequence assessment codes to integrate medium- and long-term impacts at the macro-economic level.

- The “input-output” method should be used to show the relationships between local, regional and national economies, particularly with respect to macro-economic effects. Data supply difficulties, similar to those mentioned above will be encountered here.

- The need for a more precise and detailed evaluation of economic consequences is driven by increasing decision-making needs. In this respect, it is probably necessary in the future to improve the economic models employed for the management of post-accidental situations.

- Model analyses which are limited in time and space, will have to reflect more accurately the economic impacts and consequences of reorganising the conditions of living, farming and production in affected communities.

Annex I

EXTERNAL COSTS OF NUCLEAR REACTOR ACCIDENTS: A SHORT SURVEY OF NUCLEAR ACCIDENT EXTERNAL COST STUDIES

This annex provides a general description of the various studies devoted to the calculation of the external costs of the nuclear reactor accidents. It does not aim at presenting a critical review of these studies but rather to present the various approaches adopted in this domain.

"Top-down" studies

Hohmeyer (1988 and 1990)[61,62]

Since other studies of this type follow in their spirit the work of Hohmeyer, more space is given here to the description of his studies. Hohmeyer estimated external costs of accidents at a German plant (Biblis), using the Chernobyl-specific collective dose to the world population as the starting point and upgrading it by a factor (of seven) supposed to reflect the higher population density in Germany. In the study of 1990 an additional factor (of five) was introduced to represent the largest possible release for the Biblis plant. This was combined with the total core damage frequency which, however, was assigned to the maximum source term (whose frequency is only a share of the total); accident mitigation measures which further reduce this frequency were not credited. The upper result for a Chernobyl accident in Germany was in the 1988 study obtained as follows:

> [2.4 10^6 person-Sv (collective dose from Chernobyl) × 10 (higher population density) × 100 000 cancers/10^6 person-Sv (dose-response factor) × 0.75 10^6 DM (cost of each cancer case) × 5 10^{-4} accidents/reactor-year (accident frequency)] : 7.5 TWh (energy produced/reactor-year) = 12.0 Pf/kWh

For the lower bound an accident frequency lower by a factor of 10 was used, resulting in a corresponding reduction. However, the author concludes that the upper value is in his opinion closer to the expected costs of the corresponding accident in Germany. Using the current best estimate of the collective Chernobyl-specific dose, actual difference in population density and range of accident frequencies valid for a plant with good safety standards and for the Chernobyl type of accident (in terms of a comparable source term), the above estimated external costs would be reduced by three orders of magnitude. In 1990 Hohmeyer's study,[62] the collective dose was further increased by a factor of five in order to reflect possibly higher source terms for the German plant. The resulting external costs were 3.48-21.0 Pf/kWh.

Ottinger* et al. *(1990)[63]

The approach is very similar to Hohmeyer. There is, however, no correction factor for the differences in population density and much higher monetary values are used for fatal cancers. In addition to the costs of health effects farm production losses were included. The assessed external cost is 2.3 cents/kWh.

Ewers and Rennings (1992)[64]

Also in this case the basic approach of Hohmeyer has been adopted. The differences include a somewhat lower correction factor for population density, a lower dose-response factor and the accident frequency slightly lower than the lower value in the studies by Hohmeyer. This results in an external cost of 4.3 Pf/kWh.

Apart from specific problems in the implementation, common limitations of "Top-down" studies are as follows:

- Only the "worst case" is examined while the assigned frequencies are not representative for such a case. One extreme accident which occurred at a plant with specific (flawed) design, operating in a specific environment (low safety culture) and located at a specific site, is chosen to represent the whole spectrum of hypothetical accidents with varying consequences.

- The path leading to the estimation of consequences conditional on specific releases is purely deterministic (Chernobyl case); different weather conditions, accident management strategies, sheltering conditions and evacuation practices are not considered.

Limited "Bottom-up" studies

Friedrich and Voss (1993)[65]

The estimate by these authors is based on the work of Burke *et al*.[47] Adjustments were made for the higher population density in Germany in comparison with the US sites. The authors point out that "the results of Burke *et al*.[47] can only be transferred to a limited extent to Germany". The basic difference between this study and the ones belonging to the "Top-down" type is that instead of the Chernobyl accident, a PSA (for a US plant) was used as a reference for evaluating a hypothetical accident in Germany. The resulting external costs are 0.008 to 0.07 Pf/kWh.

Energy Research Group, Inc. (ERG, 1993)[66]

This study concerning CANDU plants is based on the input provided by Ontario Hydro and covering the frequencies, population doses and off-site financial damage for five categories of reactor accidents. It is stated that these categories cover the full range of design basis and catastrophic accident consequences. The frequencies and consequences used were considered to be bounding estimates, pending the publication of the results of station-specific risk assessment. The accident category representations were those used in the Darlington Probabilistic Safety Evaluation and were assumed to apply to both Pickering and Bruce plants. ERG increased all probabilities of occurrence by a factor of 2 to account for external events. High and low cases were considered based on the application of a ±20 factor of error. The range of results is between 0.000013 and 0.096 cents/kWh.

Masuhr and Oczipka (1994)[41]

This work was a contribution to the Swiss INFRAS & PROGNOS external cost study.[67] The approach shares with "Top-down" studies the use of the Chernobyl-specific collective dose. However, the major improvement is that the lower range of consequences is based on some release frequencies from the Swiss regulatory review of the PSA for the Mühleberg plant.[68] The same frequencies were then applied to the other four Swiss nuclear power plants which have very different designs. An additional extremely high release category was assumed. Furthermore, an arbitrary set of much higher frequencies was postulated in order to estimate the upper range of consequences. The analysed consequences were limited to health effects and some losses in agricultural production (the latter were based on Ottinger *et al*.[63]). The results are in the range between 0.001-0.17 Rp/kWh. Another set of results (1.0-31.8 Rp/kWh) reflects the use of subjective risk aversion.

Centre d'étude sur l'évaluation de la protection dans le domaine nucléaire (CEPN; Volume 3 in European Commission, 1995)[69]

CEPN postulated four different source terms, assigned a core melt probability considered representative for a large PWR, based on NUREG-1150[58] assumed conditional containment failure or bypass probability, and carried out consequence calculations for a hypothetical site in Germany using COSYMA (i.e. the calculations concern all cost elements in COSYMA). The range of the results, 0.0023 to 0.104 mECU/kWh, corresponds to the different source terms. Health effects dominate, followed by cost of food bans, while evacuation and relocation costs are relatively small.

Fisher and Williams (1994)[70]

This work was carried out as a part of the EC/US study on external costs of fuel cycles. The approach used is very similar to that employed by CEPN. A large, hypothetical Westinghouse PWR was cited at two US locations. Also in this case four accident scenarios were analysed and the conditional probability for containment failure or bypass was based on the Zion plant analysis within NUREG-1150.[58] For consequence calculations MACCS was used. The results are 0.0059 cent/kWh for one of the sites and 0.0103 cent/kWh for the other. As opposed to CEPN non-health effects are dominant.

Limited "Bottom-up" studies are more diversified with respect to the approaches used than the more homogenous "Top-down" studies. A common feature is use of extrapolations on different levels of the analysis. Furthermore, a very limited number of scenarios has been analysed; these scenarios are in several cases postulated rather than derived; this may or may not include the worst possible case (in terms of source terms). Some studies use hypothetical sites.

Full scope "Bottom-up" studies

Hirschberg and Cazzoli (1994)[43]

This study, which primarily concerns the Swiss plant Mühleberg, is based on a state-of-the-art full scope PSA that covers the full spectrum of initiating events (including the frequently dominant external ones such as fires, earthquakes, floods, aircraft crashes, etc.). The Mühleberg PSA was extended by calculations of economic consequences, using the economic effect models of the MACCS code. The consequence analysis used 31 representative source terms derived from the overall number of 3 000 source terms reflecting all the credible end-states of the containment matrix for Mühleberg. The analysis includes a systematic propagation of uncertainties and an integration of the full spectrum of contributing release scenarios. The estimated external costs for Mühleberg are as follows:

0.0012 cent/kWh (mean); 0.0001 cent/kWh (5th percentile); 0.0004 cent/kWh (50th percentile); 0.0038 cent/kWh (95th percentile). They are dominated by health effects and according to a sensitivity analysis are moderately sensitive to the costs of land and property. In addition to the Swiss Mühleberg plant external costs were calculated for two US plants, Peach Bottom (BWR) and Zion (PWR), using information from reports[71,72] prepared as a supporting documentation to NUREG-1150.[58] The estimated mean value for Peach Bottom is 0.0014 cent/kWh and for Zion 0.0069 cent/kWh.

Wheeler and Hewison (1994)[73]

The report addresses external costs related to the proposal for a PWR located at Hinkley Point in United Kingdom. Although in the available report there is no reference to a PSA, the information given indicates that plant specific accident frequencies were used as the basis for the calculations. Twelve degraded core accidents, eight containment by-pass accidents and three design basis accidents were analysed. Consequences were first estimated using the MARC-1 computer programme. Later the accident consequence code CONDOR[52] was used in order to cover two aspects not included in MARC-1 (long-term relocation of people from contaminated land and food restrictions). The total external cost based on CONDOR was 0.00011 p/kWh and 0.00013 p/kWh based on MARC-1. Health effects dominate in both cases.

Table I.1 summarises the main characteristics of the studies described above.

Table I.1 **Characteristics of selected studies of external costs of nuclear reactor accidents**

Table I.1 **Characteristics of selected studies of external costs of nuclear reactor accidents**

Type of study	Author(s)	Object	Estimated external costs	Some key analysis characteristics	Risk aversion considered
"Top-down".	Hohmeyer (1988 and 1990).	Biblis, Germany (PWR).	1.2-12.0 (Pf/kWh) 3.48-21.0 (Pf/kWh).	Use of Chernobyl consequences (further increased) CDF= "Worst" case freq.	No.
"Top-down".	Ottinger (1990).	US plant (unspecified).	2.3 (cents/kWh).	Same as Hohmeyer (1988)	No.
"Top-down".	Ewers and Rennings (1992).	Biblis, Germany (PWR).	4.3 (Pf/kWh).	Same as Hohmeyer (1988)	No.
Limited "Bottom-up"	Friedrich and Voss (1993).	German plant.	0.008-0.07 (Pf/kWh).	Based on PSA analysis for a US plant (Burke *et al*., 1984).	No.
Limited "Bottom-up".	ERG (1993).	Darlington, Bruce and Pickering, Canada (CANDUs).	0.000013-0.096 cents/kWh.	Five categories of accidents for Darlington (frequencies assumed to represent bounding estimates).	No.
Limited "Bottom-up".	Masuhr and Oczipka (1994).	Swiss plants (BWRs and PWRs).	0.001-0.17 1.0-31.8 (Rp/kWh).	Use of Chernobyl consequences as reference value; Mühleberg source term frequencies for lower bound and arbitrary for higher	Yes, in the second case.
Limited "Bottom-up"	CEPN (1994).	French PWR.	0.0023-0.104 (mECU/kWh).	Assumed CDF and rough conditional containment failure probabilities; based on US PWR (NUREG-1150); hypothetical site in Germany.	No.
Limited "Bottom-up".	Fisher and Williams (1994).	Large hypothetical US PWR.	0.0059-0.0103 cents/kWh	CDF and containment probabilities as in CEPN analysis; two sites in US.	No.
Full scope "Bottom-up".	Hirschberg and Cazzoli (1994).	Mühleberg Switzer-land (BWR). Peach Bottom, US (BWR). Zion, US (PWR).	0.0012 (mean). 0.0001 (5-th). 0.0004 (50-th). 0.0038 (95-th). (cents/kWh). 0.0014 (mean). (cents/kWh). 0.0069(mean). (cents/kWh).	Fully based on state-of-the-art PSA Level 3. As above. As above.	No. No. No.
Full scope "Bottom-up".	Wheeler and Hewison (1994).	Hinkley Point, UK (proposed PWR).	0.00011-0.00013 (p/kWh).	Plant-specific (unclear origin).	No.

Table I.1 **Characteristics of selected studies of external costs of nuclear reactor accidents**

External events included	Uncertainty propagation	Full set of source terms	Computer code for probabilistic analysis	Cost Elements	Remarks
No.	No (two CDFs used).	"Worst" case.	Not applicable.	Health effects.	Correction for population density (over-estimated).
No.	No.	"Worst" case.	Not applicable.	Health effects and farm production losses.	
No.	No.	"Worst" case.	Not applicable.	Health effects.	Correction for population density (lower than Hohmeyer's).
Yes.	No.	Yes (for US plant; conservative).	CRAC (in Burke *et al*., 1984).	Broad set of health effects and countermeasures.	Correction for population density.
Yes (arbitrary factor of two).	No (arbitrary factor of 20 included).	No (but bounding cases represented).	Not clear.	Health effects and property damage.	Extrapolation of Darlington results to Bruce and Pickering
Yes (implicit).	No (arbitrary set of frequencies postulated to reflect uncertainty).	No (but bounding cases represented).	Not applicable.	Health effects and some losses in agricultural production.	Mühleberg source term frequently used for all other Swiss plants.
No.	No.	No (four source terms).	COSYMA.	Full set in COSYMA.	Dominance of health effects.
No.	No.	No (four source terms).	MACCS.	Full set in MACCS plus health effects.	Dominance of non-health effects.
Yes. No. No.	Yes (LHS method). Yes (but not fully available). As above.	Yes. Yes. Yes.	MACCS. MACCS. MACCS.	Full set in MACCS plus health effects As above. As above.	Dominance of health effects. As above. As above.
Unclear.	No.	Broad (23 source terms).	CONDOR and MARC-1.	Full set in CONDOR Limited set in MARC-1.	Dominance of health effects.

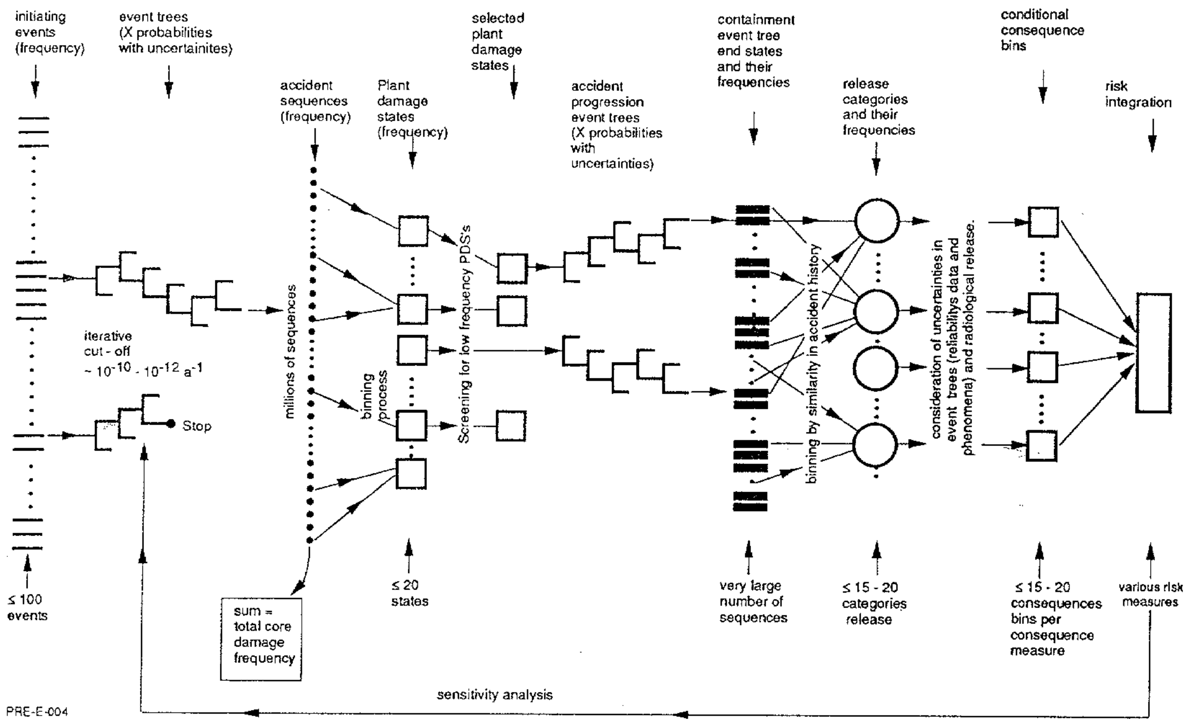
Annex II

THE FULL-SCALE PSA APPROACH TO ASSESSING THE EXTERNAL COST OF REACTOR ACCIDENTS

Methodology

Figure II.1 shows the overview of the PSA methodology as applied in the study for the Swiss plant Mühleberg, including the flow of data in the entire process. The approach is similar to the methodology applied in the NUREG-1150 studies.[58]

Figure II.1 **PSA methodology**[74]



This art approach encompasses two elements:

- Use of a well-established, reviewed, full scope plant-specific PSA; the PSA should preferably cover a very broad range of initiating events, including the external ones. Propagation of uncertainties through the model (normally using a Monte Carlo method) is highly desirable. The rationale for the preference for using a plant-specific PSA as the most relevant basis for estimating the economic consequences of nuclear accidents is the demonstrated strong dependence of the results on plant-specific features (including site characteristics).

- Use of economic models of established consequence codes such as COCO-1, CONDOR, COSYMA, MACCS or MECA2. Improvements/extensions of these models are desirable and in several cases are being implemented.

The basic steps involved in a PSA Level 3 include:

- Assessment of Plant Damage States (PDS) frequencies.
- Accident progression evaluation for these pdss.
- Source terms evaluation for each of the end-states of the accident progression.
- Conditional consequence evaluation for a representative set of source terms.
- Integration of risk measures.

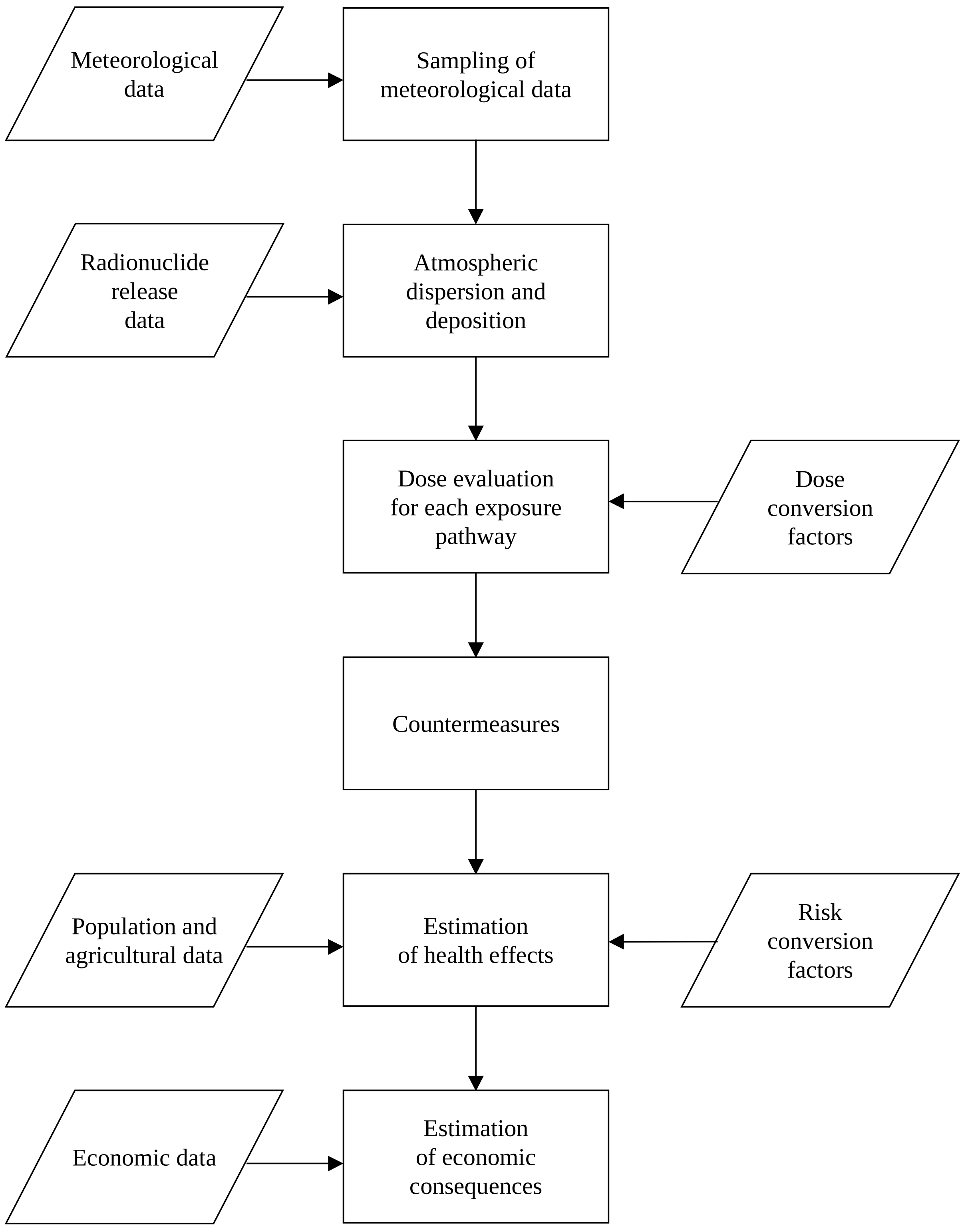
The starting point of a PSA is the establishment of a set of initiating events (about 80 in the Mühleberg case). In the next step millions of accident sequences were generated, based on event trees developed for the different initiating events. The sequences add to the total core damage frequency. Among them 8 000 (those having frequencies exceeding 10^{-10} per reactor-year) were bound into 20 plant damage states, defined by a list of descriptors that identify the characteristics important to containment failure and radionuclide transport (e.g. status of the primary system and the containment, pressure in the primary system at time of core degradation, pressure and temperature in the containment at the time of core degradation, status of AC power, status of heat removal). The Level 2 calculation was performed with all 20 plant damage states. The accident progression event tree constructed for the Level 2 analysis led to several thousands sequences bound into 15 to 20 release categories (i.e. groups having similar accident progression histories). A set of "source term clusters" was then established taking into account physical and chemical phenomena acting after the containment failure. The source terms and the associated frequencies constitute the input to the consequence analysis which together with the preceding steps constitutes PSA Level 3. Conditional consequences are calculated for a representative set of the source terms. Finally, the risk measures are integrated.

The elements of probabilistic consequence assessment are depicted in Figure II.2. The main types of release and site specific input data are shown on the left of the figure, whilst the more general input data requirements are shown to the right. In the centre of the figure, the main calculational steps are identified. The following comments on the tasks within probabilistic consequence analysis are based on the OECD/NEA referenced as [2].

For the radionuclide dispersion (i.e. transport and diffusion processes) calculations, the Gaussian plume model is widely used in PSA Level 3; the Gaussian shape of the concentration profile has been found to be approximately valid in many situations. Typically, the Gaussian dispersion model will be run around a hundred or more times with different weather samples and, in some cases, each plume profile is rotated over a number of azimuthal sectors to generate a large statistical set of consequence estimates. Deposition mechanisms ("dry and wet") for removal of radioactive material from the passing plume are considered in consequence calculations.

The choice of meteorological data often represents a compromise between the ideal, the available and what is adequate for a particular assessment. Thus, normally data from the meteorological station nearest to the release point are used but also data compiled at other stations may be used if they are found representative. Data from one or more years is sampled and a representative set of weather sequences is selected, each of these having an assigned probability of occurrence.

Figure II.2 **Basic elements of probabilistic consequence assessment**[2]



The exposure pathways by which people can accumulate a radiation dose after an accidental release are:

- **External irradiation** from radioactive material in the passing plume, deposited on the ground, or deposited on the skin and clothing.
- **Internal irradiation** from radioactive material inhaled directly from the passing plumed, inhaled following resuspension of the ground deposit, or ingested due to contamination of foodstuffs or drinking water.

For each pathway a dosimetric model is used to convert the distribution of radioactive material in the atmosphere and on the ground, to distributions of dose in man.

Data on the spatial distribution of population and agricultural production are necessary for evaluating the collective dose and health effects, and if required for calculating the economic impact of implementing countermeasures, such as relocation and food bans.

Typical off-site consequences calculated in PSA Level 3 include:

- Number of early (acute) fatalities and injuries.
- Number of latent (chronic) cancer fatalities.
- Total population dose from all pathways.
- Individual risk of death and individual probability of latent cancer fatality.
- Interdicted and condemned land area.

The cost elements to be included in the economic consequence analysis are associated with early protective (emergency response) actions, long-term protective actions and costs resulting from long-term protective actions. They specifically include:

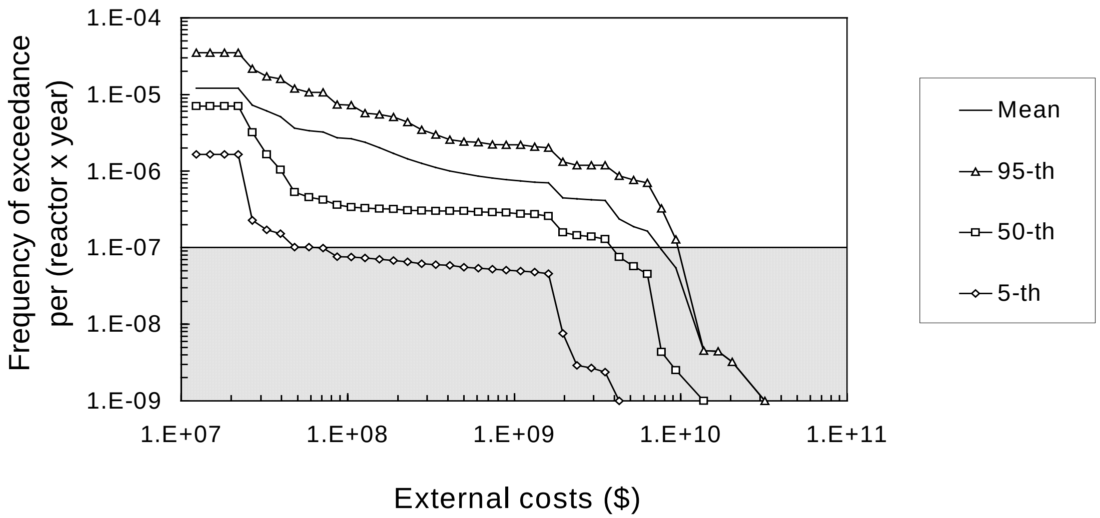
- Cost of countermeasures:
  - Population movement (transport away from the affected area, temporary accommodation and food, loss of income, loss of capital).
  - Agricultural restrictions and countermeasures (e.g. food bans).
  - Decontamination (e.g. Cleaning process, labour, health effects induced in work force).

- Cost of radiation-induced health effects (early, cancers, hereditary):
  - Direct health care costs.
  - Indirect costs (lost income).

Indirect or secondary effects as well as intangible effects have been discussed in Chapter 2 and will be further commented below.

As an example, Figure II.3 shows the frequency of exceedance of external costs for the Swiss Mühleberg plant, based on the full spectrum of initiating events (including external events). The curves cover only the costs of early and long-term protective actions. In order to arrive at the total external costs given in Hirschberg's and Cazzoli's report,[43] the costs of radiation-induced health effects (totally dominated by latent cancers) were quantified separately and added to those implicitly covered in the figure. As noted in the short summary of this study the MACCS code was used for calculation of the consequences, including the economic costs.

Figure II.3 **Mühleberg-specific frequency of exceedance of external costs of severe accidents with radiation-induced health effects excluded**[43]



Note: The mean can be regarded as the main reference, while the 95th percentile can be interpreted as providing a bounding value.

A line was introduced over the shadowed area at the frequency level of 10^{-7}/year, in order to emphasise that the large damage predicted at and below this level are associated with extremely small probability of occurrence. The resolution and completeness of the PSA-technique in this domain are disputable. In fact, some experts[75] advocate the use of cut-off values at the level of 10^{-7}/year or even 10^{-6}/year in non-engineering PSA applications (assessment of external costs belongs to this category). The main argument for a cut-off at this level is the heavy burden to demonstrate validity when the probabilities become extremely small.

Use of a plant-specific PSA, if available, is the most rational basis for the estimate of consequences of severe accidents and the associated external costs. The results obtained from such an approach are by definition representative for the case being studied. In addition, it enables treatment of uncertainties in a transparent and disciplined way. In case this approach is not feasible, any extrapolation of results obtained for a specific plant in a specific environment must be done with great care; the reference case should be carefully selected with a view to similarities in the design philosophy and in the operating environment. Some past applications do not exhibit such a care.

Limitations

The following limitations have been identified:[39]

- **Limitations of PSA techniques**: Specific limitations of PSA methodology and the progress achieved in handling them have been discussed elsewhere. Some specific issues concern reliability data, common cause failures, human interactions, external events, phenomena related to accident progression and source terms, and containment performance. Nevertheless, the physical impact models employed in the state of the art PSAs are by and large adequate as a basis for estimation of external costs.

- **Limitations of economic models**: The current economic models connected to the consequence codes are still relatively primitive. Consideration of ecological damage is limited to agriculture and recreational value of land or impacts on tourism are not considered. Generally, the analyses performed in the context of external cost estimations are limited to the land areas that are directly affected by the accident. For accidents which lead to long disruption periods there will be impacts on other areas and many sectors of the economy are likely to be affected. To simulate such effects, both at regional and national level, the input-output methodology that accounts for the interactions between the economic sectors, could be employed. A recent example of such application is the Spanish analysis[76] of an agricultural scenario together with other scenarios in mainly industrial and touristic areas. Applications of the input-output approach are in turn subject to limitations associated with standard problems of input-output analysis and the difficulties to achieve compatibility between the regional economic data and the area impacted by the accident.

  Within the limited scope of the economic consequence models that have been applied, the most important cost-driving parameters in the case of an accident with very extensive external consequences are: the value of life and the price of interdicted/condemned land. Both these parameters may be assigned according to different principles and the absolute levels are disputable. There is a particularly large potential variability with respect to the assigned prices of rural and urban land. In this context it is important to emphasise that cost parameters may be interdependent. For example, based on success of decontamination within a given period of time, land may be classified as habitable (relocation is necessary for a short period of time), temporarily interdicted (relocation is necessary for a protracted time), or permanently interdicted (condemned, the population will not be able to return for an indefinite period). Given a relatively low price of land (typical for rural land), high contamination levels and high decontamination costs, cost effectiveness criterion (as employed in several models) will lead to abandonment of the decontamination effort and condemnation of the land from the beginning. On the other hand, for more expensive land (such as urban areas), the habitability criterion is going to weigh very heavily in the definition of interdiction and condemnation.

- **Limitations in the treatment of subjective risks**: The issue of risk aversion in the context of external costs associated with severe accidents remains unresolved. The empirical foundation for aversion factors that have been employed remains weak and needs to be strengthened. This is necessary independently of the debate on external costs. While risk aversion certainly plays a role in the public debate (acceptability of specific technology), there is no general consensus that it should be reflected in external cost estimates.

Annex III

REGIMES AT THE INTERNATIONAL LEVEL GOVERNING CIVIL LIABILITY AND COMPENSATION FOR NUCLEAR DAMAGE TO THIRD PARTIES

The international conventions

As was noted in Chapter 3, the special regimes which have been established at the international level to address issues of civil liability and compensation for nuclear damage incurred by third parties are reflected in a number of international conventions, all of which are founded upon certain basic principles.

The earliest of these conventions to be adopted was the *Convention on Third Party Liability in the Field of Nuclear Energy of 29 July 1960* (the "Paris Convention"). It was concluded under the auspices of the OECD/NEA, and it has been amended twice by Protocol, once in 1964 and again in 1982. The Convention applies when a nuclear incident occurs in the territory of a Contracting Party to the Paris Convention and causes damage in the territory of another Contracting Party to that Convention. However, Contracting Parties may, by national legislation, extend the territorial application of the Convention to non-Contracting States. In addition there are two non-binding Recommendations by the OECD Steering Committee for Nuclear Energy relating to the territorial scope of the Convention: the first states that the Paris Convention is applicable to nuclear incidents occurring on the high seas or to damage suffered on the high seas; the second provides that the scope of application of the Convention should be extended by national legislation to damage suffered in a Contracting State, or on the high seas on board a ship registered in the territory of a Contracting State, even if the nuclear incident causing the damage has occurred in a non-Contracting State. The Paris Convention has 14 Contracting Parties: Belgium, Denmark, France, Finland, Germany, Greece, Italy, Norway, Netherlands, Portugal, Spain, Sweden, Turkey and the United Kingdom.

Shortly after the Paris Convention was adopted, many of its Signatories thought that it would be desirable to develop a supplementary compensation regime which would apply in the event that the amounts available under the Paris Convention were inadequate to compensate the damage caused by a nuclear incident to which that Convention applied. As a result, the *Convention of 31 January 1963 Supplementary to the Paris Convention of 29 July 1960* (the "Brussels Supplementary Convention") was adopted. It, too, has been amended twice by Protocol, once in 1964 and again in 1982. The 11 Contracting Parties to the Brussels Supplementary Convention are: Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Spain, Sweden and the United Kingdom. The "Paris-Brussels" regime is clearly "regional" in character, although any Member country of the OECD has the right to accede to it.

At about the same time, that is, in the early 1960s, *the Convention on Civil Liability for Nuclear Damage of 21 May 1963* (the "Vienna Convention") was concluded under the auspices of the International Atomic Energy Agency (IAEA). It is largely based upon the provisions contained in the Paris Convention and, although its territorial application is not specified in the Convention itself, it has been generally understood to cover nuclear damage occurring in the territory of any Contracting Party to that Convention and on or over the high seas, regardless of where the nuclear incident which caused the damage has occurred. It did not cover damage suffered in a non-Contracting State. The Vienna Convention is open to all States Members of the United Nations, or of any of its specialised agencies or of the International Atomic Energy Agency and thus is very much considered to have a "world-wide" character. It currently counts the following 30 Contracting Parties: Argentina, Armenia, Belarus, Bolivia, Bosnia and Herzegovina, Brazil, Bulgaria, Cameroon, Chile, Croatia, Cuba, Czech Republic, Egypt, Estonia, Hungary, Latvia, Lebanon, Lithuania, Mexico, Niger, Peru, Philippines, Romania, Slovak Republic, Slovenia, the former Yugoslav Republic of Macedonia, Trinidad and Tobago, Ukraine and Yugoslavia.

Following the nuclear accident at Chernobyl in 1986, several inadequacies were clearly demonstrated in the then existing international regimes of liability and compensation for nuclear damage suffered by third parties. For example, none of the various Conventions applied to the damage incurred as a result of that accident, simply because the then USSR (of which Ukraine formed a part) was not a Contracting Party to any of them. Thus the need for a broader scope of application of the Conventions was shown. It was also evident from the nature and extent of the nuclear damage suffered that neither the types of damage addressed under the various Conventions nor the liability amounts required to be made available, were sufficient to handle a serious nuclear incident.

One practical result was that in 1988 a *Joint Protocol Relating to the Application of the Vienna Convention and Paris Convention* was adopted under the joint auspices of the OECD/NEA and the IAEA. Prior to its coming into force on 27 April 1992, victims in the territory of a Contracting Party to one Convention could not claim compensation against the operator of a nuclear installation situated in the territory of a Contracting Party to the other Convention. The aim of the Joint Protocol was to bridge the two Conventions by extending the benefits of one Convention to the Contracting Parties to the other Convention. The result is that the provisions of each Convention will now apply, without discrimination, to the Contracting Parties of either Convention. Another objective was to prevent both Conventions from applying to the same nuclear incident, in order to avoid the necessity of double insurance in the case of transport, and as well, problems of conflict of laws. There are currently 20 Contracting Parties to the Joint Protocol: Bulgaria, Cameroon, Chile, Croatia, Czech Republic, Denmark, Egypt, Estonia, Finland, Hungary, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Romania, Slovak Republic, Slovenia and Sweden.

Another response to the Chernobyl accident was the decision, in 1989, to commence revising the existing liability Conventions. The Paris and Brussels Supplementary Conventions had been revised in 1964 and again in 1982, but the Vienna Convention had not been amended since its adoption in 1963. It was therefore decided that the revision process should begin with the Vienna Convention. The negotiations to revise that Convention took many years to complete, but in September 1997, the *Protocol to Amend the Vienna Convention* (the "1997 Amending Protocol") was finally adopted. One of its most significant amendments is to make the revised Vienna Convention apply to nuclear damage wherever suffered, subject to certain permitted exceptions[1]. The 1997 Amending Protocol is not yet in force, but as of mid-June 1998, thirteen States had signed the instrument, these being: Argentina, Czech Republic, Hungary, Indonesia, Italy, Lebanon, Lithuania, Morocco, Peru, the Philippines, Poland, Romania and Ukraine.

Finally, in September 1997 as well, a new *Convention on Supplementary Compensation for Nuclear Damage* (the "Compensation Convention") was adopted under the auspices of the IAEA. This

1. The permitted exceptions relate to non-Contracting States with nuclear installations which do not extend equivalent reciprocal benefits to Contracting States.

instrument is a free-standing Convention open to all States[2] who are willing to accept the basic principles of nuclear liability law. As such, a country may become part of a global regime of liability and compensation for nuclear damage without having to become a member of either the Paris Convention or the Vienna Convention. This is significant because, as was noted in Chapter 2, many nuclear power generating countries are not members of either of these two Conventions. The Compensation Convention enables additional funds to be made available to compensate nuclear damage for which an operator is liable under the Paris Convention, the Vienna Convention or under national law complying with the requirements of the Annex which reflects the basic principles of nuclear liability law. There is no general provision regarding the territorial scope of application of the Convention, although there is a specific provision addressing the scope of application of the special international fund called for under that Convention.[3] The Compensation Convention has not yet come into force, but as of mid-June 1998, thirteen States had signed the instrument, these being: Argentina, Australia, Czech Republic, Indonesia, Italy, Lebanon, Lithuania, Morocco, Peru, the Philippines, Romania, Ukraine and the United States.

The basic principles

A number of basic principles underlie all of the nuclear liability regimes reflected in the international conventions described above. These are as follows:

***A*. *Liability is channelled:*[4]** The operator of a nuclear installation is exclusively liable for damage suffered by third parties as a result of an accident at or in relation to that nuclear installation, including accidents in the course of transport of nuclear substances.

B*. *Liability is absolute (Strict): Unlike the general principles of tort law which are based upon the concepts of fault or negligence, the operator of a nuclear installation is liable for damage suffered by third parties regardless of whether it can be shown to have been at fault or to have been negligent.

***C*. *Liability is limited in amount*:**[5] The Paris Convention provides that the maximum liability of an operator is 15 million Special Drawing Rights (SDRs),[6] but a Contracting Party may, taking into account specific criteria set out in the Convention, establish by legislation a greater or lesser amount,

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2. The Compensation Convention is not entirely free-standing in that it requires a country with at least one civil nuclear power plant on its territory to be a Party to the Convention on Nuclear Safety before it can join the Compensation Convention.

3. This is described in more detail under Section 2. Basic Principles, Part F: Non-Discrimination.

4. The Paris and Vienna Conventions prescribe "legal channelling" of nuclear third party liability, pursuant to which an operator of a nuclear installation is the only person legally liable for nuclear damage. The Compensation Convention includes a provision (in the Annex) that would allow a country, albeit in a very restricted manner, to join that Convention even where its national law provides for economic channelling instead of legal channelling. Economic channelling occurs where the operator bears all of the economic consequences for nuclear damage, even though other persons might be legally liable and where persons other than the liable operator are indemnified for any costs incurred because of that legal liability.

5. The principle that the amount of an operator's liability should be limited has come under increasing criticism in recent years. A number of Member countries of the OECD/NEA, some of whom are either Signatories or Contracting Parties to the Paris Convention, have already provided for an operator's unlimited liability under their national law. In addition, the 1997 Amending Protocol contains a provision permitting a Contracting Party to establish such unlimited liability in respect of its operators, but in such a case there is a corresponding obligation under the Convention to ensure that a minimum amount of 300 million SDRs of financial security is in place.

6. A Special Drawing Right is a unit of account defined by the International Monetary Fund. It is calculated on the basis of a basket of currencies of five of the most important trading nations. In May 1997, one SDR was worth approximately US$1.39.

subject to a lower limit of 5 million SDRs. The Steering Committee for Nuclear Energy (the governing body of the OECD/NEA) has made a non-binding recommendation that Parties to the Paris Convention aim at setting the maximum liability of an operator at not less than 150 million SDRs and many, but not all, of the Contracting Parties have done so.

For countries who are Party to both, the Brussels Supplementary Convention adds two additional tiers of available compensation to the amount provided for under the Paris Convention. The first of these two tiers comprises the difference between the amount provided for under the Paris Convention and 175 million SDRs which difference is to be provided by the Party concerned from public funds. The second of the two tiers comprises the difference between 175 million SDRs and 300 million SDRs, which amount is to come out of public funds to be contributed jointly by all the Parties to the Brussels Supplementary Convention.

Under the 1963 Vienna Convention, the liability of an operator may be limited to not less than US$ 5 million[7]. However, under the 1997 Amending Protocol, the amount of liability of an operator, or of an operator together with the State in whose territory the liable operator's nuclear installation is situated, is substantially increased, to an amount not less than 300 million SDRs.[8]

Under the Compensation Convention a two-tier system of compensation for nuclear damage is established. The first tier comprises 300 million SDRs[9] which must be made available by the State in whose territory the liable operator's nuclear installation is situated, while the second tier is comprised of a fund made up of contributions from the Contracting Parties determined in accordance with a formula that is set out in the Convention. The exact size of the fund will depend on the installed capacity of the Contracting Parties at the time of the nuclear incident that triggers the operation of the fund.[10]

In no case do the amounts fixed for the operator's liability under the above described Conventions include interest and costs awarded by a court in actions for compensation. Such amounts are payable either by the operator or by one or more of the Contracting Parties to the Convention pursuant to which compensation is to be paid.

D*. *Liability is limited in time: The basic rule under both the Paris Convention and the 1963 Vienna Convention is that the right to compensation expires if an action is not brought within ten years of the nuclear accident, but national legislation may establish a longer period as long as two conditions are met: first, the operator is covered by insurance or other financial security during such longer period, and secondly, the extension does not affect the right to compensation of any person who has brought an action in respect of loss of life or personal injury against the operator before the expiry of the original 10-year period. In addition, States may further restrict the bringing of claims by providing that operators will not be liable for nuclear damage after a period of (at least) two years (Paris Convention) or three years (Vienna Convention) from the time when the victim knew, or ought reasonably to have known, of the damage and the operator liable.

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7. This amount is defined by reference to its value in terms of gold on 20 April 1963; that is US$35 per one troy ounce of fine gold. This amount is worth approximately US$60 million today.

8. Note that the 1997 Amending Protocol allows for the phasing-in of the increased liability amount by permitting a transitional amount of liability of 100 million SDRs during a period of 15 years from the date of entry into force of the Protocol.

9. The Compensation Convention also provides for a phasing-in of the first tier amount, permitting Contracting Parties to establish a transitional amount of not less than 150 million SDRs during the period of 10 from the date of the adoption of the Convention.

10. If most of the nuclear power generating countries join the Compensation Convention, the fund will provide approximately 300 million SDRs of compensation.

However, under the 1997 Amending Protocol, the prescription periods have been significantly modified. Claims for personal injury may be brought within a 30-year period from the date of the nuclear incident rather than the 10-year period called for under the 1963 Convention and actions must now be brought within 3 years of the victim having knowledge of the damage. Where funds are insufficient to compensate all damage suffered, priority is to be given to claims for personal injury or death.

Since the Compensation Convention is intended to supplement the system of compensation provided for under national law which implements either the Paris Convention, the Vienna Convention or the national law of an Annex State, no prescriptions periods are specified. However, the Convention does contain a requirement that the national law of Annex States contain provisions regarding prescription periods that are identical to those found in the 1963 Vienna Convention, including the three year restriction on the institution of claims

E*. *Financial security requirements: The operator must have insurance or some other form of financial security equivalent to the amount of its maximum liability as prescribed by national legislation pursuant to the relevant Convention. The sums provided as insurance or other financial security may be used only for compensation, and not, for example, to cover administrative costs. It is to be noted that the 1997 Amending Protocol contains provisions permitting the State in whose territory the nuclear installation of the liable operator is located, to limit the amount of financial security required to not less than 300 million SDRs where the liability of the operator is unlimited.

F*. *Non-discrimination: The provisions of all the liability Conventions and of national legislation adopted pursuant to those Conventions are to be applied without any discrimination based upon nationality, domicile or residence, with one important exception. That exception is found under the Compensation Convention, and in particular, its provisions concerning the geographic scope of nuclear damage covered by the second tier of compensation (the international fund). Specifically, the Compensation Convention stipulates that one half of its second tier, that is one half of the international fund, will be reserved exclusively for transboundary damage, that is, to compensate claims for nuclear damage suffered outside the territory of the State in which the nuclear installation of the liable operator is situated.

G*. *Unity of jurisdiction: One of the basic principles common to all of the nuclear liability conventions is that exclusive jurisdiction over a nuclear incident lies with the courts of the Contracting Party where the incident occurs, or with the courts of the State within whose territory the liable operator’s installation is situated.

The damage to be compensated

The concept of “damage” is not precisely defined in either the Paris Convention or the 1963 Vienna Convention. Both Conventions simply provide for compensation to be paid in respect of physical injury to persons, including death, and for damage to or loss of property resulting from a nuclear incident. Property damage specifically excludes damage to the nuclear installation itself or any other nuclear installation on the same site, as well as damage to property on the same site which is used or to be used in connection with any such installation. Given the differences between the national legal systems of the Contracting Parties to these Conventions, it was decided that more precise definitions should be formulated by national legislation and, if necessary, by the courts having jurisdiction to consider claims for compensation.

Following the Chernobyl incident, it became clear to many countries that damage to the environment, economic loss, the costs of preventive measures and consequential losses were likely to constitute major portions of the damage following a significant nuclear incident. It was also recognised, however, that if such damage were to be compensated under the Paris Convention and the 1963 Vienna Convention, it would have a serious impact on the amount of funds available to compensate personal injury, death and direct property loss or damage.

The result of these considerations was that in the course of negotiating both the 1997 Amending Protocol and the Compensation Convention, States determined that it was necessary both to increase the amount of compensation to be made available to victims and to amend the definition of "nuclear damage" to permit compensation in respect of these other heads of damage which were not specifically referred to in the existing Conventions. The new definition of "nuclear damage", which now appears in both instruments, has now been expanded to cover the following more comprehensive list of heads of damage:

(i) loss of life or personal injury;

(ii) loss or damage to property;

(iii) economic loss arising from loss or damage referred to in sub-paragraph (i) or (ii) insofar as not included in those sub-paragraphs, if incurred by a person entitled to claims in respect of such loss or damage;

(iv) the costs of measures of reinstatement[11] of impaired environment, unless such impairment is insignificant, if such measures are actually taken or to be taken, and insofar as not included in sub-paragraph (ii);

(v) loss of income deriving from an economic interest in any use or enjoyment of the environment, incurred as a result of a significant impairment of that environment, and insofar as not included in sub-paragraph (ii);

(vi) the costs of preventive measures[12], and further loss or damage caused by such measures;

(vii) any other economic loss, other than any caused by the impairment of the environment, if permitted by the general law on civil liability of the competent court.

Note: From (iii) to (vii): To the extent determined by the law of the competent court.

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11. "Measures of reinstatement" are also defined in the 1997 Amending Protocol and in the Compensation Convention as "any reasonable measures which have been approved by the competent authorities of the State where the measures were taken, and which aim to reinstate or restore damaged or destroyed components of the environment, or to introduce, where reasonable, the equivalent of these components into the environment. The law of the State where the damage is suffered shall determine who is entitled to take such measures."

    Note that the term "reasonable measures" has also been defined under both instruments as follows: "Reasonable measures" means measures which are found under the law of the competent court to be appropriate and proportionate, having regard to all the circumstances, for example,

    (i) the nature and extent of the damage incurred or, in the case of preventive measures, the nature and extent of the risk of such damage;

    (ii) the extent to which, at the time they are taken, such measures are likely to be effective; and

    (iii) relevant scientific and technical expertise."

12. "Preventive measures" are defined under the 1997 Amending Protocol and under the Compensation Convention as "any reasonable measures taken by any person after a nuclear incident has occurred to prevent or minimise damage referred to in sub-paragraphs (i) to (v) or (vii) (of the definition of "nuclear damage"), subject to any approval of the competent authorities required by the law of the State where the measures were taken.

Precisely what is covered by this expanded definition is still open to question. Some States take the view that the question of what constitutes nuclear damage is still entirely left up to the law of the competent court, regardless of the fact that the phrase “and each of the following to the extent determined by the law of the competent court” is placed *after* the first two heads of damage. Other States have taken the view that even with the inclusion of this phrase, they remain at liberty to make *no* provision under their national law for the heads of damage enumerated under (iii) to (vii), while still other States support a completely opposing point of view.

There is general agreement, however, that the economic loss referred to under heading (iii) is to be distinguished from that described under heading (v), this latter intending to address losses deriving from a business interest in the use/enjoyment of the environment rather than one associated with an individual’s personal use/enjoyment. It is also generally acknowledged that the inclusion of definitions for terms such as “measures of reinstatement” and “reasonable measures” are designed to ensure that the scope of the “costs” contemplated by this sub-paragraph will not be unreasonable. The same may be said of heading (vi) in that, once again, the definition of “reasonable measures” ensures that the scope of “preventive measures” is reasonably restricted. Finally, heading (vii) is to be viewed as a “catch-all” for other types of economic loss that are not caused by an impaired environment, as long as such losses are recoverable under the general civil liability law of the competent court.

It should be noted as well in this connection that both the 1997 Amending Protocol and the Compensation Convention contain a definition of “nuclear incident” which differs significantly from those found in the Paris Convention and the 1963 Vienna Convention. The new definition makes it clear that, in the absence of an actual release of ionising radiation, preventive measures can be taken only in response to a grave and imminent threat of a release of radiation that could cause other types of nuclear damage. The use of the phrase “grave and imminent” makes it clear that preventive measures cannot be taken on the basis of speculation that radiation might be released and that some damage might occur.

Annex IV

COMPENSATION AFTER A NUCLEAR ACCIDENT AND THE ROLE OF INSURANCE

Definition of "nuclear damage"

What constitutes "nuclear damage" then? Since it has only been defined in the context of legal regimes, whether national or international, one must look at legal definitions. Annex III to this report reviews the various definitions of "nuclear damage" that are provided for under the international conventions which constitute the regimes addressing civil liability and compensation for nuclear damage suffered by third parties, that is, the 1960 Paris Convention, the 1963 Vienna Convention, the 1997 Protocol to Amend the Vienna Convention and the 1997 Convention on Supplementary Compensation for Nuclear Damage. There is, potentially at least, a significant difference between the definition contained in the first two of these Conventions and that found in the last two.

What is specifically included in the notion of "damage to persons" or "damage to property" and the extent to which such damage will be compensated is a matter of interpretation, to be determined by the competent court in accordance with the applicable national law. And unless the applicable national law is so clear and unequivocal as to preclude otherwise, a competent court will naturally refer to jurisprudence in similar fields and may even be swayed by public or political pressure in making its interpretation. Thus, what might be compensable in one country may not be in another.

Finally, it must be remembered that one of the major principles underlying the international liability regimes for nuclear damage is that, although compensation is guaranteed by mechanisms of financial security that are required to be put into place, the total amount of compensation available is limited. Thus, if the notion of nuclear damage is extended to include heads of damage not currently covered by the existing regime, the result may simply be that more damage is compensable, but there is no commensurate increase in the amount of funds available to provide that compensation.

Proof of causality and prescription periods

The methodology based on the use of an Economic Methodology attempt to estimate the health effects of a nuclear accident, by estimating the collective radiation dose resulting from the accident and then using this estimate to calculate the extent of potential health effects, is not especially useful when determining compensation for individual damage claims. This is because in all known legal regimes such claims will only succeed if there is a proven connection between the radiation dose received from the nuclear incident and the illness or death which has resulted from that dose.

For example, Article 3 of the Paris Convention provides that the operator of a nuclear installation shall be liable for nuclear damage "upon proof that such damage or loss was caused by a nuclear incident in such installation or involving nuclear substances coming from such installation …". The Vienna Convention similarly provides in Article II that the operator of a nuclear installation shall be liable for nuclear damage "upon proof that such damage has been caused by a nuclear incident in his installation, or involving nuclear material coming from or originating in his nuclear installation …".

It can readily be seen, therefore, that "causality" becomes a major obstacle for victims who do not suffer serious health effects until some considerable time after the occurrence of the nuclear incident. In most cases, these victims will not have been examined at the time of the accident, will not have had their radiation dose measured and may not be in a position to have their doses validly reconstructed. There will thus be no evidence of the link between the radiation dose received at the time of the accident and their later illness.

One relatively recent attempt to overcome this particular problem was the introduction into the Congress of the United States, of a bill which was designed to incorporate into that country's legislative system dealing with nuclear liability, the concept of "probability of causation". This concept was based upon a grid which reflected increasing percentages of probability, linked to the percentage of claims which would be entitled to compensation. The bill was not approved.

A "prescription period" is a limitation upon the time within which an action may be brought or a claim can be made. As noted above, since an injury or illness may not become noticeable until a considerable time after the nuclear incident has occurred, the prescription period for claims for compensation for nuclear damage is very important.

National governments have attempted to find a compromise between, on the one hand, nuclear operators and their insurers who do not wish to maintain large reserves over long periods of time for potentially large but indeterminable amounts of liability, and on the other hand, victims whose damage does not become noticeable until some considerable period of time after the incident has occurred and who should still be entitled to compensation.

The prescription period provided for in the Paris Convention is set out in Article 8, paragraph (a) which reads as follows:

> "The right of compensation under this Convention shall be extinguished … within ten years from the date of the nuclear incident. National legislation may, however, establish a (longer) period … if measures have been taken by the Contracting Party in whose territory the nuclear installation of the operator liable is situated to cover the liability of that operator in respect of any actions … begun after the expiry of the ten years and during such longer period: provided that such extension … shall in no case affect the right of compensation … of any person who has brought an action … against the operator before the expiry of the … ten years."

However, pursuant to paragraph (c) of this same Article, national legislation may establish a shorter prescription period, although it may not be less than two years from the date at which the victim actually knew of the damage and of the liable operator or ought reasonably to have known of the damage and of the liable operator. National legislation may not, however, extend the period beyond the ten years provided for in paragraph (a).

Similar provisions with respect to prescription periods are contained in the Vienna Convention which also sets out a general ten year time limit for making claims for compensation.

It is not difficult to imagine how the two factors of causation and prescription periods can affect estimates of the potential negative health effects resulting from a nuclear incident. Essentially, unless an individual claimant can establish that his damage were caused by a nuclear incident and he is able to make his claim within the prescription period that is applicable to his claim, his damage will not be compensable, not withstanding that they may nevertheless be very real.

Summarising the above, it can be said that the economic methodology thus attempts to determine, on a local, regional or global basis, the economic consequences of a nuclear accident. There are no restrictions as to the types of consequences or the time frame within which these consequences can occur. The methodology, however which is used to determine the extent of compensation, focuses on the individual situation of the victims who have suffered specific types of damage as a direct consequence of a nuclear accident.

After having looked at the economic consequences of a nuclear incident through the use of an economic methodology, it becomes evident that the amounts which national governments have made available for the compensation of damage suffered by victims of a severe nuclear incident are probably not adequate to properly address all economic consequences.

It is also evident that there is increasing pressure, at least in some nuclear countries, to provide compensation for certain types of damage which are not currently recognised as "nuclear damage" either under national legislation or under the international regimes; for example, the view that even though there is no individual claimant for damage to the environment, it is nevertheless an asset whose loss is worthy of compensation.

Furthermore, it must be acknowledged that the existence of national legislation dealing specifically with compensation for nuclear damage and the adherence to international conventions may not limit the financial exposure of national governments even though it would limit the ability of victims to be compensated. Under such legal regimes, a severe nuclear incident could result in significant additional costs to a national government wishing to take all necessary steps to minimise the damage that has occurred, to prevent any future damage from occurring, to compensate injured or disabled workers through worker compensation schemes and to voluntarily provide for the potentially wide variety of other benefits to which it believes its population is entitled.

The role of insurance

In general, the existence of financial protection for the compensation of damage which have been suffered as a result of a nuclear incident is a prerequisite to obtaining a license to operate a nuclear installation. The regimes which have been established to address the specific issues associated with liability for nuclear damage suffered by third parties require that financial security be obtained and maintained to ensure that funds will be available for compensation.

Insurance coverage is a suitable means of supplying the required financial protection or the third party liability of operators, transporters or any other party which may be liable towards third parties in connection with nuclear processes or dangers of radioactivity.

The role of the insurance industry is to transfer a risk from one legal entity, be it a person, partnership or corporation, to the insurer, who redistributes it among a greater number of other similarly exposed entities. This transfer and risk distribution allows a particular risk, the cost of which cannot otherwise be estimated, to be converted into a known, fixed expenditure over a specified period of time.

If the risk to which one legal entity is exposed is completely redistributed, the premiums which are paid by the insured should be equal to the economic value of the risk that is transferred. In the case of a commercial enterprise, the premiums may then be factored into the price of the goods or services offered by the enterprise.

The private insurance industry can fulfil these functions, but only within certain limitations. The amount of insurance that can be offered is dependent upon the issued capital of the insurer, the total number of insured entities, the total premium volume and the assessment (whether objective or subjective) of the risk which has to be transferred and redistributed.

Unlimited amounts of insurance coverage cannot be provided by the private insurance industry. Such a commitment would involve an insolvency risk to the insurers themselves, which, if realised, would undermine the entire transfer/distribution scheme. No business enterprise can accept such a risk without ensuring that adequate countermeasures are in place to prevent its realisation.

Besides the obvious measure of requiring the enterprise's shareholders to increase their capital contributions, one effective countermeasure is to redistribute the risk through the mechanism of re-insurance. In other words, the insurer insures itself. With re-insurance in place, the insurer can accept more costly risks from its customers and can redistribute these risks to a wider base of risk carriers. However, even with this mechanism, there is still a limit to what the industry can assume by way of risk.

The insurance industries of the world have responded to nuclear risks by the formation of market-wide pools in which a number of insurers merged their operations in order to offer the greatest possible capacity commitment in close world-wide co-operation between all 28 existing nuclear risk insurance pools. Despite the co-operation between pools, which supply the world-wide available insurance capacity for nuclear risks, this capacity is not sufficient to cover extremely high amounts of potential losses to the public.

The insurance industry has a great deal of experience with compensating losses suffered by third parties with respect to personal and property damage. Information has been published by the industry on both the practice and the compensation provided in Western Europe, an example of which is the 1992 publication of the Swiss Reinsurance Company, "Compensation for personal injury in Western Europe".

The handling and settlement of claims is a service which is normally connected to and cannot be separated from the coverage of risk in third party liability insurance. It becomes a very important issue in an area like nuclear third party liability insurance where a great number of claimants have to be served in the settlement of losses out of one single event.

The necessary number of skilled persons required to handle such losses can become a problem, as well as the expense of the claims service. Insurers are prepared to make their services for the handling and settlement of claims available to their clients. For the settlement within the sums insured, this may only present a problem when the insurance industry is asked to increase its coverage up to the total amount of available capacity, because the expenses for handling claims reduce the maximum coverage which can be made available.

Methods of calculating premiums

Normally, insurers calculate the amount of premiums which they charge to their customers on the basis of statistical analyses of the losses incurred within a certain period of time. In order to calculate the amount of the premiums on an ex-post basis, the total amount of losses which have been paid out is divided by the total amount of premiums collected in the same period of time. This so-called loss ratio should normally not exceed 100% of the premiums net of commission and net of internal expenses of the insurer.

In order to calculate the amount of premiums on an ex-ante basis, it is usual to view the amount of expected losses as the product of two risk factors: (i) the probability of occurrence (also called the average loss frequency); and (ii) the average loss amount. The resulting figure is refereed to as the "expectation value", and represents the total cost of the customer's risk relative to the activities undertaken by that customer. In this calculation, the two factors used in determining expected losses will vary depending upon the size of the losses investigated. For example, smaller losses generally have a higher probability of occurrence (frequency) than larger ones.

In the case where an insurer accepts the transfer of an additional risk, the premium which should be charged is equal to the expectation/economic value of that risk. Each layer of risk will have its own particular risk factors to be taken into account. Similarly, the expectation/economic value of a risk that remains uninsured over and above a fixed amount of existing coverage can usually be calculated by multiplying the risk factors that are particular to that risk, taking into account once again that the probability of occurrence becomes smaller as the magnitude of the losses becomes larger.

Evaluation of accident scenarios

In many areas where insurers traditionally have transferred risk through their insurance programmes, the events covered have occurred a sufficient number of times such that statistical probability of occurrence can be calculated from existing statistical data. This is not the case for reactor accidents leading to off-site economic consequences. In this case, the probability of occurrence must be estimated and this is done using probabilistic safety assessment (PSA) techniques (see Annexes I and II).

For widespread distribution of greater quantities of radioactive matter into the atmosphere which might result in an accident scenario with damage to third parties, very low probabilities have to be considered. The total amount of such losses to third parties has to be multiplied by these low probabilities in order to arrive at the economic value of expenses, which today are "external", that means not paid for by operators through insurance premiums. It can be estimated that all scenarios which are not falling under the insurance coverage provided today have probabilities of occurrence of 10^{-6} per reactor-year or lower.

Alternative means of financial security

Generally speaking, financial protection is supplied by insurance coverage, which is offered by the insurance industry for certain maximum amounts per installation, which represent the world-wide available insurance capacity.

Nevertheless, it has been deemed by many countries to be necessary to establish higher limits of liability and higher amounts of financial protection than the insurance industries are able to provide.

To address these higher limits, government guarantees have been added to insurance coverage to ensure a combined level of financial protection that is deemed acceptable. For example, in Germany, Switzerland and in the United States, the Government has provided guarantees which come into force when other means of financial protection, such as insurance, have either been exhausted or do not respond to the operator's liability.

In addition to government guarantees, mechanisms of risk distribution between the operators of nuclear installations have been established in some countries. For example, in Germany, a mutual scheme of post loss distribution of indemnities between all operating nuclear power stations, which is fronted by policies issued by a small group of insurers, supplies DM 300 million financial protection after the present insurance cover of DM 200 million is exhausted. In the United States, the Price Anderson Act requires post loss contributions of all operating reactors, which at present establishes a financial guarantee for the public of US$ 8.96 million (October 1995).

The insurance industry in these countries has offered to settle claims above their own sums insured. Under special agreements, they render the service to the other means of financial protection – be it government guarantee or supplementary funding. Such an agreement needs to include clear provisions concerning the basis on which expenses involved in the claims service will be compensated by the other financial protection. The obligation of insurers to settle claims for the post loss assessment scheme of operators is also part of the legal provisions of the Price Anderson Act in the United States.

Who bears the costs?

To the extent to which the economic consequences of a nuclear accident are insured in a compensation system which is provided by third party liability insurance, these costs are internalised into the cost of the energy production by paying an adequate premium which is included in the price of the electricity sold to clients.

Also, when the compensations are financed by the alternative means of financial security mentioned above, the costs will mostly be shared between all operators of nuclear power stations who again will charge them to their clients within the electricity price.

In both cases, the ultimate payer of the expenses is the consumer of electricity prorated to the amount of electricity used. The difference between these two systems is only that in case of insurance contracts, the premium has to be paid in advance and will be charged immediately during the production of electricity, whereas in the models of risk distribution between operators, the contributions to the costs of a nuclear accident will normally be collected after the loss and have to be borne, therefore, not by those consumers who use the nuclear energy during the time when the operating installation presents the risk during production, but by those customers who use electricity after the accident has occurred.

In some cases, when victims of an accident can not be compensated through the liability regimes, it will fall to their own expense to bear the consequences of an accident. This will be the case when the proof of causation is not successful, and/or when health effects materialise after the expiration of the prescription period. Also, for pure economic losses or for indirect effects of the nuclear accident, compensation is normally not granted within the compensation systems based on liability regimes in place.

In addition to the victims themselves, public health organisations, sickness insurance, be it social security or private insurance, in some countries also workman’s compensation schemes will have to bear parts of the economic consequences of a nuclear accident for treatment costs of the persons who suffer health effects after the accident.

Governments may decide to compensate victims through public welfare if they are not compensated under liability regimes. In that case, and for all compensations borne by governments as a result of government guarantees when the underlying means of financial security are exhausted, these costs will have to be taken up by a general tax budget of the states affected and will by that be distributed to the majority of the population. An exception is Switzerland, where the operators have to pay a fee for the government’s guarantee into a special fund established by the government who in this case acts more like an insurer than as a public body giving a guarantee.

In principle, in most developed countries it does not make too much of a difference for the population whether the ultimate payer for the costs of a nuclear accident are electricity consumers or tax payers, because most people who live in these countries are both paying taxes and their electricity bills. The difference could only be gradual and have different distribution parameters so that the individuals may have to contribute different amounts in the one or the other way of risk distribution. For the society and economy as a whole under macro-economic perspectives, this difference will completely disappear and the question who pays does not matter any more.

The question of internalisation, however, and of its influence on the amount of electricity consumption still remains an open issue.

Annex V

AN ASSESSMENT OF THE ECONOMIC CONSEQUENCES OF THE CHERNOBYL ACCIDENT IN NORWAY

Summary

It was estimated by the Norwegian Radiation Protection Authority that about 6% of the caesium released from Chernobyl was deposited in Norway. This was a result of very unfortunate combinations of wind directions and precipitation conditions. The situation has created serious difficulties for Norwegian agriculture in the contaminated areas. In 1986 significant amounts of food had to be destroyed, but already from 1987 various types of less drastic countermeasures had been adopted. Although there has been a decrease in the amount of caesium in the agricultural products (without countermeasures), the need for the countermeasures is still there, and will be for years ahead.

Here are summarised the economic consequences to agriculture in Norway over the years 1986, 1987 and 1988.

The term “economic consequences” in this annex means actual compensations, for condemned agricultural products or extra labour or additional expenses due to modifications of agricultural practices (countermeasures). These compensations have been paid to the producers of agricultural products by the Norwegian state. There are additional economic consequences, e.g. due to contamination of freshwater fish and game, and to tourist industry in general (the latter only relevant in 1986). No compensations have been paid in these connections, and these economic consequences have not been included in the numbers presented in this annex.

It is seen that the economic consequences are considerable, particularly when it is kept in mind that Norway is at a distance of around 3 000 km from the site of the accident.

Application of the various types of countermeasures, described in the following, has drastically reduced the economic consequences relative to what they would have been if food interdiction had been utilised as the only option. The valuable experience gained in Norway and the countermeasure techniques developed have later been applied in other parts of the world, like Belarus and Ukraine.

This summary is based upon earlier reports by the same authors, published by the Institute for Energy Technology and by the Nordic Safety Programme. The work has been sponsored by the Nordic Council of Ministers.[4]

Mitigating actions administrated by the Ministry of Agriculture, Norway

During the summer 1986 the National Institute of Radiation Hygiene (now the Norwegian Radiation Protection Authority) collected soil samples from all municipalities in Norway; and it was found that Norway was probably the most heavily contaminated country in Western Europe. In large areas the activity was above 100 kBq/m^2. The areas where ground concentrations are highest are mostly in sparsely populated mountain areas. These areas are, however, important in connection with several nutritional pathways; notably sheep, goats, reindeer and wild freshwater fish.

The mitigating action programme described in this subchapter is organised by the Ministry of Agriculture. The sampling programme is approved by the Norwegian Radiation Protection Authority.

Milk

Cattle had not started feeding outdoors at the time of the accident, and iodine in milk was never high. The cattle were let out at the normal time. Caesium was found in the milk from late May 1986, and the content increased for some time. Only in one limited area were the action levels exceeded. The milk from this area was used as animal fodder. Following ancient agricultural practices, a lot of cattle are still brought up to the mountain areas in the summer months, to graze at random in these rich natural pastures. The milk with high content came from these herds.

Sheep

It was decided not to put restrictions on the use of grazing areas for sheep. In most of Norway sheep are brought up to the mountain commons in early summer, where they are free to move around until early fall. Towards the end of July 1986 it was found that the content in mutton was above the action level in some areas, and 31 July 1986 it was decided by the Ministry of Agriculture, in co-operation with regional agricultural/veterinarian officers, to initiate a programme for surveillance, mitigating actions and economic compensation. Information material on feeding etc. was sent to about 30 000 farmers in 1986, 1987 and 1988. The Ministry of Agriculture, in co-operation with regional veterinary officers, was responsible for dividing the country into three types of zones. Roughly 70% of the sheep were in free zones (average content below 600 Bq/kg). Roughly 3% of the sheep were in so-called ban zones (average content above 2 000 Bq/kg). Slaughtering proceeded as usual, but the meat was classified as unfit for human consumption. Initial plans for burying the interdicted meat was later changed to using the meat as fur-animal (mink, fox etc.) fodder. The remaining areas, containing 27% of the sheep, were referred to as special measure zones. Here the caesium content was reduced below the action level by the use of caesium-free fodder for periods of 4 to 8 weeks. This involves letting the sheep graze on the home farms in the valleys, where the uptake of caesium in the grass is much lower than in the mountain areas, due to difference in soil types. In addition to clean fodder, concentrates containing bentonite have also been given to the animals.

The problem areas in 1987 were the same as in 1986, though somewhat smaller in size. No areas were classified as “forbidden”. Roughly 77% of the sheep were in free zones, and 23% in the special measures zones. The “down-feeding” programme, covering a total of ca. 280 000 sheep, has been very successful. The conditions in 1987, however, were especially favourable, since the autumn was unusually mild and the first snow-fall unusually late. In the down-feeding programme a half-life in sheep of 21 (initially 24 days) was used. In 1986 the division into zones mainly was built upon measurements on meat samples. The problems were easier to handle in 1987, in part because live animal measurements were adopted. The Norwegian Radiation Protection Authority and the Division of Veterinary Services of the Ministry of Agriculture have co-operated in the testing and calibration of equipment for measuring levels in live reindeer, cattle and sheep. The equipment has also been tested and calibrated for direct measurement of radioactivity in carcasses from the species at slaughter.

Because 1988 was an exceptionally good year for mushrooms, one observed levels of radiocaesium in sheep 3-4 times the levels of the previous year in many parts of the country; and roughly 30% of the sheep were in special measures zones, and 70% in free zones. The downfeeding programme involved a total of about 360 000 sheep. Sheep with levels up to 40 000 Bq/kg before down-feeding were successfully included in the programme. The conditions in 1987 and 1988 were, however especially favourable for carrying out the down-feeding programme, since the years were unusually mild and the first snowfall unusually late.

Reindeer

Levels up to 150 000 Bq/kg were found in reindeer from mountain areas in Southern Norway, as summer 1986 proceeded. Only in three areas was the content below the action level. The content decreased from June to August, but increased in September 1986, with further increase through the winter, since the reindeer then feed mostly on lichen. On 31 July 1986 it was decided by the Government to initiate a programme for economic compensation. In November 1986 it seemed that 85% of the production for 1986 could not be used. Because of the severity of this impact (which also mainly hits a minority population group, the Lapps), and because reindeer meat is not an important part of the diet of the average Norwegian, the Health Directorate decided in November 1986 to increase the action level for reindeer meat by a factor of ten. With this action level, much of the production was saved from interdiction. However, about 560 tonnes of reindeer meat were interdicted, converted into meat/bone flour and buried.

However, in 1987 several different types of mitigating actions were employed. This programme involved individual measurement of the animals before slaughtering, early slaughtering, use of less contaminated areas for feeding, use of saltlickstone with Prussian Blue, and down-feeding. A special bowel tablet containing Prussian blue (a caesiumbinder) was also developed at the Norwegian Agricultural University, but successful large-scale use was not attained until 1988. Early attempts failed because the tablets, when mass-produced, dissolved too fast to last through the required time period. In 1987 almost 14% of the production (312 tonnes) of reindeer meat was saved in the early slaughtering programme. The amount of animals with access to saltlickstone is not known, nor is the number of animals using areas with lower fallout levels. The number of animals in both cases is undoubtedly high. On the other hand, the number of animals in the down-feeding programme is small. Even after these mitigating actions 10% of the production (216 tonnes) had to be interdicted.

Also in 1988 these mitigating actions were employed. About 6% of the production (126 tonnes) had to be interdicted in 1988.

Beef and horse meat

In some samples of beef and horse meat from the most affected areas one measured caesium content above the action level in 1986. These products were from animals that had been grazing in the mountain areas. Accordingly it was decided that animals that had been grazing in cultivated fields for a period of at least 4 weeks, or that had been fed indoors for at least 4 weeks, would be approved for slaughtering. This restriction was issued on 8 September 1986. In addition to the caesium-free fodder, cattle in the affected areas were fed concentrates containing bentonite, a clay mineral proven to be a caesium-binder in ruminants.

The approach in 1987 was somewhat different. Some areas were classified as “precautionary measures zones” or “special measures zones” respectively, while most parts of the country had no restrictions. In the precautionary measures zones the cattle were fed caesium-free fodder, to the extent this was possible, and in addition concentrates to which about 5% bentonite had been added. Compensation was not granted in these areas. Live cattle from these areas were measured at arrival to the slaughtering house, but were returned to the farm, if it was found that the content was above 600 Bq/kg. The mitigating actions in the special measure zones were the same, but a compensation was given of 8 kr per day and animal. Compensation equivalent to the value of the animal was given in addition to this, if downfeeding was not successful, and the animal had to be discarded. Cattle with levels of radiocaesium up to 3 000 Bq/kg were measured in 1987. The number of animals in the down-feeding programme is not known exactly, but is estimated at 45 000 for the whole country.

In 1988 the problems were of the same character as in 1987. Cattle with levels up to 6 000 Bq/kg were measured. The number of animals in the downfeeding programme in 1988 is assumed to be of the same order of magnitude as in 1987.

Ploughing and use of fertiliser

In 1987 the Division of Agriculture of the Ministry of Agriculture described how the activity levels in vegetation could be reduced by simple mitigating actions like e.g. additional ploughing and administration of fertiliser. These practices have probably been effective in reducing the activity levels in the animal feed from the home farm, leading to corresponding reduction in activity levels in the milk and meat from cattle. The available information on these aspects are, however, much too sparse to allow estimation of the resulting activity reduction, but there is reason to believe it is considerable, and that it will continue to be so for a number of years to come.

Dietary advice

In addition to the types of mitigating actions that are aimed at reducing the levels of radioactive materials in various foodstuffs, there are other types of mitigating actions that function by aiming at reducing the intake of specific foodstuffs. To population groups with a particularly large intake of reindeer meat, game and/or wild freshwater fish, dietary advice was given containing recommendations upon how frequently one could consume foodstuffs with activity levels above the action levels. In 1987 a survey of the changes in diet caused by the Chernobyl accident was carried out in the municipality of Sel in Norway, covering two population groups: one consisting of specially selected persons and one chosen at random. This municipality is in one of the areas of Norway where the fall-out level was high. The survey indicated that a reduction in annual intake per person of 30 000 Bq was attained the first year after the accident, compared to what the intake would have been if there had been no change in the diet. It appears that dietary advice has been the most cost-effective manner in which to reduce activity intake.

The cost of mitigating actions in Norway after Chernobyl

The Chernobyl accident created serious problems for various parts of Norwegian agriculture; in particular in connection with sheep, goats, reindeer and freshwater fish.

In this chapter is summarised the economic consequences of the deposited radioactive materials to Norwegian agriculture in the years 1986, 1987 and 1988, or more correctly in the slaughtering periods 86/87, 87/88 and 88/89.

The current action levels (through most of 1986 and until 1994) are 370 Bq/kg in milk and baby-food, and 600 Bq/kg for all other foodstuffs; except for meat from domestic reindeer, game and freshwater fish, where the level is 6 000 Bq/kg. (In 1994 the action levels for reindeer, game and freshwater fish were lowered to 3 000 Bq/kg).

The economic loss in the time soon after the Chernobyl accident was limited to lettuce from a specific area in mid-Norway, where this was grown outdoors, even though it was very early in the season. It was decided by the authorities that this lettuce should be destroyed. The value is reported to be roughly NOK 300 000 ($45 000) by the Ministry of Agriculture. The actual economic consequence may, however, have been considerably larger, as local farmers complained that it was difficult to sell any type of agricultural product from this area, at least in the early part of summer, because of general fear of radiation. There has been no condemnation of vegetables in 1987 or 1988.

Concerning cow's milk, cattle had not yet started feeding outdoors at the time of the accident. Later, when cattle were brought up to the mountain pastures, the caesium levels in milk increased, but exceeded the action level only in one limited geographical area, where the milk was interdicted. In 1987 and 1988 the levels were somewhat similar. Although downfeeding (feeding with caesium-free or -low fodder) had to be carried out in some areas, in some cases including administration of bentonite; cow's milk was not interdicted.

In goat's milk the caesium content increased from mid-June 1986, when the goats were brought to the mountain grazing areas, but the content rarely exceeded the action level. However, goat milk is mainly utilised in the production of a special and very popular type of brown cheese, in which the content will be much higher than in the milk. It was therefore decided to use goat milk from certain areas as fodder instead of in cheese production. The production of brown goat cheese has been affected even in 1987 and 1988 in the same manner as in 1986, but to a somewhat smaller extent, because of special measures taken.

Loss of production of goats cheese amounts to a value of NOK 10 million ($1.4 million) in 1986 (the value of the interdicted cows milk is included here), and NOK 7 million ($1 million) in 1987, after taking into consideration the savings because the goat's milk was used as animal fodder.

The levels in butter and ordinary cheese have been consistently low. Pork and poultry are primarily fed with grain products, and have accordingly also very low content of radioactive caesium.

Although the levels in salt-water fish have not been higher than normal, the levels in wild fresh water fish have in some cases been quite high, and levels up to 60 000 Bq/kg have been reported. Summer 1986 the Health Directorate decided to forbid sale of fresh-water fish from altogether 37 municipalities. The levels in spring 1987 had not decreased significantly compared to the levels measured in fall 1986, and actually rose to a peak in June 1987 (although lower than the peak in 1986). Fresh-water fish from the affected areas is not important commercially, and the economic consequence has not been estimated. No compensation has been offered to fresh-water fishermen.

Sheep has turned out to be one of the largest problems. Between two and three thousand tonnes of mutton was interdicted in 1986, representing a value of roughly NOK 100 million ($14 million). The down-feeding programme cost NOK 4/animal-day. The total cost of this mitigating action is estimated to NOK 30 to 35 million ($5 million), and involved ca. 3 000 animals. The sale of mutton turned out to be 10% below normal, which was equivalent to the amount that was interdicted. This indicates that the consumers generally felt that the protective measures adopted were adequate. In 1987 it was estimated that only about 8 000 animals were from the areas with content exceeding 5 000 Bq/kg, and only 73 tonnes of mutton was interdicted, representing a value of roughly NOK 2.5 million

($350 000). The down-feeding programme had the same basic cost as in the slaughtering season 86/87 (NOK 4/animal-day), but the compensation was NOK 8/animal-day if the animals had to be moved. Generally the animals were moved within the same district, and mostly they were moved from areas in the mountains to areas in the valleys. The total cost of the down-feeding programme was roughly NOK 40 million ($6 million), and involved ca. 280 000 sheep. In addition there were costs of control and surveillance (including instruments), and administration of the programme; estimated at NOK 13 million ($1.8 million). Because 1988 was an exceptionally good year for mushrooms, one observed levels of radioactive caesium three to four times the levels of the previous year in many parts of the country. Roughly 30% of the sheep were in special measures zones in 1988, and 70% in free zones. The down-feeding programme covered a total of ca. 360 000 sheep and cost NOK 60 million ($8.5 million) in 1988, and in addition there were costs of control and surveillance of the same order of magnitude as in 1987.

The value of interdicted reindeer meat (about 560 tonnes) in 1986 was roughly NOK 20 million ($2.9 million). This was after the authorities decided, in November 1986, to raise the action level on domestic reindeer meat from 600 Bq/kg to 6 000 Bq/kg. The cost of the whole programme related to control and surveillance of reindeer etc. was roughly an additional NOK 8 million ($1.1 million). The value of interdicted reindeer meat (216 tonnes) in 1987 was roughly NOK 8.5 million ($1.2 million), and the cost of the whole programme related to control and surveillance of reindeer was roughly an additional NOK 10 million ($1.4 million). This includes a special compensation given when early slaughtering is carried out, of NOK 5 and NOK 2 per kilo in addition to the regular price of the meat when slaughtering was carried out before October and 27 November respectively. In 1988 the value of the interdicted reindeer meat was roughly NOK 5 million ($0.7 million).

The cost of the mitigating actions to obtain content in beef below the action level was roughly NOK 5 million ($710 000) in 1986, but the costs in 1987 were insignificant. Levels up to 3 000 and 6 000 Bq/kg respectively were measured in these two years.

No compensations have been offered to game hunters or fresh-water fishermen, although claims have been sent to the Ministry of the Environment.

It is very difficult to estimate the total economic consequences of an accident like Chernobyl, e.g. concerning tourist trade or boycott of products from specific areas of high contamination (even if the content in the product is below the action levels). Most of the costs quoted in this annex are prices the producer would have obtained and direct costs of down-feeding programmes etc. The major portion of the costs of research activities, planning and administration of the programmes, and the measurement programmes in Norway are not included in the costs quoted.

Annex VI

THE MACRO-ECONOMIC IMPACTS OF A NUCLEAR ACCIDENT

In assessing the economic consequences of a nuclear accident, one should not merely consider direct costs. At the macro-economic level, impacts on employment, value added, government expenditures and receipts, tourism industry and balance of payments are interesting to measure. Methods based on the use of input-output Tables can be useful, since the input-output economic analysis is based on the transactions existing between all the economic sectors and thus offers, in principle, a good representation of the economic system of a region or a country. A second method of evaluation of induced effects is also proposed. Both of them only cover certain aspects of the economic consequences considered. Yet other effects exist, including positive effects, the expenses of certain people being revenues for others.

The input-output table

Before describing models and case studies, it is probably worthwhile to take a short look to the definition and structure of the input-output tables. The main equation in the I-O Table is the equilibrium between input (resources) and output (employment) for each economic branch i, so that it is possible to write:

$$\text{Production}_i + \text{VAT}_i + \text{Commercial margins}_i + \text{Imports}_i = \text{Total Intermediate Consumption}_i + \text{Final Consumption}_i + \text{Gross Formation of Fix Capital}_i + \text{Stock Variations}_i + \text{Exports}_i$$

Looking in the left side of the above equation, production means total production: Gross Value Added (GVA) at factors cost plus the intermediate consumption of the corresponding branch. There exists a direct relation between income and taxes (VAT) and GVA. Resources are normally considered as (production + imports - exports).

On the other side of the equation, Final Demand can be seen as the sum of Final Consumption, Gross Formation of Fix Capital (investments), Stock Variations and Exports.

In summary, the I-O Table is a good schematic representation of the structure of a given economic system. It is normally presented as shown in Table VI.1. Table VI.2 shows an example of a reduced input-output Table for Spain: the original 44 branches were lumped into 7.

In order to meet the demand, firms must produce a certain quantity of goods and services: not only those which will actually be meant for final consumption, but also those which enter into the intermediate consumption of the production process. The ratios between these intermediate consumption and the total Input of a given branch are known as technical coefficients, which are thus defined as:

$$a_{ij} = X_{ij} / I_j \qquad \text{(VI.1)}$$

Combining the technical coefficients of the input-output table, the following system of equations can be obtained:

$$\begin{aligned} a_{11}\cdot I_1 + a_{12}\cdot I_2 + \ldots + a_{1n}\cdot I_n + FD_1 &= O_1 \\ a_{21}\cdot I_1 + a_{22}\cdot I_2 + \ldots + a_{2n}\cdot I_n + FD_2 &= O_2 \\ a_{n1}\cdot I_n + a_{n2}\cdot I_n + \ldots + a_{nn}\cdot I_n + FD_n &= O_n \end{aligned} \tag{VI.2}$$

Since, for the same sector (i=j) the input is equal to the output ($I_i = O_j$), it results

$$\begin{aligned} (1-a_{11})\cdot I_1 - a_{12}\cdot I_2 - \ldots - a_{1n}\cdot I_n &= FD_1 \\ -a_{21}\cdot I_1 + (1-a_{22})\cdot I_2 - \ldots - a_{2n}\cdot I_n &= FD_2 \\ (-a_{n1})\cdot I_1 - a_{n2}\cdot I_2 - \ldots + (1-a_{nn})\cdot I_n &= FD_n \end{aligned} \tag{VI.3}$$

which can be expressed with matrices as shown in equation (VI.4).

$$\begin{Bmatrix} FD_1 \\ . \\ . \\ . \\ FD_n \end{Bmatrix} = \begin{Bmatrix} (1-a_{11}) & -a_{12} & . & . & -a_{1n} \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ -a_{n1} & . & . & . & (1-a_{nn}) \end{Bmatrix} \cdot \begin{Bmatrix} I_1 \\ . \\ . \\ . \\ I_n \end{Bmatrix} \tag{VI.4}$$

The expression above can be abbreviated as:

$$\{FD_j\} = \{I - A_{ij}\}\cdot\{I_j\} \tag{VI.5}$$

where: $\{FD_j\}$ is the array column of final demand,
I is the unit matrix,
A_{ij} is the technical coefficient and
I_j is the array column of total outputs (=inputs).

The matrix $\{I - A_j\}$ is usually known as Leontieff's matrix.

Table VI.1 **Structure of the input-output table**

	S_1	S_2	…	S_n	FD_i	O_i
S_1	X_{11}	X_{12}	…	X_{1n}	FD_1	O_1
S_2	X_{21}	X_{22}	…	X_{2n}	FD_2	O_2
…	…	…	X_{ij}	…	…	…
S_n	X_{n1}	X_{n2}	…	X_{nn}	FD_n	O_n
F_j	F_1	F_n	…	F_n		
I_j	I_1	I_2	…	I_n		

Where:

- S_i – Economic Sectors.
- Fd_i – Final demand of each sector: private and public consumption, investment, stock variations and exports.
- F_j – Payments to the productive factors of each sector: GVA at factors cost, indirect taxes, subsidies to companies and imports
- Oi – Output or total production of each sector.
- Ij – Input of each sector.
- Xij – The production sold by sector i to j (Intermediate Consumption).

The impact of countermeasures in production

Inverting Leontieff's matrix, the variations in Inputs could be expressed as a function of the variations in the final demand. That is, once known the final demand $\{FD_j\}$, the total productions can be obtained as:

$$\{I_j\} = \{I - A_{ij}\}^{-1} \cdot \{FD_j\} \tag{VI.6}$$

Which means that any modifications of the inputs will be a function of the increments of the final demand:

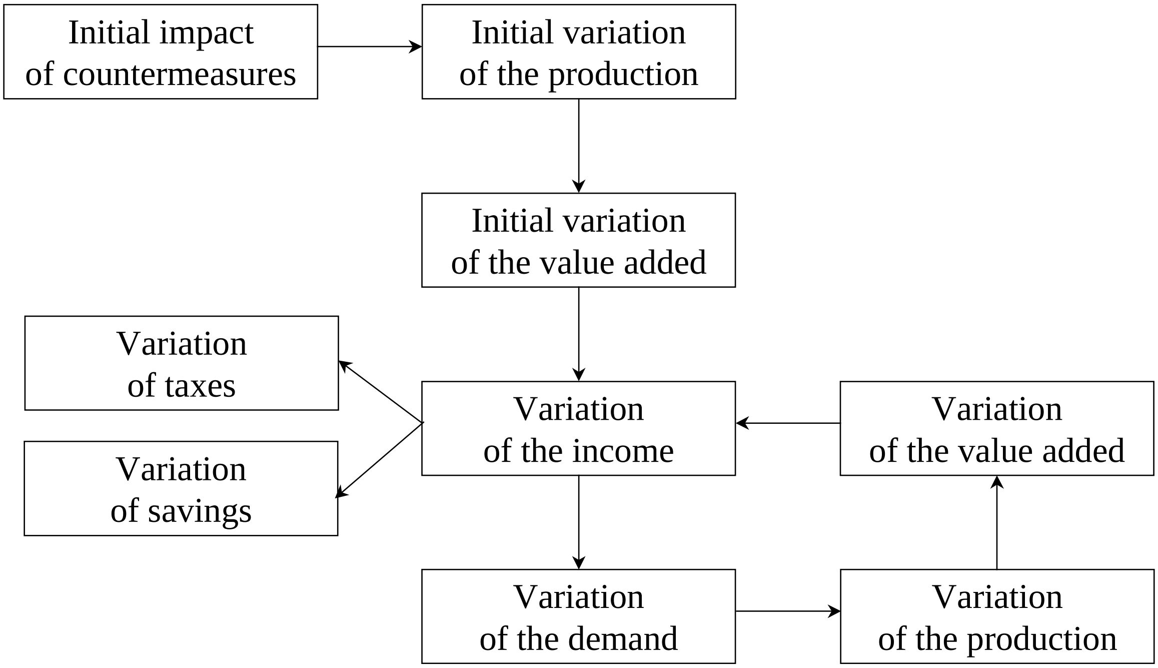
$$\{\Delta I_j\} = \{I - A_{ij}\}^{-1} \cdot \{\Delta FD_j\} \tag{VI.7}$$

Therefore, the model can be used to evaluate the impact on the total production of an economic system, in case of variations in their final demand, like in the case of countermeasures being implemented in a certain area. This kind of models are "demand models" (known as demand driven), which consider that variations in demand will influence the output level and the amount of productive factors employed.

Once estimated this loss of total Input, the corresponding loss of Value Added can be obtained from the ratio (Value Added / Total Input) existing for each branch.

After the initial impact it could be possible to consider a feedback, since the loss of input will be linked to a new loss of final consumption (demand) initiating an iterative process through the economic system (see Figure VI.1), which will reach an asymptotic value for the total loss of production.

Figure VI.1 **Effects induced in the economic system by an initial decrease in production (adapted from Assouline)**[77]



There are some examples of this kind of application of the input-output methods. Two of them were performed in France: Assouline[77] studied a scenario in the North of France-Pas de Calais (Gravelines), considering one month evacuation of an industrialised area. Only the losses in the affected area were considered, with resulting initial and induced losses of Value Added amounting:

Initial:	1 829	MFF	(1980)
Induced:	500	MFF	(1980)

More recently, Cour[17] analysed a scenario in the region of Champagne/Ardenne (Nogent-sur-Seine). A set of "realistic" countermeasures was defined after an accident analysis with the COSYMA code, with the result of some areas being relocated for up to 1 year (66 000 persons) and 10 years (1 091 persons). Only the losses in the affected area were considered, with resulting total initial and induced losses of Value Added for the first two years:

Initial:	7 424	MFF	(1989)
Induced:	4 900	MFF	(1989)

The analysis included more detailed distributions of the effect by economic branches.

The mentioned case studies give some hint to value the importance that the induced effects can have on the global economic impact of an accident (almost 30% of the initial impact for the first study and 66% for the second). It is also clearly seen that such induced effects are undoubtedly dependent on the characteristics of the site being studied.

The impact in the surrounding regions

After the descriptions made in Chapter 3 of this report about the cost elements associated with the different countermeasures, it is reasonable to think that countermeasures implemented in a given area will affect directly the demand of that area, but also that of the surrounding regions.

Countermeasures like evacuation or relocation, meaning a stop in the economic activity, will imply a loss of the final demand of the affected areas. For the surrounding regions, a loss will come from the loss-of-demand normally going to the relocation area (no exports can be made during the relocation period to the affected area). But also positive effects can be estimated from the consideration that private consumption of the relocated population is transferred to the non-relocation areas, thus originating an increase in their final demand, and an input increase at the end.

Other countermeasures, like crop banning, will only affect the agricultural branch, and also the economic branches using agricultural products as raw material. Decontamination activities, that may be for instance needing use of additives for soils, or replacement of some surfaces, could have a positive effect in the industrial branches producing these materials needed.

However, to develop a model for such effects, a certain number of difficulties arise, that have been summarised in Table VI.3. The Table also shows some of the assumptions that the user of these models can be forced to make.

Some studies of this kind have been performed in Spain, as part of the development of the MECA code (described in Chapter 4 of this report). The first type of studies were deterministic, with two scenarios defined from consequence analyses made with COSYMA for two sites: one mainly agricultural (Zorita, scenario A) and the second more industrial and touristic (Vandellós, scenario B).[76] These studies were based on detailed statistical information about the affected provinces. The studies only considered losses in the affected and non-affected areas, with no attention being paid to induced effects or positive impacts. The results are summarised in Table VI.4. The different economic structure of each site is clearly reflected in the results. Also interesting is to note that the impact on the non-affected areas (defined in this study as the non-affected part of the provinces in which countermeasures are implemented) is well below that of the regions affected by the countermeasures.

Table VI.3 **Difficulties for a model of the impact of countermeasures based on the input-output table**

Difficulties	Assumptions Needed
There are no I-O Tables at regional or local level.	• Scaling of Final Demand and Input according to ratio of regional/local GVA to national GVA • Technical Coefficients constant (same technology all across the country)
There are no I-O Tables for the areas affected and non-affected by the countermeasures.	• Scaling of Final Demand and Input according to ratio of area GVA / region GVA
The duration of countermeasures is different in different areas.	• Construction of as many I-O Tables as time periods for the affected areas in each. • The structure of the economy is unaltered after implementation of countermeasures. • Economic impacts must be discounted in each time period.

Table VI.4 **Summary of the results of two scenarios analysed in Spain**[76]

	Scenario A Losses in millions pesetas (1988)		**Scenario B** Losses in millions pesetas (1987)	
Affected Area:	Total production (Input) losses: 24 358	Agriculture: 11 084	Total production (Input) losses: 16 740	Agriculture: 2 995
		Industry: 5 213		Industry: 7 522
Non-Affected Area:	Total production (Input) losses: 6 818	Agriculture: 5 558	Total production (Input) losses: 6 404	Agriculture: 1 754
		Industry: 1 036		Industry: 3 783

More ambitious is the implementation of input-output models in the MECA code, aiming to cover full probabilistic assessments of the economic impact of population movements, both in the affected and in the non-affected zones; in this last case also considering positive effects. The basic results of the test cases[78] of this new models, linked as a post-processor module to the COSYMA code, are presented in Table VI.5. For the Vandellós scenarios, since an I-O table is available for Catalonia, it was used as a test to compare with the results using the national I-O table of Spain. As it appears in the table, no significant effects were observed, thus indicating that, probably, for many sites within a given country, the non-availability of specific I-O tables is not a serious limitation for the kind of exercise that a probabilistic consequence assessment represents.

Table VI.5 **Mean economic impact in the areas affected and non-affected by the countermeasures for three scenarios analysed with the system COSYMA-MECA**[78]

Zorita scenario A

Economic Impact (MPTA, 1989)	**Total**
Areas directly affected	$8.30\ 10^{2}$
Areas non-affected, Loss of Input	$1.48\ 10^{2}$
Areas non-affected, Increase of Input	$4.78\ 10^{2}$

Vandellós scenario B

Economic Impact (MPTA, 1989)	**Total (Spain I-O Table)**	**Total (Catalonia I-O Table)**
Areas directly affected	$2.44\ 10^{2}$	$2.91\ 10^{2}$
Areas non-affected, Loss of Input	$6.66\ 10^{1}$	$7.15\ 10^{1}$
Areas non-affected, Increase of Input	$1.14\ 10^{2}$	$1.27\ 10^{2}$

Vandellós scenario C

Economic Impact (MPTA, 1989)	**Total (Spain I-O Table)**	**Total (Catalonia I-O Table)**
Areas directly affected	$9.81\ 10^{4}$	$1.19\ 10^{5}$
Areas non-affected, Loss of Input	$8.86\ 10^{3}$	$9.02\ 10^{3}$
Areas non-affected, Increase of Input	$5.15\ 10^{4}$	$5.73\ 10^{4}$

Through the use of this method, an interesting observation is that positive effects in the areas not directly impacted by the countermeasures should be considered as well as effects in the affected regions. However, it is also recognised that for some scenarios these can be only partially considered, given the limited capacity to model ex-ante some effects like the aforementioned on tourism or on food marketing.

Some conclusions on the use of input-output methods

After the description presented in the former paragraphs, both on the models and cases studied, some conclusions can be extracted. The first one is that input-output modelling is only useful for countermeasures directly affecting the economic system, like population movements, agricultural countermeasures, and, maybe not without large uncertainties, decontamination.

Several difficulties are found to make a rigorous application of I-O models to accident scenarios. The most important can be the unavailability of Regional or local I-O Tables; the time effects associated with long-duration countermeasures and, probably introducing a larger uncertainty, the variations in the economic structure that can be caused by a large accident.

However, it is the feeling of the Expert group, that reasonable estimates of the economic impact can be obtained using the existing models, probably in the same range of uncertainty than for other steps of Consequence Assessment.

Some hints for an alternative method: the economical accessibility

An alternative method to the input-output described above is briefly presented here. The approach of economical accessibility was first introduced by J. Poulit in 1973 and further developed in 1993.[79] Its original aim was to allow the interpretation of certain economical disturbances. But its application to studies related to nuclear accident consequences might be promising.

The method is based on the statistical study of the behaviour of an individual in an urban environment. Living at location I, he makes some displacements to locations J. The probability that he moves to J depends on the interest of the destination (in terms of services offered or job opportunities) and on distance. This interpretation has been generalised to the explanation of value added per capita of an agglomeration in function of its size. Indeed, population is determinant for the extent of the employment network. Access to an extended market of working population is a source of productivity for the employer; access to an extended job market is a source of productivity for the worker.

This approach leads to an empirical expression of value added per working person in an urban area, R, as a function of its population, P. The expression can be used to obtain the following results, where R_o is an empirically obtained reference value added per working person.

- 1.69 R_0 for a 100 000 people agglomeration.
- 2 R_0 for a 1 000 000 people agglomeration.
- R_0 for a 10 million agglomeration.

Thus, population growth in the agglomeration has a double effect: an increase in value added per capita and an increase in the value added of the whole area. The total increase in value added is measured by R(P) * P.

Conversely, it is possible to assess the effects of an evacuation (i.e. fall in P) on the value added of a geographical area. The evacuated area represents a hole in the network of possible displacements.

This method could be used to obtain an estimation of the consequences of economical disturbances in a given area (the damaged zone) on the surroundings. In particular, it can be used to assess the loss due to a prolonged interdiction of access to the evacuated area. Indeed, if production recovers after two years, the I-O method will show no economic loss after this period. By contrast, the method of economical accessibility will account for the longer-run loss due to the disturbance in the economic interactions that existed prior to the accident.

Accounting for positive effects?

One could recall the saying "Nothing but a good war to boost growth". Catastrophes can indeed revitalise the economy. Thus, a more comprehensive study should also take into account some positive effects, such as growth in demand and employment in the building industry and civil engineering, in chemical industries involved in the decontamination operations, etc. According to Haywood and al.,[11] positive effects should be of limited range. But their conclusions rely on the hypothesis of a pre-accidental economy in full use of its capacity. Hence, any effort invested in the recovery of the situation prior to the accident is merely a misappropriation of resources. As such, it does not create any benefit.

This hypothesis is more than disputable. If a certain flexibility of the economy is assumed (this is implied by an under-use of the capacities in the pre-accidental economy), positive effects should then be considered. Costs due to the accident are not losses. The production loss of the region will be partly balanced by an increase in the production of neighbour regions. Yet, costs studied in Chapter 3 must still be considered, because they give a useful information to planning authorities in post-accidental situation, as well as a basis for the assessment of compensatory payments. Positive effects could be expressed by rises in demand for the relevant products, using the I-O method.

Table VI.2 **Reduced input-output table of Spain** (in millions of Pesetas) (1988)

	Agriculture	**Energy**	**Industry**	**Construction**	**Commerce**
Agriculture	625 746	1	2 410 556	1 092	187 627
Energy	218 973	1 066 328	836 269	104 725	360 691
Industry	921 491	108 911	7 800 933	1 603 158	1 407 927
Construction	6 351	22 604	65 212	0	221 271
Commerce	75 813	47 463	622 000	207 650	370 866
Commercial Services	196 105	153 346	1 740 191	571 781	912 666
Non-commercial Services	0	0	0	0	0
GVA at factor cost	1 917 993	2 230 434	8 912 307	31 037 87	7 425 466
Imports	381 145	850 532	5 869 667	0	80 520
Taxes	28 064	215 037	1 304 947	211 767	573 100
Productive Factors	2 327 202	3 296 003	16 086 921	3 315 554	8 079 086
Total Input	4 371 681	4 694 656	29 562 082	5 803 960	11 540 134

Source: Hidalgo *et al*., 1995 (Original I-O table from Instituto Nacional Estadistica of Spain, 1993).

Table VI.2 **Reduced input-output table of Spain** (in millions of Pesetas) (1988)

Commercial Services	**Non-commercial Services**	**Consumption**	**Capital formation**	**Exports**	**Final Demand**	**Total Output**
9 242	15 659	666 876	49 287	405 595	1 121 758	4 371 681
482 089	168 474	1 288 528	-55 840	224 419	1 457 107	4 694 656
1 120 205	735 680	8 129 219	3 880 708	3 853 850	15 863 777	29 562 082
576 819	84 221	75 931	4 751 551	0	4 827 482	5 803 960
293 091	95 158	9 426 388	173 371	228 334	9 828 093	11 540 134
4 610 591	726 242	6 801 096	703 312	889 648	8 394 056	17 304 978
0	0	6 375 455	0	0	6 375 455	6 375 455
9 393 682	4 550 021					
527 125	0					
292 134	0					
10 212 941	4 550 021					
17 304 978	6 375 455					

Source: Hidalgo *et al*., 1995 (Original I-O Table from Instituto Nacional Estadistica of Spain, 1993).

Annex VII

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REFERENCES

[1] OECD/NEA (Nuclear Energy Agency), (1999), *INEX 2 – Second International Nuclear Emergency Exercise: Final Report of the Swiss Regional Exercise*, Paris, France.

[2] OECD/NEA (Nuclear Energy Agency), (1994), *Probabilistic Accident Consequence Assessment Codes. Second International Comparison. Overview Report*, Paris, France.

[3] Commission of the European Communities, (1994), *International Comparison Exercise on Probabilistic Accident Consequence Assessment Codes*, Technical Report, Report EUR 15109.

[4] CRICK, M.J., Hofer, E., Jones, J.A, Haywood, S.M., (1988), *Uncertainty analysis of the foodchain and atmospheric dispersion modules of MARC*, NRPB-R184.

[5] TVETEN, U., (Editor) (1990), *Environmental Consequences of Releases from Nuclear Accidents. A Nordic Perspective*, Nordic Liaison Committee for Atomic Energy.

[6] International Commission on Radiological Protection (ICRP), (1993), *Principles for Intervention for Protection of the Public in a Radiological Accident*, ICRP Publication 63, Annals of the ICRP, Vol. 21, No. 4, Pergamon Press.

[7] International Atomic Energy Agency, (1993), *Intervention Criteria in a Nuclear or Radiation Emergency*, Safety Series No. 109, pre-publication draft version 2.0, Vienna, Austria.

[8] OECD/NEA (Nuclear Energy Agency), (1995), *Chernobyl: Ten Years on Radiological and Health Impact*, Paris, France.

[9] ROMANOV, G.N., Buldakov, L.A., Shvedov, V.L. (1990), *Comparative Analysis of the Effectiveness of Measures to Protect the Public from Radiation Following the Kyshtym Accident*, in Proceedings of a CEC Seminar held in Luxembourg on 1-5 October 1990 on Comparative Assessment of the Environmental Impact of Radionuclides Released during Three Major Nuclear Accidents: Kysthym, Windscale, Chernobyl.

[10] BELYAYEV, S.T., Demin, V.F. and Zakharchenko, I.E., (1992), *The Chernobyl Accident: Consequences and Countermeasures*, in Proceedings of an International Seminar on Intervention Levels and Countermeasures for Nuclear Accidents, Cadarache, France, 7-11 October 1991, Report EUR 14469, Commission of the European Communities.

[11] HAYWOOD, S.M., Robinson, C.A., Heady, C., (1991), *COCO-1: Model for Assessing the Cost of Offsite Consequences of Accidental Release of Radioactivity*, Report NRPB-R243, National Radiological Protection Board.

[12] ARAPIS, G., Millán, R., Iranzo, E., (1990), *Comparison of the Countermeasures Taken for the Recovery of Rural Areas Contaminated by Radioactivity*, in Proceedings of a Seminar on Comparative Assessment of the Environmental Impact of Radionuclides Released during Three

Major Nuclear Accidents: Kysthym, Windscale, Chernobyl, Luxembourg, 1-5 October 1990, Report EUR 13574, Commission of the European Communities.

[13] TAWILL, J.J., Bold, F.C., Harrer, B.J., and Currie, J.W., (1985), *Off-site Consequences of Radiological Accidents: Methods, Costs and Schedules for Decontamination*, Report NUREG/CR-3413 (PNL-4790), Pacific Northwest Laboratory.

[14] International Atomic Energy Agency (IAEA), (1989), *Cleanup of Large Areas Contaminated as a Result of a Nuclear Accident,* Technical Report Series No. 300, IAEA, Vienna, Austria.

[15] BROWN, J., Haywood, S.M. and Roed, J., (1992), *The Effectiveness and Cost of Decontamination in Urban Areas*, in Proceedings of an International Seminar on Intervention Levels and Countermeasures for Nuclear Accidents, Cadarache, France, 7-11 October 1991, Report EUR 14469, Commission of the European Communities.

[16] NIEVES, L.A., Currie J.W., Hood L.J. and Tierney Jr. T.M., (1983), *Estimating the Economic Costs of Radiation-induced Health Effects,* Report PNL-4664, Pacific Northwest Laboratory.

[17] COUR, Ph., (1994), *Conséquences macroéconomiques d'un accident nucléaire*, CEPN.

[18] BEHLING, U.H., Behling, K., (1994), *The Economic Costs and Benefits of Potassium Iodide Prophylaxis for a Reference LWR Facility in the United States*, Proceedings from an NEA Workshop held in Stockholm (Sweden), 1-3 June 1994 on the Implementation of Short-Term Countermeasures after a Nuclear Accident.

[19] MOHSENI, A, McKenna, T., (1994), *Effectiveness and risks associated with sheltering and evacuation*, Proceedings from an NEA Workshop held in Stockholm, Sweden, 1-3 June 1994 on the Implementation of Short-Term Countermeasures after a Nuclear Accident.

[20] LAKEY, J.R.A., Ed. (1992), *Off-site Emergency Response to Nuclear Accidents*, Textbook based on training course organised at SCK/CEN, Mol, Belgium in 1991 and 1992, a joint project of the SCK•CEN and the Commission of the European Communities, Brussels, Belgium.

[21] International Commission on Radiological Protection, (1991), *1990 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 60, Annals of the ICRP, 21 (1-3), Pergamon Press.

[22] Commission of the European Communities, (1997), *Radiation Protection Principles for Urgent Countermeasures to Protect the Public in the Event of Accidental Releases of Radioactive Material*, Radiation Protection – 87.

[23] LOCHARD, J., Schneider, T., (1992), *Countermeasures to be taken after 1990 to Ensure Safe Living Conditions for the Population Affected by the Chernobyl Accident in the USSR*, in International Chernobyl Project – Input from the Commission of the European Communities to the Ivaluation of the Relocation Policy adopted by the Former Soviet Union, EUR Report 14543.

[24] Commission of the European Communities, (1993), *Radiation Protection Principles for Relocation and Return of People in the Event of Accidental Releases of Radioactive Material*, Radiation Protection – 64, Doc. XI-027/93.

[25] International Atomic Energy Agency, (1996), *International Basic Safety Standards for Protection against Ionising Radiation and for the Safety of Radiation Sources*, Jointly sponsored by FAO, IAEA, ILO, OECD/NEA, PAHO, WHO, Vienna, Austria.

[26] HEDEMANN JENSEN, P., (1997), *Application of Basic Principles for Later Interventions: Relocation and Foodstuff Restrictions*, Seventh Training Course on Off-Site Emergency Planning and Response to Nuclear Accidents, ERPET, SCK•CEN, 23-27 June 1997, Mol, Belgium.

[27] KULA, E., (1992), *Economics of the Natural Resources and the Environment*, London, New York, Tokyo, Melbourne, Madras: Chapman & Hall.

[28] MARSHALL, A., (1890), *Principles of Economics*, MacMillan, London, United Kingdom.

[29] PIGOU, A.C., (1920), *The Economics of Welfare*, MacMillan, London, United Kingdom.

[30] KAPP, K.W., (1950), *The Social Costs of Private Enterprise*, Cambridge: Cambridge University Press.

[31] OECD, (1975), *The Polluter Pays Principle*, Paris, France.

[32] OECD/NEA (Nuclear Energy Agency), (1992), *Broad Economic Impacts of Nuclear Power*, Paris, France.

[33] OECD/NEA (Nuclear Energy Agency), (1994), *Proceedings of the International Symposium on Power Generation Choices: Cost, Risks and Externalities*, Paris, France.

[34] Commission of the European Communities, (1995), *Externe, Externalities of Energy*, vol. 5, Nuclear EUR 16524 EN.

[35] Oak Ridge National Laboratory (ORNL), (1993), *Damages and Benefits of the Nuclear Fuel Cycle: Estimation Methods, Impacts and Values*.

[36] Komanoff Energy Associates, (1986), *Costs of the Three Mile Island Accident*, in Le vrai coût d'un accident nucléaire, Science et Vie, No. 829, pp. 36-39.

[37] Nucleonics Week, (1994), *Outlook on International Nuclear Liability*, Special report to the Readers of Nucleonics Week; Inside N.R.C., and Nuclear Fuel, Nucleonics Week, 29 September 1994, Inside N.R.C., 3 October 1994, Nuclear Fuel, 10 October 1994.

[38] SÖRENSEN, B., (1994), *Impacts of Major Nuclear Accidents*, Private Communication to N. Eyre, M. Dreicer and A. Rabi.

[39] HIRSCHBERG, S., (1995), *External Costs of Electric Power Generation: Are Accidents Adequately Treated?*, Schweizer Ingenieur und Architekt, No. 20, pp. 469-473.

[40] KRUPNICK, A. J., Markandya, A. and Nickell, E., (1993), *The External Costs of Nuclear Power: Ex Ante Damages and Lay Risks*, American Journal of Agricultural Economics, 75, pp. 1273-1279.

[41] MASUHR, K.P. and Oczipka, T., (1994), *Die externen Kosten der Stromerzeugung aus Kernenergie*, Materialen zu PACEr, Bericht 724.270.2d, Bundesamt für Konjunkturfragen, Bern, Schweiz.

[42] EHRHARDT, J., Päsler-Sauer, J., Schüle, O., Benz, G., Rafat, Richter, M., (1993), *Development of RODOS, a Comprehensive Decision Support System for Nuclear Emergencies in Europe: an Overview*, Radiation Protection Dosimetry, Vol. 50, pp. 2-4.

[43] HIRSCHBERG, S. and Cazzoli, E., (1994), *Contribution of Severe Accidents to External Costs of Nuclear Power*, ENS Topical Meeting on PSA/PRA and Severe Accidents, (Ljubljana, 17-20 April, 1994).

[44] U.S. Atomic Energy Commission (USAEC), (1957), *Theoretical Consequences of Major Accidents in Large Nuclear Power Plants*, Report WASH-740, Washington D.C., USA.

[45] United States Nuclear Regulatory Commission (U.S. NRC), (1975), *Reactor Safety Study. Appendix VI*, U.S. NRC Report WASH-1400 (NUREG-75/014).

[46] STRIP, D.R., (1982), *Estimates of the Financial Consequences of Nuclear Power Reactor Accidents*, U.S. NRC Report NUREG/CR-2723, Washington D.C., USA.

[47] BURKE, R.P., Aldrich, D.C., Rasmussen, N.C., (1984), *Economic Risks of Nuclear Power Reactor Accidents*, U.S. NRC Report NUREG/CR-3673 (SAND84-0178), Sandia National Laboratories.

[48] MIETTINEN et al., (1976), *Risk-benefit Evaluation of Nuclear Power Plant Siting*, Annals of Nuclear Energy, Vol. 3, pp 489-500.

[49] EHRHARDT, J., Burkhart K., Hasemann I., Matzerath C., Panitz, H-J., and Steinhauer, C., (1988), *The Program System UFOMOD for Assessing the Consequences of Nuclear Accidents*, Report KfK 4330, Kernforschungszentrum Karlsruhe.

[50] JOW, H-N., Sprung, J.L., Rollstin, J.A., Ritchie, L.T., Chanin D.I, (1990), *MELCOR Accident Consequence Code System (MACCS). Model Description*, U.S. NRC Report NUREG/CR-4691, (SAND86-1562), Vol. 2., Sandia National Laboratories.

[51] EHRHARDT, J., and Jones, J.A, (1991), *An Outline of COSYMA, a New Program for Accident Consequence Assessments*, Nuc. Tech., Vol. 94, No 2, p. 196.

[52] SRD, NE and NRPB (1993), *CONDOR 1: A Probabilistic Consequence Assessment Code Applicable to Releases of Radionuclides to the Atmosphere*, Report SRD R598, TD/ETB/REP/7021, NRPB-R258.

[53] HASEMANN, I. and Jones, J.A, (1993), *COSYMA: User Guide*, CEC Report EUR 13045, Brussels, Belgium.

[54] GALLEGO, E., (1995), *MECA3. Model for Economic Consequence Assessment, Version 3. Reference Guide*, Report CTN-50/95, Cátedra de Tecnología Nuclear, UPM.

[55] FAUDE, D., (1992), *COSYMA. Modelling of Economic Consequences*, Report KfK 4336, Kernforschungszentrum Karlsruhe.

[56] CARTWRIGHT, J.V., Beemiller, R.M. and Gustly, R.D, (1981), *Regional Input Output Modelling System (RIMS-II); Estimation, Evaluation and Application of a Disaggregated Regional Impact Model*, Department of Commerce, Washington, USA.

[57] CLARK, M.J., and Dionian, J., (1982), *ECONO-MARC: A Method for Assessing the Cost of Emergency Countermeasures after an Accident*, NRPB-M85, National Radiological Protection Board.

[58] United States Nuclear Regulatory Commission, (1990), *Severe Accident Risks: An Assessment for Five U.S. Nuclear Plants*, Final Summary Report, Report NUREG-1150, Washington D.C., USA.

[59] LONERGAN, S.C., Goble R.L. and Cororaton, C., (1990), *Estimating the Financial Consequences of a Severe Nuclear Accident in Canada*, Energy, Vol. 15, No. 6, pp. 507-522.

[60] OECD/NEA (Nuclear Energy Agency), (1984), *International Comparison Study on Reactor Accident Consequence Modelling*, Paris, France.

[61] HOHMEYER, O., (1988), *Social Costs of Energy Consumption: External Effects of Electricity Generation in the Federal republic of Germany*, New York, Springer-Verlag.

[62] HOHMEYER, O., (1990), *Latest Results of the International Discussion on the Social Costs of Energy – How Does Wind Compare Today?*, The European Commission's Wind Energy Conference, September 1990, Madrid, Spain.

[63] OTTINGER, R.L., Wooley D.R., Robinson N.A., Hodas D.R., Babb S.E., (1990), *Environmental Costs of Electricity*, Pace University Center for Environmental Legal Studies, Oceana Publications Inc.

[64] EWERS, H.-J. and Rennings K., (1992), *Abschätzung der Schäden durch einen sogenannten "Super-GAU"*, in Prognos-Schriftenreihe Identifizierung und Internalisierung externer Kosten der Energieversorgung, Band 2, Prognos, Basel, Schweiz.

[65] FRIEDRICH, R. and Voss A., (1993), *External Costs of Electricity Generation*, *Energy Policy*, 21 (1993), pp. 114-122.

[66] ERG, (1993), *Calculation of Environmental Externalities for Ontario Hydro's Nuclear Power Plants*, Energy Research Group Inc., Waltham, MA, USA.

[67] OTT, W. et al., (1994) *Externe Kosten und kalkulatorische Energiepreiszuschläge für den Strom und Wärmebereich*, Bericht 724.270 D, Bundesamt für Konjunkturfragen, Bern, Schweiz.

[68] HSK, (1991) *Gutachten zum Gesuch um unbefristete Betriebsbewilligung und Leistungserhöhung für das Kernkraftwerk Mühleberg*, Bericht HSK 11/250 (KSA 11/150), Hauptabteilung für die Sicherheit der Kernanlagen, Würenlingen, Schweiz.

[69] DREICER, M., Tort, V., Manen, P., (1995), *ExternE: Externalities of Energy*, Volume 5: Nuclear, EC Report, EUR 16524 EN

[70] FISCHER, S.E. and Williams, K.A., (1994), *Social Costing Approach for Nuclear Power Plant Accidents*, Proceedings of ANS Winter Meeting, 13-17 November 1994, Washington DC, U.S.A.

[71] United States Nuclear Regulatory Commission, (1990), *Evaluation of Severe Accident Risks: Peach Bottom: Unit 2*, Report NUREG/CR4551, Appendices, Vol. 4, Rev. 1, Part 2, Washington D.C., USA

[72] United States Nuclear Regulatory Commission, (1993), *Evaluation of Severe Accident Risks: Zion, Unit 1*, Report NUREG/CR-4551, Vol. 7, Rev. 1, Part 2B, U.S. Nuclear Regulatory Commission, Washington, D.C., USA.

[73] WHEELER, G. and Hewison R.C., (1994), *The External Costs of Accidents at a UK PWR*, Report IS3538-2, Version 2.0, Intera Information technologies, Oxfordshire, United Kingdom.

[74] CAZZOLI, E., Khatib-Rahbar M., Schmocker U., and Isaak H.P., (1993), *Approach to Quantification of Uncertainties in Probalistic Safety Assessment*, Proceedings of the European Safety and Reliability Conference, 10-12 May 1993, Munich, Germany.

[75] FARMER, R., (1990), *An Appreciation of the Sante Fe Workshop Contribution to the Question of Cut Off Criteria for Low Probability Sequences (and Numbers),* in Final Report to CSNI, Note on the Outcome of a Workshop on “Applications and Limitations of Probalistic Safety Assessment”, 4-6 September 1990, Santa Fe, New Mexico, U.S.A.

[76] HIDALGO, A., Gallego, E., Muñoz, A., Pavón, J., (1995), *Evaluación del impacto económico externo de los accidentes nucleares*, Report CTN-88/94 (Rev.1), Cátedra de Tecnología Nuclear, UPM.

[77] ASSOULINE, M., (1984), *Evaluation des conséquences socio-économiques d’une évacuation de population en cas d’accident grave d’origine industrielle*, CEA-IPSN, Rapport DPS 84/06 SEAPS, Département de la Protection Sanitaire.

[78] GALLEGO, E., (1997), *Contribution of UPM to the final report of the CEC MARIA-4 Project*, in Radiation Protection Research Action. Final Report. pp 4319 - 4328, Report EUR 16 769, Vol. 3, Brussels, Belgium.

[79] POULIT, J., (1993), *Approche économique de l’accessibilité, 1973; Cercle de réflexion: infrastructure et aménagement*, Documents des Ponts et Chaussées.

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