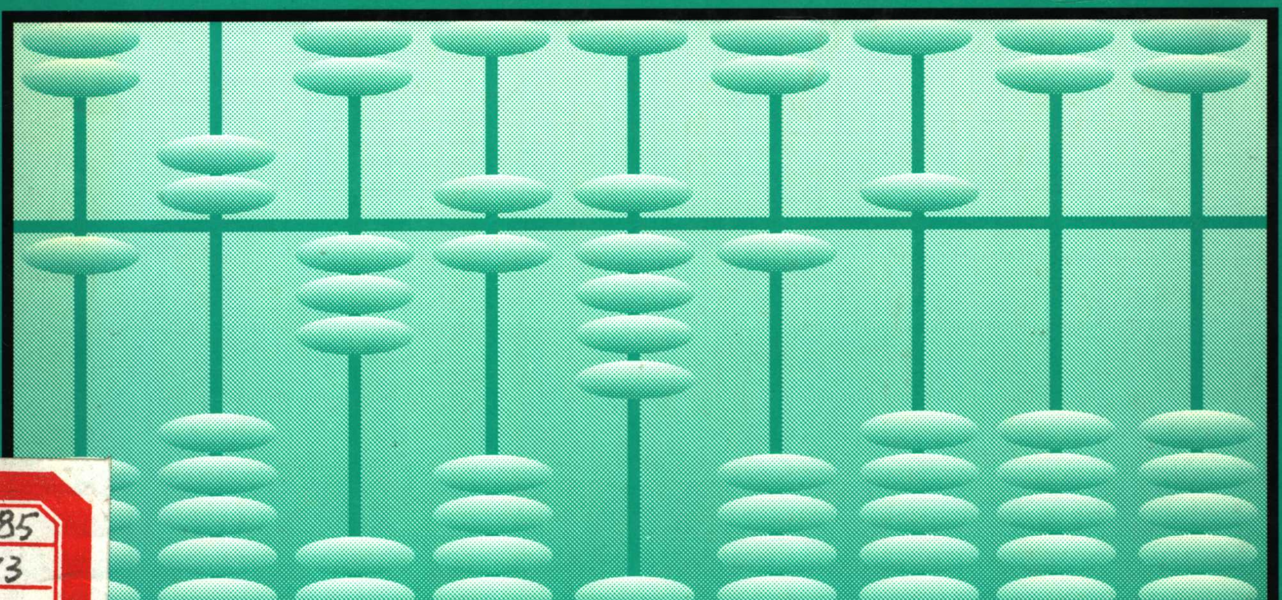
RADIATION PROTECTION

Probabilistic Accident Consequence Assessment Codes

Second International Comparison

Overview Report



Report by the OECD Nuclear Energy Agency and the Commission of the European Communities

OECD
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PROBABILISTIC ACCIDENT CONSEQUENCE ASSESSMENT CODES

SECOND INTERNATIONAL COMPARISON

OVERVIEW REPORT

A joint Report by the OECD Nuclear Energy Agency
and the Commission of the European Communities

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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— to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

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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 all European Member countries of OECD as well as Australia, Canada, Japan, Republic of Korea and the United States. The Commission of the European Communities takes part in the work of the Agency.

The primary objective of NEA is to promote co-operation among the governments of its participating countries in furthering the development of nuclear power as a safe, environmentally acceptable and economic energy source.

This is achieved by:

— *encouraging harmonization of national regulatory policies and practices, with particular reference to the safety of nuclear installations, protection of man against ionising radiation and preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;*
— *assessing the contribution of nuclear power to the overall energy supply by keeping under review the technical and economic aspects of nuclear power growth and forecasting demand and supply for the different phases of the nuclear fuel cycle;*
— *developing exchanges of scientific and technical information particularly through participation in common services;*
— *setting up international research and development programmes and joint undertakings.*

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

Publié en français sous le titre :
PROGRAMMES D'ÉVALUATION BROBABILISTE DES CONSÉQUENCES D'ACCIDENTS

FOREWORD

Increasing use is being made internationally of quantitative risk assessment as an input to the evaluation and improvement of safety, both for nuclear and other types of installation. The nature and extent of the risk assessment performed may vary considerably according to its intended purpose. At one extreme, it may be limited to quantifying the probability with which major damage may occur to an installation; at the other extreme, a comprehensive assessment may be made of the health and environmental risks presented by an installation. Assessments of the latter sort are more common in those countries which have developed quantitative guidance or targets for nuclear and/or other installations that are expressed in terms of risk to health.

With the increasing use of quantitative risk assessment in the evaluation of safety, greater attention has been given to, and demands placed on, the reliability of the methods used and the inherent uncertainty associated with their predictions. In this context, the Commission of the European Communities (CEC) and the OECD Nuclear Energy Agency (NEA) initiated in 1991 a study to compare the predictions of probabilistic consequence assessment (PCA) codes. These codes are used in level 3 probabilistic safety analyses (PSA) and are concerned with the estimation of the health and environmental risks from postulated accidents at nuclear installations. The initiation of this comparison was particularly opportune in that a number of new PCA codes had been developed in the late 1980s and early 1990s. A comparison of PCA codes developed in the late 1970s was undertaken previously under the auspices of the NEA [3]; given the state of development of PCA codes at that time this earlier comparison was somewhat simpler and less comprehensive than the present study.

The results of the study have been compiled in four reports: firstly, this overview report which is intended for those not specialist in PCA but who may use the results from such assessments as an input to their decisions on safety; secondly, a detailed technical report [6] which is intended for specialists in PCA and which contains the detailed results of the comparison; and, thirdly, two reports [4,5], intended for PCA code users and specialists, which contain the results of comparisons between multiple users of the same code. These last two studies, while strictly not comparisons between codes, were particularly important given the wide distribution of some PCA codes and extensive use being made of them by many organisations.

The results contained in this report, and in the three more detailed reports on which it is based, need to be qualified in several respects. Firstly, in order to facilitate the comparison and ensure, in so far as was practicable, that like was being compared with like, many simplifications and assumptions were made in specification of the calculations to be performed. **Consequently, the values of the particular consequences predicted by the codes have no absolute significance; their significance is strictly limited to that of comparison**. Secondly, the characteristics of the accidental releases postulated for this exercise were chosen to provide a comprehensive and demanding test of PCA code features without any consideration given to the likelihood with which such releases may occur; **it must be recognised, however, that releases of the magnitude postulated have exceedingly low probabilities of occurrence in well designed and operated reactors**. Thirdly, differences are to be expected in the predictions of the respective codes (indeed their absence would be alarming) given their varying complexity and purposes for which they were developed; the spread between the predictions of the codes must not, however, be misinterpreted as an indication of the inherent uncertainty associated with any of their predictions. The latter is a matter requiring separate evaluation. Fourthly, PCA codes have been developed largely to assess the risk from postulated accidents; **they are not an appropriate tool for assessing the health and environmental impacts in "real-time" following an actual accident**.

This comparison has made an important contribution to enhancing the quality assurance of the various participating codes and has provided many insights into their strengths and limitations. It will continue to provide a valuable benchmark for some time to come against which new or improved codes can be measured.

ACKNOWLEDGEMENT

This report was drafted on behalf of the ad hoc Group by AEA Technology consultancy Services (SRD) whose management role in the project was supported, inter alia, with funding from the UK Department of Trade and Industry and the Commission of the European Communities. The ad hoc Group wishes to express its thanks to Anne Fairclough of SRD for typing the English version of this report.

The major contribution of the participating institutions, which ensured the success of the code comparison, is also gratefully acknowledged.

Finally, the IAEA is gratefully acknowledged for having sponsored participation in the Intercomparison Exercise by non-OECD countries.

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EXECUTIVE SUMMARY

Background

Probabilistic consequence assessment (PCA) codes are an integral part of nuclear risk assessment. These methods essentially model the behaviour of radioactive material postulated in the risk assessment process to be released to the atmosphere and evaluate the possible effects on humans via a number of exposure pathways. The effects of various countermeasures, eg evacuation of population, banning of foodstuffs, are also accounted for. By considering how released material might behave under a range of weather conditions, each of which will have some probability of occurrence, probability distributions are determined for various consequences, such as numbers of particular health effects in an exposed population and quantities of foodstuffs banned. These distributions characterise risk.

A number of PCA codes have been developed throughout the world, reflecting their importance in the management of nuclear safety. Given this, it is relevant to ask if there are differences in the various estimates of consequences, which would be significant in the contexts in which these codes are used. The present study, comprising a systematic and rigorous comparison of several PCA codes, was devised to investigate, inter alia, this issue.

Objectives

The main objective of the study was to compare the predictions of participating codes for a range of postulated accidental releases and to assess the significance of any differences observed. However, a number of other key objectives were established. It was considered important that the exercise should contribute to code quality assurance programmes and guide future research and development. It was also expected that the study would facilitate interaction between code developers and code users, including regulators, and as such would enhance the general appreciation of the usefulness of PCA codes and perhaps encourage the harmonisation of methods where appropriate. A final objective was to prepare a report on the study which would represent a major landmark in the risk assessment field.

Technical Specification

In order to perform the study, a detailed specification was drawn up. Population, agricultural production and economics data for the region of interest were constructed. Information on various countermeasures were also prepared; four different measures were considered: sheltering, evacuation, relocation and food banning. This information included criteria for countermeasures implementation, eg thresholds for foodbans. Data characterising a nuclear reactor were also prepared. This included the radionuclides inventory of the system and the characteristics of the postulated accidental releases (eg, the amounts of each radionuclide released, the release duration, the energy content of the release, the physico-chemical forms of the released material). The characteristics of the postulated releases covered a wide range and were chosen to provide a rigorous and comprehensive test of the main features of the participating codes. For example, some of the postulated releases are characterised by a very short release duration, around one hour, while others are spread over much longer timescales, up to one day, with some comprised of a few discrete phases.

The releases considered in the exercise were based on those contained in a major US study, NUREG 1150. However, they were developed specifically for the purposes of the comparison exercise and the consequences calculated from them do not reflect conditions at any particular nuclear facility. It should also be appreciated that the site characteristics referred to above (ie population, agricultural production and economics data) have also been constructed solely for the purposes of the exercise and do not relate to any specific location. **Thus, the validity of the consequence estimates produced in the study is limited to providing a comparison between the various code predictions and should not be interpreted in any other way. Finally, it should be noted that releases of the general kind considered in this study are assessed to have an extremely low probability of occurrence.**

Results

Seven codes from various countries participated in the exercise: ARANO (Finland), CONDOR (UK), COSYMA (CEC), LENA (Sweden) MACCS (USA), MECA2 (Spain) and OSCAAR (Japan). They calculated a wide range of consequences, for example: collective doses, early and late health effects, economic costs and the effect of countermeasures on people and agriculture. In each case, the probability distributions predicted by the codes were compared, with the main focus on the mean and 99th percentile values of these distributions.

As expected, in view of known modelling and other differences between these codes, there were differences between the predicted consequences. The magnitude of the spread depended on the particular consequence endpoint being considered. However, with few exceptions, the spreads were within a factor of a few. This spread or variation between code predictions is small in comparison with the overall uncertainty associated with the estimation of risk from postulated accidents at nuclear installations (ie, including the estimation of the probability of a release, the characteristics of the released material and the resulting consequences). While of scientific and technical interest, the observed differences are not, therefore, material to decisions on the acceptable use of any of the participating codes within a complete risk assessment. Additionally, the spread observed between predictions provides little, if any, insights into the magnitude of the inherent uncertainties associated with the predictions of the participating codes. These inherent uncertainties were not addressed in this exercise.

Two of the code systems are used by several institutes and, in a parallel exercise, a comparison was also made between the predictions of users of the same code. Differences were observed between the respective predictions and these were either resolved or explained; they arose, mainly, from differing interpretations and simulations of the specification. As a direct outcome of this exercise, international users groups have been established for some of the codes, which should greatly enhance their reliable application and provide an effective forum for exchange between PCA code developers and users.

Conclusion

This major exercise has provided a valuable opportunity to compare approaches and methods for probabilistic consequence analysis from many organisations and countries throughout the world. The principal aim of comparing the predictions of these codes and assessing the significance of differences observed under a wide range of conditions has been achieved through the development of a comprehensive technical specification.

As noted earlier, the results from the comparison process, where spreads covering a factor of a few are typical, are considered to represent acceptable agreement, in the light of general uncertainty levels in the overall assessment of risks.

Through the development of the comprehensive benchmark specification, the exercise has served to enhance the quality assurance aspects of the participating codes. The exercise has also provided a valuable forum for discussion on various approaches to PCA model and code development. This has increased the general awareness of the applicability of these methods and has facilitated the process of international harmonisation.

The results of the exercise, along with the interactions between the various participants, has also led to a number of suggestions for future developments in the field. The developments suggested include: obtaining a better understanding of uncertainty, extending the relatively simple agricultural countermeasures currently modelled, improving the estimation of economic costs and investigating further the modelling of early health effects. Additionally, with the increasing use of PCA codes by many institutes and organisations, it is recommended that greater attention than hitherto be given to providing appropriate documentation and training to ensure the proper use of the codes. The creation of user groups for particular codes should further assist in this respect.

In conclusion, with the publication of this report on its activities, the study has achieved its main objectives. The study represents a major initiative in the international arena and has provided a key reference point for future activities in the field of risk assessment.

1. INTRODUCTION AND OBJECTIVES

1.1 Background

Probabilistic Safety Assessment (PSA) is an effective tool for nuclear safety evaluation. One major part of a full PSA is the evaluation of offsite consequences. Probabilistic Consequence Assessment (PCA) models developed for offsite consequence assessment describe the dispersion of released radioactive materials, and predict the resulting interaction with and influence on the environment and man. Predicted consequences may include early fatalities and injuries, latent cancer fatalities, the effect of countermeasures on people and agriculture, and the magnitude of economic impacts. Releases of radioactive material which could cause major offsite consequences are very unlikely for they arise only from accidents in which both the reactor core is severely damaged and the containment fails.

The Reactor Safety Study [1], published in 1975, was the first comprehensive assessment of the consequences and risks to society from potential accidents at nuclear power plants. As part of this study, the CRAC model was developed to predict the public consequences of releases of radioactive material to the atmosphere [2] (and appendix VI of Ref [1]). Since 1975 there has been a sustained development of consequence modelling techniques, and many PCA models have been developed around the world. These models have been widely used in many countries to examine the risk posed by reactors and other types of nuclear installation at specific sites and to provide guidance for planning and decision-making. Besides use in risk evaluation, areas of application include assessment of alternative design features, evaluation of reactor siting recommendations, and development of acceptable risk criteria or safety goals.

Given the existence of a number of different PCA models, which are invariably embodied in computer codes, it is relevant to ask how the calculations of each compare; do the various methods invoke different assumptions and how significant are any differences in calculated risks, from the point of view of the decision-making and regulatory process? In addition consideration must be given to the role of quality assurance (QA) of risk assessment techniques. It is essential that assessment methods are able to demonstrate an adequate level of quality in order to justify their use in the decision-making context. Given all of this, it is clear that an international comparison of PCA codes is of some considerable value. Such activities not only facilitate a comparison of assumptions and results, they can also be considered as contributing to quality assurance, in that a particular set of assumptions and models may be more clearly understood and, thereby, better defended; moreover, by participating in the exercise, residual software problems may be discovered. An additional advantage of such code comparisons is that they serve to enhance the understanding of PCA methods.

An international PCA code comparison exercise of the kind referred to above was performed under the auspices of the OECD/NEA in the early 1980's [3]. This proved to be valuable, providing a good check on the quality of the codes in general use at that time and providing a benchmark against which subsequent developments could be judged. However, since then, a significant number of new models and codes have been produced and in 1990 it was felt appropriate to initiate a further study. In addition to its QA role, the new study was designed to complement the earlier exercise. In contrast to the earlier work where much attention was focused on the output from the individual modelling components of a consequence analysis (eg atmospheric dispersion, dosimetry), the new work had a greater focus on the modelling endpoints of more immediate relevance to risk assessments (eg doses, health effects, number of people affected by countermeasures). Moreover, whereas the earlier exercise was limited in the exposure pathways and consequences addressed, these being determined by the state of development of PCA codes at that time, the new exercise was comprehensive. Finally, the new exercise was also intended to encourage the harmonisation of PCA codes.

1.2 Objectives

The following specific objectives were established for the study:

- To compare the predictions of the participating codes under a range of conditions.
- To contribute to PCA code quality assurance programmes.
- To guide future developments in the PCA field by identifying the merits and appropriate use of different methods.
- To enhance the general appreciation of the applicability of PCA codes by those who develop and use them, particularly in decision-making and regulatory contexts.
- To provide a forum for discussion on various international approaches to PCA model and code development, and to encourage harmonisation of codes.
- To provide a forum for exchange between code users and developers.
- To produce a report on the exercise which will act as a basic PCA code comparison reference.

In addition to the above, it was also expected that the exercise would generally increase the understanding of uncertainties in PCA codes and thereby assist in the identification of priorities for future research.

1.3 Organisation

This international comparison exercise was organised by the Commission of the European Communities (CEC) and the OECD Nuclear Energy Agency (NEA). An Ad-hoc Group was set up by the NEA (the Committee on Radiation Protection and Public Health and the Committee on the Safety of Nuclear Installations) to assist it in this task. A Project Management Group was created to be responsible and accountable for the planning, co-ordination and management of the exercise. The members of these groups are listed in Appendices D and E respectively. One organisation, SRD (represented on the Project Management Group by Mr P J Cooper and Dr W Nixon), was given the prime responsibility for developing the specification and data for the exercise, evaluating the results of calculations, and drafting the Overview Report and supporting Technical Report.

It was recognised by the Ad-hoc Group that the code comparison exercise could benefit from the fact that two of the participating codes, namely MACCS and COSYMA, have been distributed to many organisations in different countries. This offered the opportunity not only to compare the predictions of different codes, but also to use the framework of the exercise for a comparison of the predictions of different users of the same code. It was felt that the results of such an internal comparison could be supportive for the explanation of differences encountered in the code comparison exercise and the conclusions drawn from it.

It was therefore thought beneficial if the users of MACCS and COSYMA took part in an internal comparison exercise. This resulted in the establishment of a MACCS users group and a COSYMA users group. Some of the exercises calculated were the same as for the code comparison. Additional exercises were also specified in order to study in more detail the sources of differences in the predictions.

The results of the internal comparisons are published in separate reports [4, 5]. An overview of the activities of the groups is given in Appendices F and G. In this report only the results of the organisation(s) who developed the MACCS and COSYMA codes are included.

This comparison exercise was divided into three phases. First, a detailed specification for the study and all the data to be used by participants were prepared. Secondly, a pilot study to test the specification and data provided was performed. Finally, seven calculations with either different source terms or other assumptions were performed.

1.4 Outline of Report

The results of the comparison exercise are summarised in this Overview Report. A full set of results is presented in a supporting Technical Report [6]. Section 2 provides a brief overview of probabilistic consequence assessment. The participating PCA codes are described in Section 3. The data presented to participants, the types of calculation performed and the consequences evaluated are summarised in Section 4; the full specification for this exercise is given in Appendix A. Section 5 summarises the results obtained by participants and explains the major differences observed. Finally, Section 6 presents some important conclusions.

Finally, it should be noted that the results presented in this report are for a hypothetical site and source terms and have therefore no absolute significance; moreover, a number of simplifications were made to facilitate the comparison. The validity of the consequence estimates is limited to providing a comparison between the various code predictions and should not be interpreted in any other way.

2. OVERVIEW OF PROBABILISTIC CONSEQUENCE ASSESSMENT

2.1 Introduction

This section describes the main elements of consequence modelling; they are shown schematically in Figure 2.1. 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 on the right. In the centre of the figure, the main calculational steps are identified. Invariably these calculational steps and their associated data are incorporated into a computer program, referred to as a consequence modelling code. In any particular code the order of the calculational steps may differ from that shown in Figure 2.1, in particular the dose evaluation for each exposure pathway may be done both before and after the countermeasures have been calculated.

This section provides a general description only. The extent to which the individual codes involved in the present exercise correspond to this description is considered in Section 3.

2.2 Description of the Radionuclide Release

The starting points for a consequence assessment are postulated radionuclide releases to the atmosphere. This information is required for each of the representative accidents to be assessed and it is referred to as the accident source term. The accident source term specifies both the magnitude of the release (ie quantity of each radionuclide released to the atmosphere) and, by defining a number of release parameters, the manner of the release. These release parameters include: the time between reactor shutdown and beginning of the release to the environment, the duration of the release, the amount of energy associated with the release and the height of release. For those accidents which give rise to a number of separate releases, the above information is required for each distinct release. Often the time available for the initiation of countermeasures before the release of radioactive material to the environment begins, the warning time, is also given.

In principle, to fully define the source term, information on the physical and chemical form of the released radionuclides, is also required. The size spectrum of the released aerosol and the chemical forms of its constituents are important, particularly for determining the deposition of particulate material in both the environment and in the respiratory tract of individuals. In practice detailed information on the physical and chemical form is seldom available, and it is generally assumed that the radionuclides are released as a 1 μm AMAD (activity median aerodynamic diameter) aerosol with each chemical element in oxide form, apart from the noble gases and the fraction of iodine released in particular gaseous forms (eg I_2, CH_3I). Even in those cases where very detailed information is available, most current consequence modelling codes are limited in their treatment of the physical and chemical form of released radionuclides, so a simplified approach, based on the above assumptions, may still have to be adopted.

Figure 2.1. **Basic elements of probabilistic consequence assessment**