THE ACTIVITIES, OBJECTIVES AND RECENT ACHIEVEMENTS OF THE NEA PROBABILISTIC SYSTEMS ASSESSMENT CODES (PSAC) USER GROUP

Stefan G. Carlyle

OECD/NEA
38, boulevard Suchet
75016 PARIS, France

ABSTRACT

The NEA Probabilistic Systems Assessment Codes (PSAC) User Group was established in early 1985 by the Agency's Radioactive Waste Management Committee (RWMC) as part of its program devoted to the advancement of performance assessment methodology development for radioactive waste disposal applications. This paper shows how the PSAC User Group fits into the overall strategy of the RWMC program, gives the background to the creation of PSAC, its aims and recent achievements.

INTRODUCTION

Since its inception in 1975, the NEA Radioactive Waste Management Committee (RWMC) has devoted a considerable part of its program of work to environmental and safety evaluations of radioactive waste management systems. This has included the coordination, at an international level, of activities devoted to the disposal of radioactive waste in deep geological formations (1), disposal of high activity wastes into the seabed (2), sea dumping of low level wastes (3,4), to the disposal of uranium mining and mill tailings (5). In 1984, the RWMC reviewed its program of work and decided that the major part of its program should be devoted to the development of performance assessment methodologies (6). This was in part based on the realisation that the level of sophistication necessary to carry out comprehensive system performance assessments had given rise to new challenges that could best be overcome by sharing experience and co-ordinating R&D at an international level. This was particularly the case when the PSAC User Group was established. The UK Department of the Environment was developing and evaluating computer based methods for probabilistic assessment of low and intermediate waste disposal. It was recognized that similar developmental work was also being carried out by AECL, Canada; SKB, Sweden; and that other countries were about to begin development work. The UK DOE proposed therefore the setting-up of an NEA group to coordinate development activities so as to avoid duplication of effort, to exchange information and experience and to plan aspects of code development of potential mutual benefit. A meeting of prospective participants was held in London in December 1984. It was concluded that such a group was desirable and would facilitate the efficient development of PSA codes provided that the activity was limited to computer code related activities and included participants from countries actively developing such codes. It was thought that information exchange and peer reviews would be the primary goals. The RWMC subsequently agreed to the creation of the Probabilistic Systems Assessment Codes (PSAC) User Group (initially known as the Users' Group for Systems Variability Analysis Codes) in February 1985. This paper describes the reason for using PSA codes to carry-out assessments of potential radioactive waste disposal systems, the main activities and achievements of PSAC to date and its future plans.

WHY USE PSA CODES FOR SAFETY ASSESSMENTS OF RADIOACTIVE WASTE DISPOSAL SYSTEMS

It has become increasingly clear over the past few years that classical approaches to predicting the radiological consequences of potential nuclear accidents and radioactive waste disposal systems can be improved by the use of statistical techniques for assessments of the implications uncertainties in parameters. Previously, it was considered sufficient to treat uncertainties in parameter values by using a combination of expert judgement, pessimistic assumptions to give worst cases and by placing caveats on the predictions. Recent advances in calculating uncertainties in predictions may mean that more definitive and quantifiable information can be produced to indicate the level of confidence that can be given to the results. Furthermore, these 'uncertainty analysis' techniques can be used to assess the risk associated with the long term performance of a radioactive waste disposal facility by predicting the probabilities of occurrence of certain events in combination with the concomitant consequences. This capability is extremely important vis à vis the assessment of the safety of radioactive waste disposal systems as the need to make predictions of performance many years into the future itself generates uncertainty in the parameter values that are used in making computer model predictions. Figure 1 gives a schematic representation of an engineered and natural barrier to the migration of radioactive waste from a repository for spent fuel.

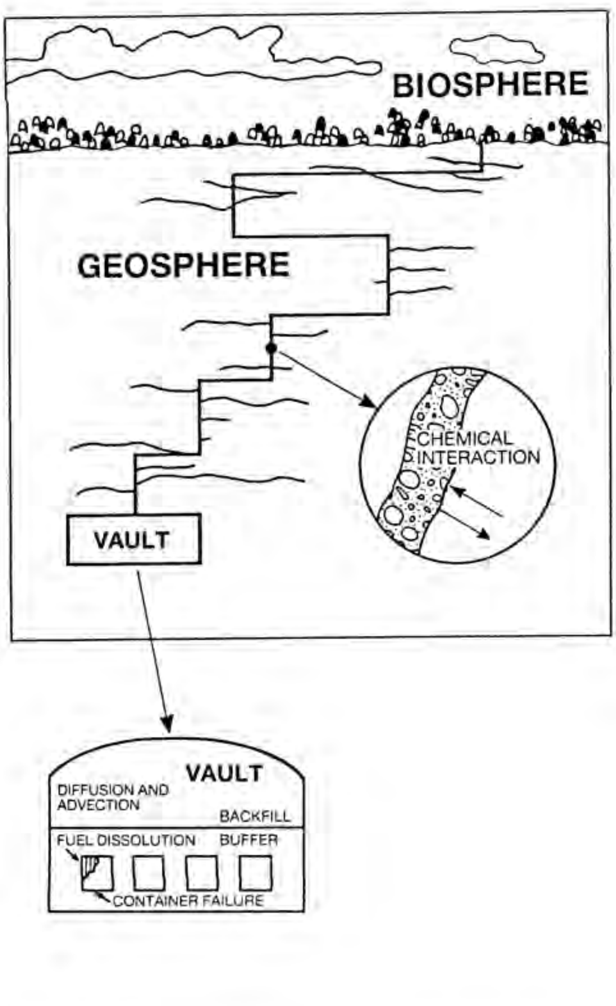

Fig. 1. Schematic representation of natural and engineered barriers to the migration of radioactive waste (based on reference 11)

The use of the concept of risk for radioactive waste disposal assessments has been pioneered by the NEA RWMC. It established an expert group which prepared a report on long term protection objectives for radioactive waste disposal in 1984 (7) that recommended inter alia the use of risk as an indicator of the performance of a waste repository. Risk was defined as the product of the probability of occurrence of an event, or sequence of events, and the predicted consequence of the event i.e., potential harmful effects. It was suggested that national authorities should judge waste disposal practices against an individual risk limit for members of the public which corresponded to the risk associated with the current ICRP dose recommendations. A maximum risk objective of 10^{-5} per year was suggested, corresponding approximately to the objective of 1mSv per year recommended by the ICRP for those scenarios where exposure is expected to persist for a decade or more in the lifetime of individuals in a critical group. Also, for future exposures of limited duration, a risk of 5×10^{-5} per year would correspond broadly with the individual dose limit of 5mSv per year. Such recommendations were taken into account when the ICRP prepared recommendations on radiation protection principles for radioactive waste disposal (8). Figure 2 gives the 'criterion curve' contained in the ICRP recommendation of the maximum probability that can be permitted for an estimated annual dose from all initiating events, based upon the annual risk constraint of 10^{-5} to the critical group.

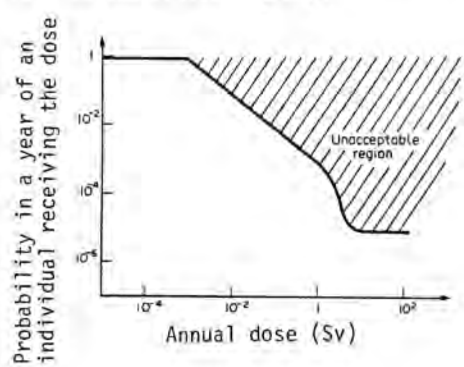

Fig. 2. Criterion curve corresponding to an annual risk constraint of 10^{-5} from all events (8)

The concept of risk was also introduced to systematically account for extremes in performance of a repository. At one end of the spectrum it is possible to envisage high consequence/low probability events such as intrusion directly into a repository (eg. by an inquisitive archaeologist in 12000 AD !). On the other hand, low consequence/high probability events may have greater frequency, such as discharges to surface water systems via engineered and geological barriers. A balance between events of varying probability and consequence within a given system can be achieved by using *probabilistic* analysis techniques that take account of parameter uncertainty. Computer codes that take account of parameter uncertainty are called Probabilistic Systems Assessment Codes.

WHAT ARE THE MAIN FEATURES OF PSA CODES

As mentioned above, probabilistic systems assessment codes are being developed in several member countries of the NEA, largely to take account of uncertainties arising from predictions of the radiological impact of radioactive waste disposal, in particular uncertainties arising from an incomplete set of data and the need to extrapolate current knowledge into the distant future. Work on the application of PSA codes for assessments of radioactive waste disposal systems has been carried out in several countries over the past few years; notably, in the USA (9,10) Canada (11,12) and the UK (13,14). The PSAC User Group currently has 15 member organisations drawn from Belgium, Canada, the Federal Republic of Germany, Finland, Japan, Sweden, Switzerland, the United Kingdom, the United States and the Joint Research Centre of the Commission of European Communities. Each is at a different stage in the development and application of PSA codes. The AECL in Canada has developed the SYVAC code (11) a schematic representation of which is shown in Figure 3. SYVAC contains a set of sub-models representing the major components of the disposal system; the vault, geosphere and biosphere. Uncertainty and variability in the data needed to drive the models are taken into account by using probability distributions to define the input parameters, rather than single 'best estimate' or 'worst case' values. SYVAC selects a simulation (defined as a possible state of the system) by randomly sampling (using Monte Carlo sampling) a value for each parameter from its pre-specified distribution. This set of parameter values is then used deterministically within the sub-models to estimate the radiological consequences. SYVAC repeats this procedure many times, typically several thousand runs are made and the results are combined for example, as a histogram of predicted consequences versus their frequency of occurrence.

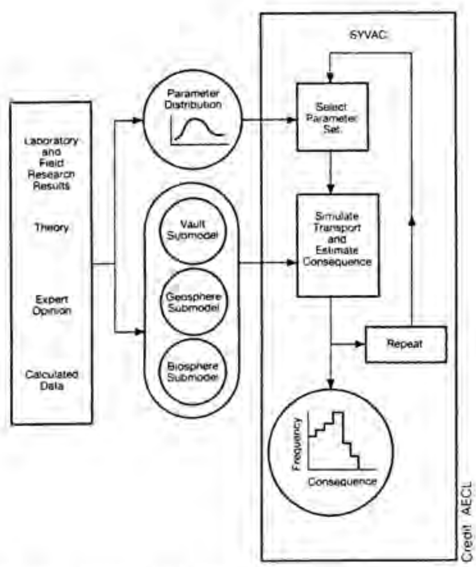

Fig. 3. Schematic representation of the post-closure assessment procedure and the SYVAC computer code (12)

A similar PSA code has been developed in the UK called SYVAC A/C [13] which, although based on the Canadian SYVAC code, has been modified to perform assessments of the shallow land burial of low level wastes and disposal of intermediate level wastes in mined rock cavities. A 'Dry Run' assessment has recently been carried out on an hypothetical repository site in clay (14). Similarly the Joint Research Centre of the CEC has developed the LISA (Long term Isolation Safety Assessment) code for estimating radiation exposures from nuclear waste repositories (15). In Sweden the Swedish Nuclear Fuel and Waste Management Company (SKB) is in the process of developing the PROPER code (16). Like SYVAC it uses a Monte Carlo technique to find the variability of the results and uses simplified sub-models representing radionuclide transport. Figure 4 shows the core of the PROPER code i.e. the executive program, which contains systems for linking the sub-models, handling communication between them, sampling input data and compiling statistics from calculations. The 'monitor' allows two kinds of input to the sub-models i.e. parameter and time series, and one output i.e. time series (see Fig. 5). The 'post-processor' is a separate program for statistical processing of the results.

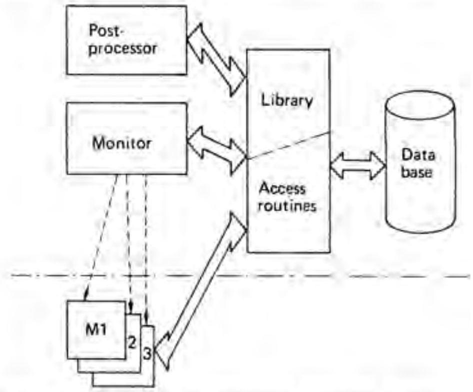

Fig. 4: PROPER executive system (16)

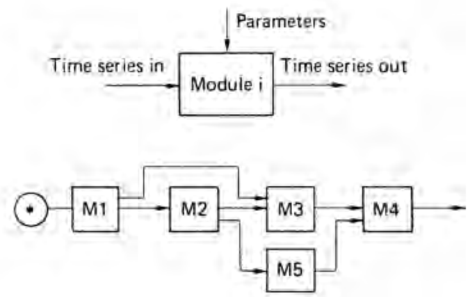

Fig. 5. PROPER modular communication (16)

Similar developments are being made at AERE Harwell where the MASCOT code is being developed, at GSF Braunschweig, FRG on the EMOS code, at BWIP on the SPAM code, at Mol in Belgium, within the National Uranium Tailings Program in Canada, where the Uranium Tailings Assessment Programme (UTAP) code is being developed, in Japan based on MIGRAT-3 (source term and geosphere) and CIRCLE (biosphere), at CRNL, Canada on the COSMOS code, at NRPB UK for sub-seabed assessments, at VTT in Finland where a 'semi-probabilistic' model is being developed for assessments of spent fuel disposal in crystalline rock, while at Battelle, PNL in the USA the Analytical Repository Source Term (AREST) code is being developed to assess near field performance. The latter is an example of a detailed model within a stochastic framework which will be used to estimate the containment times and the eventual release rates of radionuclides from waste packages emplaced in geologic repository. Figure 6 shows the main components of the source-term conceptual model (AREST) being developed under the PASS Program of the US DOE at the Battelle Pacific Northwest Laboratories (17). The model is part of an overall strategy for assessing the post-closure performance of a geological repository system in order to demonstrate compliance with requirements of the US Environmental Protection Agency and the US Nuclear Regulatory Commission (NRC) for the safe isolation of spent nuclear fuel and high level waste (18).

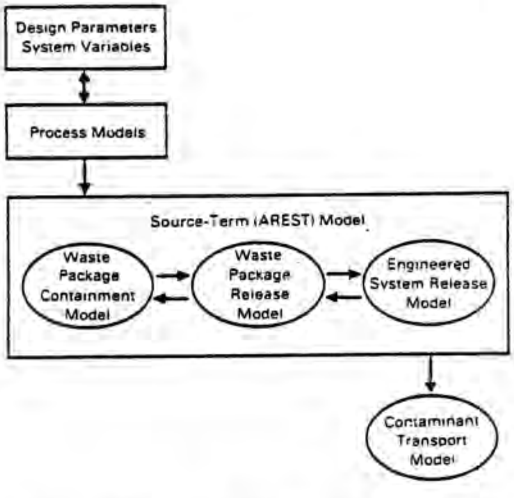

Fig.6. The PNL Geologic Repository Performance Model (17).

THE AIMS OF THE NEA PSAC USER GROUP

The codes described above are all being developed by organisations that currently participate in the PSAC User Group. The diversity of codes and the large effort needed to develop and implement them provided the stimuli for an international forum to be set-up to co-ordinate their development. The objectives of PSAC are to:

- exchange information and experience;
- compare and verify codes;
- carry out peer review activities;
- carry out joint code development activities; and
- discuss technical issues of topical interest.

The group has met twice a year since it began in early 1985. Discussion ranges from simply informing each other of developments over recent months to an informal exchange of views (one day) on topical issues such as:

1. Input data acquisition and handling.
2. Methods and procedures for sensitivity analysis.
3. Presentation of results from PSA codes.
4. Statistical sampling procedures, their theory and application to PSA codes.
5. Software quality assurance and validation.
6. Time dependent processes.
7. Reduction of research models to PSA sub-models.

These informal workshops have revealed useful insights into alternative approaches to, for example, quality assurance, the difficulty in presenting results and future development needs.

THE NEA DATA BANK'S CONTRIBUTION

One of the PSAC objectives - to exchange codes and develop an inventory of PSA codes - is being met to a large extent by the NEA Data Bank.

The Data Bank was established in 1978 when it was decided to combine the functions of two earlier NEA information centres the Neutron Data Compilation Centre at Saclay and the Computer Program Library, then located at Ispra, Italy. The combined center at Saclay is now housed in a building provided by the French Commissariat à l'Energie Atomique, which also provides central library and documentation services.

Data and program information, drawn from many sources and in various stages of refinement, is processed and provided to Data Bank Subscribers in standard form at no direct cost to the user. Each year more than 1000 program packages and about five and a half million numerical data are distributed by the centre. The Data Bank's own contribution to this exchange has now moved beyond the simple collection and testing of information to assembly and testing of evaluated data sets and full verification of computer codes.

In the search for savings in government-sponsored research Member countries have devolved onto the Data Bank some other projects more economically carried out in an international centre. Access to highly efficient computing facilities, and the wide range of professional skills available make it possible for the Data Bank to take on complementary projects without extra resources. The emphasis is on limited projects giving high "added value" such as: benchmark comparisons of computer programs and data, the Joint Evaluated File, and the International Sorption Information Retrieval System (ISIRS).

Until recently the Data Bank contribution to PSAC has concentrated on the acquisition of fully developed and documented codes including SYVAC 1 and 2 from AECL, SYVAC A/C from the UK Department of Environment, and LISA from the CEC Joint Research Centre. These codes have been made available to the Data Bank and have been fully tested, documented and packaged, ready for distribution on request to other members of the Group.

Work has now begun at the Data Bank on the development of a library of computer modules used in the various PSA codes. The aims to allow members of the Group to exchange specific pieces of code. Under discussion is the development of a standard interfacing system so that particular modules may be easily exchanged. This is particularly important as it will help avoid duplication of effort, reducing development time and therefore costs. In addition, the use of standardized output files would simplify the analysis of the results of code intercomparison exercises, and the Data Bank is collaborating with the PSAC User Group in the design of standard output specifications for PSA codes.

CODE INTERCOMPARISONS

Confidence is an essential element in the development of new computer codes, especially where they are to be applied in the regulation of radioactive waste disposal systems. For this reason, PSAC has devoted considerable effort towards the verification of codes i.e. confirming that the codes correctly perform the operations and calculations as intended. The main way of doing this is to compare a number of similar codes by running a test case and to identify and explain or correct, any differences that occur. As a first step in developing a structured series of code intercomparisons, PSAC agreed to an exploratory Level 0 exercise. A specification was therefore prepared that focussed on comparing large codes as well as gaining experience in preparing, running, compiling and comparing the results (19). Simplified models for the Waste Form, Buffer, Geosphere and Biosphere were specified with specific guidance on the type and form of results to be prepared so as to ease comparison. Preliminary results indicate (these are being compiled at the time of writing) that there is clearly scope for further intercomparisons. Twelve organizations from the PSAC group participated and there was generally good agreement between the results. It was therefore agreed that further intercomparisons should be carried out

The objective of this series of intercomparisons will be to enhance confidence in the ability of different PSA codes to represent adequately the performance of a disposal systems for the purposes of estimating the radiological consequences and risk associated with implementation. In order to meet this objective the PSAC Intercomparison Exercise will involve:

- Using specific solution algorithms to compare the estimating capability of different PSA codes;
- comparing the ability of different PSA codes to represent repository systems performance;
- comparing specific pieces of code to verify that they meet their design specifications.

In order to meet these broad objectives the following preliminary series of intercomparisons have been agreed by PSAC:

Level 0 -
Test of Executive Modules of PSA Codes

Level E -
Comparison with Exact Solutions

Level 1(a)
Hypothetical deep disposal site

Level 1(b)
Hypothetical shallow disposal site

Level 0, as mentioned above, was designed as a straightforward test of executive routines. Level E will consist of a case where an exact solution exists for the transport of a single nuclide chain from the source term through the geosphere to the biosphere (20). Calculations using PSA codes will be compared with this simple exact analytical solution in order to verify their numerical accuracy.

Levels 1a (deep disposal) and 1b (shallow disposal) are intended to provide PSAC members with experience in carrying out probabilistic assessments of hypothetical disposal systems; one for high level waste or spent fuel and one for low and intermediate level waste. Comparisons will be made among the various results in order to gain confidence that specific codes can provide estimates of the performance of different disposal systems.

FUTURE PLANS

Following two years of operation PSAC has become an important part of the NEA Radioactive Waste Management Committee's strategy for helping the development of performance assessment methodologies for radioactive waste disposal applications.

It has been, and will continue to be focussed on code development activities aimed at gaining confidence among specialists that the codes are of the necessary quality for carrying out probabilistic assessments of disposal systems. An integral part of this confidence building will be the code intercomparison exercises as well as peer review of ongoing development and the informal discussion of topical issues.

As the NEA PSAC User Group progresses it will play a key role in the development of what will probably become one of the major tools for assessing the safety of potential radioactive waste disposal systems.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the helpful advice and comments of Dr. Bruce Goodwin of AECL, Canada (Chairman of PSAC) and Mr. Claes Thegerström of the NEA Secretariat during the preparation of this paper.

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