



Baudouin ARIEN

Reactor Safety Analysis

Scientific staff

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RISK ASSESSMENTS of nuclear installations require more and more accurate safety and reliability analyses to estimate the consequences of accidental events and their probabilities of occurrence.

Objective

- to develop expertise in probabilistic and deterministic reactor safety analysis.

Programme The research programme relates to four main activities:

- developing a software for reliability analysis of large systems;
- developing an expert system for the aid to diagnosis;
- developing and applying a probabilistic reactor dynamics method;
- participating in the international PHEBUS-FP programme for severe accidents.

Achievements The achievements encompass several aspects.

Development of CAMERA CAMERA is a software for computer-aided reliability analyses of large systems using two optional techniques, the Markovian approach and the Monte Carlo simulation, both allowing the treatment of much more general systems than the classical fault-tree method. The software is developed in collaboration by ULB (Markovian processor) and SCK•CEN (Monte Carlo simulation module and preprocessor aiming at a user-friendly introduction of the data describing the system to be analysed).

SCK•CEN's contribution in 1997 consisted in

- completing the coupling of the Markovian processor with the preprocessor;
- improving the preprocessor by adding options (for example, various models for the common-cause failures);
- further developing the Monte Carlo simulation processor to broaden the application field of the software; the program can now handle components with nonconstant tran-

sition rates. For that purpose, we built a library of the frequently used probability density functions. The program can also handle a state-dependent ageing of the components. Other results have been obtained in the field of variance reduction. This work is carried out in the framework of a PhD thesis.

Aid to diagnosis of pressurized-water loop transients This work, carried out in the framework of a PhD thesis, focused in 1997 on the modelling dependencies in complex systems. The approach of modelling dependencies in real application was developed and implemented on real examples, taken from the experimental facility CALLISTO. By then, the PhD thesis was ready to be submitted.

Probabilistic Reactor Dynamics The reliability study of a dynamical system needs to consider many sequences or branches of a dynamic event tree. The difficulty linked to the many possible orderings of the branching points corresponding to failures or control actions is compounded by the fact that many uncertain parameters influence the results of the analysis.

A first method to deal with uncertain parameters which are exclusively transition times has already been developed, in collaboration with ULB, and applied on a simple model of a level-1 PSA scenario. In the framework of another PhD thesis, we are extending the method to every kind of uncertain parameter, to allow the computation of level-2 accidents in which many parameters are poorly known (for example, those coming from expert judgment).

Severe accidents To acquire expertise in severe accident modelling, SCK•CEN participates in the international PHEBUS-FP programme. Of the six scheduled experiments, two have already been performed. SCK•CEN initiated its participation some years ago by detaching one scientist to CEN Cadarache for the phenomenological understanding of the degradation, notably by post-test examinations, and another one to JRC Ispra for the modelling of the tests with the ICARE2 code. The phenomenological work showed the importance of nonmodelled factors such as the interactions of the

structural and absorber materials with the fuel. These lead to a higher degradation than expected and to a strong lowering of the corium melting temperature (2 500 K, compared to the 2 800 K foreseen by the classical UO_2/ZrO_2 phase diagram).

SCK•CEN is now using the RELAP5/SCDAP code for similar modelling and will compare the results with those produced by ICARE2. To this end, it also initiated a collaboration with FZK. The simulation of the first test FPT0 with RELAP5/SCDAP has been started.

Perspectives for 1998 The application of CAMERA to real problems in nuclear power plants is now investigated. Living PSA seems to be one of the most promising applications, in particular for the reliability analysis of systems involved in the safety of the nuclear power plant and placed in outage situations. In a first step, demonstrative examples will prove the feasibility of such analyses.

The Monte Carlo module will be coupled with the CAMERA software. It will be further developed to take into account different maintenance policies and will be applied to a concrete case, to be selected.

In Probabilistic Reactor Dynamics, the method able to treat the parameter uncertainties will be implemented in a C program and will be applied first on a level-1 PSA scenario.

A model of a level-2 scenario with realistic data will be developed in collaboration with ULB and proposed as a benchmark exercise. We will then compare the results obtained by our method to those obtained, for instance, by a Monte Carlo simulation.

The participation in the PHEBUS-FP programme will continue. Pre- and post-test calculations with ICARE2 at JRC Ispra will proceed and the modelling of the second test FPT1 with RELAP5/SCDAP will be undertaken.

Partners, sponsors, and customers

Scientific partners Université Libre de Bruxelles (ULB) — Vrije Universiteit Brussel (VUB) — University of Maryland — Tractebel Energy Engineering (TEE) — European Commission (EC) — Forschungszentrum Karlsruhe (FZK)

Scientific output

Publication in 1997

J.-L. DELCOUX, P.E. LABEAU, J. DEVOOGHT, "Approximate Zero-Variance Monte Carlo Estimation of Markovian Unreliability," *Annals of Nuclear Energy* 25:4-5, 259-283 (1998).

Presentations delivered in 1997

B. ARIEN, "The CAMERA Software in Markovian Reliability," Topical day on Safety Studies: SCK•CEN, Mol, Belgium, December 10, 1997.

J.-L. DELCOUX, "Variance Reduction for Simultaneous Monte Carlo Estimation of Many Markovian Unreliability Functionals," Int. conf. on Advances in Safety and Reliability (ESREL'97): Lisbon, Portugal, June 17-20, 1997. Proc., 2123-2128.

J.-L. DELCOUX, "A Variance Reduction Method for Function Estimation and Its Application to System Reliability Analysis," Workshop on Rare Event Simulation: Aachen, Germany, August 28-29, 1997.

J.-L. DELCOUX, "Application of the Monte Carlo Methods to the Non Markovian Cases," Topical day on Safety Studies: SCK•CEN, Mol, Belgium, December 10, 1997.

N. DESSARS, "Dynamic Reliability—The Influence of Uncertain Parameters," Topical day on Safety Studies: SCK•CEN, Mol, Belgium, December 10, 1997.

N. DESSARS, J. DEVOOGHT, "Role of Time Delays in Event Trees," Int. conf. on Advances in Safety and Reliability (ESREL'97): Lisbon, Portugal, June 17-20, 1997. Proc., 2105-2112.

K. OULIDDREN, A. NOWÉ, "Incremental Fuzzy Modelling of Dependencies in Complex Physical Systems," Annual meeting of the North American Fuzzy Information Processing Society (NAFIPS'97): Syracuse, New York, USA, September 21-24, 1997. Proc., 136-141.