Proceedings of ICAPP 2011
Nice, France, May 2-5, 2011
Paper 11399

Probabilistic Safety Assessment and Reliability Engineering:

Reactor Safety and Incomplete Information

B. BEAUZAMY
Société de Calcul Mathématique

H. BICKERT
Société de Calcul Mathématique

O. ZEYDINA
Société de Calcul Mathématique

G. B. BRUNA
Institut de Radio-protection et de Sûreté Nucléaire

Position of the problem

The Nuclear Power Reactors of third generation use Self-Powered-Neutron-Detectors which provide indirect measurements of the neutron flux and allow the reconstruction of the core hot spot, that is the place in the core where the power peaks.

The question is : what do we know if one or several of these SPND fail ?

Do we still have sufficient information to guarantee the safety of the reactor ?

Two difficulties:

- This is an inverse problem, of non-linear nature ;
- The SPNDs do not receive the neutrons emitted by the hot spot, but only their descendants.

Our approach:

1. Direct problem

For a given position and intensity of the hot spot, count how many neutrons will be collected in each SPND.

In order to solve this question, we discretize the core into regular parallelepipeds and compute the emission of neutrons from one parallelepiped to its nearest neighbours.

Each cell has its own "multiplicative factor" and two types of neutrons are considered : fast and thermal. The hot spot emits fast neutrons, and the SPNDs count only thermal neutrons.

A probabilistic approach is used, by means of random variations of the transfert function from one cell to the next. So we have an answer to the following question : if the hot spot emits N neutrons, what is the probability law of the number of neutrons seen by each SPND ?

The method we use is very fast, in terms of computation time. It comes from our work in image analysis for the French Ministry of Defense. We use a cross, with 4 neighbours in 2D, 6 neighbours in 3D, and we move this cross all over the reactor. It calculates the number of neutrons at the central point of the cross, from the emission of the neighbours.

Probability laws

We take into account the uncertainties in the materials composition, as well as in the isotropy of the neutrons emission from a cell, as follows :

– An uncertainty of 10% is assigned to the probability for a neutron to go to one of the neighbouring cells ;

– An uncertainty of 2.5% is assigned to the value of the multiplication factor of the cell material.

These uncertainties are independent from one cell to another.

This way, we obtain a "transfer function" for each SPND : it gives the probability law of what each SPND sees, assuming for instance that the hot spot emits 10 000 neutrons. So we have a probabilistic solution of the direct problem.

2. Inverse problem

We have to reconstruct the hot spot from what each SPND sees.

SCM has developed a method for propagating information, in a probabilistic manner. Originally, this method was created as a part of a contract with Framatome, but it was later developed in full with IRSN. Its name is "Experimental Probabilistic Hypersurface" (EPH).

Under this method, the information propagates, just like a gravitational field. It deteriorates with the distance. The way it deteriorates is governed by a principle of "maximal entropy", which means that no artificial assumption is ever made.

In the basic situation, if at a point A the measurement gives a value a, at a point X the information will be given by a gaussian law, with mean value a (the value of the measurement) and a variance which deteriorates exponentially with the distance between A and X : the further we go from the measurement, the less concentrated this probability law will be : this is quite normal. Several measurements will then recombine, at a given point, into a single probability law.

However, in our case, several difficulties had to be solved :

- The media is not homogeneous : it consists in several cells, with different propagation factors. So the propagation of the information has to take this diversity into account.

- The neutrons do not follow only one path ; there are infinitely many paths from the hot spot to any single SPND. We have to deal with each of them separately, find those for which the contribution can be neglected, and treat individually all which cannot be neglected.

Results

We are interested in the dispersion of the probability law, giving the hot spot emissions. Indeed, if this dispersion is large, it means that the uncertainty is high, and, in this case, our knowledge of the hot spot is not precise.

In order to measure this dispersion, we could use the variance of the law, but experts in the sector prefer another definition, which uses the difference between the expectation and the 5 % and 95 % quantiles.

More precisely, we introduce :

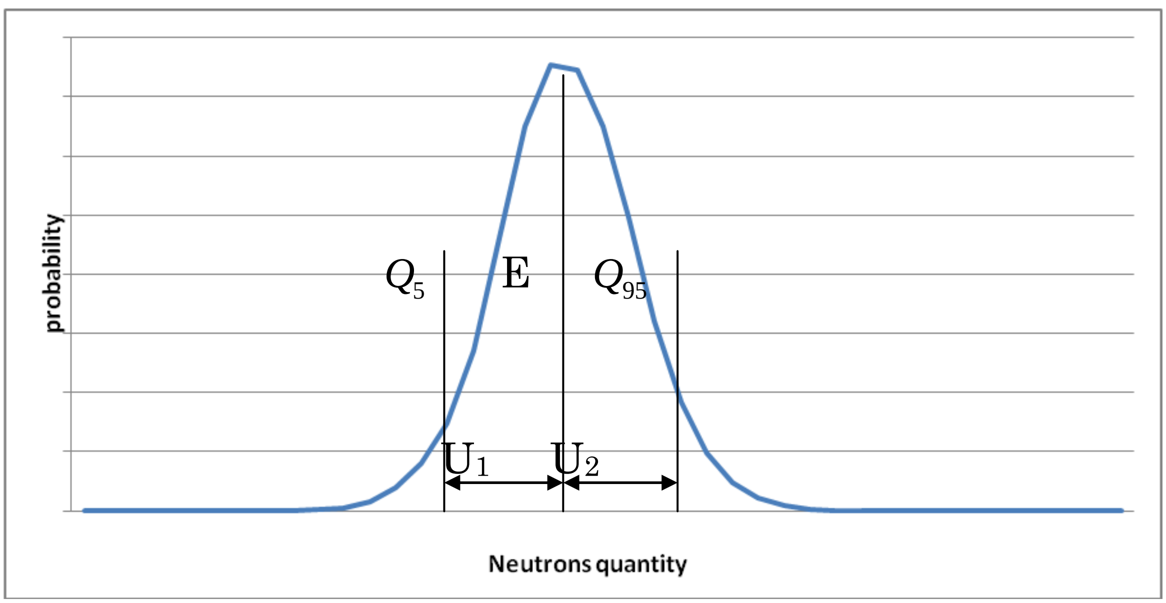
$$U_1 = E - Q_5$$

where E is the mean value (expectation) of the law "emission of the hot spot" and Q_5 is the 5% quantile (probability to be under this value is 0.05).

Similarly, we introduce :

$$U_2 = Q_{95} - E$$

where Q_{95} is the 95 % quantile (the probability to be under this value is 0.95).



Then we normalize these values, dividing by the expectation :

$$V_1 = \frac{U_1}{E}, \quad V_2 = \frac{U_2}{E}$$

These numbers can be viewed as relative deviations (in proportion of the mean value).

The Institut de Radioprotection et de Sûreté Nucléaire would consider the information as insufficient if one of these numbers is >5% : it would mean that our knowledge is too imprecise.

Using these definitions, our results are as follows :

	V_1	V_2
if all SPND work	1.19 %	1.06 %
closest fails	1.39 %	1.10 %
two closest fail	1.40 %	1.11 %

So, the failure of one or two SPNDs, close to the hot point, does not bring a significant deterioration of the information.

Even if 5 SPNDs fail, the deterioration is below 5 %.

This indicates that the number of SPNDs is large enough to compensate the possible failure of some of them.

Of course, our results rely upon simplified assumptions :

- Simplified geometry and structure of the cells ;
- Simplified families of neutrons.

So these results should only be considered as indicative. But both our mathematical models and computer implementation will accept more detailed representations.

bernard.beauzamy@scmsa.com
helene.bickert@scmsa.com
olga.zeydina@scmsa.com
giovanni.bruna@irsn.fr