THE TECHNICO-ECONOMIC OPTIMIZATION OF THE IMPROVEMENT OF THE SAFETY LEVEL OF THE PWR 900 MWE UNITS FOR THEIR THIRD TEN-YEARLY OUTAGE THANKS TO THE COST - BENEFIT ANALYSIS

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Abstract:
In order to maximise the improvement of the safety level of its units while controlling the cost of safety assessment, EDF, within the scope of the third ten-yearly outage of the 900 MWe PWR series, decided to implement a method for ranking the modifications according to the ratio "safety benefit gained from the modification" over the "cost of the modification". The exercise showed the true interest of this type of method, of which the principles should be shared between the Safety Authority and plant operators and, once certain adjustments have been made, should then become an irreplaceable element in the safety assessment process.

1 GENERAL FRAMEWORK OF THE COST-BENEFIT METHOD

Within the context of an increasingly competitive power-generation sector and taking account of the ever-increasing importance of safety related issues, the environment, radiological protection and the fact that resources, whether human or financial, are finite, the need to rank actions and consolidate decisions has become essential for a plant operator such as EDF.
In order to achieve these objectives, according to the principle that aims at integrating safety in an industrial logic, EDF decided to develop a safety cost-benefit method and use it as an aid to ranking and decision making.
The method consists in assessing the impact of dealing with safety-related problems and site operation files by establishing the relationship between:

- the added value or impact in the broad sense, with regard to the safety of the workforce and the population, of which the impact in terms of environmental and radiological protection can be identified as the "benefit",
- and the impact on the investment costs, direct and indirect production costs, operating dosimetry, as well as on the industrial, socio-organisational and human fields, which can be identified as the "cost".

"Cost-benefit" analyses are quantified as far as is possible; when it is not possible to do so, qualitative analyses are developed to contribute to decision-making.
The method can be used for consolidating decisions with regard to:

- taking or not taking action (changing a reference system, modifications, repairs),
- choosing the most suitable solution for a given problem,
- the time required to deal with a discrepancy that needs to be brought into conformity,
- ranking a set of modifications within a given framework of actions, such as the modifications corresponding to the ten-yearly reassessment of a standard plant series.

One of the first large scale uses of this method was the analysis of the safety cost-benefit ratios of the modifications envisaged within the scope of the third ten-yearly outage of units in the 900 MWe PWR series, in order to rank the list of modifications.

2 PRINCIPLES OF THE COST-BENEFIT METHOD

2.1 Definition of a cost-safety benefit analysis

This assessment is carried out in two stages:
From the "safety benefit" point of view: the safety benefit of the physical or operational change (or changes) is assessed taking a safety assessment as the basis. When the field of application allows, probabilistic safety assessment (PSA) are used to obtain a quantitative assessment of the impact. The benefits associated with a modification under study are assessed according to the criterion considered the most important with regard to safety and radiological consequences. When they are quantified, the results are expressed in units corresponding to the analysis (frequency, dosimetry units). The non-quantifiable impacts considered significant are the subject of a qualitative analysis in order to characterise them.
All safety impacts are taken into account: not only the expected positive impacts, but also the possible negative impacts, such as a spurious signal associated with the actuation of an automatic control.
From the "cost" point of view: the overall costs (direct, induced, avoided) of a change (or changes) that allows a problem to be solved are estimated according to the method applied by the engineering departments, and based on the feedback on changes or maintenance actions. This cost covers the costs of studies, the costs of performing the work, the operating costs and the impacts, expressed as gains and losses, on availability, maintenance ...
All impacts are analysed. The true or potential impacts are characterised. Those that can have a significant impact on the overall cost are quantified, initially in terms of work units, then in thousands of euros (for example, one day's outage = x K€). The non-quantifiable impacts considered significant must be qualitatively analysed (potential risks and contingencies).

2.2 The safety criteria adopted

The fundamental criteria in terms of impact on safety are:

- the impact on the workforce during plant operation;
- the impact on the population under incident or accident conditions.

Given the difficulty of assessing the above impacts directly, particularly in terms of monetary units, and in the interests of obtaining an objective quantification, more accessible criteria were adopted:

- Risk of core melt without loss of containment,
- Risk of core melt with early loss of containment; (major releases occurring within the first 24 hours, referred to as a "S1" in the terminology of the American WASH 1400 report);
- Risk of core melt without early loss of containment (releases filtered, occurring after 24 hours, referred to as "S3" in the terminology of the American WASH 1400 report);
- Doses in h*mSv/yr (with regard to the population and the workforce, under normal, incident or accident conditions).

These criteria enable the majority of files that have safety implications to be processed.
In order to make ranking and comparison easier, the number of assessment criteria is limited to four.

2.3 The estimation of impacts on plant operation and their valuation in terms of gains or expenditure

The impact on plant operation, and the resulting costs, can be broken down into two types:

- The direct costs, associated with the study and the implementation of the modification on the sites (investment cost, including costs relating to the dosimetric impact during the work involved in implementing the modification),
- The costs induced or avoided, such as maintenance costs, improvements in availability ... (operating costs).

To estimate the above, those in charge of the file base their calculations on the impact analysis methodology already in current use in the affairs or analyses of power plants in service.
Only the main impacts are assessed, as far as possible, quantitatively so as to obtain a "reliable" estimate of the cost of having the modifications. Those responsible for the files estimate them in work units (days outage, improvements in availability...), and then in k€. The operating costs are assessed over a period of 10 years inclusive, between two ten-yearly inspections.

As a general rule, dosimetry is still valued in h*mSv, to allow its specific impact to be clearly identified (doses on rare or specialised resources), which might otherwise be masked given the generally high investment costs, and above all to distinguish clearly the workforce field from the technical-economical field. On account of this, dosimetry constitutes a specific additional parameter, especially where ranking is concerned.

3 APPLICATION OF THE METHOD TO A SET OF MODIFICATIONS TYPICAL OF 3TYO FOR THE 900 MWE SERIES

The safety reassessment carried out within the scope of the third ten-yearly outage inspections (3YTO) of the thirty four 900 MWe units gave EDF its first opportunity to apply the cost-benefit method on a large scale, the objective being to rank a set of modifications during the decision-making phase of strategic planning.
In the absence of probabilistic safety assessments taking account of external and internal hazards, certain modifications relating to these problems were not analysed.
After assessing the costs and the safety benefit that they involve, the modifications were positioned in a diagram with the costs marked along the x axis and the safety benefits along the y axis: see Figure 1.

Positioning of the scales

So as to be able to compare the various modifications, correspondences between the four safety assessment criteria were established. This work was carried out on the basis of international state-of-the-art evaluation of the cost of the economic consequences of accidents (work mainly carried out by NRC and NEA) and a monetary evaluation of the avoided dose unit (work carried out by NRC, CEPN and EDF). These evaluations arrive at the following correspondences:

- a risk of core melt (without further specification of the nature of the potential releases) and a risk of delayed, filtered S3-type releases are considered to be equivalent;
- an annual frequency of S3 releases of 10^{-6} subsequent to core melt and an annual release of 3 h*mSv subsequent to incidents or accidents are considered equivalent;
- the consequences of an S1 release are considered to be 20 times greater than those of an S3-type release.

This positioning allowed us to rank the modifications according to their cost-benefit ratio.

4 RESULTS AND ANALYSIS

4.1 Presentation of the results

By standardising the safety benefit using the correspondences defined in § 3 above, we assessed the cumulative safety benefit by implementing the n first modifications on the list and the cumulative cost of these modifications (where n varied between 1 and 31). These cumulative safety benefits and costs are presented in Figure 2 (taking account of the number of units on which the modification has an impact, the 1st modification being the one that achieves the most favourable cost-benefit ratio and the 31 rd modification being the one that achieves the least favourable ratio).
This figure shows that the greater part of the safety benefit (more than 97% of the safety benefit achieved by all the modifications together) is achieved by implementing the 10 first modifications, for a little less than one-third of the total cost (31%).
Modifications can be adopted according to criteria other than the cost-benefit ratio alone, such as observing the regulatory criteria or improving the safety of the personnel (notwithstanding the radiological risk that is already taken into consideration in the safety section). Moreover a certain number of modifications had already been decided upon (at the request of either the DGSNR or EDF) before this exercise was carried out. The modifications adopted will not be limited to the first 10 modifications on the rank list and will therefore account for a much larger proportion of the overall cost.
Furthermore, sensitivity studies were carried out on the respective positioning of the four criteria. This positioning is indeed somewhat subjective, as it is essentially based on a synthesis of the opinions of international experts. It was therefore of interest to assess the influence of this positioning on the results obtained by the method. Each safety criterion was successively over evaluated and under evaluated by a factor of 10 relative to the other criteria. These studies disclosed the robustness of the ranking relative to variations in positioning. Indeed, the list of modifications to be adopted in the light of the cost-benefit ratio was never brought into doubt during these analyses.

4.2 Analysis of the safety benefits

For the third ten-yearly inspection programme, the main safety gains relate to taking severe accidents or external hazards into consideration: these areas also correspond to the strong points of the EPR in comparison to the reactors currently in operation.

Conversely, the modifications envisaged within the scope of the third ten-yearly inspections of the 900 MWe plant series have, in principle, a limited impact on level 1 probabilistic safety assessment. As would have been the case for the second ten-yearly inspection programme (subsequent to a retrospective cost-safety benefit analysis), the analysis does not disclose a significant gain at a reasonable cost in respect of the risk of core melt associated with initiating events occurring inside the NSSS.

Although there are uncertainties associated with the safety benefits and the costs, the orders of magnitude that led to the ranking, for a given category of safety benefit, appear to be robust. The analytical method is nevertheless iterative and the analyses could, if necessary, be fine-tuned to take possible new elements that arise during the proceedings into account.

Furthermore the ranking of all the safety benefits regardless of type, is a direct function of the adjustment of the scales relative to each other. The sensitivity studies have confirmed that this adjustment is relatively robust and therefore provides an initial methodological validation, on a large scale, of using this correspondence between the various types of safety benefit.

Cost-benefit analyses constitute an aid to decision-making. When the safety benefit is estimated using a probabilistic approach, as carried out here, it is not possible to take all the parameters associated with the file into consideration (particularly deterministic parameters). Consequently, the positioning in the diagram of each modification is supplemented by comments, in this respect, in the analysis sheets specific to each modification, so as to optimise the traceability of the reasons that led to certain modifications being included in, or excluded from, the definitive list.

5 OUTLOOK

The cost-benefit method, as well as the results obtained during the safety reassessment carried out within the scope of the third ten-yearly inspections of the 900 MWe series, were presented to the DGSNR at the end of 2004 and to the members of the Standing Reactor Committee at the beginning of 2005 for the initial exchanges.

The exercise carried out during 3TYO, which was the first to be carried out by EDF in the strategic phase over a large sample of modifications with varying safety implications, has served to confirm the interest of this decision-making tool. In the context of economic competition where cost control is of paramount concern, such a tool, which first ranks then helps to select, within given financial means, the modifications that provide the greatest gains in terms of safety, is now becoming essential. Although decision-making can by no means be devolved automatically to cost-benefit analysis, the knowledge of the information it provides has now become a key element in any assessment of nuclear power units.

This tool should be a vector for change in the dialogue with the Safety Authority, in that it will now enable the economic issues and constraints, from which EDF cannot escape, to be brought into its discussions with the plant operator.

In order to encourage exchanges on this subject, a review of the Standing Reactor Committee has also been scheduled for the first half of 2007 to discuss this cost-benefit method, currently being assessed by the IRSN, the technical support arm of the DGSNR in the interests of sharing the principles and allowing certain adjustments to be made before extending its use further.