Expert Judgement Methodology for Failure Anticipation in Nuclear Power Plants.

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ABSTRACT: Risk analysis is a tool for investigating and reducing uncertainty related to outcomes of future activities. We are interested here in failure anticipation in nuclear power plants. This involves very specific systems with little or no existing historical failures. In such cases, both engineering judgement and historical data are used to quantify uncertainty related to the predictions, like probabilities and failure rates. This paper is focussed on this aspect. The purpose is to provide an expert judgement elicitation methodology for anticipating the failures of a component, up to the end of its design life cycle period, including eventually an extension period.

1 INTRODUCTION

Failures of a component are generally well known during the design process. However if some failures are effectively observed, others are never observed, the degradation speeds being very low, often lower than the previously expected ones.

Moreover , generally for economic reasons, when degradation mechanisms are considered well controlled, the question is to extend the lifetime of the component beyond its design lifetime. New problems not considered at the design stage by functional analysis or FMEA, can occur. These problems can occur when modifying for instance the operation procedures or when improving the performance of installations or when ageing has not been detected or is not correctly managed. Consequently failures not predicted can occur, maintenance programmes can be inadequate and it is indispensable to anticipate these potential failures which can occur during the end of life phase, or during the extension life phase, of the component. This anticipation problem and its consequences in terms of decreasing the performance of a component (availability, safety, costs) have to be determined.

This paper is focussed on this aspect. The purpose is to provide an expert judgement elicitation methodology for anticipating the failures of a component, up to the end of its design life cycle period, including eventually an extension period.

We define failure anticipation as «the identification of events which are potentially objectionable as concerns cost, safety or availability, before they occur to evaluate the risks which they represent and to prepare and implement the appropriate preventive or exceptional measures which may be required.»

This paper is divided into three parts.

The first part deals with the use of expert judgement as an essential source of information in a decision-making context. As risk analysis typically deals with rare events, this makes relevant data scarce. For this reason, the use of expert judgement is strengthened. This is even truer when dealing with nuclear systems with a high quality design and a very demanding maintenance programme, where failures are very rare.

The second part, is a state of art on expert judgement methodologies. Some expert judgement methodologies already used in nuclear studies are presented, analysed and compared. Each methodology is described in a sheet including the characteristics, the phases, the strong and weak points and the references. Theses methodologies are then compared to our case study and classified according to the effort required for implementation and their appropriateness to anticipation. The objectives of the methodology, the creativity aspects, the expert team (multidisciplinary or not), and the existing applications are the main criteria to evaluate this appropriateness.

This leads us to identify recommendations aimed at building an expert judgement methodology well suited to failure anticipation.

2 FAILURE ANTICIPATION AND EXPERT JUDGEMENT

This study has been carried out within the framework of equipment life cycle considerations (Life Cycle Management). Replacements of certain equipment represent major investments for the company. In addition to the cost of design, manufacturing and installation, such equipment can often require significant maintenance. However, if an equipment has been designed with a high level of quality and is properly maintained, it is possible to envisage extension of its service life beyond the service life defined during the design process. This life cycle extension would make it possible to further amortise the initial investment.

Problems other than those identified during the defined process can appear. For this reason, it is useful to anticipate these potential failures which can occur during the end of life cycle period. To anticipate, it is necessary to take account of past feedback concerning the equipment and also of feedback relative to similar equipment installed in other units under the same environment, operating and maintenance conditions. It is also necessary to take account of modifications with respect to the design and current and forecast operating and maintenance conditions.

Two important aspects must be considered :

- management of physical ageing of component,
- cost management.

Due to the very special framework which the nuclear context represents, equipment used in this context presents several special characteristics :

- specific equipment,
- importance of safety,
- high quality design,
- stringent maintenance.

These characteristics result in limited feedback (low number of failures) which can make a statistical study difficult.

To compensate for this limited information, the classic solution consists in gathering expert survey information. The expert survey contributes to filling in the gaps of the feedback data. The expert is considered as a relevant source of information.

3 STATE OF THE ART ON EXPERT JUDGEMENT METHODOLOGIES

For this study, we have considered 10 expert judgement methodologies already used in nuclear studies. Six of them were considered on a benchmark exercise for a PSA Study, experiment L-24 of the JRC-ISIS, FARO facility for fuel coolant interaction studies in a nuclear reactor accident [1] :

- NNC methodology,
- FEJ-GRS methodology,
- STUK-VTT methodology,
- NUREG-1150 methodology,
- KEEJAM methodology,
- CTN-UPM methodology.

Other methods covering different safety applications have also been studied:

- Procedure guide for structured expert judgement,
- LCM methodology developed by EPRI (Life Cycle Management),
- TRIZ-AFD methodology (failure anticipation),
- RIPBR, Risk-Informed, Performance-Based Regulation, developed by the Department of Nuclear Engineering, MIT (risk management and maintenance optimisation).

3.1 Presentation of the methodologies

- NNC methodology[1]

This methodology was developed in 1996. It is based on the quality principles and procedures in the NNC Quality Procedures and Engineering Manual, U.K.. NNC is a Quality based methodology : based on quality assurance methods of the sources of information and of the problem solving processes, this approach is based on individual estimates. It involves a multi-disciplinary team, defined as a set of individuals with different but complementary skills.

As there is no rigorous formal elicitation process, the NNC approach may be called informal expert judgement.

- FEJ-GRS methodology[1]

This methodology was developed in 1985 by GRS, Germany. The methodology has been developed to quantify the state of knowledge in elements of a breakdown of the question and to propagate it through this breakdown to arrive at a quantitative uncertainty statement for the answer.

The methodology aggregates the judgements at lower levels and propagates them through the breakdown to arrive at a quantitative expression of the resulting state of knowledge at the model output level.

- VTT- STUK methodology [1]

This methodology was developed in 1997 by VTT Automation, STUK, Finland. It is based on the NUREG-1150 method (next paragraph). The use of belief networks allows an adaptation of the elicitation efforts according to the available resources. This is a simplification of NUREG-1150. The methodology was originally intended for use in various kinds of quantitative risk and reliability assessments, and in engineering and economical analyses, where remarkable uncertainties are present.

The methodology is based on probabilistic representation of uncertainties. The predictions obtained from experts are expressed as probability distributions. The combination of these assessments is based on hierarchical Bayes models (belief networks). Due to this property, it is also possible to deal with experts who are not familiar with the concepts of probability. Although, there are no restrictions as to the applicability of the method, it is at its best when applied to generate predictions to physical parameters

- NUREG-1150 methodology[1, 2, 3]

This methodology was developed in 1987-1990 by US-NRC, USA.

Highly structured, this approach includes training of the experts, review of discussions, individual elicitations, composition and aggregation of the opinions and review by experts.

In the NUREG-1150 approach, the domain experts write reports on the issue and their final estimates are elicited individually after expert's discussions, then averaged on an equal weight basis.

- KEEJAM methodology[1, 3]

This methodology was developed in 1997 at JRC-ISIS in collaboration with the University of Brescia and the University of Bologna, Italy. Knowledge based methodology : the method employs Knowledge Engineering techniques, and includes explicit modelling of the knowledge and problem solving procedure of the domain expert.

The approach provides structured and disciplined support to the knowledge engineer in eliciting the knowledge and reasoning strategies of the experts, building consistent knowledge models, and applying these models to the solution of the expert judgement task.

- CTN-UPM methodology[1]

This methodology was developed in 1997 by the Department of nuclear engineering, University of Polytechnics of Madrid, Spain.

It was developed and adapted on the basis of the NUREG-1150 methodology, although there exists a very important difference between them regarding the way to aggregate experts evaluations. The CTN protocol has been developed to get estimates of subjective probabilities for unknown parameters and uncertain events. It consists of nine steps executed sequentially.

- Procedure guide for structured expert judgement SEJ [4]

This methodology was developed in 2000 by Delft University of Technology, The Netherlands.

This is a European Guide for Expert Judgement in Uncertainty Analysis. It deals with procedures to perform an expert judgement study with the aim of achieving uncertainty distributions for an uncertainty analysis. In that field of application, the methods developed at the Delft University of Technology have benefited from experience gained with expert judgement in the US with the NUREG-1150 methodology. The procedure guide represents a mix of these developments.

- LCM methodology[5]

This methodology was developed by EPRI, USA as part of the Life Cycle Management/Nuclear Asset Management studies.

In order to guarantee long-term equipment reliability risk in nuclear power plants, LCM helps managing ageing degradation and obsolescence of important systems, structures and components. It gives an optimal solution for life cycle management based on an economical comparison between the different possible solutions.

- TRIZ-AFD methodology[6]

This methodology was developed in 1997 by KAPLAN, USA. Il allows identification and analyses of failures based on the TRIZ methodology. AFD (Anticipatory Failure Determination) was recently developed in the United States.

AFD consists of two tools: AFD 1 and AFD 2. AFD 1 is used to analyse failure causes. AFD 2 completes AFD1 with a number of steps for failure anticipation.

- RIPBR, Risk-Informed, Performance-Based Regulation developed at the Department of Nuclear Engineering, MIT [7].

RIPBR is an evolving alternative to the current prescriptive method of nuclear safety regulation. RIPBR is goals oriented while the prescriptive method is means oriented.

RIPBR is capable of justifying simultaneous safety and economic nuclear power improvements. It includes the formulation of probabilities through expert elicitation and the review of risk-informed, performance-based engineering analyses used to evaluate proposed changes to existing technical specifications.

3.2 Description of the methodologies

For each of these methodologies, a method sheet has been prepared to provide a summarised description of each.

Each sheet contains :

- the date and country of development,
- the organisation which developed the methodology,
- the characteristics of the method (presented to underscore its originality),
- the input data available to the expert, and the output data are both described.

The sheet then presents the various phases involved in the method and the existing tools. The main applications of the methodology are given, as well as the methodology's weak and strong points. Finally, the background references are given.

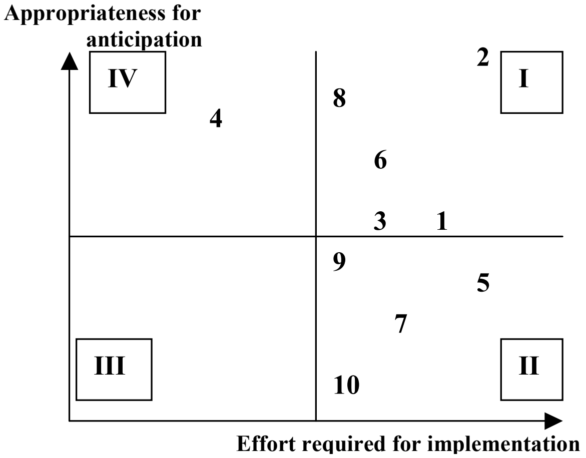
3.3 Classification of the methodologies

To compare the methods studied, we have classed them with respect to their appropriateness for anticipation and to the effort which they require, in an anticipation/effort diagram. To evaluate this appropriateness we considered for each methodology the objectives, the creativity aspects, the expert team (multidisciplinary or not), and the existing applications.

Part I at the top right shows those methods which are more appropriate to anticipation but which require high elicitation efforts.

Parts II and III at the bottom bring together the methods which are only moderately appropriate for anticipation purposes.

Part IV at the top left corresponds to those methods which are appropriate for anticipation and which do not require major efforts for implementation.



1 NNC
2 FEJ-GRC
3 STUK-VTT
4 NUREG-1150
5 KEEJAM
6 CTN-UPM
7 Procedure Guide for SEJ
8 LCM
9 TRIZ-AFD
10 RIPBR

Figure 1. Classification of the expert judgement methodology. Note : The effort/anticipation diagram represents an initial look at the various methodologies. A more precise classification, based on the expertise of a few major experts will be issued in the near future.

Method NUREG-1150 is located by expertise in this frame In our context, methodology NUREG-1150 appears to provide the best basis and it would be useful to adapt it to our failure anticipation context by further developing the aspects specific to anticipation and reducing the elicitation efforts. In this respect, the experts are not very available and the expertise time must therefore be reduced.

3.4 Analysis of the methodologies

The comparison of the various methodologies reveal a set of generic phases which have been developed to a greater or lesser extent in each depending on its objectives.

These generic phases are:

1. Definition of elicitation objectives.
2. Choice of experts to be elicited.
3. Training session in probabilities for experts.
4. Preparation of a questionnaire.
5. Elicitation.
6. Aggregation of expert replies.
7. Synthesis.

With respect to the generic phases described above, the phase concerning training of experts in probabilities has not been opted for at this time. Furthermore, this phase can be replaced by questions adapted to the experts interviewed and by work involving translation of the qualitative replies into probabilities. This would lighten the load of the expert and best responds to the expert's availability constraints.

4 SPECIFICATIONS OF AN EXPERT JUDGEMENT METHODOLOGY WELL SUITED TO FAILURE ANTICIPATION

The objective of the methodology is to allow the analyst to call on the expert to anticipate potential failures of a given equipment based on his own knowledge and on the data gathered by the analyst. The expert, here, is not only required to apply the knowledge which he has in tacit form, but also to provide imagination and creativity in anticipating an event.

4.1 Constraints

- Limited study time and experts which have only limited availability.

This constraint will limit the choice with respect to the type of elicitation to be chosen. The accent is placed on individual interviews. However, a return to the experts, as used in the Delphi method, should not be excluded.

- Reticence of experts with respect to elicitation

The objective of the study is to stimulate the expert's creativity to anticipate failures which may never have yet occurred. It is important for the expert to be able to express himself free of any constraints or pressure which can be created by interactive groups. The Delphi approach therefore does not seem very well suited to our study context as it results in systematically eliminating the most original replies [3]. This could be counter-productive in the anticipation context.

4.2 Preliminary inputs for elicitation input data generally available before expertise

Preliminary inputs for elicitation input data generally available before expertise:

- Objectives and context of the elicitation
- Data concerning the studied component: boundaries, design, functions, materials, op-

erating conditions, environment, procedures (safety, maintenance,…),…

These data are generally very heterogeneous. Operating feedback, procedures (like maintenance procedures), knowledge reports (rules, reliability reports,…), physical data,…can be found.

4.3 Outputs

1. Identification of potential and relevant degradation mechanisms and failures of the component.
2. Assessment of degradation and failure evolution.
3. Evaluation of potential failure effects : safety, unavailability and maintenance costs, dosimetry.
4. Solutions to apply to avoid, postpone or mitigate failures (and their efficiency and costs).

4.4 Expert judgement methodology for failure anticipation

In our present state of advance, the two main elicitation phases of the NUREG-1150 approach have been retained: the first one is a collective elicitation phase and the other one is an individual elicitation phase. The contents of these two phases are defined according failure anticipation requirements.

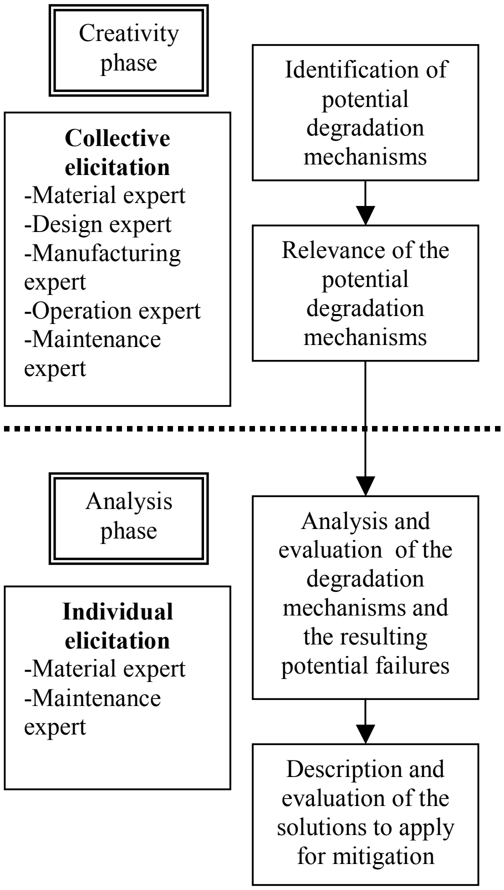


Figure 2. The two main phases of the expert judgement methodology for failure anticipation.

Phase 1 is based on a creativity approach. The purpose here, is to identify all potential and relevant degradation mechanisms of the component.

Phase 2 is the analysis phase. Identified degradation mechanisms and kinetics and the solutions to be applied are described and evaluated. The main tasks of the phase 2 are described on the figure 3 below.

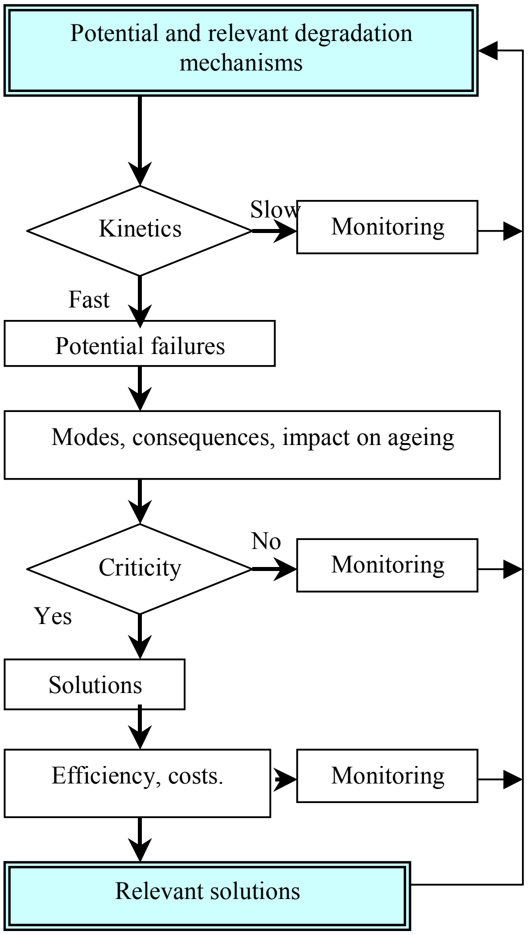


Figure 3. The main tasks of the analysis phase.

5 CONCLUSION

Through this state of the art on expert judgement methodologies used in nuclear studies, we have been able to compare the existing approaches. They have been classified according to their appropriateness to failure anticipation and to the effort required for their implementation. This has allowed us to identify the methodology that seems the most useful. This identified methodology, NUREG-1150, must, nevertheless, be better adapted to anticipation problems.

In our present state of advance, two main elicitation phases have been retained: the first one, the creativity phase based on collective elicitation and the second one, the analysis phase based on individual elicitation.

The question we have to answer now is “how to formulate the questions to be easily understood by experts according to their skills ?”

In order to carry on and validate these results, this failure anticipation methodology, here presented, will be applied to a nuclear power plant component.

6 REFERENCES

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