PSA-based Evaluation and Rating of Operational Events

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OBJECTIVES: WHY DO WE WANT TO USE PSA FOR THIS PURPOSE?

- To gain insights in NPP weaknesses in relation to the occurred situation
- To obtain a measure of the event severity
- To validate and backfit the PSA models

GLOSSARY OF TERMS

CDF	Core Damage Frequency
CCDP	Conditional Core Damage Probability
IE	Initiating Event
HRA	Human Reliability Analysis
ASP	US-NRC project on Accident Sequence Precursor analysis
LER	Licensee Event Report
IRS	IAEA Incident Reporting System
INES	International Nuclear Event Scale

CONTENTS:

1. HISTORICAL BACKGROUND

- US-NRC Accident Sequence Precursor (ASP)
- Other National Projects: Germany, Sweden, Finland, France

1.1 US-NRC ASP (Accident Sequence Precursor)

- Analysis of precursors using probabilistic approaches
- Started in 1979 at the Oak Ridge Laboratory
- Applicable to USA commercial plants
- Use of *generic & simplified* BWR and PWR PSA models
- Used to evaluate safety significance of the events reported through the LER programme:
  - . Calculation of CCDP due to each event
  - . CCDP was used as a means of ranking events

Important benefits:

- ASP showed that PSA-based methods are a good approach for evaluation and ranking of events
- ASP showed that PSA-based evaluation of events is a good approach for making PSA more complete and realistic (Search for events not or poorly predicted in the PSA)

Limitations:

- Use of generic models
- Use of simplified models

1.2 Other national projects: Germany, Sweden, Finland, France

- Several national projects have developed since the mid eighties
- i. e. German Precursor Study (1985): To validate German Risk Study using the operational experience of the Biblis NPP: $\mathbf{CDF_{operexp} < CDF_{risk\ study}}$.
- References:

"Precursor Studies", H. Hoertner and P. Kafka, published in IAEA-TECDOC-387 "Combining Risk Analysis and Operating Experience", 1986.

"Demonstration Case Studies on Living PSA", SKI Technical Report 93:33, NKS/SIK-1 (92)27, August 1993.

"Safety Evaluation by Living Probabilistic Safety Assessment. Procedures and Applications for Planning of Operational Activities and Analysis of Operating Experience", SKI Report 94:2, January 1994.

"TVO II - Risk Follow-up study of precursors and component failures leading to LCO's, Jan 1985 - May 1994", Finnish Centre for Radiation and Nuclear Safety (STUK) Nuclear Safety Department, Draft Report, October 1994.

"Incidents Analysis", Ph. Francois (EdF), Topic 4, International Seminar, November 21-23, 1994.

2. PROCEDURES FOR EVENT EVALUATION USING PSA

2.1 Background

IAEA-TECDOC-611: "Use of plant specific PSA to evaluate incidents at nuclear power plants" (1991)

- Initiated in the framework of the IAEA-IRS project: optimizing experience feedback requires selection of events with higher safety significance
- Purpose: To characterize the relative importance of incidents
- Starting point: Use of plant-specific PSA in order to:
  - . allow better understanding of NPP vulnerabilities
  - . check the PSA model for appropriateness and completeness

2.2 Methodology

- Selection of incidents for analysis
- Understanding of the incident and its safety implications
- Establishment of the relationship between the incident and the PSA model
- Modification of the models to reflect the incident
- Calculation of new PSA results
- Analysis of the results

2.2.1 Selection of incidents for analysis

Initial qualitative screening to select those of most value to the analysis:

- Any incident which degrades safety functions is a candidate for selection: Incidents that involve safety function failure or degradation

- Any incident which results in unexpected or significant challenges to the safety functions is a candidate for selection: Initiating events and precursors to initiating events
- Events occurring at a frequency greater than the estimated frequency for the PSA
- Multiple failures or degradations
- Events that are not well modelled in the PSA

2.2.2 Understanding of the incident and its safety implications

- It requires knowledge of the NPP design and operation in order to determine if the incident impacted or had the potential to impact a safety function
- It requires knowledge of the contents of the PSA to determine if the potential impacts are within the scope or resolution of the PSA models

2.2.3 Establishment of the relationship between the incident and the PSA model

To determine:

- **Accident sequences** involved
- **Fault trees** and **basic events** that model the components and operator actions concerned
- Which **recovery actions** could be claimed and which are impossible

2.2.4 Modification of the models to reflect the incident

i.e.:

- Restoring accident sequences that were originally truncated out in the final results
- Changing basic event probabilities
- Evaluating new human error rates

2.2.5 Calculation of new PSA results

Calculation of the new results conditional on the existence of the incident:

- Events that could have lead to an initiating event but no IE occurred
- Initiating events
- Events that jeopardize NPP response to an initiating event but no IE occurred

2.2.6 Analysis of the results

- Comparison of new and existing results
- Determination of the new dominant contributors
- Determination of the new importances of the remaining systems, components and operator actions to prevent core damage

2.3 Detailed procedure

- Review of the incident
- Identification of all the event tree sequences affected by the incident
- Review of the identified sequences and cut-sets to determine if the affected systems and basic events were not truncated in the original results
- Determination of the best estimate failure probabilities for all basic events impacted by the incident
- Calculation of the new accident sequence conditional probability
- Determination of the recovery actions to be applied to the cut-sets
- Calculation of importance measures for the new results
- Performance of the required sensitivity analyses
- Documentation of the analysis

2.3.1 Review of the incident

- Identify the chronology of events
- Identify all equipment failures, degradations and unavailabilities
- Note all operator actions taken, specially those not covered by procedures and training
- Review related problems and conditions that occurred a period before and after the event

2.3.2 Identification of all the event tree sequences affected by the incident

- The full event tree models should be used
- The analyst must know which event tree headings include the equipment and operator actions involved in the event
- The sequences of concern are those with a failure branch for at least one of the headings of concern

2.3.3 Review of the identified sequences and cut-sets to determine if the affected systems and basic events were not truncated in the original results

If the sequences or cut-sets of concern were not retained, they have to be generated. The cut-off criteria should be properly selected

2.3.4 Determination of the best estimate failure probabilities for all basic events impacted by the incident

- Failed components can be modeled as house events "1" to correctly generate the Boolean logic
- Unavailabilities: their duration must be taken into account:
  - . Multiplying the IE frequency by the unavailability time (fraction of the year)
  - . Introducing the real unavailability event (instead if a failed house event)

- Equipment or operator degradations: Detailed analyses may be required to calculate the new failure probabilities

2.3.5 Calculation of the new accident sequence conditional probability

- Events that could have lead to an initiating event but no IE occurred: Development of new event trees may be required
- Initiating events: calculation of the Conditional Core Damage Probability with the NPP boundary conditions at the time of the incident (based on the NPP status)
- Events that jeopardize NPP response to an initiating event but no IE occurred: calculation of all Conditional Core Damage Probabilities for all IEs for which plant response could be degraded by the incident

WARNING: Impossible combinations

2.3.6 Determination of the recovery actions to be applied to the cut-sets

- Based on the events of the incident
- Available personnel should be considered
- The operating procedures should be taken into account
- Dedicated HRA may be required
- Recovery actions included in the original PSA should be reconsidered

2.3.7 Calculation of importance measures for the new results

- Fussell-Vesely
- Risk Reduction Worth
- Risk Achievement Worth

2.3.8 Performance of the required sensitivity analyses

For key contributors that are subject to uncertainty, sensitivity analyses should be performed to evaluate the impact on the results and therefore on the conclusions and lessons learned from the event evaluation

2.3.9 Documentation of the analysis

- The documentation should be clear concise and traceable
- All the steps of the process should be fully documented

3. USE OF PSA FOR EVENT RATING

3.1 Objective

To develop a consistent measure of the relative safety significance of each event

3.2 Warnings

- The relative significance of an event might be different depending on the "risk index" used, i.e. Core Damage Frequency vs. Frequency of Large Release
- A PSA-based approach to rate events will not be useful for all the events that happen at the plant (i.e. radiation exposure, waste production). Care must be taken when comparing the safety significance of all NPP events that have safety implications

3.3 Proposals

3.3.1 First proposal: Measures of importance

Events can be rated based on the importance or weight of the relevant cut-sets. The following approach could be followed:

- Modification of the event/s frequency/ies according to the observations
- Calculation of the new CDF due to the impacted sequences (CDF_c)
- Normalization of the obtained CDF_c with respect to the baseline CDF

3.3.2 Second proposal: PSA direct results

Operational events could be rated according to the *Probability of Core Damage conditional to the occurrence of the event*

3.4 Conclusions

Whatever risk-based method, existing or newly developed, is used for event rating:

- The measures developed should be comparable for all events analyzed

- The measures should be calculated on a consistent basis
- The rating scale should be understood, by the analysts that perform the analyses and by the organizations who might receive rating reports and possibly base decisions on these

4. EXAMPLES OF CURRENT ACTIVITIES

- Risk-based Approach to Analyzing Operating Events (US-Department of Energy)
- Probabilistic Incident Analysis (EdF, France)

This information has been extracted from the Proceedings of the PSAM-96. Crete, Greece. July 1996

4.1 Risk-based approach to analyzing operating events (US-Department of Energy)

The proposed risk-based approach for evaluation of operational events consists of the following steps:

1. Qualitative estimations of conditional probability and consequence -> qualitative estimation of risk
2. Comparison to risk criteria
3. Semi-quantitative estimations of conditional probability and consequence -> semi-quantitative estimation of risk (using simplified models)
4. Comparison to reference value
5. Refinement of the risk estimate
6. Cost-benefit analysis of possible system and procedure modifications

4.2 Probabilistic Incident Analysis (EDF, France)

4.2.1 Objective

Identification and analysis of all the incidents that might degenerate and result in core damage or radioactive release

4.2.2 Systematic selection of events

Qualitative criteria based on safety significance

4.2.3 Analysis

Calculation of conditional probability of core meltdown

4.2.4 Definition of accident precursor

Is any incident whose conditional probability of core melt is greater that 1E-6 when all the parameters are adjusted

4.2.5 Key points

- Promotion of a *risk-analysis culture* among operators
- Value of *accident feedback*
- Understanding of *how serious it is and why it is serious*