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Living PSA - risk monitoring - current use and developments

Kafka, P.

Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, Garching, Germany

ABSTRACT

In the area of PSA application the most rapidly growing area is the development of Living PSA and Risk Monitoring models. Both are used for Operational Risk Management of NPPs. The paper summarizes definitions, aims, realized examples, and recommendations for further use and developments.

1. PSA - HISTORICAL BACKGROUND

The first generation of Probabilistic Safety Assessment (PSAs) usually focused primarily on identification of hidden design weaknesses and the improvement of inadequate operational procedures. These PSA applications may concern different plant life stages as well as various NPP concepts.

After the TMI accident the world nuclear industry was preoccupied with additional hardware installations and quality control procedures, neglecting all the man - machine and managerial aspects, and a risk-based decision making procedure.

Nowadays the most rapidly growing area of PSA applications is their use to support NPP operation, in particular, the risk-based configuration control [SAM91], risk-based test-, repair- and maintenance activities [KIM92], and the risk-based aging control [LEV91]. This came from the two facts that, firstly, much more plants are under operation (approximately 430 world-wide) than in construction and therefore the risk associated with the peaceful use of nuclear power has to be controlled and managed most effectively at the plants during operation, and secondly, the operational costs of the NPPs should be lowered holding the same baseline risk level. Operational Risk Management (ORM) based on Living PSAs (LPSA) and Risk Monitoring (RM) represents the key wording for that twofold challenges for today's safety experts [IAEA94, NRC94].

2. OPERATIONAL RISK MANAGEMENT (ORM) BASED ON LPSA AND RM

The objective of ORM [JOK94] is to detect and to control plant configurations and plant operational actions from a risk perspective (see Fig. 2.1). To control these two issues is important because all NPP risk, all incidents and accidents, and all accident precursors arise because critical configurations and/or operational actions have occurred. If configurations and actions were managed so that critical, high-risk configurations and actions did not occur, then risk would be small and practically no severe accidents would occur; the argued safety philosophy that NPPs take advantage consisting of fault tolerant systems would be true.

It exists a widespread common understanding within the nuclear community today that ORM can be well outlined and supported with the specific use of PSA technology

tailored as computerized tools named as Living PSA (LPSA) or as Risk/Safety Monitor (RM).

Basic Definitions for LPSA and RM Models

The PSA applications using computerized modeling techniques covered in this paper divided into two broad groups:

- Living PSA (LPSA), and
- Risk Monitoring (RM)

A distinction between LPSA and RM can be expressed from [IAEA93] as following:

♦ **LPSA:**

A formally documented PSA model of a plant used to determine the average risk based on the expected unavailability of systems and components. It is updated on a regular, but not necessary frequent, basis. It is usually operated by the engineering staff in support of medium and long-term activities (system modifications, AOTs (Allowable Outage Time) change, data base change, etc.). It normally forms part of the overall plant safety case.

♦ **RM:**

A PSA model of the plant used to determine the instantaneous risk based on the actual status of the systems and components. It is up dated on at least the same frequency as the LPSA for plant design and data but can reflect the current status of test in progress and maintenance activities. The RM is based on and consistent with a LPSA. It is usually operated by responsible plant staff in support of operating, test, maintenance and repair decisions.

These definitions can be re-arranged for explanation that a LPSA represents a generic long-term trend model which can adopt and used specifically for four basic issues:

1. for risk assessment (averaging) for a given time period (e. g. one year) of interest,
2. for risk prognosis (predictive) for the future behavior of the plant (e.g. the next five years),
3. for risk evaluation of operational experience (retrospective, e.g. for the last year; named as precursor studies [HOE87]), and
4. for risk monitoring (RM) (e.g. a risk snapshot at a given day at the plant)

This explanation is graphically shown in Fig. 2.1.

Fig. 2.1: Schematic Distinction between LPSA and RM Models [KAF92]

3. LIVING PSA (LPSA)

3.1 Aims and Objectives

Based on the above definition the aims and objectives of a LPSA is the evaluation of the average risk caused by the operation of the plant. The primary objective is to verify the average risk level of the plant and to identify the major risk contributors. These results are applicable for long term planning in order to improve the identified actual weaknesses of the plant. The long term planning includes evaluation and comparisons of risk effects of changes in the plant design, maintenance and test strategies, the operating procedures, technical specifications and statistical data. The aim of the LPSA is to optimize the plant operation, including test and maintenance, the redesign if new systems will be installed, with respect to risk minimizing and operational flexibility.

3.2 Basic Methods

Within a LPSA the representation of the plant safety status is the key issue. Thus, the model should reflect the knowledge about which condition each system and component is in and how this effect the plant risk level. The conditions can be: operation, standby, repair, test, maintenance, etc.

Different to the basic PSA within a LPSA we have to distinguish between evident events (e.g. repair) and hidden events (e.g. standby component failure).

Successful components can be treated as a standby component or a non-detectable. An unsuccessful component can be treated with a latent unavailability $q(t) = 1$, since the latest successful test, or with a linear probability for the failure to occur at any time in the interval from the latest successful test to the detection of the failure. Details for that see also [JOH94, SAM94].

3.3 Limitations

In all the LPSA there exist some limitations but most of them are the limitations of the basic PSA itself. Nevertheless, developers and users of LPSAs should be aware of these limitations and therefore the limitations are summarized below.

- Incompleteness of the Scenarios and Failure Models
- Test Effectiveness of Standby Components
- Time Effects and Constraints
- Parameter and Model Uncertainties
- Common Cause Failures (CCF).

4. RISK MONITORING (RM)

4.1 Aims and Objectives

The objectives of a RM - as a snapshot model appropriate for monitoring the actual risk at a given moment during plant life - can be summarized as following:

- To obtain an information regarding the instantaneous risk level at the plant under operation;
- To obtain an evaluation of risk significance of configuration management of the systems;
- To obtain an evaluation of the surveillance and maintenance activities in the plant;
- To identify areas of emphasis for maintenance and test personnel based on risk-based way of thinking;
- To identify areas where regulatory requirements e.g. regarding AOTs can be risk-based modified without compromising plant safety.

4.2 Basic Methods

The basic method for a RM is to calculate the Core Damage Frequency (CDF) considering the actual status of all components involved in the basic PSA model. Normally, we have to consider two possibilities for all the components. Regularly standby or out of service, caused by various reasons like a random failure, test or maintenance. The

increase of the CDF caused by the components down is normally expressed as a factor $CDF_{actual} / CDF_{nominal}$. Typical values for this factor are between 2 and 8 during planned maintenance actions at the plant. In some specific cases, if we have observed a serious combination of components down, then a factor between 10 and < 100 might be realistic.

The actual calculation of the CDF can be done in two ways. Firstly, an update of the pre-calculated cut sets including the Boolean reduction procedure needed and secondly, a recalculation of the fault trees consisting the components questioned by an fault tree evaluation code. Both methods has some advantages and disadvantages. The first method is obviously faster but it needs the full scale cut set list without truncations and artificial super-components. The second method needs a fast cut set generator in the fault tree code. Developments in the last year fulfill more and more this requirement.

Additionally to the recalculation of the CDF most of the RMs calculates various Importance Measures (IM) e.g. the Risk Achievement Worth, Risk Reduction Worth and the Fussel - Vesely Importance. That answers the questions what happens if a given component is totally worth ($\lambda = 1$) or what happens if a given component is totally perfect ($\lambda = 0$) and what is the contribution of a given component to the unavailability of a system function. This IMs can be calculated for the systems without any failed component or for systems if one, two or more components are down.

The IMs can be formulated at different levels. At system function level, at sequence level for a given event tree and finally at CDF level. These large spectrum of various IMs provides detailed insights where weaknesses are located in the system and where maintenance work would be not appropriate at a given situation.

Some RMs calculates a repair prioritization, if more then one component is down (e.g. PRISIM and RELADS, see Table 1). In this calculation procedure the sequence of the repair actions is changed in such a way that the area defined by the stepwise increase of the CDF (if a component fails) and the duration of this steps (defined by the repair time of the various components) becomes minimal.

Finally, Sensitivity Calculations (SC) (e.g. with the 5% fractile and 95% fractile of a given failure rate λ) are possible with most of the RMs. This type of SC provides insights for which component we need particular statistically hard failure rates based on operational experiences. Details see also [JOH94, SAM94].

4.3. Experiences with RMs

The evaluation of configuration changes regarding the CDF studied for various plants by various experts provided the following insights:

- Some equipment configurations can cause large increases in CDF, e.g., larger than two orders of magnitude over the baseline risk level. Several such configurations are currently controlled by Technical Specifications. The expected frequency of occurrences of the impacting configurations is small and their contributions to CDF are generally small.
- Many such significant configurations can result from double component combinations, but, in some instances, single-component outages can result in significant increases in CDF. This indicates that a plant can very quickly move from a normal to high CDF level and that the process is not always gradual, i.e., plants do not necessarily get into high-risk impact configurations gradually by the accumulation of out-of-service components.
- Marginal combinations of components can cause significant CDF contributions if the duration of outage is not controlled.

When plants operate near baseline CDF, increased operational flexibility can be provides for outage durations of low risk impact components and configurations.

5. REALIZED EXAMPLES

An overview regarding realized examples will be given at Table 1. All these examples are described in detail within the open literature (References see Chapter 7 "Literature") and therefore here some short characterizations and comments are given only. Additionally see Literature.

Table 1: Overview regarding LPSA and RM Systems (s. also [APO90,IAEA93])

System Name, State, Organisms.	Status	Key Features	Level of Details	Type Remarks
ARIESE/EVA SP(UTESA) [GEO92]	Full use	Use by plant operation and management staff, "what if" calculations,	Level 1, human factor, CCF, full power only	LPSA licensed
DRM U.K. (NE)	Pilot use	Use by plant operation and management staff, "what if" calculations, AOT, STI management	Level 1, human factor, CCF, full power only	RM
ESOP U.K. (NE) [WAD90]	Full use	Use by plant operation and management staff, "what if" calculations, AOT, STI management, compliance with targets	Level 1, human factor, CCF, full power only	RM
ESSM, Vers. 2.2 U. K. (NE) [EVA94] ESSM, Vers. 4.0	Full use Under Development	Use by plant operation and management staff, "what if" calculations, AOT, STI management, compliance with targets	Level 1, human factor, CCF, full power only	RM licensed
LIPSAS J (PNC) [AIZ94]	Full use	Use by plant operation and management staff, "what if" calculations, AOT, STI management, compliance with targets	Level 1, human factor, CCF, full power and shut down risk	RM (LPSA)
PRISIM USA (Fussell) [KIR88]	Full use in the past	Use by plant operation and management staff, "what if" calculations	Level 1, human factor, CCF, full power only	RM
RBI Man H (Veiki)	Under development	Risk advice within the NPP information system, "what if" calculations	Level 1, human factor, CCF, full power only	RM
RELADS, D (GRS) [KAF94]	Under development	Use by plant operation and management staff, "what if" calculations, AOT, STI management	Level 1, human factor, CCF, full power only	RM
REVEAL_W™ USA (Scientech) [DEZ94]	Under development	Use by plant operation and management staff, "what if" calculations, AOT, STI optimization, compliance with targets	Level 1, human factor, CCF, various plant states	RM
RISK Spectrum™ (Relcon) [REL92]	Full use	Use by plant operation and management staff, "what if" calculations, use for risk follow-up	Level 1, human factor, CCF, full power only	LPSA (RM) licensed
SAFETY MONITOR™, USA (NUS) [MOR93]	Pilot use	Use by plant operation and management staff, "what if" calculations, AOT, STI management, compliance with targets	Level 1, human factor, CCF, full power only	RM
SAIS D (TÜV-Nord) [BOH94]	Pilot use	Use by plant operation and management staff, "what if" calculations, use as safety related, info. system	Level 1, human factor, CCF, full power only	LPSA (RM)
SAPHIR 5.0 USA (NRC, EG&G) [RUS93]	Full use	Use by Safety Analysts, Recalculation of PSAs, "what if" calculations, Package includes Data management MARD, Fault tree analyser IRRAS, and System analysis and Risk Assessment SARA	Level 1 and 2, Human factor, CCF, any plant state	LPSA
SAS USA (SAIC) [PUG94]	Pilot use	Use by plant operation and management staff, "what if" calculations, AOT, STI management compliance with targets	Level 1, human factor, CCF, full power only	RM

STARS EU (JRC) [BES94]	Pilot use	use for plant design and plant operation, "what if" calculations, fault tree generation	Level 1, human factor, CCF, full power only	LPSA
What2 South Africa, (ESCOM)	Full use	Use by plant operation and management staff, "what if" calculations	Level 1, human factor, CCF, full power and non-power operating, fire and security risk	LPSA licensed

6. RECOMMENDATIONS

The risk-based method represented by LPSA and RM should be better integrated with other safety management methods for an effective Operational Risk Management. Many examples make it clear that deterministic judgments and rules can not handle adequate random elements e.g. moments of component failures, uncertainties regarding the state of knowledge and the skill-, rule-, and knowledge-based plant personnel actions. Thus, there is a great need to use the probabilistic methods and models in all the fields where the traditional deterministic approach is inadequate.

It is the merit of the powerful computers available today to assess plant safety not only with deterministic formulas based on point values of the variables, but also to treat the distributed variables and the additional parameter "probability" with expanded models. Thus, one can understand and model much more realistic (as a few years ago) the "real world".

However, beyond the use of powerful computers, the LPSA and RM activities require a close relationship to the plant operation and maintenance personnel compared to the basic PSA application. These activities will always require specialists to operate and maintain the computerized model.

Based on the practical experience demonstrated and on the well known great potential of LPSA and RM regarding safety improvements and cost reductions in NPPs the implementation of Risk Monitoring (RM) based on LPSA model is strongly recommended.

The implementation can be divided into two steps:

1. Specification and preparation of procedures, models, and data needed,
2. Specification and preparation of criteria and procedures for risk-based decision making.

The implemented RM could be applied to the following issues:

- Operational Risk Management (ORM),
- Short-term risk control and risk-based configuration management,
- Risk-based evaluation of surveillance test intervals (STIs),
- Risk-based evaluation of allowable outage times (AOTs) and maintenance planning,
- Risk-based analysis of operating experience generating severity ranking and probabilistic safety indicators,
- Management support based on "what happens if" answers from the RM,
- Training for plant staff to familiarize them with PSA-type models, problems and decisions.

7. LITERATURE

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