Annals of Nuclear Energy 91 (2016) 142–147

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Risk monitor riskangel for risk-informed applications in nuclear power plants

Fang Wang, Jiaqun Wang, Jin Wang, Yazhou Li, Liqin Hu *, Yican Wu

Key Laboratory of Neutronics and Radiation Safety, Institute of Nuclear Energy Safety Technology, Chinese Academy of Sciences, Hefei, Anhui 230031, China

ARTICLE INFO

Article history:
Received 21 June 2015
Received in revised form 12 December 2015
Accepted 17 December 2015
Available online 28 January 2016

Keywords:
Risk
Probabilistic Safety Assessment
Risk-informed
Risk monitor

ABSTRACT

This paper studied the requirements of risk monitor software and its applications as a plant specific risk monitor, which supports risk-informed configuration risk management for the two CANDU 6 units at the Third Qinshan nuclear power plant (TQNPP) in China. It also describes the regulatory prospective on risk-informed Probabilistic Safety Assessment (PSA) applications and the use of risk monitor at operating nuclear power plants, high level technical and functional requirements for the development of CANDU specific risk monitor software, and future development trends.

1. Introduction

Risk is precisely described as a multiplication of undesirable consequences and their occurrence frequencies. In a nuclear power plant, risks are commonly presented in terms of Core Damage Frequency (CDF) and Large Early Release Frequency (LERF), resulted from the occurrence of an initiating event and failure of the expected mitigating system functions.

Probabilistic Safety Assessment (PSA) is an effective analysis approach that systematically analyses the accident sequence following a postulated initiating event, estimates the occurrence frequency, and identifies the associated dominant contributors to the defined end state of the accident sequence (Keller and Modarres, 2005).

Insights from PSA are considered as an important fact in a risk-informed integrated decision making process (USNRC, 2003) that is required to assess the following elements (USNRC, 2011):

(1) The proposed change meets the current regulations.
(2) The proposed change is consistent with the defense-in-depth philosophy.
(3) The proposed change maintains sufficient safety margins.
(4) The increase in Core Damage Frequency or risk should be small.
(5) The impact of the proposed change should be monitored.

For a timely assessment of various risks in a nuclear power plant, A plant specific risk monitor (RM) tool is required to provide technical support in the risk-informed integrated decision making process. It consists a well-developed RM software and a solid plant specific operational PSA model. A well-developed RM tool has the following benefits:

(1) Flexibility for the evaluation of plant outage maintenance schedule to minimize risks at shutdown and increase capacity factor.
(2) Reduce spurious trip frequency and maintain grid stability.
(3) Optimization of allowed outage time (AOT) under limiting conditions for operation and Surveillance Test Interval (STI) specified in Technical Specification (TS).
(4) Enhance plant safety by proper configuration control, compliance with maintenance rule.
(5) Provide an integrated data management system.
(6) Technical support to plant life and asset management.

This study discusses an overall picture of the risk monitor software application for the two CANDU 6 units at TQNPP to support various risk-informed PSA applications.

2. Risk-informed applications' requirements on risk monitor

2.1. Regulatory prospective

Following the white paper issued in June 1998 and the implementation plan published in February 2000, the USNRC is

* Corresponding author. Tel.: +86 551 65593687.
E-mail address: liqin.hu@fds.org.cn (L. Hu).

http://dx.doi.org/10.1016/j.anucene.2015.12.019
0306-4549/

consistently prompting and pursuing the risk-informed and performance based regulation (USNRC, 1998). This symbolizes the beginning of systematic application of PSA. In April 2006, NRC issued a working draft report "Framework for the Development of a risk-informed, Performance-Based, Technology-Neutral Alternative to 10 CFR Part 50" as a major milestone in the implementation plan of the risk-informed regulation.

As part of the risk-informed Reactor Oversight Process (ROP), NRC also established a risk-informed performance monitoring process for safety significant mitigating systems of each operating NPP known as Mitigating System Performance Index (MSPI).

Chinese National Nuclear Safety Administration (NNSA) is also actively working on this subject, including a PSA guide. In December 2007, nuclear safety center of NNSA hosted a first PSA forum in Beijing, and drafted a technical policy on the application of PSA at operating nuclear power plants in China. In the recently issued regulatory codes, NNSA emphasizes the use of PSA for severe accident sequence identification and promotes risk-informed PSA applications in operating nuclear power plants.

Since US NRC imposed Maintenance Rule, 10 CFR 50.65 (a) (4) USNRC, 2007, which requires a licensee to assess and manage the increase in risk that may result from the proposed maintenance activities before entering the maintenance configuration and right after entering a non-voluntary configuration during all plant operation modes, the application of RM tool is widely adopted in nuclear power plants. It is one of the most influential regulatory rules in the risk-informed regulation and PRA applications.

2.2. The need of risk monitor

Risk monitor (RM) tool is a key analysis tool in risk-informed PSA applications (Wall et al., 2001), which loads an operational PSA model into a software platform. It provides an on-line monitoring capability of tracking risk changes under different plant configurations and operation modes, support risk-informed decision making to cope with emergent events that may occur during normal plant operation or while routine in-service equipment maintenance/testing activities are carried out.

The difficulties of developing a RM software includes:

(1) A high-performance real-time risk computation method, which can solve large operational PSA model in one to three minutes.
(2) Users located in different departments can use the software collaboratively (via network).
(3) Optimization of large-scale maintenance plan, equipment allowed outage time and test intervals can be evaluated fast, reliably and steadily.
(4) Most of the users are not PSA professionals, and how can the RM software interact with them friendly and expediently via a user friendly GUI for various mapping activities, such as equipment to basic event(s), maintenance to equipment etc.
(5) Data exchange is expected with other plant management tools used for maintenance, asset and plant life management.

The RM tool is also used to optimize TS and justify maintenance activities during power production. RM software is requiredfor both on-line and off-line usage to support the risk-informed decision making process.

2.2.1. Requirements for on-line usage

The RM should be able to properly quantify the PSA model and present the final results as CDF or otherwise specified risk measures under a given plant configuration associated with unexpected event(s).

(1) Risk measures
Risk measures, such as annual average risk, instantaneous risk to be quantified can be easily specified with no confusion via RM interface.
(2) Plant configuration
Unexpected plant configuration can be identified and addressed in an effective way (e.g. mapping). Expected plant configuration can be pre-defined and stored in the RM for easy interface with limiting conditions operations (LCOs) in TS.
(3) Mapping
The RM should provide a user friendly window for various mapping activities, such as equipment to basic event(s), maintenance to equipment etc. It should also provide a practical tool to verify the correctness of the mapping process.
(4) Priority order
The RM should be able to determine the priority order as which component should be returned to service at first.
(5) Estimate allowed outage time
The AOT, sometimes referred as allowed configuration time (ACT) when dealing with multiple equipment outage, should be advised properly, not contradict to the existing regulatory requirement.
(6) Dynamic interfacing database
The RM should be able to address events with variable probability or failure rate (including plant specific reliability data) within a given observation time and, in long-term, over the plant lifetime. Data exchange is expected with other plant management tools used for maintenance, asset and plant life management.

2.2.2. Requirements for off-line usage

RM should have characteristics as a user friendly PSA tool to support plant outage maintenance planning and optimize component allowed outage time and test intervals.

(1) Shutdown risk measure
The RM should be able to quantify shutdown state risk models according to pre-defined plant operating states using a user friendly man–machine interface.
(2) Outage maintenance planning
The RM should be able to import and modify multiple plant maintenance schedules and automatically determine the corresponding plant configurations for the quantification of risk profiles for risk-informed comparison and decision making.
(3) Plant configuration control
Maintenance related plant configuration should be predefined either on system level or component level and stored in the RM or imported into the RM. Input and modification of the plant configuration should be user friendly. Configuration control should be risk-informed but not contradict to the existing regulatory requirements.
(4) Mapping capabilities
The RM should provide a user friendly window for various mapping activities, such as equipment to basic event(s), maintenance to equipment etc. It should also provide a practical tool to verify the correctness of the mapping process.
(5) Optimizing TS
The RM should be able to optimize the component allowed outage time and test intervals specified in Tech Specs, and cope with multiple LCOs that are not addressed in the current Tech Specs.

To overcome the above difficulties and achieve the expected functional requirements, FDS team has developed a multipurpose