Application of PSA in Qinshan Nuclear Power Plant

Liu Donglin
CNNP Nuclear Power Operation Management Co., Ltd. , Haiyan, China

Abstract: Probabilistic Safety Analysis (PSA) technology, as a mature safety evaluation technology for nuclear power plants, has been widely used in the design, operation, maintenance and technical alteration of nuclear power plants. The PSA work in China started in the 1980s and has developed rapidly in recent years. In China, the regulatory body NNSA (National Nuclear Safety Administration) also encourages nuclear power plants to use the combination of PSA and deterministic approach to evaluate and optimize the safety of production, operation and maintenance activities of power plants.
There are 9 units in operation in Qinshan site, which are technically supported by CNNO(CNNP Nuclear Power Operation Management Co., Ltd.). The development of PSA by CNNO began in 2001. Since then, the PSA model of each unit has been continuously improved. All these lay a solid foundation for the application of PSA in CNNO. In addition, PSA is introduced into the safety evaluation of power plants and corresponding management procedures are established. Thus, a set of risk-informed application systems has been formed for the use in plant maintenance, operation and other production activities. It plays an important role in ensuring the safe and stable operation of power plants and improving the operation efficiency of power plants. Specific PSA applications in the nuclear operation are mainly manifested in two aspects: on the one hand, in nuclear safety supervision, on the other hand, in operation optimization. The following article describes the work of PSA application in these 2 aspects:

Keywords: Qinshan; PSA model； PSA application； Risk-informed

1. BACKGROUND

1.1. International

Based on the traditional nuclear safety regulations to determine the accident analysis method, a set of design basis accidents is artificially assumed, and the most unfavorable parameters for the accident consequences and the single failure criteria of the safety system are used for safety analysis, and for different design basis accidents. The corresponding acceptance criteria were formulated separately. The nuclear safety regulatory system established on the basis of deterministic analysis has played a huge role in the development of nuclear power. However, the Three Mile Island nuclear accident and subsequent series of studies show that the deterministic method has great limitations, and the Probabilistic Theory-based Probabilistic Safety Assessment (PSA) method can make up for the deficiencies of determinism. The advantage of PSA method is that it can systematically, quantitatively and realistically evaluate the safety status of nuclear power plants, and find defects in design and procedures, important human factors, and the relevance of safety systems under various adverse conditions.
The US Nuclear Regulatory Commission (NRC) issued a policy statement on the application of PSA in 1995, hoping to use PSA to improve the effectiveness of nuclear safety decisions, more effectively use the resources of safety management authorities and owners, and reduce unnecessary The burden. The NRC issued a series of risk-informed management guidelines (RG 1.174-1.178) in 1998, marking a major shift in nuclear safety regulatory policies and a transition to a risk-informed management model. This management model concentrates on the advantages of deterministic and probabilistic methods, emphasizing that determinism and probability theory are the two pillars of security management. PSA is an important complement to the deterministic approach, supporting traditional defense-in-depth theory and reducing unnecessary Conservative regulations make nuclear safety supervision and management more reasonable, and improve the operation performance of power

plants on the premise of effectively ensuring the safety of nuclear power plants.

1.2. Domestic

In 2010, China National Nuclear Safety Administration released the technical policy "Application of Probabilistic Safety Analysis Technology in Nuclear Safety" to demonstrate to the nuclear energy industry and the public the development of PSA technology by regulatory authorities and the promotion of risk management in nuclear safety regulatory activities. position. In 2012, it organized a PSA application discussion meeting for domestic nuclear power plants, and officially started the pilot project of PSA application for nuclear power plants. Each power plant has been piloted in the areas of in-service inspection optimization, technical specification optimization, outage optimization, and so on. The pilot work has achieved the intended purpose, and the National Nuclear Safety Administration encourages nuclear power plants to further expand the scope of application pilots on the basis of voluntary participation.

In August 2017, the National Nuclear Safety Administration issued the "Technical Policy for Improving the Effectiveness of Nuclear Power Plant Maintenance (Trial)", and each nuclear power plant optimizes related maintenance activities in accordance with the maintenance technical policy. Before the National Nuclear Safety Administration approves the validity period of its operation permit, the nuclear power plant shall establish a maintenance effectiveness evaluation system to implement maintenance rules for its active equipment, systems and structures containing active equipment.

At present, the planning of the work related to the risk-informed supervision system by the State and the National Nuclear Safety Administration and the Nuclear and Radiation Safety Center mainly includes the following aspects:

- It is proposed formulate standard or technical documents such as《Nuclear Power Plant Risk-informed Decision Method: Technical Specification》, 《Nuclear Power Plant Risk-informed Decision Method: In-Service Inspection of piping》;
- It is proposed to formulate nuclear safety guidelines such as 《The Risk-informed Decision on Nuclear Power Plant specific changes to License Base Change》;
- Upgrade the Nuclear Power Plant Operation Safety Regulations (HAF103-2004) in time to reflect risk guidance and new management requirements
- In the near future, it is proposed to release technical policies related to power plant operation and planned risk monitoring, requiring nuclear power plants to carry out operation and planned risk monitoring, and monitoring power plant safety simultaneously with current technical specifications. For power plants that have not completed full-scope PSA development, the monitoring indicators are more stringent
- For nuclear power plants using FRANCE technical specifications, it is planned to complete the conversion of FRANCE technical specifications to US technical specifications by the end of 2020.

With the successful implementation of the risk-guided nuclear safety supervision pilot project, the National Nuclear Safety Administration is gradually improving the risk-informed nuclear safety supervision system and strengthening supervision. For nuclear power plants, the strengthening of supervision is conducive to the promotion and application of risk-informed technology and maintenance rules in nuclear power plants. At the same time, the development progress of the PSA model and application tools also pose challenges.

2. STATUS OF PSA MODEL AND APPLICATION TOOL DEVELOPMENT

2.1. PSA model development

There are 9 units in operation in Qinshan site, which are technically supported by CNNO (CNNP Nuclear Power Operation Management Co., Ltd.). The development of PSA by CNNO began in 2001. Since then, the PSA model of each unit has been continuously improved. At present, CNNO has completed the development of the level 1 PSA in Qinshan 1,Qinshan 2 and Qinshan 3 plants, and has

also completed the level 2 PSA flooding PSA,spent pool PSA, fire PSA and seismic PSA in Fangjiashan plant. The level 2,fire and flooding PSA in Qinshan 1 are also in the process of development. The specific completion is shown in the table below.

Table 1

UNIT	LEVEL 1	LEVEL 2	FLOOD	FIRE	SEISMIC
QINSHAN 1	F	D	D	D	N
QINSHAN 2	F	D	P	P	N
QINSHAN 3	F	P	P	P	N
FANGJIASHAN	F	F	F	F	F

NOTE: F-FINISH D-DEVELOPING P-PLAN N-NONE

2.2. PSA application tool development (LEVEL 1)

Table 2

UNIT	RISK MONITER	MSPI	SDP
QINSHAN 1	F	F	F
QINSHAN 2	F	F	F
QINSHAN 3	F	F	P
FANGJIASHAN	F	F	F

NOTE: F-FINISH P-PLAN

3. POWER PLANT APPLICATION BASED ON PSA MODELS AND APPLICATION TOOLS

The PSA was introduced in the safety evaluation of Qinshan nuclear power. The corresponding management procedures were established and forming a set of risk-oriented application system. PSA has been widely used in production activities such as maintenance and operation of power plants. It plays an important role in ensuring the safe and stable operation of power plants and improving the efficiency of power plant operation. The specific PSA application is mainly manifested in two major aspects in the operation of the plants. One is the application of nuclear power management in power plants. The other is the optimization of production operations and maintenance of power plants. The following paper describes the work carried out in the aspects of safety supervision and operation management of the PSA work of the nuclear operation.

3.1. Power plant supervision application

3.1.1. Risk monitor

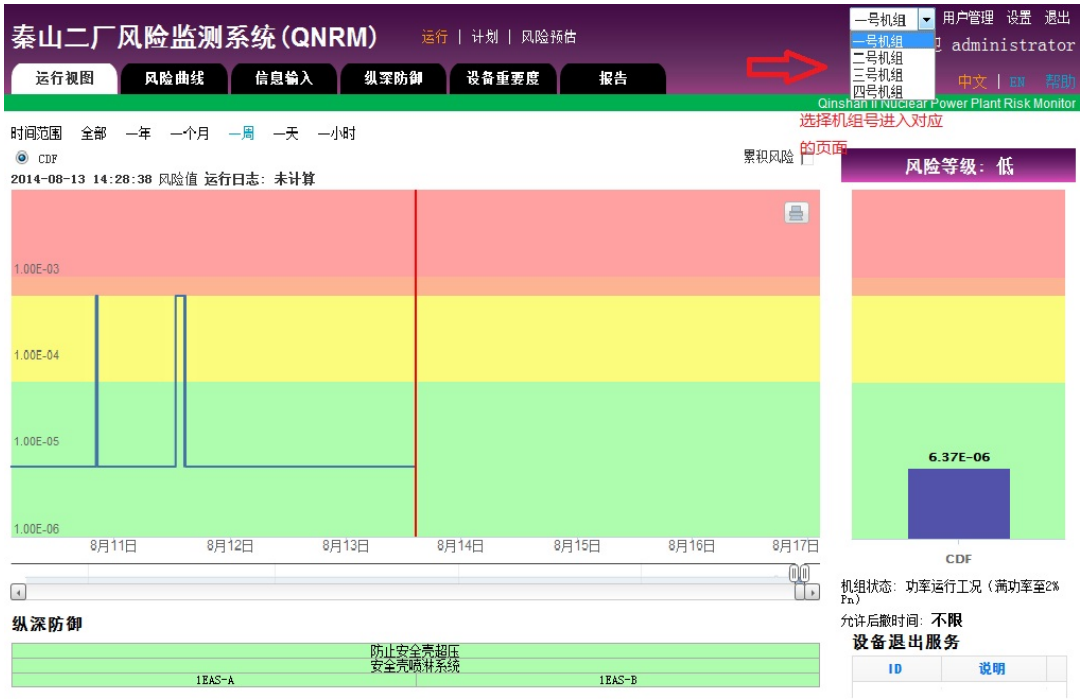
The Probabilistic Safety Assessment (PSA) method was applied to evaluate the impact of power plant production activities on the risk of power plant core damage using RM. It also refers to the corresponding control and preventive measures according to the results of the risk assessment, so as to effectively reduce or control the risk of core damage. The application of Risk Monitor in the safety management process of Qinshan Nuclear Power Plant is reflected in the following four aspects:

- The application of the system in nuclear power plants can quantify the abstract nuclear safety

state, which is more intuitive and easy to compare, and is conducive to enhancing confidence in nuclear safety.

- Using Risk Monitor to conduct risk assessment and management according to different needs of different departments, so that the personnel of the power plant and the risk of the power plant are more specific and clear, thus promoting the risk awareness of the power plant personnel and the overall improvement of the nuclear safety culture.
- The use of Risk Monitor helps to avoid the emergence of high-risk activities, and provides more intuitive risk management advice for high-risk activities that cannot be changed, making risk management more targeted.
- Through the use of Risk Monitor, it can quickly and timely evaluate power plant emergencies, support the decision-making of nuclear power plants, avoid unplanned shutdowns that are not beneficial to nuclear safety, or maintain a low-risk operating state.
- With the use of Risk Monitor, you can allocate limited resources to work/tasks that are important to plant safety and optimize resource allocation.
-

The following picture shows the software interface of Qinshan Nuclear Power Risk Monitor.



3.1.2. MSPI Mitigation System Performance Indicators

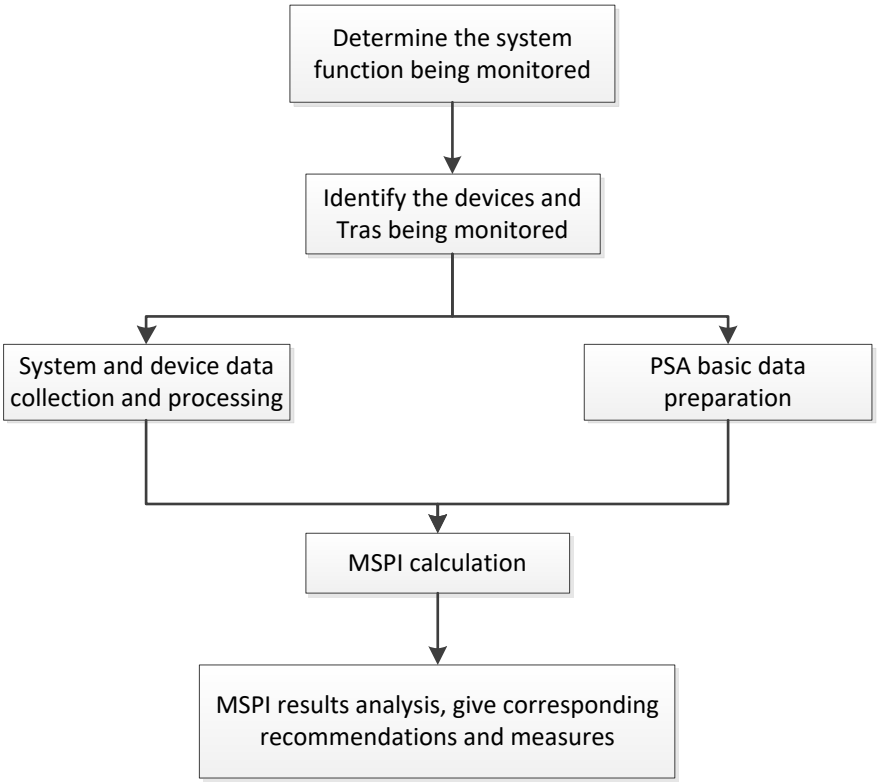
As a risk-informed indicator, MSPI tracks the unavailability and unreliability of system equipment, and avoids the shortcomings of SSUI tracking system reliability. From the perspective of risk, quantitatively and regularly monitor the performance of the system, and pay attention to the degradation of system equipment performance, so as to more scientifically and reasonably monitor the safety status of the power plant, and guide the safety decision, equipment management and maintenance of the power plant.

The six important mitigation systems identified by Qinshan Nuclear Power using MSPI management include:

- Emergency AC power system
- High pressure injection system
- Auxiliary feed-water supply system
- Residual heat removal system
- Cooling water support system – equipment cooling water system and important plant water

system

The MSPI indicator calculation steps are as follows:



The MSPI results are evaluated as follows:

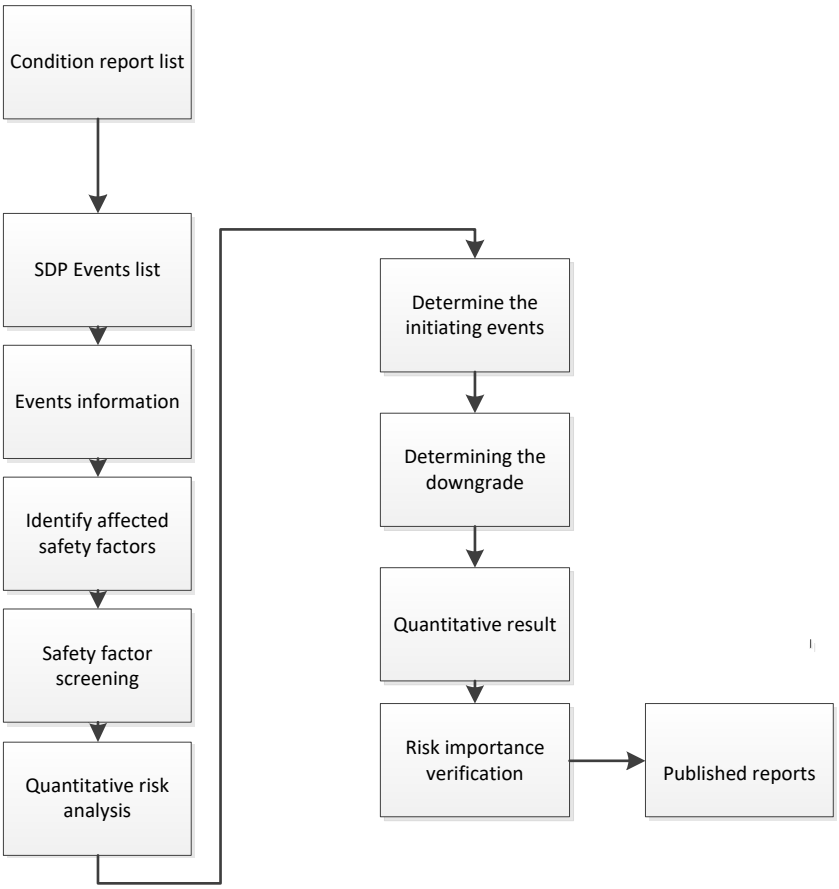
condition	Performance area	Performance attribute	Regulatory action
MSPI≤$1.0\times10^{-6}$and Fa≤Fm	G	Good maintenance	Routine management
MSPI≤$1.0\times10^{-6}$and Fa > Fm, or 1.0×10^{-6} < MSPI≤1.0×10^{-5}	W	Regression	Strengthen management
1.0×10^{-5} < MSPI≤1.0×10^{-4}	Y	Severe downgrade	Limited time improvement
MSPI≤1.0×10^{-4}	R	Unacceptable	Immediate improvement

3.1.3. SDP Significant Determination Procedure

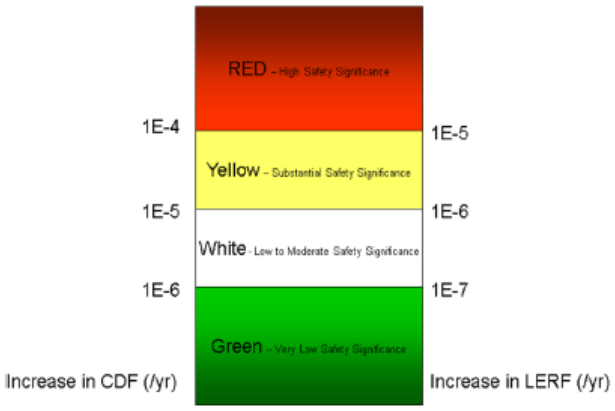
National Nuclear Safety Administration and the internal supervision department of the nuclear power plant are based on the calculation results of the SDP (the safety importance of the status report obtained after SDP analysis) as an important indicator for evaluating the performance level of a nuclear power plant during this period. Provide a basis for the response of the regulatory authorities

and nuclear power plants. The SDP analysis responsibility department in the nuclear power plant obtains the safety importance of the status report to be analyzed according to a certain period of time. At the end of each year, the SDP implementation of the year is summarized, the overall results of the analysis are evaluated, and the implementation plan for the next year is determined.

Analysis process:



Risk importance rating

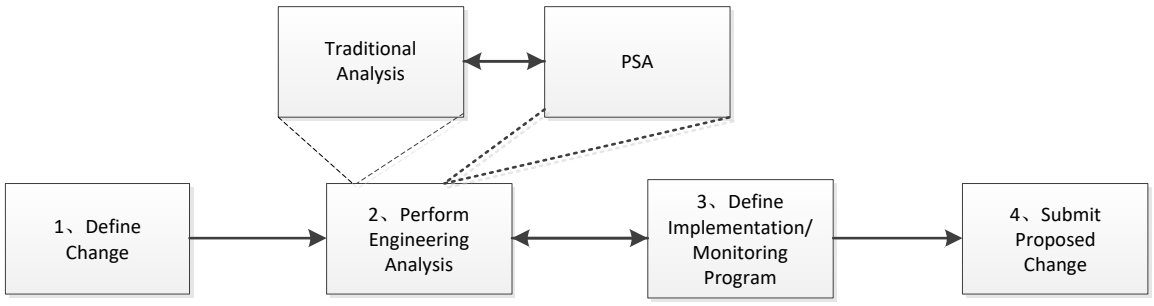


3.2. OPTIMIZATION OF PRODUCTION ACTIVITIES SUCH AS POWER PLANT OPERATION AND MAINTENANCE

3.2.1. Risk-informed periodic test period optimization

On the basis of the PSA technology application seminar held in Qinshan area in August 2012, CNNC actively responded to the technical policy of the National Nuclear Safety Administration and applied the risk-informed safety management method based on PSA technology to Qinshan Plant. Regularly test frequency optimization and analysis to help power plants further improve safety and economy. This argument mainly uses the PSA method, and combines the feedback of power plant operation experience for analysis and evaluation. In the analysis, the main provisions are related to the periodic test changes of nuclear power plants described in the Risk Assessment Decision Method for Probabilistic Risk Assessment for Specific Power Plant License Basis (RG.1.174) (NNSA-0147).

The specific process is as follows:



In 2016, the periodic test period of the No. 2 shutdown system of Qinshan 3 plant was completed, and the test period was adjusted from 7 days to 14 days.
Completed the optimization analysis of the shutdown test of the Qin 3 plant shutdown system in 2018 (22 in total), and has submitted it to the Nuclear Safety Administration.
Qinshan 2 Nuclear Power Plant 1/2&3/4 Unit PTXSAP001 periodic test period is extended from one week to one month. The current analysis report has been submitted to the Nuclear Safety Administration.

3.2.2. Risk-informed piping in-service inspection optimization

IAEA pointed out that: RI-ISI is one of the most successful applications of risk-informed decision-making technology in nuclear power plants. Full implementation of RI-ISI can save a lot of work and costs for in-service inspections, and if pipeline in-service inspections are mostly during overhaul if it is carried out, it is also possible to optimize the overhaul plan or shorten the overhaul period. It is also possible to identify new important safety pipes and welds through the RI-ISI and pay sufficient attention to the subsequent operations.
Qinshan Plant 2 is carrying out corresponding work, and has achieved results in other nuclear power plants in China. Take Tianwan Nuclear Power plant as an example:

- After the optimization of Unit 1, the number of inspections decreased by 6.23% relative to the total number of welds, which was 37.96% less than the number of conventional inspections.
- After the optimization of Unit 2, the number of inspections decreased by 4.69% compared to the total number of welds, which was 32.31% less than the number of conventional inspections.

3.2.3. Maintenance rules MR development provides technical support

In 2017, the Nuclear Safety Administration issued a notice on “Technical Policy for Improving the Effectiveness of Maintenance of Nuclear Power Plants (Trial)”, encouraging nuclear power plants to gradually carry out optimization studies on related maintenance activities. The aim is to monitor the overall effectiveness of maintenance activities. On the one hand, effective maintenance ensures that the plant's safety-related SSC can perform its pre-designed functions and that the CDF/LRF level of the plant's actual operation is consistent with the plant's safety commitment (consistent with the PRA

calculations). On the other hand, power plants can also benefit from it.

The implementation of Qinshan nuclear power maintenance rules is divided into two steps: technical preparation and supervision and management.

The technical preparation includes four parties:

- Screening of maintenance rules
- Determine the importance of risk
- Set performance indicators
- Establish MR reference file

The content of supervision and management mainly includes four aspects:

- Supervision
- Status assessment
- Regular assessment
- Risk monitoring

3.2.4. Provide technical support for the plant specific changes to the licensing basis

The main task of the PSA in this regard is to quantify the risks posed by the specific application to provide technical support, to justify its rationality and feasibility, and to obtain approval from the Nuclear Safety Administration. The PSA's risk insights can also help the plant to be aware of the risks and control, and take appropriate measures to reduce or limit the risks posed by the franchise application and ensure that the crew has sufficient safety levels. The following is an example of Qinshan Nuclear Power Fangjiashan unit to illustrate the application of Qinshan in this respect.

The Fangjiashan Nuclear Power plant Qinfang 2P70 (220KV) was shut down, causing the Fangjiashan Nuclear Power Plant to be out of power. The PSA analysis was used to evaluate the risk of the power plant during the time when the auxiliary power supply was out of service, and was approved by the National Nuclear Safety Administration. The power plant can make temporary technical specification changes without ensuring the shutdown of the reactor, while ensuring sufficient safety margins and adopting appropriate management measures.

4. PROSPECTS AND PLANNING OF PSA APPLICATION

Qinshan Nuclear Power will continue to improve the development of PSA models and application tools for each unit, and continue to carry out risk-informed application work in response to the technical policy of the Nuclear Safety Administration. The operation and planned risk monitoring shall be carried out, and the safety of the power plant shall be monitored simultaneously with the current technical specifications. It plays a role in both the optimal operation of the power plant and safety supervision.

5. REFERNENCE

[1] USNRC · *Use of Probabilistic Risk Assessment Methods in Nuclear Activities*: Final Policy Statement · Federal Register, Vol. 60：p. 42622 (60 FR 42622) · August 16, 1995.

[2] IAEA · *Applications of probabilistic safety assessment (PSA) for nuclear power plants* · IAEA-TECDOC-1200 · February 2001.

[3] USNRC · *An Approach for Using Probabilistic Risk Assessment In Risk-Informed Decisions On Plant-Specific Changes to the Licensing Basis* · Regulatory Guide 1.174 · July 1998.

[4] USNRC · *An Approach for Plant-Specific, Risk-Informed Decision-making: Technical Specifications* · Regulatory Guide 1.177 · August 1998.

[5] NEI · *Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants* · NUMARC 93-01 · Revision 3 · July 2000.