Proceedings of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 1995

Analytical Insights for Improving Technical Specifications from a Risk Perspective

Inn Seock Kim*
Korea Atomic Energy Research Institute

Yong Ho Ryu, Kyu Sik Do, and Won Ky Shin
Korea Institute of Nuclear Safety

Abstract

Technical Specifications (TSs) for a nuclear power plant is an important licensing document which defines various operational requirements or conditions. Recently, many researchers have evaluated the risk impacts associated with the TS requirements, using probabilistic safety assessments becoming widely available. This paper presents insights gained from our review of recent risk-based analyses of TSs, focussing on surveillance requirements and AOT (allowed outage time) requirements.

1. Introduction

Technical Specifications (TSs) for a nuclear power plant define limits and conditions to assure that the plant is operated in a manner that is consistent with the analyses and evaluations in the plant's Safety Analysis Report. The TSs typically comprise the following major sections: 1) safety limits, 2) limiting conditions for operation (LCOs), which include allowed outage times (AOTs) for Required Actions, and surveillance requirements (SRs), 3) design features, and 4) administrative controls.

As the discipline of probabilistic safety assessment (PSA) becomes mature and the PSA becomes available for many nuclear plants, it is increasingly used as a tool to evaluate risk associated with TSs. The risk-based analyses of TS typically focussed on the LCOs and SRs, which constitute an important part of the TS requirements to ensure safe operation of the plants, and also are more readily amenable to risk analysis than other parts of the TS, such as administrative controls.

In this paper, we summarize insights gained from our review of recent risk-based analyses of TSs. Sections 2 and 3 discuss the insights for surveillance requirements and AOT requirements, respectively. Section 4 gives our conclusion.

2. Surveillance Requirements

The amount of surveillance testing required by, Technical Specifications is enormous. Thus, substantial resources are spent on planning, conducting, and verifying surveillances by the nuclear industry or by the nuclear regulatory agency. Furthermore, these surveillances are not always conducive to improving plant safety.

The primary purpose of surveillance testing is to detect failures that may have occurred since the last test or since the time when the equipment was known to be operational. However, the operating

* Visiting Scientist under Brain Pool program

experience of nuclear power plants indicates that, in addition to the beneficial effect of detecting failures, tests may have adverse impact on safety, because of their potential undesirable effects, such as occurrence of plant trips or equipment wearout. Therefore, we should consider both beneficial and adverse effects when evaluating surveillance requirements.

At the US Nuclear Regulatory Commission (NRC), a comprehensive study was made to identify the adverse effects for almost all types of testing at PWRs and BWRs, based on the operating experience in the United States.[1] For example, the partial stroke testing of main steam isolation valves (MSIVs) at PWRs was identified as having caused plant transients, and the frequent testing of emergency diesel generators (EDGs) as having caused considerable degradation of the EDGs.

The NUREG/CR-5775 study by Kim et al.[2] indicates that the risk contribution of testing caused by adverse effects, i.e., R_C, can be generally represented by:

$$R_C = R_{trip} + R_{wear} + R_{config} + R_{down}$$

where R_{trip} = risk from test-caused plant transients
R_{wear} = risk from test-caused equipment wear
R_{config} = risk from potential misconfiguration following test
R_{down} = risk associated with test downtime

There are two other adverse effects of testing that may be sometimes encountered, i.e., unjustified radiation exposure to plant personnel and unnecessary burden of work on plant personnel. These adverse effects differ from those contributions included in the equation above in that they are not generally subject to a risk analysis (based on the risk measure of core-damage frequency). However, they can be considered qualitatively along with the results of quantitative risk analysis in evaluating surveillance requirements.

For any specific test, some contributions may be irrelevant or insignificant compared to the others. Thus, we can focus on only those adverse effects that are known to have been associated with the test under consideration. The NUREG-1366 report[1] can be a good start for identifying those major adverse effects for many different types of testing. If there has been another type of adverse effect unique to the plant being analyzed, then this effect can be taken into account in evaluating the test.

The method to quantify the beneficial effect of testing in the framework of a PSA is given in NUREG/CR-5200 by Samanta et al.[4] The core-damage frequency impact associated with adverse effects of testing are quantified using a PSA model, and the optimal test interval is derived in Refs. [2,3]. More details of these insights and example applications are also presented in "Handbook of Methods for Risk-Based Analyses of Technical Specifications"[5] which has been recently published.

Table 1 shows the impact of changing surveillance test intervals (STIs) especially from a risk perspective. As shown in the table, the primary purpose of testing is to control the fault-exposure time. This fault-exposure time is linearly proportional to the surveillance test interval. Namely, as we extend the STI, the equipment will be correspondingly more exposed to failures (strictly speaking, only to standby time-related failures, but for simplicity, we may disregard demand-related failures).

However, extending STI may be associated with some or all of the following six benefits (Table 1):

1) Plant transients are less likely to be caused due to testing.
2) The (tested) equipment is less likely to wear.

Table 1. Impact of Changing Surveillance Test Interval
from a Risk Perspective

Impact of STI Change		Shorten STI	Extend STI
Fault-Exposure Time		Decreased	Increased
Adverse Effects	Plant transients	More likely	Less likely
	Equipment Wear	More wear	Less wear
	Component Misconfiguration	More likely	Less likely
	Unavailability due to Test Downtime	Increased	Decreased
	Unnecessary Radiation Exposure	Increased	Decreased
	Unnecessary Burden on Plant Personnel	Increased	Decreased

3) The components involved in the test (e.g., isolation valves) are less likely to be misconfigured following test.
4) The equipment unavailability due to test downtime will be decreased, because tests will be performed less frequently.
5) Unnecessary radiation exposure to plant personnel will be reduced.
6) Unnecessary burden on plant personnel also will be reduced.

These considerations will be useful in making engineering judgment which still plays an important role even in a risk-based analysis of STI requirements.

3. AOT Requirements

Allowed outage time is a major part of LCO (limiting conditions for operation) requirements. If the repairs cannot be made within the AOT, then the plant should be shut down. To evaluate an AOT or LCO from risk insights based on a PSA, one first need to understand various risks associated with the LCO, that is, LCO risks. The LCO risk is sometimes called AOT risk.

Table 2 shows the various LCO risks. The LCO risk basically consists of two different types of risks, LCO operating risk, and LCO shutdown risk. In determining the AOT requirements, the LCO shutdown risk often has been assumed to be negligible compared to the LCO operating risk.

However, recent PSAs on the low-power and shutdown stages of plant operation (e.g., low-power and shutdown PSA for Surry Unit-1 PSA by Brookhaven National Laboratory, and for Grand Gulf BWR by Sandia National Laboratories) suggest that the risk of shutdown is not insignificant when compared to the risk of full-power operation. Especially, when systems needed to remove decay heat, such as residual heat removal (RHR), standby service water (SSW), or auxiliary feedwater (AFW) systems,

Table 2. Various Risks Associated with LCO Requirements

LCO Operating Risk:	The risk from accidents incurred while the plant is operating with the equipment inoperable.
Instantaneous LCO Risk:	The risk at a specific moment during an LCO.
Cumulative LCO Risk:	The risk accumulated over a given period during an LCO.
Single LCO Risk:	The cumulative risk associated with a one-time occurrence of the LCO condition.
Yearly LCO Risk:	The cumulative risk associated with occurrence of the LCO condition over one year.
LCO Shutdown Risk:	The risk from accidents incurred while the plant is shut down with the equipment inoperable.

are inoperable, the LCO shutdown risk may even exceed the LCO operating risk according to the NUREG/CR-5995 study by Mankamo et al.[6]

Therefore, the shutdown risk should be taken into account in the decision process to determine AOT requirements, especially in a such case. The NUREG/CR-5995 shows how to evaluate and compare the risks of continued power operation and LCO plant shutdown, so as to define risk-effective AOT requirements that will minimize the total risk impact associated with failure situations in such systems required to remove decay heat.

Among the various LCO risks in Table 2, the most useful is the instantaneous, or conditional LCO risk. This instantaneous LCO risk, conditional upon the failure, can be relatively easily estimated given a computerized PSA model. Basically what we need to do is to re-run the PSA code after setting the unavailabilities of those basic events associated with the inoperable equipment equal to one, sometimes with necessary adjustment to common-cause failure parameters. This process is essentially the same as that used in assessing configuration risks, studied in Ref. [7].

The TS submittals for advanced nuclear power plants, such as General Electric's Advanced Boiling Water Reactor (ABWR), ABB-CE's System 80+, and Westinghouse's AP-600, also were evaluated, mainly considering the instantaneous LCO risk and the single LCO risk, which is the product of the instantaneous LCO risk by the AOT. This process is illustrated in Ref. [8].

Table 3 shows the impact of changing AOT particularly from a risk standpoint. This concept may be useful in engineering judgment that still plays an important role in risk-based analysis of AOT requirements.

As shown in this table, the primary purpose of AOT requirements is to control the equipment downtime, i.e., the time during which the equipment is inoperable. If we extend AOT, then the equipment downtime may correspondingly increase. For short repairs, the plant people may not use the whole AOT, provided that more than sufficient AOT is granted in the Technical Specifications.

Table 3. Impact of Changing Allowed Outage Time from a Risk Perspective

Impact of AOT Change		**Shorten AOT**	**Extend AOT**
Equipment Downtime		Shorter	Longer
Other Impact of Changing AOT	Hasty, minimal repairs due to time constraints	More likely	Less likely
	Operational flexibility	Worse	Better
	Frequency of LCO shutdown and implication of shutdown risk	Greater	Smaller
	Request for one-time extension	More likely	Less likely
	Implication of power operation risk	Smaller	Greater
	Concern of multiple component outages	Less	More

For major repairs, they will try to complete repairs within the AOT limit to avoid plant shutdown. However, for simplicity we may assume, with these considerations in mind, that the equipment downtime is directly proportional to the AOT. Hence, the larger AOT is given, the larger the unavailability contribution from the equipment downtime will be.

Furthermore, the extension of AOT is associated with the following additional drawbacks (Table 3):

1) There will be greater concern about accumulation of power operation risk during the extended AOT (strictly speaking, this is related to the increased unavailability mentioned earlier). Although the core-damage frequency impact (i.e., the instantaneous LCO risk) remains the same throughout the whole equipment downtime if there is no other failure, the cumulative probability of core-damage (i.e., the single LCO risk) is proportional to the AOT. This issue depends on the practice of the nuclear industry. For example, if the plant personnel try to restore failed equipment as quickly as possible without undue delay even if more than necessary AOT is granted by the Technical Specifications, then the accumulation of the risk will not be as serious as in the plants which have undesirable practices, e.g., tending to delay repairs without due reasons just because long AOTs are given.
2) There also is greater concern about multiple-component outages, i.e., outages of several components simultaneously, which may significantly increase the plant's risk. Technical Specifications have been defined mainly on a system-by-system basis. As the AOT is extended, there is a higher chance that several trains of different systems may be inoperable at the same time (i.e., overlapping of component outages).

On the other hand, by extending AOT, we obtain the following four benefits (Table 3):

1) Hasty, minimal repairs due to time constraints are less likely to be made.
2) More operational flexibility can be provided to the plant personnel, so that they can schedule the repairs from a perspective of the whole plant status.
3) The LCO shutdown (i.e., the shutdown forced by the LCO requirement) is less likely to occur, and also as a result, there would be less concern about the shutdown risk. Note that the LCO shutdown risk is larger than the shutdown risk estimated by the low-power and shutdown PSA with mean unavailabilities for all standby safety components, because the LCO shutdown is made with the LCO-controlled equipment unavailable (i.e., with the unavailability set to one).
4) There will be less requests for one-time extension of AOT.

More details on the risk-based analysis of AOT requirements can be found in the reports referred to above and also in the manuscript, "Handbook of Methods for Risk-Based Analyses of Technical Specifications."[5]

4. Conclusions

This paper summarizes the analytical insights for improving Technical Specifications, especially surveillance requirements and AOT requirements, from a risk perspective, based on recent studies in this area. These qualitative insights can be used in the decision-making process to evaluate the risk implications associated with TS requirements. Even in a risk analysis of TS requirements based on PSA, such deterministic considerations will be useful.

References

[1] R. Lobel and T.R. Tjader, "Improvements to Technical Specifications Surveillance Requirements," NUREG-1366, U.S. Nuclear Regulatory Commission, August 1990.

[2] I.S. Kim, S. Martorell, W.E. Vesely, and P.K. Samanta, "Quantitative Evaluation of Surveillance Test Intervals Including Test-Caused Risks," NUREG/CR-5775, Brookhaven National Laboratory February 1992.

[3] I.S. Kim, S. Martorell, W.E. Vesely, and P.K. Samanta, "Risk Analysis of Surveillance Requirements Including Their Adverse Effects," *Reliability Engineering and System Safety*, **45** (1994), 225-234.

[4] P.K. Samanta, S.M. Wong, and J. Carbonaro, "Evaluation of Risks Associated with AOT and STI Requirements at the ANO-1 Nuclear Power Plant," NUREG/CR-5200, Brookhaven National Laboratory, 1988.

[5] P.K. Samanta, I.S. Kim, T. Mankamo, and W.E. Vesely, "Handbook of Methods for Risk-Based Analyses of Technical Specifications," NUREG/CR-6141, December 1994.

[6] T. Mankamo, I.S. Kim, and P.K. Samanta, "Technical Specification Action Statements Requiring Shutdown: A Risk Perspective with Application to the RHR/SSW Systems of a BWR," NUREG/CR-5995, November 1993.

[7] P.K. Samanta, W.E. Vesely, and I.S. Kim, "Toward Risk-Based Control of Nuclear Power Plant Configurations," *Nuclear Engineering and Design*, **134** (1992), 355-370.

[8] I.S. Kim, P.K. Samanta, F.M. Reinhart, and M.L. Wohl, "Application of PSA to Review and Define Technical Specifications for Advanced Nuclear Power Plants," International Conference on Probabilistic Safety Assessment Methodology and Applications, Seoul, Korea, November 26-30, 1995