Conf-911114--3

BNL-NUREG--45919

DE91 010374

RISK EFFECTIVENESS EVALUATION OF SURVEILLANCE TESTING[a]

I.S. Kim, S. Martorell[*], W.E. Vesely[†], and P.K. Samanta

Engineering Technology Division
Brookhaven National Laboratory
Upton, New York 11973, USA

[*]Universidad Politecnica of Valencia, Spain
[†]Science Applications International Corporation, USA

1991

ABSTRACT

To address the concerns about surveillance tests, i.e., their adverse safety impact due to negative effects and too burdensome requirements, it is necessary to evaluate the safety significance or risk effectiveness of such tests explicitly considering both negative and positive effects. This paper defines the negative effects of surveillance testing from a risk perspective, and then presents a methodology to quantify the negative risk impact, i.e., the risk penalty or risk increase caused by the test. The method focuses on two important kinds of negative effects, namely, test-caused transients and test-caused equipment degradations. The concepts and quantitative methods for the risk evaluation can be used in the decision-making process to establish the safety significance of the tests and to screen the plant-specific surveillance test requirements.

I. INTRODUCTION

Surveillance tests are required in nuclear power plants to detect failures in standby equipment as a means of assuring their availability in case of an accident. However, the operating experience suggests that the surveillance tests may have an adverse impact on safety because of their potential negative effects, as evidenced by the occurrence of plant trips or excessive wear of equipment due to testing.[1] The concern with the surveillance tests, i.e., the potential for adverse safety impact has become aggravated due to the volume and frequency of the present surveillance requirements that is often characterized as too much-too often.[2]

Therefore, it is important that the safety significance or risk effectiveness of surveillance requirements be evaluated, explicitly considering the associated negative effects. The purpose of this paper is to present concepts and methodologies that are needed to evaluate the risk effectiveness of surveillance test requirements, along with an example of applications to a selected set of tests.

Section 2 defines the various effects associated with testing from a risk perspective. Sections 3 and 4 then presents the methodologies to evaluate the risk effectiveness and application to two important kinds of negative effects of surveillance testing, i.e., transients and equipment degradations. Section 5 has the concluding remarks.

II. RISK CONTRIBUTIONS FROM TESTS

The risk associated with a test has two different aspects: (a) a positive aspect, i.e., the risk contribution "detected" by the test, and (b) a negative aspect, i.e., the risk contribution "caused" by the test. The risk contribution detected by a test, R_D, results from the detection of failures which occur between tests. The risk contribution caused by the test, R_C, results from degradations or failures that are due to or related to the test, and from the component unavailability during or as a result of the test.

The R_D associated with a test consists of only one type of contribution, namely, from the detection of failures. The R_D can be relatively easily quantified in the framework of a PRA (probabilistic risk assessment) model, as demonstrated in NUREG/CR-5200.[3] However, in contrary to the R_D, the R_C may have several different kinds of risk contributions. Table 1 lists the different risk contributions which can be associated with a test, along with the root causes of the risk.

MASTER

---

[a] Work performed under the auspices of the U.S. Nuclear Regulatory Commission.

From Table 1, the test-caused risk can be expressed in a general form as

$$R_C = R_{trip} + R_{wear} + R_{state} + R_{down} \qquad (1)$$

where, for any specific test, some contributions may be irrelevant or insignificant compared to the others. When a test program or procedure that involves a conduction of tests on several individual components is evaluated for its risk effectiveness, then the contributions for each test plus the contributions from any test interactions need to be considered.

Table 1. Test-Caused Risk Contributions and Root Causes

Identifier	Risk Contribution from the Test	Root Causes of the Risk
R_{trip}	Risk from transients or trips	Human error, equipment failure, procedure inadequacy.
R_{wear}	Risk from equipment wear	Inherent characteristics of the test, procedure inadequacy, human error.
R_{state}	Risk from misconfigurations or errors in component restoration	Human error, procedure inadequacy.
R_{down}	Risk associated with downtime in carrying out the test	Unavailability of the component during the test. Affected by the test override capability.

Besides those effects defined in Table 1, two other negative effects of a test may be sometimes encountered, i.e., unjustified radiation exposure to plant personnel and unnecessary burden of work on plant personnel. These two negative effects differ from those in the table, in that they are not generally subject to a risk analysis, i.e., based on the risk measure of core-damage frequency. However, they can be considered qualitatively along with the results of quantitative risk analysis in the decision making to evaluate the surveillance requirements.

Once the R_D and the R_C are quantified for a given test, the risk effectiveness of a test can be simply defined as follows: a test is risk effective if $R_D > R_C$, otherwise, it is risk ineffective. The quantification of test-related risks also allows the degree or margin of risk effectiveness or ineffectiveness to be determined.

III. TEST-CAUSED TRANSIENTS

The operating history of nuclear power plants indicates that the conduct of a surveillance test at power may cause a transient that will lead to or require a reactor trip. The risk impact of such transients depends on the various responses of the plant safety systems and also on plant operators following the transient until the plant condition is recovered or stabilized. These considerations are typically done in PRAs, in which the various plant or operator responses that may affect the plant risk are taken into account using event trees to delineate accident sequence progressions and system fault trees for identifying the failure modes and their effects on the system unavailabilities. Hence, the risk contribution from test-caused transients to the plant risk can be evaluated within the context of a PRA model.

Given a PRA model on the plant, the risk impact of a test-caused transient R_{trip} can be evaluated through that of the PRA initiating event group associated with the transient as follows:

$$R_{trip} = \phi \, R_{IE-j} \qquad (2)$$

where R_{IE-j} denotes the risk impact of the j-th initiating event group which is assumed to be associated with the test-caused transient, and ϕ is the proportion by which the frequency of the PRA initiating event group is attributable to these transients. The proportion ϕ can be estimated from the analysis of plant operating data as follows:

$$\phi = \frac{N_{test}}{N_{IE-j}} \qquad (3)$$

where,

N_{test}	=	the number of test-caused transient events, and
N_{IE-j}	=	the number of transient events belonging to the initiating event group associated with the test-caused transient.

To obtain ϕ, the test-caused transients must be associated with the relevant initiating event groups. The EPRI (Electric Power Research Institute) transient categories[4] that were originally developed to analyze the historical transient events in the anticipated transients without scram (ATWS) study can be used. The use of the transient categories will facilitate and improve the accuracy of the data analysis because the extent of detail on the test-caused transients and the PRA initiating event groups are usually quite different. The ATWS study defined 37 BWR and 41 PWR categories based on the different characteristics of the variety of transient events that had occurred or might occur in the plants.

For sensitivity studies in terms of risk impact versus test interval that will be discussed later, we can first get the following equation for the probability p_{trip} that a transient will occur during or as a result of a test:[5]

$$P_{trip} = I_j \, T \, \phi \tag{4}$$

where T and I_j denote the test interval and the frequency of the j-th initiating event group used in the PRA model, respectively. Substituting an expression for ϕ from eq. (4) into eq. (2) we have

$$R_{trip} = \frac{P_{trip}}{I_j \, T} R_{IE-j} \tag{5}$$

The formulas discussed above were used in the framework of a NUREG-1150 PRA for a boiling water reactor (BWR) to evaluate the risk effectiveness of the following tests: a) quarterly test of the main steam isolation value (MSIV) operability, and b) weekly test of the turbine overspeed protection system (TOPS).

Table 2 shows the BWR transient categories that were identified as being associated with the tests, based on a consideration of the test characteristics and the effects of the test-caused transients on the plant. For example, a performance of the TOPS test may cause the turbine control valve to fail closed resulting in high steam pressure in the main steam system, and consequently, in a turbine trip. Hence, the transient due to the TOPS test can be classified into Category 3, "Turbine trip," and Category 13, "Turbine bypass or control valves cause increased pressure (closed)."

In order to use the transient categories in the context of the PRA model, the transient categories were then associated with the initiating event groups modeled in the plant-specific PRA based on the characteristics of the transient categories and the initiating event groups. The plant-specific PRA initiating event groups which were identified to be associated with the transient categories are also listed in Table 2. Categories 3 and 13 of the TOPS test are associated with initiating event group T3A, i.e., transients with the power conversion system initially available except those due to an inadvertent open relief valve in the primary system and those involving loss of feedwater. Categories 6 and 7 of the MSIV operability test are associated with initiating event group T2, which incorporates transients with the power conversion system unavailable.

The evaluation results of R_{trip} and p_{trip} based on the use of transient categories and the risk impacts of the associated initiating event groups, are as follows:

a) For quarterly MSIV test:

R_{trip} - 1.8E-7 per reactor year
P_{trip} - 6.7E-2 per test

b) For weekly TOPS test:

R_{trip} - 3.7E-8 per reactor year
P_{trip} - 1.7E-3 per test

Table 2. Association of Test-Caused Transients, Transient Categories, and PRA Initiating Event Groups

Test	Transient Category[4]	Description	PRA Initiating Event Group
MSIV	6	Inadvertent closure of one MSIV	T2
	7	Partial MSIV closure	T2
TOPS	3	Turbine trip	T3A
	13	Turbine bypass or control valves cause increased pressure (closed)	T3A

The results indicate that the negative risk impact due to transients and the probability of a transient occurring during a test for the MSIV test is greater than those for the TOPS test by a factor of 5 and 4, respectively.

We can also examine whether or not the test is risk effective with respect to test-caused transients by comparing the value of R_D to that of R_{trip}. The MSIV test is risk effective because the R_D is 5.2E-7 per reactor year, which is larger than the R_{trip}; the risk-effective margin is 3.4E-7 per reactor year. The risk effectiveness of the TOPS test could not be evaluated based on the NUREG-1150 PRA since the turbine control valves are not modeled in the PRA. Hence, for the TOPS test, only the quantitative values of R_{trip} and P_{trip} can be taken into account in the evaluation of the test, unless the value of R_D is obtained following the modification of the PRA model.

The results of the sensitivity study for the two tests are presented in Figure 1; the R_D curve for the TOPS test is not shown because of the reason discussed above. The figure shows that the risk impact due to transients R_{trip} decreases as the test interval is increased for both types of tests, since, as the test is conducted less frequently, less transients will occur. However, the R_{trip} value for the MSIV test is higher by approximately two orders of magnitude than that for the TOPS test, provided that the standard test intervals of the two tests are the same. On the other hand, the risk benefit, R_D, for the MSIV test increases with the increasing test interval, since the test is more likely to detect a failure when the standby time between tests is prolonged. The intersection between the R_D and R_{trip} curves for the MSIV test occurs when T = 50 days. Hence, the test interval should be longer than 50 days in order for the test to become risk effective with regard to test-caused transients.

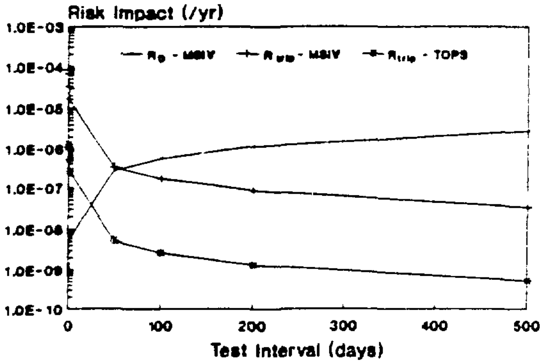

Figure 1. Sensitivity of Risk Impact to Test Interval Variation (MSIV Operability and TOPS Tests)

In this study, the LER (Licensee Event Report) data base for 30 BWRs for 1985 were used with the assumption that the operability of MSIVs is tested quarterly at all the plants.[1] However, the data analysis revealed that some plants test the operability of MSIVs more frequently. A plant was performing biweekly MSIV operability surveillance when the test failure occurred. If we assume that the result of our data analysis is applicable to this plant, we can say that the biweekly test is risk ineffective with regard to test-caused transients because the test interval is shorter than 50 days. Even if we consider other types of negative risk impacts and they are significant or are not negligible compared to the negative risk impact due to transients, the test will be risk ineffective.

IV. TEST-CAUSED DEGRADATIONS

In nuclear power plants safety-significant components such as an auxiliary feedwater pump or a diesel generator are tested so often--generally monthly and more often in certain situations--that the tests may lead to progressive wear-out of the equipment due to the accumulation of degradation effects caused by testing. Furthermore, the component will also suffer from aging effects, such as corrosion or erosion, as time passes.

The accumulating test-caused degradation and aging effects will increase the unavailability of the component, and, thereby, the unavailability of the associated safety system and function. The increase in the safety system or function unavailability will then reduce the plant's accident mitigating capability.

From a viewpoint of stress on the component, the test-caused component degradations and aging effects are induced by two kinds of stresses, i.e., demand and standby stresses.[6] Demand stress acts on equipment only when the equipment is asked to function or is operating. Standby stress acts on equipment while it is in the standby state. For standby components which are periodically tested, it is generally the combination of the two kinds of stresses that cause the equipment to degrade, and ultimately to fail.

Based on the concept of stress on equipment and other characteristics of the test-caused and aging degradation mechanisms,[5] we can formulate a component degradation model as follows:

$$q(n,t) = \rho(n) + \int_0^t \lambda(n,t')\,dt' \qquad (6)$$

where

n = the number of tests performed on the equipment

$\rho(n)$ - the demand failure probability for demand related failures, and

$\lambda(n,t)$ - the standby failure rate for standby time related failures.

The two basic degradation parameters in eq. (6), i.e., ρ (n) and λ (n,t), can be further explored in terms of their variables, n and t. First, for the demand failure probability ρ, the following expression can be formulated as a function of the number of tests, n, since the last overhaul point:

$$\rho(n) = \rho_0 + \rho_0 f_1^{\beta_1} \tag{7}$$

where

ρ_0 - the residual demand failure probability,

f_1 - $p_1 n$,

p_1 - the test degradation factor associated with demand related failures, and

β_1 - the test impact parameter associated with demand related failures.

The standby failure rate λ can be formulated as a function of the number of tests, n, and the time, t, as follows:

$$\lambda(n,t) = \lambda_0 + \lambda_0 f_2^{\beta_2} + \alpha u^{\beta_3} \tag{8}$$

$$\text{for } t \in [0,T],\ u \in [0,nT+t].$$

where

λ_0 - the residual standby failure rate,

f_2 - $p_2 n$,

p_2 - the test degradation factor for standby time related failures,

β_2 - the test impact parameter associated with standby time related failures,

α - the aging factor associated with aging, and

β_3 - the aging impact parameter.

Note in eq. (8) that the effects of test-caused and aging degradations on the standby failure rate are modeled separately, and that the time-dependent aging mechanism is represented by a Weibull distribution.

The basic degradation model, eqs. (6) to (8), provides a means by which the time-dependent component unavailability, and, thereby, the associated time-dependent risk impact can be estimated as a function of the number of tests on the component and the time elapsed since the last overhaul. Among the eight degradation parameters in the nonlinear model, especially the test impact parameters, β_1 and β_2, and the aging impact parameter, β_3, can be set equal to 1 to facilitate the estimation of degradation parameters.

The negative risk impact due to test-caused degradations $\bar{R}_{c,n}$ can then be estimated in the framework of a PRA model using the following equation:[5]

$$R_{c,n} = \Delta\bar{q}_n\,[R_1 - R_0] \tag{9}$$

where $\Delta\bar{q}_n$ represents the average increase in component unavailability resulting from n tests and can be estimated from the basic degradation model. The R_0 and R_1 in eq. (9) denote the core-damage frequency evaluated with the component assumed to be up and down, respectively.

The component degradation model presented above and the formula for the risk impact evaluation, i.e., eq. (9), was applied to diesel generator (DG) testing. Figure 2 depicts the results of DG risk effectiveness evaluations for monthly (12 tests per year) and quarterly (4 tests per year) testing as a function of the number of tests conducted on the equipment. This figure shows that in the case of monthly testing the DG test is risk-effective until 61 tests have been performed, i.e., approximately 5 years after the last overhaul point. On the other hand, in the case of quarterly testing, the DG test is risk-effective until 111 tests have been performed, i.e., about 28 years. However, the numerical results from this analysis should be interpreted with caution, because the degradation parameters were estimated from various DG reliability studies due to limited availability of data for a specific DG.

V. CONCLUSIONS

The risk impact and effectiveness of surveillance tests can be evaluated with an explicit consideration of the negative effects, based on the concepts and methods provided in this paper. The results of a quantitative risk analysis can be used in the decision-making process to establish the safety significance of and for the screening of the surveillance requirements. This quantitative information may be used in conjunction with the qualitative evaluation results from engineering considerations and operating experience. The plant-specific application of the concepts and methods will provide a risk perspective on the test requirements.

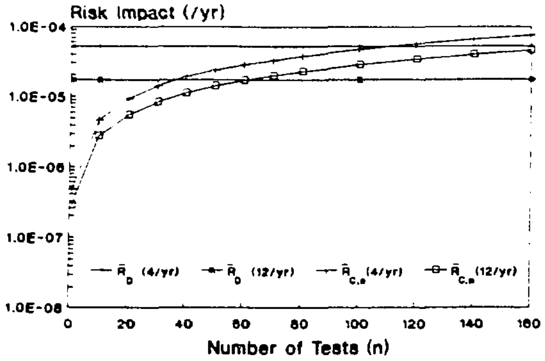

Figure 2. Risk Effectiveness Evaluation of Diesel Generator Surveillance Tests (Monthly and Quarterly Testing)

REFERENCES

1. R. Lobel, "Feasibility of Reducing Technical Specifications Surveillance Requirements," U.S. Nuclear Regulatory Commission (NRC), November 1988.
2. U.S. Nuclear Regulatory Commission (NRC), "Technical Specifications -- Enhancing the Safety Impact," NUREG-1024, November 1983.
3. 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, BNL-NUREG-52024, August 1988.
4. A.S. McClymont and B.W. Poehlman, "ATWS: A Reappraisal, Part 3: Frequency of Anticipated Transients," EPRI NP-2230, January 1982.
5. I.S. Kim, S. Martorell, W.E. Vesely, and P.K. Samanta, "Risk Effectiveness Evaluations of Surveillance Testing," BNL Draft Report, November 1990.
6. W.E. Vesely et al., "Evaluation of Diesel Unavailability and Risk Effective Surveillance Test Intervals," NUREG/CR-4810, BNL-NUREG-52022, May 1987.