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EVALUATION OF RISKS ASSOCIATED WITH AOT AND STI REQUIREMENTS AT THE ANO-1 NUCLEAR POWER PLANT

P.K. Samanta, S.M. Wong, and J. Carbonaro

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DEPARTMENT OF NUCLEAR ENERGY, BROOKHAVEN NATIONAL LABORATORY
UPTON, LONG ISLAND, NEW YORK 11973

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P.K. Samanta, S.M. Wong, and J. Carbonaro
Reliability and Physical Analysis Group
Department of Nuclear Energy
Brookhaven National Laboratory
Upton, Long Island, N.Y. 11973

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ABSTRACT

This report presents an evaluation of the core-melt frequency contributions associated with Allowed Outage Times (AOTs) and Surveillance Test Intervals (STIs) at Arkansas Nuclear One - Unit 1 (ANO-1).

The results show that the core-melt frequency contributions from present AOTs and STIs vary by more than four orders of magnitude (a factor of 10,000). This wide range of variation indicates the wide range of the risk importance of present AOTs and STIs. The core-melt contributions from specific AOTs and STIs can be used to prioritize those components which should be focused on for inspection activities, personnel training, and reliability program activities that are involved with surveillance testing and corrective maintenance.

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EXECUTIVE SUMMARY

This report provides a risk-based evaluation of two aspects of the technical specifications (TSs) requirements at the Arkansas Nuclear One - Unit-1 (ANO-1) nuclear power plant. These two aspects of technical specifications define the allowed outage times (AOTs) and the surveillance test intervals (STIs) for the safety system components. The AOT of a component is the period of time during the plant operation in which the component may be inoperable, i.e., if a component is found failed, it should be repaired within the defined AOT or otherwise the plant must be brought to a shutdown state without the approval of a waiver request. The STIs define the maximum time intervals between required testing of the standby safety system components.

The establishment of AOTs and STIs within the TS was primarily based on engineering judgments and many of these requirements are currently considered to be unnecessarily burdensome to the extent that their enforcement may be diverting attention from important safety operational aspects of the plant. This report uses a risk methodology to identify the risk contributions, which are defined below, associated with AOTs and STIs. Such an evaluation, besides providing a risk perspective, demonstrates the usefulness (or lack of it) of the many requirements in the current form.

The operating risk of a plant due to an AOT is the risk associated with the component being down and unavailable were it needed if an accident occurred. Measured at core-melt frequency level of a plant, it can define the core-melt probability for the downtime when the component is down for the AOT (called single downtime risk) and also the cumulative risk from projected downtimes which a component can suffer during a reference period of one year (called yearly AOT risk). Figure 1 shows the profile of the yearly AOT risk for the components in the ANO-1 plant measured at core-melt level. The results show that a large percentage (~80%) have a small core-melt contribution (below 10^{-7}). Also, 37% of the AOTs have negligible contributions (below 10^{-9}). A similar profile for single AOT risk shows that about 10% of the components have significant core-melt contributions (greater than 10^{-5}), given the component is down and unavailable to perform its function for the AOT period.

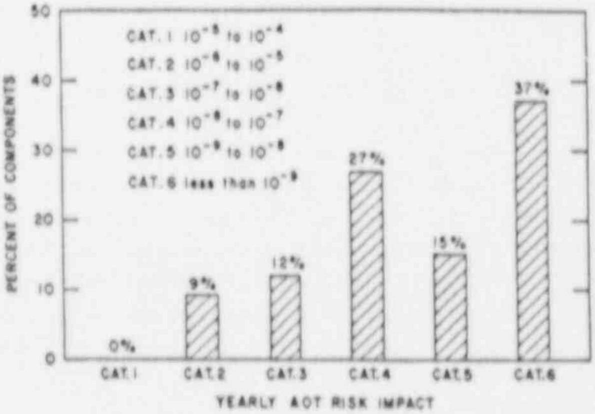

Figure 1. Yearly AOT risk impact of ANO-1 maintainable components

The risk impact of a surveillance test consists of the risk reduction due to the test and risk increase by the test. We consider the risk reduction due to the test to determine the risk impact of the test. Any risk caused by the test will lower the benefits of the test. In considering only the risk reduction, we are bounding the net benefits of the test. At the core-melt frequency level, the risk impact of a surveillance test is the decrease in core-melt frequency due to the test. Figure ii shows the decrease in core-melt frequency from current STIs for the surveillance tests in the ANO-1 plant. The results show that 53% of the surveillance tests have small benefits (below 10^{-7}) and 14% have significant benefits (greater than 10^{-5}).

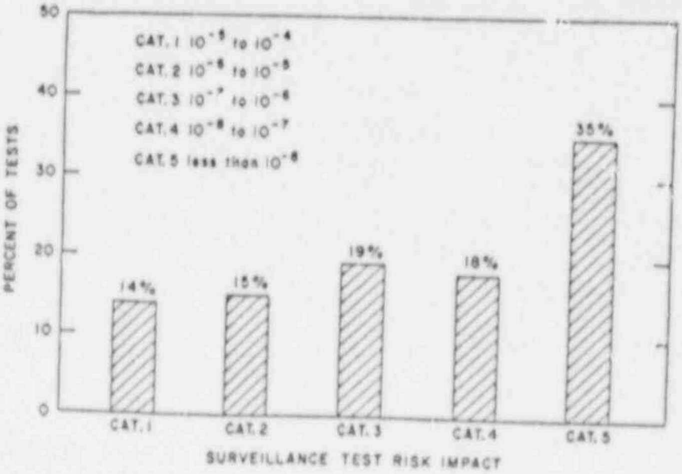

Figure ii. Risk Impact of ANO-1 Surveillance Test Requirements

This wide range of variation in the core-melt frequency contribution from present AOTs and STIs indicates the wide range of the risk importance of present AOTs and STIs. The core-melt contributions from specific AOTs and STIs can be used to prioritize those components which should be focused on for inspection activities, personnel training, and reliability program activities that are involved with surveillance testing and corrective maintenance.

Risk considerations can be used to provide a sound basis for the objectives and scope of AOTs and STIs as well as providing a sound basis for acceptable values of AOTs and STIs. From a risk standpoint, the objective of AOTs is to allow on-line repair to be performed while at the same time acceptably controlling the increased risk during the period the component is down. The objective of STIs is to allow component failures to be detected in order to control risk while at the same time controlling any risk caused by the test. The analyses in the report demonstrate how these objectives can be addressed in determining present AOT and STI risks and in assessing proposed modifications.

1. INTRODUCTION

This report provides a risk-based evaluation of two aspects of the technical specifications (TSs) requirements at the Arkansas Nuclear One - Unit-1 (ANO-1) nuclear power plant. These two aspects of technical specifications define the allowed outage times (AOTs) and the surveillance test intervals (STIs) as a part of the limiting conditions of operations (LCOs). The AOT of a component is the period of time during the plant operation in which the component may be inoperable, i.e., if a component is found failed, it should be repaired within the defined AOT or otherwise the plant must be brought to a shutdown state without the approval of a waiver request. The STIs define the maximum time intervals between required testing of the standby safety system components. The establishment of AOTs and STIs within the TS was primarily based on engineering judgment. In this report a risk-perspective is provided for these aspects of the technical specifications.

The objective of this report is to evaluate the AOT and STI requirements in a nuclear power plant, to provide a methodology for evaluating the requirements from a perspective of risk, to demonstrate whether the various requirements are consistent from the point of view of their risk implications, and finally, to rank order the requirements on a scale of risk.

Such an evaluation, besides providing a risk-perspective demonstrates, the usefulness (or the lack of it) of the many requirements in the current form. Many elements of the technical specification requirements are currently considered to be unnecessary as opposed to conducive to the safety of the plant. Accordingly, these requirements become burdensome to the utilities to the extent that their enforcement may be diverting attention from important safety operational aspects of the plant. In addition, the bases for a significant number of the specifications within the LCO requirements are not explained.[1] The result has been inadequate implementation, and, at the same time any necessary changes have been difficult. The risk consideration presented here can be used to provide a sound basis for the objective and scope of AOTs and STIs as well as providing their acceptable values.

The risk impact of AOT and STI requirements are determined using the probabilistic risk assessment (PRA) of the ANO-1 nuclear power plant performed as a part of the Interim Reliability Evaluation Program (IREP).[2] The risk impacts are calculated using the core-melt frequency as the measure of risk, i.e., the core-melt frequency contributions associated with AOTs and STIs are evaluated. Other measures at the total risk level such as the expected fatalities, man-rems, etc., also could be used. However, the AOT and STI requirements, in general, directly influence the core-melt frequency and extending the analysis at the total risk level (expected fatalities, man-rems, etc.) will not change the relative ordering of the requirements unless the consequence aspect is affected. The requirements addressed in the study do not impact the consequence aspect and accordingly, there was no need to perform any further analysis to obtain additional insights. The core-melt frequency incorporates various interactions associated with and resulting from the AOT and STI requirements.

In performing this risk-based evaluation, the objective has been to obtain realistic but conservative results. For a comprehensive risk-based evaluation of technical specification elements, many issues must be resolved.[3] The intent of this analysis, however, was to obtain a bounding evaluation of the risk associated with AOT and STI requirements. This was obtained considering the important influencing issues[4] in the risk measures. In addition, the risk measures are chosen to be conservative i.e., the calculated risk contributions are slightly higher than actual due to various assumptions. These bounding evaluations still allow AOT and STI risks to be effectively discriminated while not requiring justification for detailed data or models. This approach of realistic but conservative measures of risk contributions is considered adequate in obtaining a relative ranking of the TS elements. Moreover, the decision required to improve technical specifications without undue safety implications is safer with conservative analyses. These bounding evaluations can provide tech spec relief and improvement while simplifying the regulatory review process. It must, at the same time, be emphasized that in establishing AOTs and STIs, a more refined, comprehensive analysis must be performed considering various issues impacting their evaluation. The Procedures for Evaluating Technical Specifications (PETS) program, being conducted by Brookhaven National Laboratory (BNL) for Nuclear Regulatory Research (RES) has an objective of defining the analyses requirements in using risk basis for establishing such requirements.

Within the boundary of the analysis, the results obtained have a significant bearing on modification. The results can be used in a number of ways in seeking improvements in TSs of nuclear power plants. The risk-based methodology using PRAs of nuclear power plants can be used to develop consistent bases for technical specifications relating to AOTs and STIs, thus resulting in better clarity in the specifications. This evaluation process can be used to seek pertinent changes to many unnecessarily restrictive AOT and STI requirements resulting in fewer unscheduled shutdowns and requests for one-time extensions or exemptions. Specifications whose risk impacts are found to be insignificant can also be considered for removal from current TSs to some other form of control, if necessary. The evaluation can also be used to tighten requirements where the risk contributions are unacceptably high.

The report is organized as follows: Section 2 provides the measures of risk impacts of AOT and STI requirements used in this analysis. The determination of these measures using an existing PRA and the limitations are also discussed. Section 3 provides a brief description of the ANO-1 PRA and the technical specifications analyzed. The application of risk measures and the results of the study are presented in Section 4. Summary, conclusions, and the utilization of the results in the decision making process for improving technical specifications are discussed in Section 5. Appendices provide the detailed results for each maintainable component for which the AOT risk was evaluated and for each test requirement whose risk impact was evaluated. Appendix A presents a detailed derivation of the surveillance test interval risk measure. Appendix B provides the maintenance requirements for the on-line maintenance performed in the ANO-1 nuclear plant and Appendix C provides both the single and projected yearly AOT risks for each of the maintenances. Appendix D defines the various surveillance test requirements, the components tested in each test and the risk impact or benefit of these tests.

2. MEASURES OF RISK IMPACTS OF AOT AND STI REQUIREMENTS

In this section the measures of risk impacts of AOT and STI requirements are defined. The definitions, the development of these measures, the underlying assumptions and limitations are provided. The utilization of PRAs in calculating these measures is also explained.

2.1 AOT Risk Measure

The operating risk of a plant due to an AOT is the risk associated with the component being down and unavailable were it needed if an accident occurred. The risk can be any risk characteristic such as core-melt frequency or expected fatalities or system unavailability-depending upon the level of definition used. These definitions of AOT risks are further explained in Refs. 5 and 6.

Single Downtime Risk

Let r_i^{AOT} define the core-melt probability for the downtime when the component i is down for the AOT. The quantity r_i^{AOT} is sometimes called the single downtime or conditional risk since it occurs when the component is known (given) to be down for the one AOT. The risk r_i^{AOT} is the pertinent risk to consider when the component is found to be down and a decision needs to be made on the allowable AOT. The risk (the core-melt probability here) r_i^{AOT} when the component is assumed down for the entire AOT period is given by the simple product:

$$r_i^{AOT} = C_i^{+} \cdot (AOT) \quad , \tag{1}$$

where C_i^{+} is the (increased) core-melt frequency when the component is down.

The increase in core-melt probability due to the AOT is then:

$$\Delta r_i^{AOT} = (C_i^{+} - C_i^{o}) \cdot (AOT) \quad , \tag{2}$$

where C_i^{o} is the core-melt frequency when the component i is not known to be down. This is the representation of the "differential single downtime risk" and is one of the AOT risk measures calculated in Chapter 4 and also presented in Appendix C.

The conditional or single downtime AOT risk definition applies to the situation where the component is detected to be down and repair or maintenance is to be performed for the entire AOT period. This definition does not directly account for the frequency of maintenance or repair; rather, the implicit assumption in this measure is that the frequency is one per year, and the component is unavailable for the entire AOT period. In another point of view, this measure provides the incremental risk for a component unavailable for one AOT period over one year. The actual AOT risk, on the average, may be lower than that calculated from the conditional risk measure, since, in reality, the average repair time of a component is less than the AOT.

Yearly Downtime Risk

The risk r^{AOT} does not cover all the risks associated with the AOT. The other measure of AOT risk is the risk associated with the future occurrences of the component being down. This risk is sometimes called the yearly AOT risk and is the expected risk which will accumulate over some future time period.

Let R_i^{AOT} be this cumulative risk from downtimes which a component i can suffer during a reference period of one year. This risk R_i^{AOT} accounts for the downtime for a given AOT as well as the number of downtime occurrences. The risk R_i^{AOT} is given by:

$$R_i^{AOT} = N \cdot C_i^+ \cdot (AOT) \quad , \tag{3}$$

where N is the number of projected downtime occurrences during a defined time period of 1 year. The number N is an expected number and can be less than or greater than 1. For core-melt probability as the risk measure, R_i^{AOT} is the projected core-melt probability during the downtimes which are expected to occur.

The increase in projected risk is given by

$$\begin{aligned} \Delta R_i^{AOT} &= N \cdot (C_i^+ - C_i^o) \cdot (AOT) \\ &= (\omega_i) \cdot (C_i^+ - C_i^o) \cdot (AOT) \quad , \end{aligned} \tag{4}$$

where ω_i is the maintenance frequency (per year) of component i and $N=\omega_i$ for a time period of 1 year. This "differential yearly downtime risk" is calculated and presented in Chapter 4 and Appendix C. The maintenance frequency is usually higher than the failure rate of the component since it accounts for the maintenances to be performed for many degraded and incipient failure conditions of the component. The projected risk increase will be higher compared with the differential single downtime risk when the number of projected downtime occurrences over a year is greater than one and vice versa.

This definition of yearly downtime risk increase also assumes that every time the component is taken out for service, the entire AOT period is used. As explained before, the expected AOT risk in a plant can be lower since many repairs can be completed in shorter time periods and the average time is less than the AOT defined. Using the average repair time, one can obtain the expected differential yearly downtime risk as:

$$\Delta R_i^d = \omega_i (C_i^+ - C_i^o) \cdot d \quad , \tag{5}$$

where d is the average repair time and is typically less than the AOT for the component. This measure is also calculated in Chapter 4. The use of Eqn. (4) or (5) in obtaining the projected yearly downtime risk depends on the interpretation provided to the measure. Obviously, Eqn. (5) provides the expected risk and evaluating the risk with the entire AOT (as in Eqn. (4)) gives the risk which is allowed by the AOT.

2.1.1 Increased Allowed Risk Due to Change in AOT

In determining the risk impact of changing an AOT for a component, one can obtain the changes in both the single downtime risk and yearly downtime risk.

For a new AOT, termed as NAOT, the single downtime risk can be obtained using Eqn. (1) as:

$$r_i^{NAOT} = C_i^{+} \cdot (NAOT) \quad ,$$

and the change in the single downtime risk measure is given by

$$r_i(AOT \rightarrow NAOT) = r_i^{NAOT} - r_i^{AOT} = C_i^{+} \cdot (NAOT-AOT) \quad . \tag{6}$$

Similarly, the change in the differential single downtime risk is

$$\Delta r_i(AOT \rightarrow NAOT) = \Delta r_i^{NAOT} - \Delta r_i^{AOT} = (C_i^{+}-C_i^{o}) \cdot (NAOT-AOT) \quad . \tag{7}$$

Eqns. (6) and (7) present the additional single downtime risk allowed by a new AOT. The changes in the single downtime risk should be evaluated for each component separately since the single downtime risk is a conditional risk and is not additive.

The projected yearly downtime risk allowed by a new AOT, NAOT, can be obtained using Eqn. (3) as

$$R_i^{NAOT} = N \cdot C_i^{+} \cdot (NAOT) \quad ,$$

where N, the expected number of outages in a year, is assumed to remain the same under the new AOT. This assumption is conservative when NAOT is greater than AOT since, with longer available times, repairs are expected to be performed adequately - reducing the number of failures of the component.

The change in the differential yearly downtime risk is given by

$$\begin{aligned} \Delta R_i(AOT \rightarrow NAOT) &= \Delta R_i^{NAOT} - \Delta R_i^{AOT} \\ &= \omega_i(C_i^{+}-C_i^{o}) \cdot (NAOT-AOT) \quad , \end{aligned} \tag{8}$$

where ω_i, like N, is assumed to remain unchanged for same arguments.

The net effect of changing more than one AOT can be obtained by combining the yearly downtime risk. The cumulative impact of changes in AOTs of n components can be expressed as

$$\Delta R^{n}(AOT \rightarrow NAOT) = \sum_{i=1}^{n} \omega_i(C_i^{+}-C_i^{o}) \cdot (NAOT_i-AOT_i) \quad . \tag{9}$$

It is calculated in Chapter 4 in presenting the total impact of core-melt frequency for changes in AOTs of the maintainable components. This measure is the risk being allowed by the new AOTs additional to that being allowed by the previous AOT.

2.1.2 Discussion of AOT Risk Measure

Two types of AOT differential risks are discussed here: the differential single downtime risk, Δr^{AOT}, and the projected differential yearly downtime risk, ΔR^{AOT}. Both need to be considered since both types of risk will be generated by the AOT. Both risks need to be controlled if AOTs are to be determined using risk as a guideline. In practice, one risk will often dominate the other and the dominating one will control the other.

The risk measures are determined here in a conservative manner by focussing on the risk being allowed by an AOT. This resulted in calculating the risk associated with the entire AOT period. In addition, when the AOT is increased, the frequency of maintenance is kept constant, even though it may decrease due to the availability of additional time for more thorough repair. As discussed, these bounding evaluations are sufficient for our purpose of relative ranking of risks associated with different AOTs.

2.1.3 Calculation of AOT Risk Measures

The determination of AOT risk measures is performed utilizing the PRA of a plant to calculate the core-melt frequencies C_i^+ and C_i^o. C_i^o is obtained by assigning a zero value for the AOT. C_i^+ is calculated using the following inputs:

1. The component i is assumed to be down. This is equivalent to setting the component unavailability equal to 1.

2. Other components that must be reconfigured for the repair are identified and their unavailabilities are modified to represent the reconfigured state.

3. Other components or system trains that are required to be operable are identified and are assumed not to be down for testing or repair, since that would violate the technical specification limitations.

The representation of reconfigurations and operability requirements of other components during maintenance requires a reevaluation of the system fault tree models. Reconfiguration of components may eliminate certain unavailability contributions because of the new state of the component. In addition, the requirement of availability of redundant trains and components imply that these are checked to ensure they are not down. Human errors following previous test will therefore be corrected before the repair is begun and these human errors are eliminated for the evaluation. The dependent failures due to human errors will no longer be applicable and are also eliminated. The remainder of the inputs are the same as that used for PRA calculations for. Using the above input, the calculation of the core-melt frequency C_i^+ incorporates pertinent system and component interactions.

Representation of the reconfigured state requires an evaluation of human errors associated with the failure to reconfigure and failure to maintain the operability requirements. However, the possibility of such errors are considered to be rather low in this study and are not considered. Many times redundant trains are tested before a repair is begun and their unavailabilities will be lower than the average unavailabilities. In essence, the AOT risk depends on the effectiveness of the tests. But, this aspect is not included in the analysis.

The calculation of AOT risk using [illegible] input requirements defined above requires certain cautions.[4] When a com[illegible] unavailability is equal to 1 in minimal cut sets, the resulting cut sets [illegible] nger be minimal and may need to be transformed to the minimal form. [illegible] e minimal cut sets truncated at a certain value (10^{-6} or 10^{-8}), othe[illegible] mber of minimal cut sets may become unmanageably large. If [illegible] are used to calculate the risk during AOT, care should b[illegible] ken [illegible] containing the AOT component are not prematurely truncated. [illegible] low magnitude containing the AOT component may become a do[illegible] when the component unavailability is equated to 1. Failure to ac[illegible] the significant cut sets containing the AOT component, when the [illegible] ity is set to 1, results in underestimation of the AOT risk. In [illegible] udy, the accident sequence models were recalculated using the WAMTAP co[illegible] er code[7] to avoid any error in estimation either due to truncation or due to changes in minimal cut sets.

2.2 STI Risk Measure

The risk impact of a test consists of the risk reduction due to the test and the risk increase caused by the test. The risk reduction of a test of a component is the reduction in risk due to the ability of the test to detect a failure that may have occurred during the standby period and may otherwise have gone undetected. The risk increase due to the test is the risk caused by downtimes required for the test, test-caused degradation, and test-caused failures. The risk impact or the risk benefit of testing can be interpreted in a probabilistic sense to be the difference in the expected risk before and after the test.

We will only consider the benefits of the test to determine the risk impact of the test. Any risk caused by the test will lower the benefits of the test. In considering only the benefits, we are bounding the net benefits of the test. Tests which have (low benefits) low risk impacts in this bounding evaluation will have even lower impacts when any risks caused by the test are considered. The sample bounding approach we use here is conservative and adequate for evaluation and the relative categorization of the risks associated with STIs.

Risk Benefit of Surveillance Test on a Component

The risk benefits r_i of a test on single component i can be simply defined to be the risk R_b before the test minus the risk R_a after the test

$$r_i = R_b - R_a \quad . \tag{10}$$

We shall use core-melt frequency as a risk measure and hence r_i is the decrease in core-melt frequency due to a single test. Note that the risk impact r_i is positive since r_i is the decrease in risk and is the risk benefit of the test.

Consistent with the bounding approach of the benefits of the test, we shall assume that after the test, the component is in an up state and has an availability of one (unavailability of zero);

$$R_a = R(0) \tag{11}$$

where R(0) is the risk (core-melt frequency) evaluated with the component unavailability set to zero, i.e., the component assumed to be up.

As stated, Eqn. (11) represents the maximum benefit of the test in that it is the lowest risk that can be achieved after the test. In actuality, the component will have a residual unavailability which is unequal to zero and represents the per cycle contribution.

Consider now the risk (core-melt frequency) R_b before the test. If the component is up, the risk is R(0). The probability that the component is up is 1-q where q is the component unavailability. If the component is down, the risk is R(1), i.e., the risk evaluated with the component unavailability set to 1; the likelihood of this occurring is q. The expected value of R_b is thus

$$R_b = (1-q)R(0) + qR(1) \tag{12}$$

Using Eqns. (11) and (12), the risk impact of the test is then

$$r_i = (1-q)R(0) + qR(1)-R(0) \tag{13}$$

or

$$r_i = q[R(1)-R(0)] \tag{14}$$

where [R(1)-R(0)] is known in reliability literature as the risk importance or Birnbaum Importance of the component.

Risk Benefit of a Surveillance Test

In performing a surveillance test, in many instances, a number of components are tested together. For example, the monthly test of the HPI pump will draw water from the BWST tank and will deliver it back to the tank through the minimum recirculation flow line. Thus, the surveillance test will detect failures in all the components in the path and the risk impact of the surveillance test should account for all the components and failure modes tested. The risk benefit of a surveillance test considers all the components tested in a test, and provides an appropriate measure for deciding the effectiveness of the test and the associated interval.

For n components tested in a test,

$$R_{STI} = \sum_{i=1}^{n} q_i \cdot [R_i(1) - R_i(0)] \quad , \tag{15}$$

where q_i is the unavailability for the ith component,

$R_i(1)$ is the core-melt frequency evaluated with the ith component assumed down, and

$R_i(0)$ is the core-melt frequency evaluated with the ith component assumed up.

The risk associated with a surveillance test is measured in terms of its benefit using Eqn. (15) and is presented in Chapter 4 and Appendix D. This measure is used to differentiate between risk important and unimportant tests and is also used to study the effect of increasing the test intervals. The risk benefit of surveillance test on a component, as presented in Eqn. (14), is useful in obtaining Eqn. (15), but cannot be used for deciding the appropriateness of a surveillance test. Consider a surveillance test involving three components, and consider also that the risk benefit of testing two of the three components is small, but the risk benefit of testing the third component is significant. This means that the test is risk important as calculated using Eqn. (15). However, if Eqn. (14) is used, it will appear that test on two of the components is unnecessary, and requirements for the test can be changed. In reality, this test will need to be performed because of the third component. Use of the risk benefit of a surveillance test as opposed to the benefit associated with individual component avoids these ambiguities.

The risk benefit of a surveillance test depends upon the interval at which the test is performed. Both Eqns. (14) and (15) can be expressed in terms of test intervals when q_i is approximated as follows:

$$q_i = \frac{1}{2} \lambda_i T \quad ,$$

where λ_i is the hazard rate of the ith component and T is the test interval. The risk benefit of a surveillance test can be written using Eqn. (15) as

$$R_{STI} = \sum_{i=1}^{n} \frac{1}{2} \lambda_i T [R_i(1) - R_i(0)] \quad . \tag{16}$$

This expression assumes that component failures are all standby time related. Treating all failures as standby time related will result in a bounding, conservative estimate of the risk benefit of the surveillance test since it calculates the maximum risk benefit associated with the test. A detailed derivation of the risk benefit of a surveillance test considering the separation of time-related and demand-related failures and other aspects associated with a test is presented in Appendix A.

2.2.1 Increase in Risk Due to Change in STIs

The change in the risk benefit of a surveillance test due to a change in the interval at which the test is performed can be obtained, using Eqn. (15), as

$$\Delta R_{STI} = \sum_{i=1}^{n} \frac{1}{2} \lambda_i (T_1 - T_0) \cdot (R_i(1) - R_i(0) \quad \text{for } \lambda_i T_1, \lambda_i T_0 < 0.1 \quad ; \qquad (17)$$

$$= (T_1 - T_0) \sum_{i=1}^{n} \frac{1}{2} \lambda_i (R_i(1) - R_i(0))$$

where T_1 is the new test interval and T_0 is the current test interval. Here, ΔR_{STI} is the decrease in the risk benefit of performing the test. Equivalently, ΔR_{STI} is the increase in risk from increasing the test interval. Using the bounding evaluation, ΔR_{STI} is the upper bound on the risk increase from increasing the test interval.

The above expression has an implicit assumption that the hazard rate remains unchanged with the change in the test interval, as evidenced by the use of same λ_i for T_1 and T_0. There is reason to believe that unless the component is experiencing wear-out and the new test interval does not violate the manufacturer recommended value resulting in degradation of the component, the hazard rate (λ) will remain constant. This assumption, if invalid, will introduce nonconservativeness in ΔR_{STI}. Another approximation that requires attention is that when test intervals are increased, $\lambda_i T_1$ may become greater than 0.1 and the approximation for q_i will require higher order terms.

2.2.2 Discussion on STI Risk Measure

The above formulation of risk impact of surveillance testing in terms of risk benefits associated with the testing does not consider many factor associated with a test. The possibility of degradation due to testing, the effect of wear-out of components, separation of standby time related vs demand related failure, the test-caused transients resulting in the possibility of unscheduled shutdown can reduce the risk benefit from a test whereas the appropriate consideration of relative placement of other tests can further improve the risk benefit. Incorporation of these parameters will require much more complex evaluation and is facilitated by the use of computer codes like FRANTIC[8]. Such detailed evaluations are necessary when considering modifications to risk-important tests and when establishing STIs using risk arguments. Vesely et al.[3] discuss the detailed evaluation approach to define STIs for diesels. The analysis presented above for evaluating the risk benefit of surveillance tests is a conservative, bounding approximation to more complex models and is useful for screening purposes. In many cases, the bounding evaluations are sufficient to justify the needed improvements in the tech specs. For example, surveillance tests which have low impacts will have even lower impacts if more precise evaluations are performed and modifications to these STIs can be performed based on these evaluations. However, the determination of the specific tests to be performed in a plant and the test strategies from risk consideration will require more complex evaluations.

2.2.3 Calculation of STI Risk Measure

The determination of STI risk measure requires the evaluation of the conditional risk, in this case core-melt frequency, assuming the tested components to be up, R(0), or down, R(1). Both these quantities can be calculated using the PRA of a plant. When the risk is evaluated at the core-melt level, R(0) is obtained by calculating the core-melt frequency by assigning an unavailability equal to 0 to the tested component. R(1) is similarly obtained by assigning an unavailability equal to one to the component. Similar calculations are performed for each of the components tested in the surveillance test.

The calculation of R(1), when the component unavailability is equal to 1, requires care similar to that used for calculating the AOT risk. Namely, the cut sets generated may need to be transformed to the minimal form and the minimal cut sets used for the evaluation must not be truncated so as to eliminate cut sets containing the component in question.

The additional parameters needed are the unavailability of each of the components being tested by the test and their associated test interval. This information is obtainable from the PRA of the plant

2.3 Difference Between AOT Risk Impact and STI Risk Impact

The differences between the AOT risk impact and the STI risk impact need to be highlighted. This is important particularly if risk evaluations are to be used to help justify AOT or STI modifications. The principal differences are:

1. AOTs, in general, increase risk and hence the risk impact is an increase in risk.
2. STIs, in general, decrease risk and hence the risk impact is decrease in risk.
3. AOTs cause the risk to increase (e.g., the core-melt probability to increase): the risk is the accident frequency time the downtime.
4. STIs cause the risk frequency to decrease (e.g., the core-melt frequency to decrease).

Even though STIs in general decrease risk, in certain cases they may actually cause the risk to increase (i.e., the net risk benefits are negative) owing to the test's deficiencies. The projected risk increase caused by the AOT can be translated to an average risk frequency increase by dividing by some reference time period. For example, the increase in projected core-melt probability can be translated to an increase in projected core-melt frequency by dividing by one reactor year. This translation is sometimes useful to have AOT and STI impacts on the same scale. For the projected AOT risk increase using Δk_i^{AOT}, we use the reference timer period of 1 reactor year to make the scales comparable.

3. ANO-1 PRA AND DETERMINATION OF RISK MEASURES

3.1 Arkansas Nuclear One - Unit One Probabilistic Risk Assessment

The plant analyzed in this report is the Arkansas Nuclear One - Unit 1, which is a 836 MWe Pressurized Water Reactor (PWR). The plant is a Babcock and Wilcox (B&W) design and has been operating since 1977.

This study utilized the Probabilistic Risk Assessment (PRA) of the plant performed under the Interim Reliability Evaluation Program (IREP). The IREP analyses represent an integrated plant system analysis. Detailed analyses were performed of those systems required to respond to a variety of initiating events and those systems supporting the responding system. The analysis included unavailabilities during test and maintenance activities, human errors which could arise in restoring the systems to operability following test and maintenance and in response to accident situations, and a thorough investigation of support system faults which could affect operation of more than one system. Event tree/fault tree methodology was used to study the accident sequences that could lead to core melt. The initiating events considered consisted of eight different types of transients and loss-of-coolant accidents of six different break sizes. Seismic, fire and flood-related events were not considered. The detailed descriptions of the systems, their interfaces, and the sequences leading to core melt are provided in the document "Interim Reliability Evaluation Program: Analysis of the Arkansas Nuclear One - Unit 1 Nuclear Power Plant".[2]

3.2 ANO-1 Technical Specifications

The ANO-1 technical specifications associated with the AOT and STI requirements of the safety systems were the focus of this study. These requirements were obtained from the IREP document[2]. The ANO-1 PRA identified the maintainable components in the safety systems, the AOT and the requirement of operability of redundant trains/components. Appendices B and C summarizes these requirements for each maintenance act delineated so as to define the input requirements for the calculation of the conditional core-melt frequency. The STI requirements are presented in Appendix D. Each surveillance test identified in the ANO-1 PRA was analyzed to determine the additional components being tested. A list of these additional components also is given in the appendix. Test intervals of many of the components were obtained from the fault exposure times provided in the fault summary sheets for the systems.

3.3 Scope

The current LCO requirements, i.e., the AOT requirements, the surveillance test requirements, and the requirement of system operability during maintenances are evaluated for their risk impact. The systems evaluated are those studied in the ANO-1 PRA, and include the High Pressure Injection/Recirculation System, Low Pressure Injection/Recirculation System, Core Flood System, Reactor Building Spray System, Emergency Feedwater System, Reactor Building Cooling System, Reactor Protection System, Service Water System, Engineered Safeguards Actuation System, Class 1E AC Power System, 125V DC System, Battery and Switchgear System, and Emergency Cooling System, and Emergency Feedwater Initiation Control System.

The system models and the accident sequences defined in the ANO-1 PRA were used for calculation of core-melt frequency and no attempt was made to alter any of the models or the data base of the PRA. The models and the data base were utilized and modified as required to represent the testing and maintenance condition in the plant.

3.4 Calculation of Core-Melt Frequency

The risk impacts of AOT and STI requirements were calculated at the core-melt frequency level. The core-melt frequency was calculated using the dominant accident sequences identified in the IREP PRA. Care was taken to include sequences that may become dominant due to the unavailability of the AOT component. The baseline core-melt frequency obtained is $\sim 4\times10^{-4}$ and was benchmarked against results of the Battelle Columbus Laboratory (BCL) study on "Applications of Risk Measures at the Arkansas Nuclear One - Unit 1 Power Plant."[10] The results also are consistent with those obtained in the IREP PRA.

The ANO-1 PRA provides a very detailed analysis of the recovery actions that may be performed during an accident. The recovery actions are those human actions which restore a failed component to service within a specified time frame. In the ANO-1 PRA, each of the events in the significant minimal cut sets were analyzed for their potential to recover. Based on the analysis, which depended upon whether the fault is recoverable, the location of the fault and time available for recovery, a probability of non-recovery was assigned. This probability of non-recovery was incorporated to determine the frequency of the minimal cut set. The inclusion of recovery factors significantly reduced the core-melt frequency in the PRA by almost an order of magnitude from 4×10^{-4} to 5×10^{-5} after the inclusion of recovery.

In analyzing the risk impacts of AOT and STI requirements the recovery factor was not included, but its incorporation would further reduce the risk impacts obtained. The calculation of various conditional core-melt frequencies C^+, $R(1)$, $R(0)$, will be affected by the recovery factors and a reevaluation of the recovery factors will be necessary for their proper incorporation. For example, if a component is already in maintenance, the probability of its recovery is zero. Also, if the redundant component is under AOT, then the probability of recovery of a component would be different from that assumed in the PRA. The justification for not incorporating the recovery factor is that it will provide conservative estimates of the risk impacts so that decisions on extensions and exemptions will be safer.

4. RESULTS OF EVALUATION OF ANO-1 AOT AND STI REQUIREMENTS

In this section, results of the evaluation of AOT and STI requirements are presented. The components of the safety systems analyzed in the ANO-1 PRA are evaluated for the various AOT and STI requirements based on ANO-1 technical specification requirements. The impact on risk from changing the AOT and STI requirements are discussed and also the implications of the action statements on current specifications.

4.1 Analysis of Risk Impact of AOT Requirements

As discussed in Section 2.0, the AOT risk impact is the incremental risk when a repair is performed on a component for the entire AOT period, and depends upon the state-of-plant during maintenance, the maintenance frequency for the component, and the AOT. Appendices B and C provide the detailed results of the analyses. Appendix B identifies the components in each safety system for which on-line maintenances are performed, the type of maintenance performed, the reconfiguration performed, and the requirement of operability of alternate trains or components based on the plant technical specifications. Appendix C presents both the single AOT risk given a downtime and the projected yearly AOT risk incorporating the maintenance frequency of the component.

A summary of the results on AOT risks for the various maintainable components is presented in Tables 4.1 and 4.2 and also in Figures 4.1 and 4.2. The tables present, for selected components, the single AOT risk, the projected yearly AOT risk, and the average yearly risk due to repair. The average yearly risk due to repair represents the current repair contribution since it uses the average repair time for the component. The measure is similar to the projected yearly AOT risk except that the average repair time, as opposed to the AOT, is used. For any of the measures used, the results show a wide variation, spanning over seven decades, in the risk impact of different AOT requirements. For example, the projected yearly AOT risk varies from 6.7E-6 to the order of 1.0E-12 or lower.

Table 4.1 presents the ANO-1 maintainable components with highest projected AOT risk over one year period. The components are ranked by their projected yearly risks. The table also contains the average repair time and correspondingly, the average risk due to repair under the current AOT requirement. For the majority of maintenance conditions, the entire AOT period is not used and the average repair time is considerably less. Accordingly, the average risk due to repair is lower than the projected yearly AOT risk. In that sense, the projected yearly AOT risk calculated in this study is the AOT risk that is allowed by the requirements. The table shows that the major components of the front-line safety systems and the components in the support system have the highest AOT risk impact. In these situations, the projected risk is less than 2% of the base-line risk from the core-melt frequency of the plant.

The table also presents the single AOT risk, i.e., the increase in risk when the component is down for an entire AOT period. As evident from the table, this is typically higher than both the projected yearly AOT risk and the average yearly risk due to repair. This is because the frequency of repair for the

Table 4.1. ANO-1 Maintainable Components with Highest AOT Risk Impact

	Component	AOT (Hrs)	Average Repair Time (Hrs)	Repair Frequency (Events/ Hr)	Average Yearly Risk Due to Repair	Single AOT Risk	Projected Yearly AOT Risk
1	EFW pump P7A	36	7	3.1 E-5	1.3 E-6	2.47 E-5	6.7 E-6
2	CWU VCH4A	24	7	6.2 E-5	1.6 E-6	9.94 E-6	5.4 E-6
3	HP Pump P36C	60	7	3.1 E-5	6.0 E-7	1.88 E-5	5.1 E-6
4	SW Pump P4C	36	7	2.9 E-5	7.6 E-7	1.53 E-5	3.9 E-6
5	Diesel Generator 1	168	25	6.0 E-5	5.8 E-7	7.42 E-6	3.9 E-6
6	CWU VCH4B	24	7	6.2 E-5	8.8 E-7	5.52 E-6	3.0 E-6
7	SW Pump P4B	36	7	2.9 E-5	5.6 E-7	1.02 E-5	2.6 E-6
8	Diesel Generator 2	168	25	6.0 E-5	2.7 E-7	3.42 E-6	1.8 E-6
9	EFW MOV CVY-2	36	4	1.8 E-6	1.1 E-7	6.02 E-5	9.5 E-7
10	EFW MOV CVX-1	36	4	1.8 E-6	1.0 E-7	5.90 E-5	9.3 E-7
11	EFW MOV CV2620	36	4	1.8 E-6	1.0 E-7	5.90 E-5	9.3 E-7
12	AC Bus (Trans. X5)	24	24	5.0 E-6	6.2 E-6	1.42 E-5	6.2 E-7
13	AC Bus B6	8	4	5.0 E-6	2.1 E-7	1.14 E-5	5.0 E-7
14	Battery Charger D05	8	8	2.8 E-6	4.5 E-7	1.83 E-5	4.5 E-7
15	EFW Pump P7B	36	7	3.1 E-5	4.7 E-8	8.84 E-7	2.4 E-7
16	Bus RS2	8	8	1.0 E-6	1.9 E-7	2.17 E-5	1.9 E-7
17	ESAS C-86 Power Supply	12	4	6.4 E-6	5.7 E-8	3.03 E-6	1.7 E-7
18	ESAS C-91 Power Supply	12	4	6.4 E-6	5.3 E-8	2.85 E-6	1.6 E-7
19	Bus D01 CB 0122B	8	4	1.0 E-6	8.0 E-8	1.83 E-5	1.6 E-7
20	Battery Charger D04	8	8	2.8 E-6	1.6 E-7	6.52 E-6	1.6 E-7

Table 4.2. Selected ANO-1 Maintainable Components with Low AOT Risk Impact

	Component	AOT (Hrs)	Average Repair Time (Hrs)	Repair Frequency (Events/ Hr)	Average Yearly Risk Due to Repair	Single AOT Risk	Projected Yearly AOT Risk
1	HPI Pump P36A	60	7	3.1 E-5	1.1 E-9	3.42 E-8	9.3 E-9
2	RPS Channel A Bypass	4	4	1.4 E-3	1.1 E-9	9.0 E-11	1.1 E-9
3	RBSS Pump P35A	36	7	3.1 E-5	6.4 E-11	1.21 E-9	3.3 E-10
4	HP MOV CV1220	60	4	4 E-7	1.9 E-11	8.28 E-8	2.9 E-10
5	LP MOV CV1400	60	4	4 E-7	8.0 E-12	3.42 E-8	1.2 E-10
6	VUC14A	24	4	4 E-7	8.2 E-12	1.40 E-8	4.9 E-11
7	Bus RS4	8	8	1 E-6	3.2 E-11	9.13 E-9	3.2 E-11
8	SW MOV 3640	36	4	4 E-7	3.2 E-12	8.28 E-9	2.9 E-11
9	RBSS MOV CV2400	36	4	4 E-7	4.0 E-13	1.03 E-9	3.6 E-12
10	ESAS Logic L135	12	4	1.3 E-6	1.6 E-12	4.13 E-10	4.7 E-12
11	EFW MOV CV2626	36	4	1.8 E-6	ε	ε	ε
12	EFW MOV CVY-30	36	4	1.8 E-6	ε	ε	ε
13	A/C Unit VE1A	4	7	6.2 E-5	ε	ε	ε

ε signifies negligibly small value

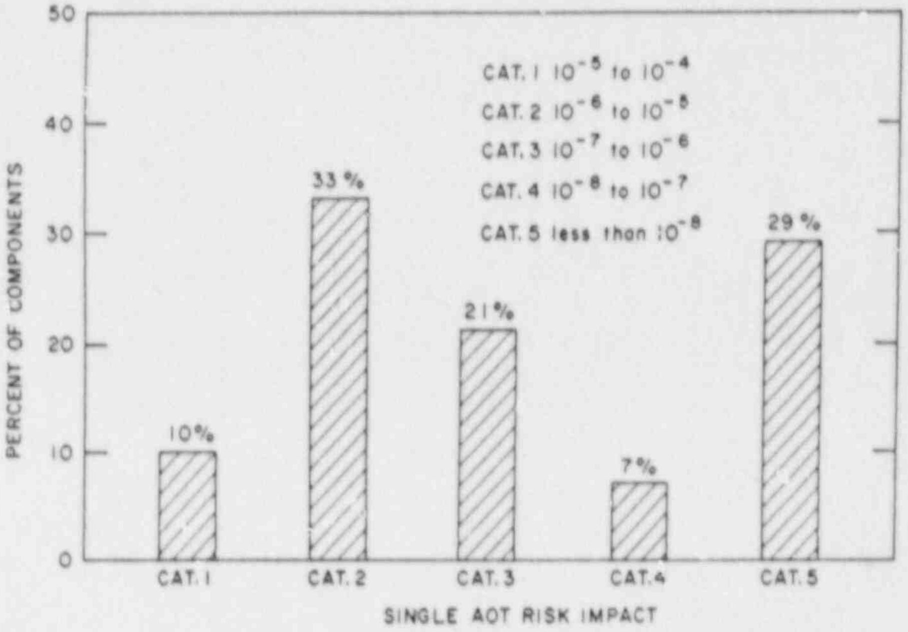

Figure 4.1. Single AOT risk impact for ANO-1 maintainable components

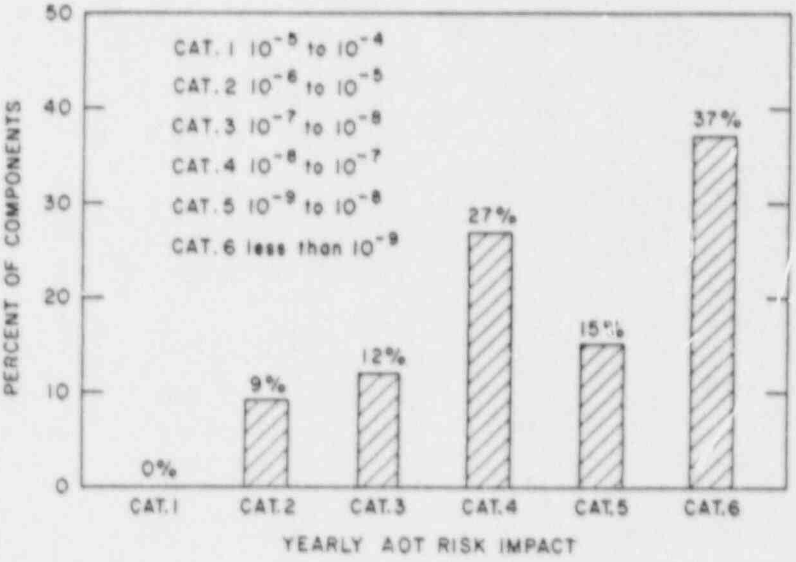

Figure 4.2. Yearly AOT risk impact of ANO-1 maintainable components

ANO-1 components is less than 1. It should also be noted that the ranking of the ANO-1 components based on the AOT risk will change if single AOT risk is used as the measure. The projected yearly AOT risk of a component is lower because the frequency of maintenance is lower, but these components can pose high risk when down for repair. An example will be the Bus D01 Circuit Breaker 0122B whose single AOT risk is over two orders of magnitude higher than the projected yearly AOT risk.

Table 4.2 presents selected ANO-1 components with low projected yearly AOT risk across a one year period. The components in this table were selected randomly over the systems to show that under the current requirements many components across the safety systems pose minimal risk due to their AOTs. The projected risk is below 10^{-8} and the AOTs of these components could be extended without any undue risk impact on the plant. The extensions could be granted in a manner such that the risk impact will still be low when taking into account the uncertainties of the calculation.

The ranking of the maintainable components on their AOT risk impacts depends on the incremental risk during the AOT, the frequency of maintenance, and the AOT. The high or low value of the risk impact is attributed to any one or a combination of the above parameters. An important illustration is provided by the risk measures obtained for high-pressure system pumps P36A and P36C. The AOT risk impact of Pump P36C is much higher than that for Pump P36A. The AOT and the maintenance frequency of the pumps being the same, the difference is attributed to the conditional core-melt frequencies for these pumps in maintenance. Based on the PRA model, during the repair of Pump P36A, the high-pressure injection system is able to deliver water to all four RCS cold legs using Pumps P36B and P36C. However, during the repair of Pump P36C, if two cross over valves (MU1223 and MU1224) are not open, two of the four RCS legs cannot receive water through Pump P36A and P36B. This results in a higher value for the conditional core-melt frequency when Pump P36C is in maintenance. Another interesting comparison will be between EFW Pump P7A and Battery Charger D05. Both components have a comparable single AOT risk even though the AOT for the EFW Pump is over 3 times higher compared to the battery charger. However, the projected yearly AOT risk for the EFW pump is over an order of magnitude higher than the battery charger since its maintenance frequency is over an order of magnitude higher. Similar explanations based on the PRA model and the system designs can be obtained for the quantitative measures of risks obtained for other components.

For maintainable components with low risk impact it is interesting to note that all three measures - single AOT risk, projected yearly AOT risk, and the average yearly risk due to repair are low. This implies that the increase in core-melt frequency when any of these components are down is insignificant and other parameters (repair time, maintenance frequency) cannot cause the risk to be significant.

4.1.1 Risk Impact of Extensions in AOTs

Based on the discussion of risk impact of current AOT requirements, it is evident that extensions could be granted for many components without undue impact on risk. Figures 4.1 and 4.2 show the current risk profiles of AOT requirements based on single AOT risk and projected yearly AOT risk, respectively. Figure 4.1 shows that for 57% of the maintainable components, the single AOT risk is below 10^{-6} and Figure 4.2 shows that for 79% of the same components, the projected yearly risk is below 10^{-7}. These figures demonstrate that, based on risk arguments, there is a wide disparity in current AOT requirements.

In this study, the impact of changes in AOT requirements were studied to analyze how the AOT risk profile would be altered. Components with low AOT risk impacts are candidates for extensions from the point of view of risk analysis. The AOTs of components with risk impacts below 10^{-7} were increased by a factor of two and the resulting risk profiles are presented in Figures 4.3 and 4.4. In this calculation, the other conditions were maintained unchanged in terms of operability requirements of alternate trains and components. The total cumulative risk increase due to the extension of AOTs is approximately 1×10^{-6}, i.e., about 0.25% of the baseline risk due to core-melt frequency. A comparison of Figure 4.3 with 4.2 shows that the impact on the risk profile is also minimal. As expected, there is a slight shift towards higher risk categories, nevertheless, the risk impacts of 73% of the components are still below 10^{-7}. However, the impact on single AOT risk, presented in Figure 4.4, shows that about 10% of the components have shifted to the high risk category. The single AOT risks of components are not additive, but the individual single AOT risks must be taken into consideration in deciding AOTs. A more conservative approach to AOT extension would allow an extensions of a factor of two for components with current

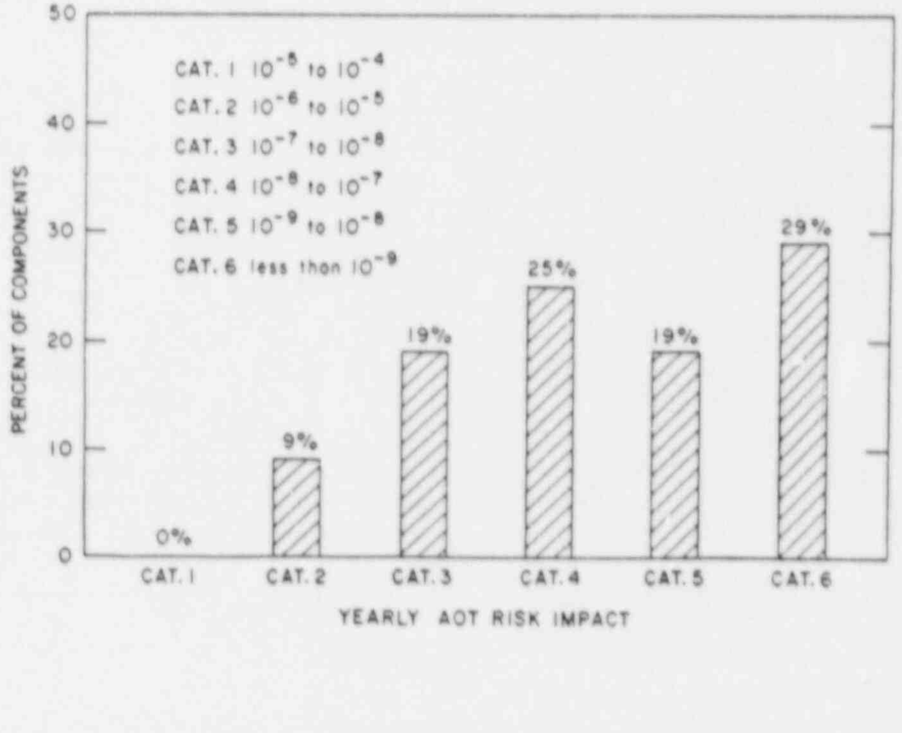

Figure 4.3. Yearly AOT risk of ANO-1 maintainable components for factor of two increase in AOTs of components with risk impact below 10^{-7}

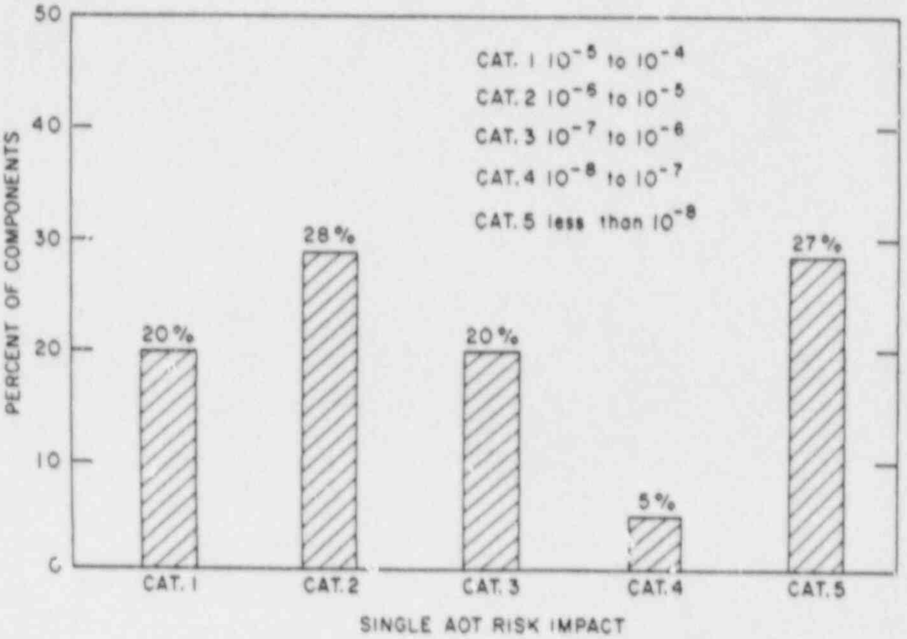

Figure 4.4. Single AOT risk impact for a factor of two increase in AOTs of components with yearly AOT risk impact below 10^{-7}.

risk impacts below 10^{-8}. This approach would allow extensions of 52% of the maintainable components and the net cumulative risk increase due to the extensions would be of the order of $4x10^{-8}$, i.e., 0.01% of the baseline risk due to core-melt frequency. Figures 4.5 and 4.6 show the AOT risk profile with such an extension and the change in the risk categorization would be limited to essentially categories below 10^{-7}. The high risk categories would remain unperturbed. In this case both single AOT risks and yearly AOT risks would have insignificant changes.

Various other approaches of changes in AOTs of the components that would incur small incremental risk to the plant is possible. In the above approaches, a group of components within the safety systems would be allowed extensions, whereas AOTs of selected components with higher risk impacts would remain unchanged. The majority of the safety systems have few selected components for which the AOT risk impact is higher. An extension of AOTs of the maintainable components in a safety system can result in higher incremental risk than that obtained in the other two extension approaches discussed above. For example, an increase in the AOTs of the High Pressure System Components by a factor of 2 (from two and half days to five days) would result in a net increase in the projected yearly AOT risk of the order of 5.2 E-6, i.e., 1.3% of the baseline risk due to core-melt frequency. However, in many systems, a similar AOT extension can be performed with minimal impact on risk. A factor of two increase in the AOTs of the maintainable components in the Low Pressure System would result in a net incremental cumulative risk of the order of 10^{-7}.

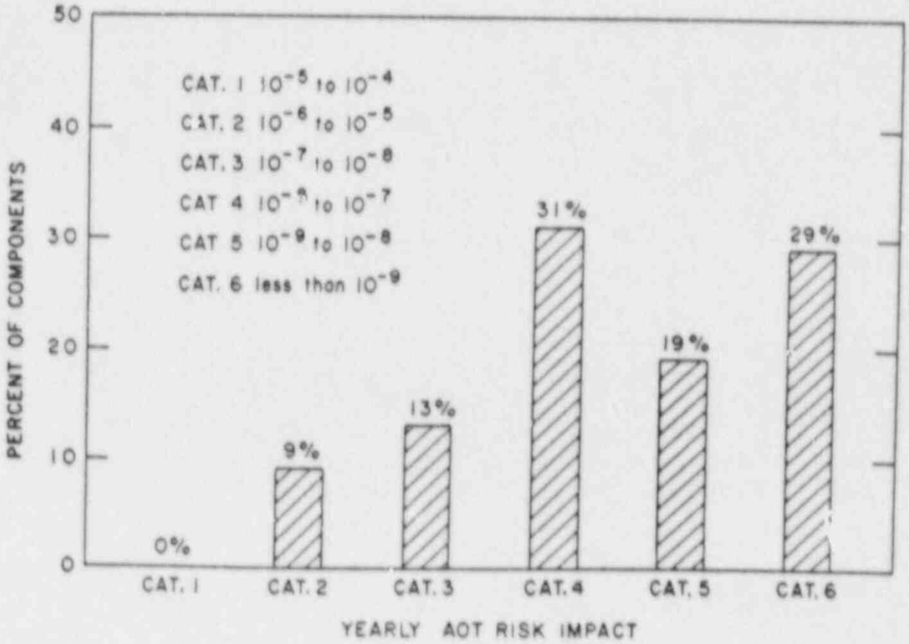

Figure 4.5. Yearly AOT risk of ANO-1 maintainable components for a factor of two increase in AOTs of components with risk impact below 10^{-8}

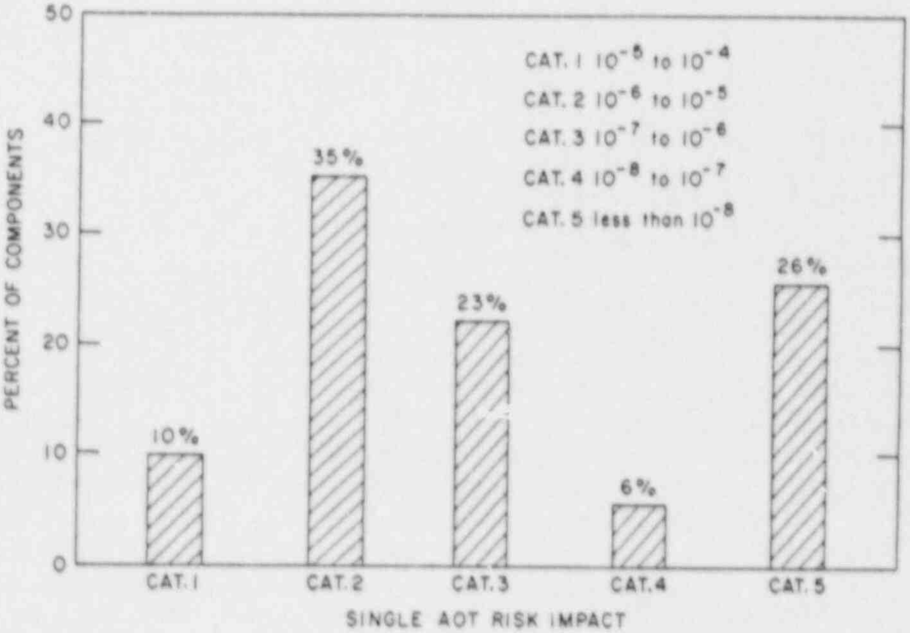

Figure 4.6. Single AOT risk of ANO-1 maintainable components for a factor of two increase in AOTs of components with risk impact below 10^{-8}

4.1.2 Evaluation of Action Statements

The action statements for limiting conditions of operations define the obligatory action if the requirement of the TS are not met. For AOTs, actions are defined if the component is not returned to operational status within the AOT defined. Usually, the action statements will require a change in the operational mode of the plant. For example, if a component in the low-pressure injection system train A is found inoperable and not repaired within 48 hrs, the plant should be in hot shutdown condition within the next 12 hrs and if not corrected, in the cold shutdown condition within the following 72 hrs.

Based on the risk implications of the AOT requirements, the action statements appear unnecessarily severe. For example, the maintenance of LPIS pump P35A for an additional 60 hrs results in an incremental risk of 3.43×10^{-7}. The expected frequency of maintenances requiring longer repair times compared to the AOT is lower than the maintenance frequency of 3.1 E-5 events/hr assumed for the pump. The additional risk is thus not expected to be more than 9.3 E-8. Under these circumstances, changes in the operational mode of the plant are unnecessary and possibly introduce more risk to plant operation than that incurred through allowing additional outage times. Alternate means of risk reduction, through monitoring and testing of alternate failure paths, may further reduce the risk of additional outage times. In addition, the punitive action statements may result in incomplete repair of components, thus increasing the frequency of maintenance. Similar risk arguments can be made for many of the action statements based on violations of AOTs. The appropriate action statements for enhancing the long-term safety of the plant would be the requirement of proper repair to reduce future occurrences of similar problems and assurance of availability of alternate means of risk reduction.

4.1.3 Transferring of AOT Requirements From Technical Specifications

The results of the risk impact of the ANO-1 AOT requirements demonstrate that many of the AOT requirements are unimportant. The expected frequency of maintenance of many of these components is low and a large increase in their AOTs would not impose undue risk. For example, a factor of ten increase in the AOT of the RBSS pump will contribute an additional risk of the order of 3.5×10^{-9}. These components are candidates for removal from technical specifications to some alternate means of control. A review of Figure 4.2 shows that the risk impact of 52% of the maintainable components is below 10^{-8}, and these would not necessarily require the strict control of technical specifications.

From a risk control point of view, technical specifications should focus on components and conditions that are significant contributors to risk. Risk and reliability analyses provide evidence that if critical combinations of components are simultaneously unavailable, this may cause a large increase in risk.[4] Current technical specifications do not always control these critical combinations of components which are identifiable through risk analysis. In considering removal of AOT requirement from TS, assurances must be provided that outage of critical combinations of safety significant component outages do not overlap.

4.2 Analysis of Risk Impact of STI Requirements

The risk impact of a surveillance test is quantified in terms of the risk benefit that result from the test. The risk benefit of the test is the reduction in risk due to the ability of the test to detect a failure that may have occurred during the standby period and may otherwise have gone undetected. The risk impact depends on a number of parameters. They include failure modes of the components tested, the test interval, the failure rates of the components, and the risk importance of the components tested. The surveillance tests identified in the safety system are analyzed with respect to their risk impacts and the detailed results are presented in Appendix D. A summary of test requirements, including the type of test, interval, duration and the list of components to be tested in each case is also provided.

The results of the analysis show a trend similar to that observed for AOT requirements. A significant number of tests provide small risk benefit. The risk benefit varies from 9.1 E-5 to below 1.0 E-12; 53% of the surveillance tests have risk benefits below 10^{-7} but 14% have benefit higher than 10^{-5}.

Table 4.3 presents the surveillance tests with highest risk benefits: in most cases these are due to the large number of components being tested. For example, the functional test of the room cooler unit tests the chill water unit, the fan, and the associated valves, while the pump flow tests will test the valves in the train along with the pump. The other reasons for the high risk benefit of a surveillance test is the impact on the core-melt frequency due to the component failure, the failure rate of the component, and the test interval.

Table 4.3. Surveillance Tests With Highest Risk Impact

	TEST	TYPE OF TEST	TEST FREQUENCY	RISK IMPACT
1.	Room Cooler Unit A	Functional	Quarterly	9.3 E-5
2.	EFIC Signal Path D_1D_2	Proper Operation	Monthly	4.7 E-5
3.	HP Pump P36C	Flow	Monthly	4.4 E-5
4.	Room Cooler Unit B	Functional	Monthly	4.3 E-5
5.	EFW Pump P7A	Flow	Monthly	2.9 E-5
6.	LP Pump P34B	Flow	Monthly	2.8 E-5
7.	SW Pump P4C	Vibration & Temp.	Monthly	2.5 E-5
8.	SW CV 3810	Stroke	Annual	2.4 E-5
9.	EFIC Signal Path AC04-BD04	Proper Operation	Monthly	2.2 E-5
10.	Diesel Generator 1	Start	Monthly	1.7 E-5
11.	EFW CV2626	Stroke	Quarterly	1.6 E-5
12.	EFIC Signal Path VCD2	Proper Operation	Monthly	1.4 E-5
13.	LP Pump P34A	Flow	Monthly	1.4 E-5
14.	HP Pump P36A	Flow	Monthly	1.36 E-5
15.	HP Pump P36B	Flow	Monthly	1.35 E-5
16.	RBSS Pump P35A	Flow	Monthly	1.3 E-5
17.	RBSS Pump P35B	Flow	Monthly	1.3 E-5
18.	SW Pump P4B	Flow	Monthly	1.3 E-5
19.	EFW CVY-1	Stroke	Quarterly	1.2 E-5
20.	EFW CV2620	Stroke	Quarterly	1.2 E-5

Another important observation is that appropriate testing schedules can be defined to increase the risk benefit or to increase the test interval without affecting the risk benefit. An analysis of the surveillance tests and the associated components tested (Appendix D) shows some components are tested as part of more than one test and, as these tests are performed sequentially, the maximum benefit from these tests is not achieved. For example, Valve CV1407B is tested for the monthly flow test of each of the pumps, P36C, P34B, and P35B. The high risk benefit of flow tests of pumps P35B and P34B is due to Valve CV1407B because of its risk importance and high failure rate. One way of maximizing the risk benefit would be to schedule the testing of pumps P36C, P34B, and P35B in a staggered manner, thus reducing the test interval by a factor of 3 and consequently increasing the benefit by the same factor. The other approach would be to perform one of the tests in short intervals to detect any failure of the valve, then the other two tests could be extended without affecting the risk in the plant. Many current surveillance tests can be redefined in this manner to design an integral test schedule for the plant through the insights of risk analyses.

Table 4.4 lists selected surveillance tests with minimal risk impacts. These types of tests are currently performed in many of the safety systems and their intervals could easily be extended without affecting risk.

Table 4.4. Selected Surveillance Tests With Low Risk Impact

TEST	TYPE OF TEST	TEST FREQUENCY	RISK IMPACT
1. ESAS Logic A110	Proper Operation	Monthly	5.0 E-8
2. CV3812 & CV3814	Valve & Interlock	Quarterly	2.3 E-8
3. EFIC Path A009	Proper Operation	Monthly	1.6 E-8
4. RPS Relay C1	Proper Operation	Monthly	6.2 E-9
5. CV2400	Stroke	Quarterly	1.2 E-9
6. Sensor PT2405	Calibration & Proper Operation	Shift	8.8 E-10
7. ESAS Logic A122	Proper Operation	Monthly	3.7 E-10
8. RPS Relay KA1	Proper Operation	Monthly	1.0 E-12
9. RPS Relay KA3	Proper Operation	Monthly	5.0 E-13

4.2.1 Risk Impact of Extensions in STIs

The risk benefit of each surveillance test will increase with an increase in the test interval. This is because the probability of a standby failure during the increased test interval will be higher and thus the probability of failure detection by the test accordingly will be higher.

Figure 4.7 shows the risk profile of current surveillance test requirements in the ANO-1 plant. The impact of changes in STIs was studied by increasing the interval requirements of tests with risk impact below 10^{-7}. Figure 4.8 shows the risk profile of surveillance tests with a factor of two increase in the intervals of tests with risk impacts below 10^{-7}. The effect on the risk profile is minimal except for small rearrangements between the third and fourth categories. The incremental risk impact due to such an extension is of the order of 1×10^{-6}, i.e., ~0.25% of the baseline risk due to core-melt frequency, and still 50% of the tests will have risk impacts below 10^{-7}. The risk impacts of many of the surveillance tests are so small that a much larger extension could easily be granted from risk considerations. Figure 4.9 presents the risk profile with a factor of four extensions in STIs with a risk impact below 10^{-7}. Such an extension would significantly reduce the burden of testing in the plant and would not result in an unacceptable risk.

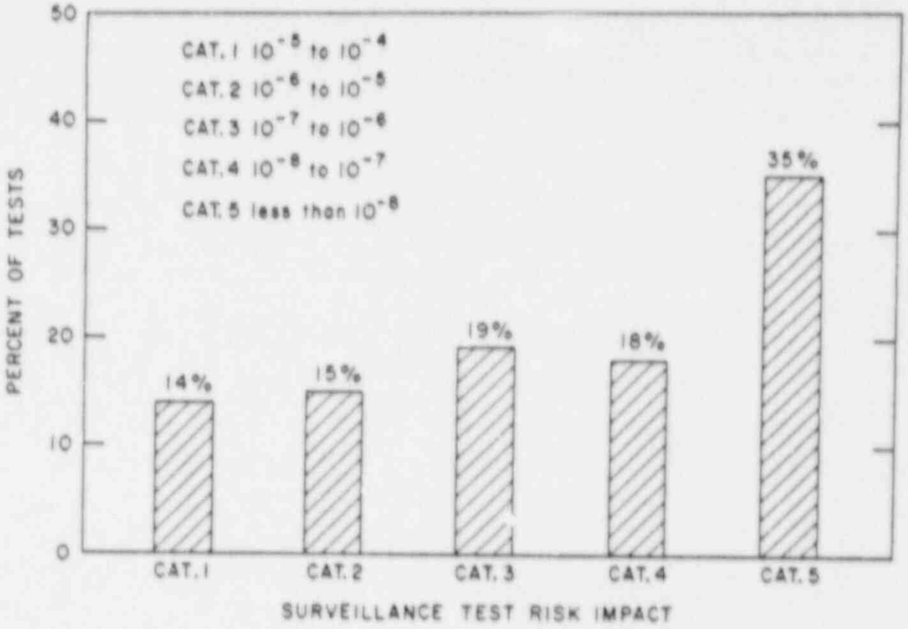

Figure 4.7. Risk Impact of ANO-1 Surveillance Test Requirements

4.2.2 Transferring of STI Requirements From Technical Specifications

Risk analyses of surveillance test requirements provide insights in deciding whether unimportant STIs should be transferred to some other form of control. As presented in Figures 4.8 and 4.9, a significant increase in the test intervals of a large fraction of the STIs would have negligible incremental risk impact. However, risk impact for at least 29% of the tests are significant and assurances are necessary that these tests are performed to detect any failures occurring in the standby period. In addition, manufacturer-recommended test intervals should not be violated, if they are necessary to maintain the integrity of the component.

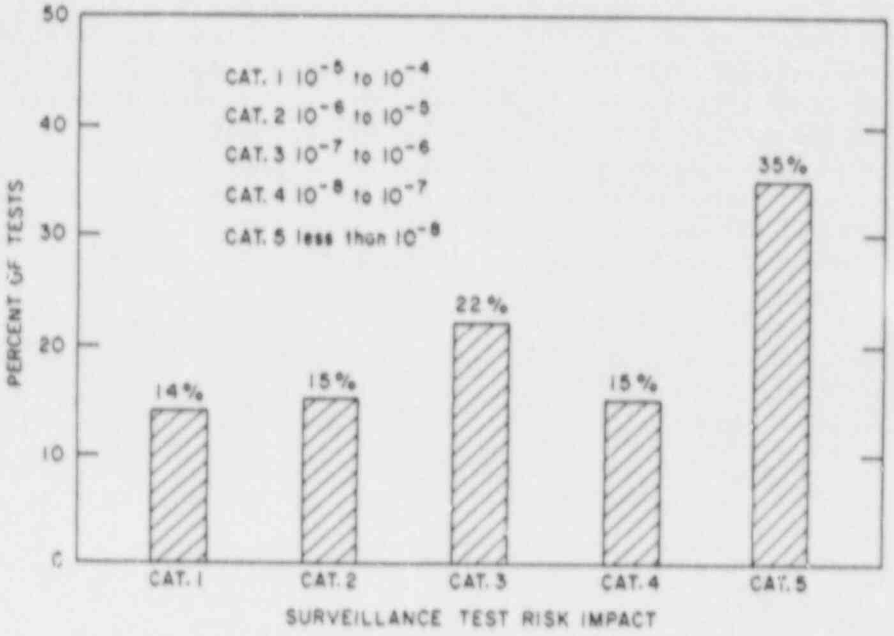

Figure 4.8. Change in risk impact of surveillance test requirements with a factor of two increase in the STIs of tests with risk impact below 10^{-7}.

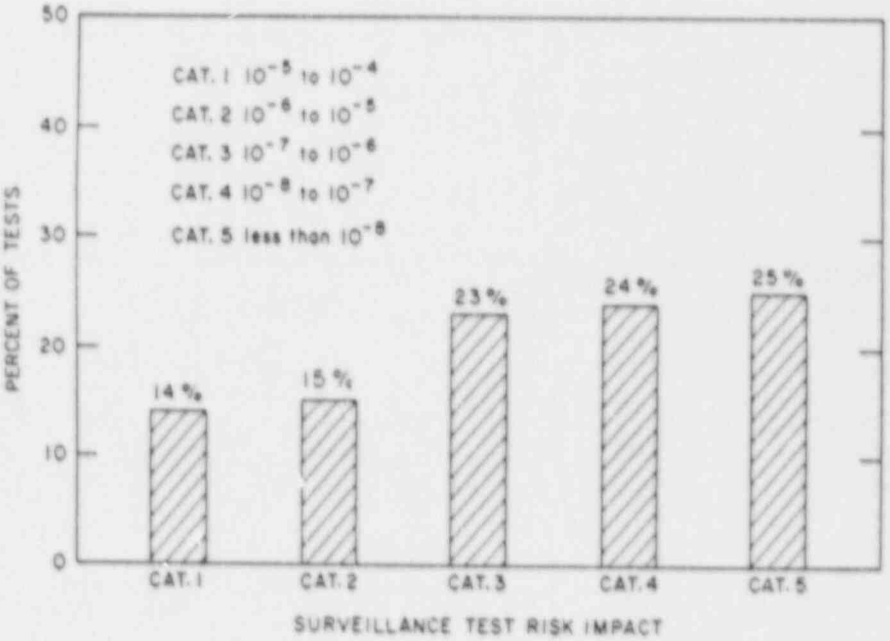

Figure 4.9. Change in risk impact of surveillance test requirements with a factor of four increase in the STIs of tests with risk impact below 10^{-7}.

The transfer of STIs from technical specifications can be performed in a variety of ways. The results of this study indicate that integral tests, i.e., tests of systems or system trains detecting failure modes of a group of components, are more risk effective. Risk insights can be used to develop fewer integral tests to control the risk and the remaining test requirements can be moved to other forms of control. Removing the entire STI requirements from technical specifications, where the test interval of risk important tests is significantly increased, may require an alternate form of risk control activity, e.g., condition monitoring of risk important failure modes of selected components.

5. SUMMARY AND CONCLUSIONS

In this report AOT and STI requirements of the ANO-1 nuclear power plant safety systems are evaluated from a risk perspective. Measures of risk impacts are defined and it is shown how they can be calculated, using the PRA of the plant. The risk impacts of current AOT and STI requirements are categorized on a risk scale that allows a study of the impact of changes in these requirements. The measure of risk impacts chosen are conservative so that decisions or conclusions based on this analysis are safer from a regulatory viewpoint. The results provide the basis for the following conclusions on various aspects of technical specification issues.

5.1 Risk Implications of Current Requirements

The risk impacts of AOT and STI requirements vary widely on the risk scale. A significant portion of these have small impacts. Approximately fifty-two percent of the risk impacts of both AOT and STI requirements studied in the ANO-1 nuclear plant are below 10^{-7}.

5.2 Bases for Technical Specification Requirements

Many items identified in technical specifications, particularly those associated with LCO requirements, do not have valid technical bases. The TSIP report[1] has addressed this issue. In many areas of technical specifications the risk-based methodology used in this report can provide the means to establish valid technical bases. A consistent basis for specifications will result in clarity of purpose and better compliance. The process of extensions and changes in the specifications also can be streamlined.

5.3 Validity of Action Statements

The results of this study indicate that the risk impact of many of the requirements are small and extensions to or relaxation of AOTs will also impose minimal incremental risks. Thus, action requirements for changes in the operational mode of the plant due to infrequent violation of an AOT are unnecessary and possibly introduce more risk, due to transfer to shutdown mode and return to operational mode. To enhance long-term safety of the plant, these action statements can be modified to be requirements for problem detection and correction. Insights based on risk and reliability can form the basis of such modifications.

5.4 Changes in AOTs and STIs

Changes in AOTs and STIs of risk-unimportant components can be granted without affecting the plant risk. Extensions in AOTs allowing for the adequate repair of components should reduce both the expected frequency of outages and unscheduled shutdowns. Extensions in STIs can be granted with little effect on risk, and concomitantly, reduce the burden on the operational staff so that they can focus on activities that are more significant to safety. Reduction in the number of tests will also reduce unscheduled plant shutdowns resulting from test-caused transients. Permanent changes in these requirements to more acceptable limits will result in reduction of one-time extensions and exemption requests. Another alternative is to reduce the requirement of testing at power whereby risk-unimportant surveillance testing are carried out during refueling outages. This approach will also have similar benefits in terms of reducing the operational burden and increasing attention to plant safety.

5.5 Improvement to Current Technical Specifications

The evaluation of AOT and STI requirements of a plant has identified that the requirements in technical specifications are not consistent from a risk viewpoint. Risk-based analysis can be used to significantly reduce the number of surveillance test requirements and fewer integral surveillance tests can be defined that would be adequate to maintain the risk level of the plant. AOTs can be defined from a risk perspective allowing adequate time for repair; and action statements then can be modified to address both the short- and the long-term safety of the plant.

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APPENDIX A

DETAILED DERIVATION OF STI RISK MEASURE

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DETAILED DERIVATION OF STI RISK MEASURE

The risk impact of a surveillance test is defined in terms of risk benefit of the test; and a bounding, conservative evaluation approach is presented in the main report (Section 2.2) for quantifying this aspect. In this section, a further detailed derivation of the risk benefit of a surveillance test on a component is presented to clarify the influence of some of the factors. This derivation will include the following additional considerations:

1. The separation of demand vs standby time-related failures.

Component unavailability can be considered to be composed of a demand failure contribution and a standby time-related failure contribution. The demand failure contribution is associated with a demand on the component and the component is susceptible to the same failure probability every time a demand is made on the component. Thus, a surveillance test does not influence this portion of the unavailability. Standby time-related failures are detected and corrected by surveillance tests. The risk benefit of a surveillance test will depend on the portion of the component unavailability that is standby time-related. However, the use of this definition requires a proper partition of the failure data into standby time-related and demand-related failure modes. An evaluation of each failure, as to whether its cause is demand or time related, is necessary to develop the data base for precise evaluation of risk benefit of a surveillance test. An example of such detailed data evaluation is presented in Ref. 9.

2. Human error associated with a test.

Surveillance testing of a component is associated with human errors, i.e., errors which can cause a tested component to be left in a failed condition. In many situations, this type of human error can be the dominant contributor to component unavailability. The derivation presented here considers human error and it will show that the risk benefit of a surveillance test is not influenced by the human error, i.e., its effect is negligible.

3. Downtime associated with a test.

Many surveillance tests are associated with downtimes during which the component is unavailable if a demand occurs. The derivation of the risk benefit presented here includes the risk due to such downtimes. However, since the test downtimes are significantly smaller than the test interval, its effect on the risk benefit of a test is usually negligible.

4. Non-detection probability.

Another consideration in the determination of the risk benefit of a test is the possibility of non-detection of component failure. The non-detection of component failure during a test will reduce the risk benefit of a test. In the derivation presented, the probability of passing a test in a failed conditional was assumed to be zero.

5. Test-cause degradation

Surveillance testing can cause wear-out of a component, resulting in test-caused degradation. The benefit of surveillance testing will be reduced if the test itself is causing wear-out of the component. When test intervals are increased, the effect of this contribution is expected to diminish. In the derivation of the risk benefit presented below, such effects are not considered, i.e., the degradation of the component due to test is assumed negligible.

In carrying out the derivation, the risk before a test (R_b), the risk after the test (R_a), and the risk during the test (R_τ) are defined separately to obtain the risk benefit of the test. The risk benefit of a test on a component is:

$$r_i = R_b - R_a - R_\tau \qquad (A-1)$$

Risk Before the Test of Component, R_b

The risk posed by a component is due to the possibility that the component is failed. The risk before the test of a component is due to the probability that the component, due to the following three reasons, may already be in a failed (down) state or may fail during the test.

1. From the previous test, the component may have bren left in a failed condition due to human errors. Let h_o define the human error probability associated with a test.

2. The component may have failed during the standby-time period following the previous test. The hazard is represented by λt, where λ is the failure rate of the component and t is the exposure time (where the exposure is on the average equal to half the test interval, T).

3. The component may fail with a probability q_o, where q_o is the demand-failure probability. A component is always susceptible to this failure probability anytime the component is demanded.

Mathematically, this can be expressed as:

$$R_b = P^{in}_{down}R(1) + P^{in}_{up}(1-q_o)\cdot R(0) + P^{in}_{up}\cdot q_o\cdot R(1) \qquad (A-2)$$

where

P^{in}_{up} is the probability that the component is up going into the test,

$P^{in}_{down} = (1-P^{in}_{up})$, is the probability that the component is down going into the test,

q_o is the demand failure probability,

$P_{up}^{in} \cdot q_o$ is the probability that the component will fail due to demand-related failure causes even if it enters the test in an up state,

R(0) signifies the risk when the component is in an up state, and

R(1) signifies the risk when the component is in a down state.

P_{down}^{in} is given by:

$$P_{down}^{in} = h_o + (1-h_o)\lambda t \quad ,$$

and (A-3)

$$P_{up}^{in} = 1-\{h_o + (1-h_o)\lambda t\} \quad ,$$

where

h_o is the human error associated with the test and signifies the probability that the component was left in a failed state, from the previous test,

λ is the failure rate of the component, and

t is the exposure time equal to half the test interval, T.

Using Eqns. (A-2 and A-3), R_b can be expressed as:

$$R_b = [q_o+(1-q_o)\{h_o+(1-h_o)\lambda t\}]R(1) + [1-\{h_o+(1-h_o)\lambda t\}](1-q_o)R(0) \quad . \qquad \text{(A-4)}$$

<u>Risk After the Test of a Component, R_a</u>

The risk following the test of a component is due to the possibility that the component may fail due to causes not correctable at the test (demand-related failure), or the test itself may have caused a failure or the test may have failed to detect a failure.

Mathematically, this can be expressed as:

$$R_a = P_{down}^{out} \cdot R(1) + (1-P_{down}^{out})R(0)$$

where P_{down}^{out} is the probability that of the component may fail after the test and is given by

$$P_{down}^{out} = h_o + (1-h_o)q_o$$

It is assumed here that the probability of non-detection of failure of the component at the test is negligible.

Accordingly, R_a can be written as:

$$R_a = \{h_o + (1-h_o)q_o\}R(1) + (1-h_o)(1-q_o)R(0) \qquad \text{(A-5)}$$

Risk During the Test, R_τ

The risk during the test results from the test-related downtime associated with the component, i.e., the time period for which the component is not available and cannot be returned to emergency safety position if a demand were to occur. The downtimes associated with a test are:

1. Test downtime, i.e., the time for which the component is unavailable for the performance of the test. In many cases, a demand can override a test and the test downtime unavailability depends on the failure to override.
2. Demand-related downtime, d, i.e., the downtime associated with the demand-related failure of the component at test.

Mathematically, R_τ can be given as:

$$R_\tau = \frac{q_\tau \cdot \tau}{T} \cdot R(1) + [1-\{h_o+(1-h_o)\lambda t\}]q_o \cdot \frac{d}{T} \cdot R(1) \qquad \text{(A-6)}$$

where the first term is the test downtime contribution, and the second term is the demand-related downtime contribution. The nomenclatures are defined as follows:

q_τ is the unavailability during the test,

τ is the duration of the test,

d is the downtime associated with a demand-related failure, and

t is the exposure time equal to half the test interval, T.

Risk Impact of a Surveillance Test on a Component

The risk impact of the surveillance test on a component is, as defined in Eqn. (A-1).

$$r_i = R_b - R_a - R_\tau$$

and using Eqns. (A-4, A-5, and A-6) one obtains.

$$r_i = [(1-q_o)(1-h_o)\lambda t][R(1) - R(0)] - \frac{q_\tau \cdot \tau}{T} R(1)$$

$$- [1-\{h_o + (1-h_o)\lambda t\}]q_o \frac{d}{T} \cdot R(1) \qquad \text{(A-7)}$$

Typically, $\tau/T \rightarrow 0$ and q_o, $h_o \ll 1$, and

$$r_i = \lambda t[R(1) - R(0)] - [1-\{h_o + (1-h_o)\lambda t\}]q_o \cdot \frac{d}{T} \cdot R(1)$$

A bounding approximation to the above equation is

$$r_i = q[R(1) - R(0) \tag{A-8}$$

where q is the component unavailability and is assumed to be purely time-related failures, which also eliminates the contribution from demand-related downtimes.

APPENDIX B

MAINTENANCE REQUIREMENT SUMMARY OF ANO-1 SAFETY SYSTEMS

Table B.1. Maintenance Requirement Summary
System: HPIS/HPRS

Component Under Maintenance	Type of Maintenance	Components Aligned Away from ES Position	System/Component Required to be Operable
HPI pump P36A	Maintenance requiring disassembly	Close valves: MU20A & MU18A Open circuit breaker A306	HPI pump train P36B, P36C ESF valve CV1227, CV1228
Valve: CV1219	Maintenance requiring disassembly	Close valves: MU1223 MU20A MU20 Open circuit breakers: B5152 B5151 Close valve CV1220 if open Open valves MU23 & MU24	HPI pump train P36B, P36C ESF valve CV1227, CV1228
Valve CV1220	Maintenance requiring disassembly	Close valves: MU1224 MU20A Open circuit breakers: B5152 B5151 Close valve CV1219 if open Open valves MU23 & MU24	HPI pump P36B, P36C ESF valve CV1227, CV1228
HPI pump P36C	Maintenance requiring disassembly	Close valves: MU20C MU18C Open circuit breaker: A406	HPI pump train P36A, P36B ESF valve CV1219, CV1220
Valve CV1227	Maintenance requiring disassembly	Close valves: MU20C MU23 MV1223 Close CV1228 Open circuit breakers: B6151 B6152	HPI pump train P36A, P36B ESF valve CV1219, CV1220
Valve CV1228	Maintenance requiring disassembly	Close valves: MU20C MU23 MU1224 Close CV1227 Open circuit breakers: B6152 B6151	HPI pump train P36A, P36B ESF valve CV1219, CV1220
HPI pump P36B	Maintenance requiring disassembly	Close valves: MU18B MU20B Open circuit breakers: A307 A407	HPI pump train P36A, P36C ESF valves CV1219, CV1220 CV1227, CV1228
Valves CV1407 or CV1408	Maintenance requiring disassembly	Close BW1 (Performed during shutdown)	

Table 3.2. Maintenance Req ant Summary
System: LPIS/LPR

Component Under Maintenance	of nce	Components Aligned Away from ES Position	System/Component Required to be Operable
Valve CV1440	Ma uiring dis	Circuit breaker B6161 open Valve BW8B closed Circuit breaker A405 open	LP pump train P34A ESF valve CV1401
Valve CV1429	Maintenance requiring disassembly	Circuit breaker B6161 open Valve CV1400 closed Valve BW8B closed Circuit breaker A405 open	LP pump train P34A ESF valve CV1401
Pump P34B	Maintenance requiring disassembly	Circuit breaker A405 open Valve CV1400 closed Circuit breaker B6161 open Valve BW8B closed	LP pump train P34A ESF valve CV1401
Valve CV1406	Maintenance requiring disassembly	Circuit breaker B6161 open Valve BW8B closed Valve CV1408 closed Circuit breaker B6164 open Valve CV1415 closed Circuit breaker B6163 open	LP pump train P34A ESF valve CV1401
Valve CV1401	Maintenance requiring disassembly	Circuit breaker B51114 open Valve BW8A closed Circuit breaker A305 open	LP pump train P34B ESF Valve CV1400
Valve CV1428		Valve CV1401 closed Circuit B51114 open Valve BW8A closed Circuit breaker A305 open	LP pump train P34B ESF valve CV1400
Pump P34A	Maintenance requiring disassembly	Circuit breaker A305 open Valve CV1401 closed Circuit breaker B51114 open Valve BW8A closed	LP pump train P34B ESF valve CV1400
Valve CV1405	Maintenance requiring Disassembly requiring	Circuit breaker B51112 open Valve BW8A closed Valve CV1414 closed Circuit breaker B51113 open Valve CV1407 closed Circuit breaker B5164 open	LP pump train P34B ESF valve CV1400
CV1415	Not allowed at power		
CV1414	Not allowed at power		

Table B.3. Maintenance Requirement Summary
System: Reactor Building Spray

Component Under Maintenance	Type of Maintenance	Components Aligned Away from ES Position	System/Component Required to be Operable
Pump P35B	Maintenance requiring disassembly	Valves: BS1B closed BW5B closed P35B circuit breaker open	RBSS pump train P35A ESF valve CV2401
Pump P35A	Maintenance requiring disassembly	Valves: BS1A closed BW5A closed Circuit breaker A405 open	RBSS pump train P35B ESF valve CV2400
Valve CV2400	Maintenance requiring disassembly	Valve BS1B closed P35B circuit breaker closed	RBSS pump train P35B ESF valve CV2400
Valve CV2401	Maintenance requiring disassembly	Valve BS1A Closed P35A Circuit breaker closed	RBSS pump train P35B ESF valve CV2401

Table B.4. Maintenance Requirement Summary
System: Emergency Feedwater (EFWS)

Component Under Maintenance	Type of Maintenance	Components Aligned Away from ES Position	System/Component Required to be Operable
Pump P7B	Maintenance requiring disassembly	Close valves: CV2800 CVX-3 CVX-2 Disable breakers: 5333 A311	EFW pump train P7A
Pump P7A	Maintenance requiring disassembly	Close valves: CV2802 CVX-1 CVX-4 Disable breakers: Y-1 Y-2 5533 6181	EFW pump train P7B
Valve CV2803	Maintenance requiring disassembly	Close valves: CV2800 CVX-2 CVX-3 Disable breakers: A311 5193 5194	EFW pump train P7A

Table B.4 (Cont'd)

Component Under Maintenance	Type of Maintenance	Components Aligned Away from ES Position	System/Component Required to be Operable
Valve CV2806	Maintenance requiring disassembly	Close valves: CV2802 CVX-4 CVY-1 CVY-2 Disable breakers: 6181 6185	EFW pump train P7B
Valve CVX-3	Maintenance requiring disassembly	Close valves: CV2800 CVX-2 CV2670 Disable breakers: X-3 A311 5193 5533	EFW pump train P7A
Valve CV2670	Maintenance requiring disassembly	Close valves: CVX-3 CVX-4 Disable breakers: 5332	ES valves CV2626, CV2620
Valve CVX-1	Maintenance requiring disassembly	Close valves: CV2802 CVX-4 CV2620 Disable breakers: X-1 Y-1 Y-2 6181 5533	EFW pump train P7B
Valve CV2620	Maintenance requiring disassembly	Close valves: CVX-1 CVX-2 Disable breakers: 6141	ES valves CV2670, CV2627
Valve CVY-1	Maintenance requiring disassembly	Close valves: CV2617 CV2666 CV2667 Disable breakers: Y-2	ES valve CVY-2
Valve CVY-2	Maintenance requiring disassembly	Close valves: CV2617 CV2666 CV2667 Disable breakers: Y-2	ES valve CVY-2
Valve CVY-3	Maintenance requiring disassembly	Disable breakers: Y-1 Y-2	ES valve CVY-4

Table B.4 (Cont'd)

Component Under Maintenance	Type of Maintenance	Components Aligned Away from ES Position	System/Component Required to be Operable
Valve CVY-4	Maintenance requiring disassembly	Disable breakers: Y-1 Y-2	Valve CVY-3
Valve CVX-4	Maintenance requiring disassembly	Close valves: CV2637 CV2802 CVX-1 Disable breakers: X-4 5533 6181 Y-1 Y-2	EFW pump train P7B
Valve CVX-2	Maintenance requiring disassembly	Close valves: CV2626 CVX-3 CV2800 Disable breakers: X-2 5533 5193 A311	EFW pump train P7A
Valve CV2626	Maintenance requiring disassembly	Close valves: CV2620 CVX-2 Disable breaker: 5335	ESF valve CV2670, CV2627
Valve CV2627	Maintenance requiring disassembly	Disable breaker: 6335 Close valves: CVX-4 CV2670	ESF valve CV2626, CV2620
Valve 2813	Maintenance requiring disassembly	Close valves: CVX-2 CVX-3 CV2800 Disable breakers: 5333 5533 A311 5193	EFW pump train P7A
Valve CV2814	Maintenance requiring disassembly	Close valves: CVX-4 CVX-1 CV2802 Disable breakers: 5333 5533 6181 Y-1 Y-2	EFW pump train P7B

Table B.5. Maintenance Requirement Summary
System: Reactor Protection

Component Under Maintenance	Type of Maintenance	Components Aligned Away from ES Position	System/Component Required to be Operable
Channel A Bypass	On-line maintenance	None	3 remaining channels
Channel B Bypass	On-line maintenance	None	3 remaining channels
Channel C Bypass	On-line maintenance	None	3 remaining channels
Channel D Bypass	On-line maintenance	None	3 remaining channels

Table B.6. Maintenance Requirement Summary
System: Service Water

Component Under Maintenance	Type of Maintenance	Components Aligned Away from ES Position	System/Component Required to be Operable
Pump P4C	Maintenance requiring disassembly	Valve SW2C CBA402 P4C (breaker disabled)	SW loop pump 4B
Pump P4B	Maintenance requiring disassembly	Valve SW2B CBA303 P4B (breaker disabled)	SW loop pump 4C
CV3804	Maintenance on valve intervals	Valve SW-86E SW-21A Breaker A-305 (P35A)	RBSS SW loop 2 (CV3805)
CV3805	Maintenance on valve intervals	Valve SW-61E SW-21B Breaker A-404 (P35E)	RBSS SW loop 1 (CV3804)
CV3840	Maintenance on valve intervals	Valve SW-86E SW-38B Breaker A-305 (P34A)	LP SW loop 2 (CV3841)
CV3841	Maintenance on valve intervals	Valve SW-61E SW-38A Breaker A-405 (P34B)	LP SW loop 1 (CV3840)

Table B.6 (Cont'd)

Component Under Maintenance	Type of Maintenance	Components Aligned Away from ES Position	System/Component Required to be Operable
CV3642	Maintenance on valve externals	CV3642 (breaker disabled)	---
CV3642	Maintenance on valve externals	CV3642 (breaker disabled)	---
CV3640	Maintenance on valve externals	CV3640 (breaker disabled)	---
CV3643	Maintenance on valve externals	CV3643 (breaker disabled)	---
CV3645	Maintenance on valve externals	CV3645 (breaker disabled)	---
CV3806	Maintenance on valve externals	CV3806 (breaker disabled)	DG2 SW loop (CV3807)
CV3807	Maintenance on valve externals	CV3807 (breaker disabled)	DG1 SW loop (CV3806)
CV3808	Maintenance on valve internals	Valve SW-18A SW-37A SW-014	SW loop to P36B and P36C
CV3809	Maintenance on valve internals	Valve SW-18B SW-37B SW-016	SW loop to P36A and P36C
CV3810	Maintenance on valve internals	Valve SW-18C SW-37C SW-017	SW loop to P36A and P36B

Table B.7. Maintenance Requirement Summary
System: Emergency Safety Actuation

Component Under Maintenance	Type of Maintenance	Components Aligned Away from ES Position	System/Component Required to be Operable
Logic L1-1	Replacement	L1-1	Remainging channels
C86 Power Supply	Power supply restoration	L1-1, L1-13, L1-19, L1-35	C-91 power supply
Logic L1-13	Replacement	L1-13	Remaining channels
Logic L1-19	Replacement	L1-19	Remaining channels
Logic L1-35	Replacement	L1-35	Remaining channels
Logic L2-1	Replacement	L2-1	Remaining channels
C91 Power Supply	Power supply restoration	L2-1, L2-12, L2-18, L2-34	C-86 power supply
Logic L2-12	Replacement	L2-12	Remaining channels
Logic L2-18	Replacement	L2-18	Remaining channels
Logic L2-34	Replacement	L2-34	Remaining channels

Table B.8. Maintenance Requirement Summary
System: 125V DC

Component Under Maintenance	Type of Maintenance	Components Aligned Away from ES Position	System/Component Required to be Operable
Battery D07	Clean; replace electrolyte	Bus D01	Battery D06 DC Bus D02, RA2 Diesel Generator DG2 Inv. Y22, Y22
Bus D01	Disassembly of D05	Battery charger D05	Battery D06 DC Bus D02, RA2 Diesel Generator DG2 Inv. Y22, Y22
Bus RS1	Disassembly of Inv. Y11	Circuit breaker 0152A Circuit breaker 5141A Circuit breaker 5141B	
Bus RS3	Disassembly of Inv. Y13	Circuit breaker 0152B Circuit breaker 5145A Circuit breaker 5145B	

Table B.8. (Cont'd)

Component Under Maintenance	Type of Maintenance	Components Aligned Away from ES Position	System/Component Required to be Operable
Battery D06	Clean; replace electrolyte	Bus D02	Battery D07 DC Bus D01, RA1 Diesel Generator DG1 Inv. Y11, Y13
Bus D02	Disassembly of D04	Battery Charger D04	Battery D07 DC Bus D01, RA1 Diesel Generator DG1 Inv. Y11, Y13
Bus RS2	Disassembly of Inv. Y122	Circuit breaker 0242A Circuit breaker 6121A Circuit breaker 6121B	
Bus RS4	Disassembly of Inv. Y24	Circuit breaker 0242B Circuit breaker 6145A Circuit breaker 6145B	

Table B.9. Maintenance Requirement Summary
System: AC Power

Component Under Maintenance	Type of Maintenance	Components Aligned Away from ES Position	System/Component Required to be Operable
Diesel Generator DG1	Disassembly of DG1, its subsystems or breaker 308	Circuit breaker 308 4.16 kV switchgear A3 480V switchgear B5 Transformer X5 MCC B51 MCC B56 MCC B52	Diesel generator DG2 MU pump P36C DH pump P34B RBS pump P35B SW pump P4C Startup transformer X4 Unit aux. transformer X2 Bus B6 Bus B61 Bus B62
Diesel Generator DG2	Disassembly of DG2, its subsystems or breaker 408	Circuit breaker 408 4.16 kV switchgear A4 480V switchgear B6 Transformer X6 MCC B61 MCC B62	Diesel generator DG1 MU pump P36A DH pump P34A RBS pump P35A SW pump P4B Startup transformer X3 Unit aux. transformer X2 Bus B5 Bus B51 Bus B52

Table B.9 (Cont'd)

Component Under Maintenance	Type of Maintenance	Components Aligned Away from ES Position	System/Component Required to be Operable
Bus B5	Disassembly of transformer X5, or circuit breaker 301 and 512	Transformer X5 Circuit breaker 301 Circuit breaker 512	Diesel generator DG2 Bus B6
Bus B6	Disassembly of transformer X6, or circuit breaker 401 and 612	Transformer X6 Circuit broaker 401 Circuit breaker 612	Diesel generator DG1 Bus B5
Bus B51	Disassembly of circuit breaker 521	Circuit breaker 521	Diesel generator DG2 Bus B6 Bus B61
Bus B52	Disassembly of circuit breaker 532	Circuit breaker 532 Bus B53	Diesel generator DG2 Bus B6 Bus B62
Bus B61	Disassembly of circuit breaker 621	Circuit breaker 621	Diesel generator DG1 Bus B5 Bus B51
Bus B62	Disassembly of breaker 641 circuit	Circuit breaker 614	Diesel generator DG1 Bus B5 Bus B52
Circuit Breaker 309	Disassembly of circuit breaker 309	Circuit breaker 309	Diesel generator DG1 Diesel generator DG Circuit breaker 409
Circuit Breaker 409	Disassembly of circuit breaker 409	Circuit breaker 409	Diesel generator DG1 Diesel generator DG Circuit breaker 309

Table B.10. Maintenance Requirement Summary
System: Battery and Switchgear Emergency Cooling

Component Under Maintenance	Type of Maintenance	Components Aligned Away from ES Position	System/Component Required to be Operable
A/C unit VE1B	Maintenance requiring disassembly	Disable circuit breaker 5516	A/C unit VE1A
A/C Unit VE1A	Maintenance requiring disassembly	Disable circuit breaker 5515	A/C unit VE1B
Chill Water Unit VCH4B	Maintenance requiring disassembly	Close valves: SW601B SW602B AC200B AC206B Disable circuit breaker 5254	Alternate cooling loop (VCH4A, VUC2D, VUC14A) SW loop 2
Chill Water Unit VCH4A	Maintenance requiring disassembly	Close valves: SW601A SW602A AC200A AC206A Disable circuit breaker 6254	Alternate cooling loop (VCH4B, VUC2B, VUC14D) SW loop 1
Ventilation Unit Cooler VUC2D	Maintenance requiring disassembly	Close valves: AC41D AC45D Disable circuit breaker 6246	Alternate cooling loop SW loop 1
Ventilation Unit Cooler VUC2B	Maintenance requiring disassembly	Close valves: AC41B AC45B Disable circuit breaker 5246	Alternate cooling loop SW loop 2
Ventilation Unit Cooler VUC14A	Maintenance requiring disassembly	Close valves: AC202A AC204A Disable circuit breaker 6135	Alternate cooling loop SW loop 2
Ventilation Unit Cooler VUC14D	Maintenance requiring disassembly	Close valves: AC202D AC204D Disable circuit breaker 5136	Alternate cooling loop SW loop 1
CV6034	Maintenance requiring disassembly	Close valves: SW601A SW600A SW605A Disable circuit breaker 6254	Alternate cooling loop CV6036
CV6036	Maintenance requiring disassembly	Close valves: SW601B SW600B SW605B Disable circuit breaker 5254	Alternate cooling loop CV6034

APPENDIX C

RISK IMPACT OF AOT REQUIREMENTS

Table C.1. Risk Impact of AOT Requirements for Maintainable Components High Pressure Injection/Recirculation System

Maint. Designator	Component Under Maintenance	AOT (hr)	Increase in Core-Melt Frequency $(C_i^+ - C_o)$ (per year)	Incremental Risk Due to a Downtime $(C_i^+ - C_o)(AOT)$	Maint. Frequency (Events/hr) (ω_i)	Yearly Risk Increase* $(\omega_i T)(C_i^+ - C_o)(AOT)$
HM-1	HPI Pump 36C	60	2.74 E-3	1.88 E-5	3.1 E-5	5.1 E-6
HM-2	HPI Pump 36B	60	1.50 E-5	1.03 E-7	3.1 E-5	2.8 E-8
HM-3	HPI Pump 36A	60	5.00 E-6	3.43 E-8	3.1 E-5	9.3 E-9
HM-4	MOV CV 1227	60	3.00 E-5	2.06 E-7	4.0 E-7	7.2 E-10
HM-5	MOV CV 1228	60	3.00 E-5	2.06 E-7	4.0 E-7	7.2 E-10
HM-6	MOV CV 1219	60	1.20 E-5	8.22 E-8	4.0 E-7	2.9 E-10
HM-7	MOV CV 1220	60	1.20 E-5	8.22 E-8	4.0 E-7	2.9 E-10

Table C.2. Risk Impact of AOT Requirements for Maintainable Components Low Pressure Injection/Recirculation System

Maint. Designator	Component Under Maintenance	AOT (hr)	Increase in Core-Melt Frequency $(C_i^+ - C_o)$ (per year)	Incremental Risk Due to a Downtime $(C_i^+ - C_o)(AOT)$	Maint. Frequency (Events/hr) (ω_i)	Yearly Risk Increase $(\omega_i T)(C_i^+ - C_o)(AOT)$
LM-1	LPI Pump 34B	60	5.10 E-5	3.49 E-7	3.1 E-5	9.5 E-8
LM-2	LPI Pump 34A	60	5.00 E-5	3.43 E-7	3.1 E-5	9.3 E-8
LM-3	MOV CV 1406	60	7.90 E-5	5.41 E-7	4.0 E-7	1.9 E-9
LM-4	MOV CV 1405	60	7.20 E-5	4.93 E-7	4.0 E-7	1.7 E-9
LM-5	MOV CV 1428	60	5.00 E-5	3.43 E-7	4.0 E-7	1.2 E-9
LM-6	MOV CV 1429	60	5.00 E-5	3.43 E-7	4.0 E-7	1.2 E-9
LM-7	MOV CV 1400	60	6.00 E-6	4.11 E-8	4.0 E-7	1.4 E-10
LM-8	MOV CV 1401	60	5.00 E-6	3.43 E-8	4.0 E-7	1.2 E-10

Table C.3. Risk Impact of AOT Requirements for Maintainable Components Reactor Building Spray System

Maint. Designator	Component Under Maintenance	AOT (hr)	Increase in Core-Melt Frequency $(C_i^+ - C_o)$ (per year)	Incremental Risk Due to a Downtime $(C_i^+ - C_o)(AOT)$	Maint. Frequency (Events/hr) (ω_i)	Yearly Risk Increase $(\omega_i T)(C_i^+ - C_o)(AOT)$
BM-1	RBS Pump 35A	36	3.0 E-7	1.23 E-9	3.1 E-5	3.3 E-10
BM-2	RBS Pump 35B	36	3.0 E-7	1.23 E-9	3.1 E-5	3.3 E-10
BM-3	MOV CV 2400	36	3.0 E-7	1.23 E-9	4.0 E-7	3.6 E-12
BM-4	MOV CV 2401	36	3.0 E-7	1.23 E-9	4.0 E-7	3.6 E-12

*T is defined as 1 reactor year in hrs.

Table C.4. Risk Impact of AOT Requirements for Maintainable Components
Emergency Feedwater System (EFWS)

Maint. Designator	Component Under Maintenance	AOT (hr)	Increase in Core-Melt Frequency $(C_i^+-C_o)$ (per year)	Incremental Risk Due to a Downtime $(C_i^+-C_o)(AOT)$	Maint. Frequency (Events/hr) (ω_i)	Yearly Risk Increase $(\omega_i T)(C_i^+-C_o)(AOT)$
EM-1	EFW Pump P7A	36	5.13 E-3	2.48 E-5	3.1 E-5	6.7 E-6
EM-2	MOV CVY-2	36	1.45 E-3	6.00 E-6	1.8 E-6	9.5 E-7
EM-3	MOV CVX-1	36	1.43 E-3	5.88 E-6	1.8 E-6	9.3 E-7
EM-4	MOV CV2620	36	1.43 E-3	5.88 E-6	1.8 E-6	9.3 E-7
EM-5	EFW Pump P7B	36	2.15 E-4	8.84 E-7	3.1 E-5	2.4 E-7
EM-6	MOV CVY-1	36	2.21 E-4	9.10 E-7	1.8 E-6	1.4 E-8
EM-7	MOV CVX-4	36	1.87 E-4	7.68 E-7	1.8 E-6	1.2 E-8
EM-8	MOV CV2627	36	1.87 E-4	7.68 E-7	1.8 E-6	1.2 E-8
EM-9	MOV CV2670	36	1.01 E-4	4.15 E-7	1.8 E-6	6.5 E-9
EM-10	MOV CVX-3	36	9.80 E-5	4.03 E-7	1.8 E-6	6.4 E-9
EM-11	MOV CVY-3	36	ε	ε	ε	ε
EM-12	MOV CVY-4	36	ε	ε	ε	ε
EM-13	MOV CVX-2	36	ε	ε	ε	ε
EM-14	MOV CV2626	36	ε	ε	ε	ε
EM-15	MOV CV2813	36	ε	ε	ε	ε
EM-16	MOV CV2814	36	ε	ε	ε	ε
EM-17	MOV CV2803	36	ε	ε	ε	ε
EM-18	MOV CV2806	36	ε	ε	ε	ε
EM-19	MOV CV2800	36	ε	ε	ε	ε
EM-20	MOV CV2802	36	ε	ε	ε	ε

Table C.5. Risk Impact of AOT Requirements for Maintainable Components
Reactor Protection System

Maint. Designator	Component Under Maintenance	AOT (Hr)	Increase in Core-Melt Frequency $(C_i^+-C_o)$ (per year)	Incremental Risk Due to Given a Downtime $(C_i^+-C_o)(AOT)$	Maint. Frequency (Events/Hr) (ω_i)	Yearly Risk Increase $(\omega_i T)(C_i^+-C_o)(AOT)$
RM-1	Channel A bypass	4	2.00 E-7	9.13 E-11	1.4 E-3	1.1 E-9
RM-2	Channel B bypass	4	2.00 E-7	9.13 E-11	1.4 E-3	1.1 E-9
RM-3	Channel C bypass	4	2.00 E-7	9.13 E-11	1.4 E-3	1.1 E-9
RM-4	Channel D bypass	4	2.00 E-7	9.13 E-11	1.4 E-3	1.1 E-9

Table C.6. Risk Impact of AOT Requirements for Maintainable Components
Service Water System

Maint. Designator	Component Under Maintenance	AOT (hr)	Increase in Core-Melt Frequency $(C_i^+ - C_o)$ (per year)	Incremental Risk From a Given a Downtime $(C_i^+ - C_o)$ (AOT)	Maint. Frequency (Events/Hr) (ω_i)	Yearly Risk Increase $(\omega_i T)(C_i^+ - C_o)$ (AOT)
SM-1	SW Pump P4C	36	3.70 E-3	1.53 E-5	2.9 E-5	3.9 E-6
SM-2	SW Pump P4B	36	2.50 E-3	1.03 E-5	2.9 E-5	2.6 E-6
SM-3	CV 3810	36	2.74 E-3	1.10 E-5	4.0 E-7	4.0 E-8
SM-4	CV 3645	36	1.41 E-3	5.80 E-6	4.0 E-7	2.0 E-8
SM-5	CV 3643	36	1.05 E-3	4.32 E-6	4.0 E-7	1.5 E-8
SM-6	CV 3806	36	3.86 E-4	1.60 E-6	4.0 E-7	5.6 E-9
SM-7	CV 3807	36	1.68 E-4	6.90 E-7	4.0 E-7	2.4 E-9
SM-8	CV 3841	36	5.10 E-5	2.10 E-7	4.0 E-7	7.4 E-10
SM-9	CV 3840	36	5.00 E-5	2.00 E-7	4.0 E-7	7.2 E-10
SM-10	CV 3809	36	1.50 E-5	6.20 E-8	4.0 E-7	2.2 E-10
SM-11	CV 3808	36	5.00 E-6	2.00 E-8	4.0 E-7	7.2 E-11
SM-12	CV 3642	36	2.00 E-6	8.22 E-9	4.0 E-7	2.9 E-11
SM-13	CV 3640	36	2.00 E-6	8.22 E-9	4.0 E-7	2.9 E-11
SM-14	CV 3804	36	3.00 E-7	1.23 E-9	4.0 E-7	3.6 E-12
SM-15	CV 3805	36	3.00 E-7	1.23 E-9	4.0 E-7	3.6 E-12

Table C.7. Risk Impact of AOT Requirements for Maintainable Components
Engineered Safeguards Actuation System (ESAS)

Maint. Designator	Component Under Maintenance	AOT (Hr)	Increase in Core-Melt Frequency $(C_i^+ - C_o)$ (per year)	Incremental Risk $(C_i^+ - C_o)$ (AOT)	Maint. Frequency (Events/Hr) (ω_i)	Yearly Risk Increase $(\omega_i T)(C_i^+ - C_o)$ (AOT)
ESM-1	C86 Power Supply	12	2.17 E-3	2.97 E-6	6.4 E-6	1.7 E-7
ESM-2	Logic L1-1	12	2.17 E-3	2.97 E-6	1.3 E-6	3.4 E-8
ESM-3	C91 Power Supply	12	2.06 E-3	2.82 E-6	6.4 E-6	1.6 E-7
ESM-4	Logic L2-1	12	1.95 E-3	2.67 E-6	1.3 E-6	3.0 E-8
ESM-5	Logic L1-13	12	7.30 E-5	1.00 E-7	1.3 E-6	1.1 E-9
ESM-6	Logic L2-12	12	7.30 E-5	1.00 E-7	1.3 E-6	1.1 E-9
ESM-7	Logic L1-19	12	1.00 E-6	1.37 E-8	1.3 E-6	1.6 E-11
ESM-8	Logic L2-18	12	1.00 E-6	1.37 E-8	1.3 E-6	1.6 E-11
ESM-9	Logic L1-35	12	3.00 E-7	4.11 E-10	1.3 E-6	4.7 E-12
ESM-10	Logic L2-34	12	3.00 E-7	4.11 E-10	1.3 E-6	4.7 E-12

Table C.8. Risk Impact of AOT Requirements for Maintainable Components in DC Power System

Maint. Designator	Component Under Maintenance	AOT (hr)	Increase in Core-Melt Frequency $(C_i^+-C_o)$ (per year)	Incremental Risk from a Given Downtime $(C_i^+-C_o)$(AOT)	Maint. Frequency (Events/ Hr) (ω_i)	Yearly Risk Increase $(\omega_i T)(C_i^+-C_o)$(AOT)
DM-1	BC D05	8	2.00 E-2	1.83 E-5	2.8 E-6	4.5 E-8
DM-2	Bus RS2	8	2.35 E-2	2.15 E-5	1.0 E-6	1.9 E-7
DM-3	BC D04	8	7.30 E-2	6.68 E-6	2.8 E-6	1.6 E-7
DM-4	CB 0122B or CB 5622B	8	2.00 E-2	1.83 E-5	1.0 E-6	1.6 E-7
DM-5	CB 022A or CB 6143A	8	7.30 E-2	6.68 E-6	1.0 E-6	5.9 E-8
DM-6	Bus RS1	8	6.23 E-3	5.69 E-6	1.0 E-6	5.0 E-8
DM-7	Battery D06	8	1.64 E-3	1.50 E-6	2.0 E-6	2.6 E-8
DM-8	Battery D07 Bus D01	8	1.26 E-3	1.15 E-6	2.0 E-6	2.0 E-8
DM-9	Bus RS3	8	1.06 E-4	9.68 E-8	1.0 E-6	8.5 E-10
DM-10	Bus RS4	8	4.00 E-6	3.65 E-9	1.0 E-6	3.2 E-11

Table C.9. Risk Impact of AOT Requirements for Maintainable Components in AC Power System

Maint. Designator	Component Under Maintenance	AOT (hrs.)	Increase in Core-Melt Frequency $(C_i^+-C_o)$ (per year)	Incremental Risk From a Given Downtime $(C_i^+-C_o)$(AOT)	Maint. Frequency (ω_i)	Yearly Risk Increase $(\omega_i T)(C_i^+-C_o)$(AOT)
ACM-1	Diesel Generator DG1	168	3.83 E-4	7.35 E-6	6.0 E-5	3.86 E-6
ACM-2	Diesel Generator DG2	168	1.81 E-4	3.47 E-6	6.0 E-5	1.82 E-6
ACM-3	AC Bus B5*	24	5.13 E-3	1.41 E-5	5.0 E-6	2.05 E-6
ACM-4	AC Bus B6 (X6)	24	4.12 E-3	1.13 E-5	5.0 E-6	4.94 E-7
ACM-5	DG1 CB	168	3.83 E-4	7.35 E-6	1.0 E-6	6.44 E-8
ACM-6	AC Bus B5 (CB)	8	5.13 E-3	4.69 E-6	1.0 E-6	4.11 E-8
ACM-7	AC Bus B6 (CB)	8	4.12 E-3	3.76 E-6	1.0 E-6	3.29 E-8
ACM-8	DG2 CB	168	1.81 E-4	3.47 E-6	1.0 E-6	3.04 E-8
ACM-9	AC Bus B62	8	3.72 E-3	3.40 E-6	1.0 E-6	2.98 E-8
ACM-10	AC Bus B51	8	3.46 E-3	3.16 E-6	1.0 E-6	2.77 E-8
ACM-11	AC Bus B61	8	2.96 E-3	2.70 E-6	1.0 E-6	2.37 E-8
ACM-12	AC Bus B52	8	2.50 E-3	2.28 E-6	1.0 E-6	2.00 E-8
ACM-13	Circuit Breaker 309	24	7.38 E-4	2.02 E-6	1.0 E-6	1.77 E-8
ACM-14	Circuit Breaker 409	24	7.38 E-4	2.02 E-6	1.0 E-6	1.77 E-8

*Bus maintenance is maintenance on "upstream" components.

Table C.10. Risk Impact of AOT Requirements for Maintainable Components in Emergency Cooling System (Battery & Switchgear Rooms)

Maint. Designator	Component Under Maintenance	AOT* (hrs.)	Increase in Core-Melt Frequency $(C_i^+-C_o)$ (per year)	Incremental Risk From a Given Downtime $(C_i^+-C_o)(AOT)$	Maint. Frequency (ω_i)	Yearly Risk Increase $(\omega_i T)(C_i^+-C_o)(AOT)$
ECM-1	C.W.U. VCH4A	24	3.62 E-3	9.9 E-6	6.2 E-5	5.4 E-6
ECM-2	C.W.U. VCH4B	24	2.05 E-3	5.6 E-6	6.2 E-5	3.0 E-6
ECM-3	MOV CV6034	24	3.62 E-3	9.9 E-6	1.8 E-6	1.6 E-7
ECM-4	MOV CV6036	24	2.05 E-3	5.6 E-6	1.8 E-6	8.8 E-8
ECM-5	VUC 2D	24	3.62 E-3	9.9 E-6	4.0 E-7	3.5 E-8
ECM-6	VUC 2B	24	2.05 E-3	5.6 E-6	4.0 E-7	1.9 E-8
ECM-7	VUC 14D	24	9.80 E-5	2.7 E-7	4.0 E-7	9.5 E-10
ECM-8	VUC 14A	24	5.00 E-6	1.4 E-8	4.0 E-7	4.9 E-11
ECM-9	A/C Unit VE1A	24	ε	ε	6.2 E-5	ε
ECM-10	A/C Unit VE1B	24	ε	ε	6.2 E-5	ε

*The AOTs for components in this system are not defined in technical specifications and are assumed to be 24 hrs.

APPENDIX D

SUMMARY OF SURVEILLANCE TEST REQUIREMENTS AND RISK IMPACTS

Table D.1 Risk Impacts of Surveillance Test Requirements in High Pressure Injection/Recirculation System

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
HP-T1	Pump P36C & SW CV3810	Flow Stroke	BW1X CV1408B BW2X MU18C SW CV3810 SW CV18C	None	Annual	1 hr	6.8 E-5
HP-T2	Pump P36C	Flow	BW1X CV1408B BW2 MU18C	None	Monthly	30 min.	4.4 E-5
HP-T3	SW CV3810	Stroke	SW CV18C	None	Annual	10 min.	2.4 E-5
HP-T4	Pump P36A & SW CV3808	Flow Stroke	BW1X CV1407A BW3X MU18A SW CV3808 SW CV018A	None	Annual	1 hr	1.37 E-5
HP-T5	Pump P36A	Flow	BW1X CV1407A BW3X MU18A	None	Monthly	30 min.	1.36 E-5
HP-T6	Pump P36B & SW CV3809	Flow Stroke	BW1X CV1407A BW3X MU16 MU17 MU18B SW CV389 SW CV18B	None	Annual	1 hr	1.36 E-5
HP-T7	Pump P36B	Flow	BW1X CV1407A BW3X MU16 MU17 MU18B	None	Monthly	30 min.	1.36 E-5
HP-T8	CV1277	Stroke	None	None	Quarterly	5 min.	3.8 E-7
HP-T9	CV1228	Stroke	None	None	Quarterly	5 min.	3.8 E-7
HP-T10	CV1219	Stroke	None	None	Quarterly	5 min.	1.9 E-7
HP-T11	CV1220	Stroke	None	None	Quarterly	5 min.	1.9 E-7
HP-T12	SW CV3808	Stroke	None	None	Quarterly	5 min.	1.0 E-7
HP-T13	SW CV3809	Stroke	None	None	Quarterly	5 min.	2.0 E-9

Table D.2 Impact of Surveillance Test Requirements in Low Pressure Injection/Recirculation System

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
LP-T1	Pump P34B & SW CV3840	Flow Stroke	BW1X CV1408B BW4B BW8B DH2B DH3A HX E35B CV1429 SW CV3841 SW CV038A	DH8B opened DH10 opened CV1429 SW 22B SW 38A	Annual	1 1/2 hr	2.9 E-5
LP-T2	Pump P34B	Flow	BW1X CV1408B BW4B BW8B DH2B DH3B HX E35B CV1428	DH8B opened DH10 opened CV1429	Monthly	3/4 hr	2.8 E-5
LP-T3	Pump P34A & SW CV3841	Flow Stroke	BW1X CV1408A BW4A BW8A DH3A HX E35A CV1428 SW CV3840 SW CV038B	DH8A opened DH10 opened CV1428 SW-22A SW-38B	Annual	1 1/2 hr	1.5 E-5
LP-T4	Pump P34A	Flow	BW1X CV1408B BW4A BW8A DH3A HX E35A CV1428	DH8A opened DH10 opened CV1428	Monthly	3/4 hr	1.4 E-5
LP-T5	SW CV3821	Stroke	None	SW 38A SW 22B	Monthly	3/4 hr	1.0 E-6
LP-T6	SW CV3822	Stroke	None	SW 38B SW 22A	Monthly	3/4 hr	1.0 E-6
LP-T7	SW CV3840	Stroke	SW CV38A 86X 63X	SW 22B	Annual	3/4 hr	7.6 E-7
LP-T8	SW CV3841	Stroke	SW CV38B 61X 64X	SW 22A	Annual	3/4 hr	7.6 E-7
LP-T9	SW CV3802	Stroke	None	SW 38A	Monthly	3/4 hr	8.1 E-7
LP-T10	SW CV3803	Stroke	None	SW 38B	Monthly	3/4 hr	8.1 E-7
LP-T11	CV1405	Stroke	None	None	Monthly	5 min.	7.2 E-7
LP-T12	CV1406	Stroke	None	None	Monthly	5 min.	6.9 E-7

Table D.3 Risk Impacts of Surveillance Test Requirements in Core Flood System

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
CT-1	CFT-2A	Instrumentation Check	None	None	8 hrs	ε	1.6 E-8
CT-2	CFT-2A	Instrumentation Check	None	None	8 hrs	ε	1.6 E-8

Table D.4 Risk Impacts of Surveillance Test Requirements in Reactor Building Spray System

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
RB-T1	Pump P35A	Flow	BW1X CV1407A BW4A BW5A BW6A BS1A BS2A BS3X DH9X DH10X	CV2401 BS2A BS3X DH9 SW-21A	Monthly	30-45 min.	1.3 E-5
RB-T2	Pump P35B	Flow	BW1X CV1408B BW4B BW5B BW6B BS1B BS2B BS3X DH9X DH10X	CV2400 BS2B BS3X DH9 SW-21B	Monthly	30-45 min.	1.3 E-5
RB-T3	Pump P35A* (without (CV1407A, BW1X)						2.4 E-9
RB-T4	Pump P35B* (without (CV1408B, BW1X)						2.4 E-9
RB-T5	CV2400	Stroke	None	None	Quarterly	None	1.2 E-9
RB-T6	CV2401	Stroke	None	None	Quarterly	None	1.2 E-9

*Test impact on pump P35A, P35B are high due to CV1407A, CV1408A, and BW1X. These valvues are test HP and LP pump tests. These tests, even though cannot be performed, show the additional minimal risk impact of tests RB-T1 and RB-T2.

Table D.5 Risk Impact of Surveillance Test Requirements in Emergency Feedwater System

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
EF-T1	Pump P7A	Flow	CS19 CS98 CS99 CV2802 CVY-3 CVY-4 CVY-1 CVY-2	CVX-1 CVX-4	Monthly	1 hr	2.9 E-5
EF-T2	CV2626	Stroke	None	None	Quarterly	5 min.	1.6 E-5
EF-T3	CV2620	Stroke	None	None	Quarterly	5 min.	1.2 E-5
EF-T4	CVY-1	Stroke	None	None	Quarterly	5 min.	1.2 E-5
EF-T5	Pump P7B	Flow	CS19 CS98 CS99 CV2800	CVX-2 CVX-3	Monthly	1 hr	9.6 E-6
EF-T6	CVX-2	Stroke	None	None	Quarterly	5 min.	7.8 E-6
EF-T7	CVX-1	Stroke	None	None	Quarterly	5 min.	6.2 E-6
EF-T8	CVY-2	Stroke	None	None	Quarterly	5 min.	2.0 E-6
EF-T9	CV2670	Stroke	None	None	Quarterly	5 min.	1.7 E-6
EF-T10	CV2627	Stroke	None	None	Quarterly	5 min.	1.7 E-6
EF-T12	CVX-3	Stroke	None	None	Quarterly	5 min.	8.2 E-7
EF-T13	CVX-4	Stroke	None	None	Quarterly	5 min.	8.2 E-7

Table D.6 Risk Impact of Surveillance Test Requirements in Reactor Building Cooling System

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
RC-T1	CV3812	Valve & Interlock	CV3814 Rad. Det 814R	CV3812 CV3814	Quarterly	5 min.	2.3 E-8
RC-T2	CV3813	Valve & Interlock	CV3815 Rad. Det 815R	CV3813 CV3815	Quarterly	5 min.	2.0 E-8

Table D.7 Risk Impact of Surveillance Test Requirements in Reactor Protection System

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
RP-T1	Breaker CCA	Proper Operation	None	None	Monthly	ε	1.7 E-6
RP-T2	Breaker CCB	Proper Operation	None	None	Monthly	ε	1.7 E-6
RP-T3	Breaker C1	Proper Operation	None	None	Monthly	ε	8.5 E-7
RP-T4	Breaker C2	Proper Operation	None	None	Monthly	ε	8.5 E-7
RP-T5	Breaker D1	Proper Operation	None	None	Monthly	ε	8.5 E-7
RP-T6	Braaker D2	Proper Operation	None	None	Monthly	ε	8.5 E-7
RP-T7	Relay CCA	Proper Operation	None	None	Monthly	ε	1.2 E-8
RP-T8	Relay CCB	Proper Operation	None	None	Monthly	ε	1.2 E-8
RP-T9	Relay C1	Proper Operation	None	None	Monthly	ε	6.2 E-9
RP-T10	Relay C1	Proper Operation	None	None	Monthly	ε	6.2 E-9
RP-T11	Relay D1	Proper Operation	None	None	Monthly	ε	6.2 E-9
RP-T12	Relay D2	Proper Operation	None	None	Monthly	ε	6.2 E-9
RP-T13	Gate Driver E2	Proper Operation	Rectifier E2	None	Monthly	ε	5.0 E-9
RP-T14	Gate Driver E3	Proper Operation	Rectifier E3	None	Monthly	ε	5.0 E-9
RP-T15	Gate Driver E4	Proper Operation	Rectifier E3	None	Monthly	ε	5.0 E-9
RP-T16	Gate Driver F2	Proper Operation	Rectifier F2	None	Monthly	ε	5.0 E-9
RP-T17	Gate Driver F3	Proper Operation	Rectifier F3	None	Monthly	ε	5.0 E-9
RP-T18	Gate Driver F4	Proper Operation	Rectifier F4	None	Monthly	ε	5.0 E-9
RP-T19	Relay E2	Proper Operation	None	None	Monthly	ε	5.2 E-11
RP-T20	Relay E3	Proper Operation	None	None	Monthly	ε	5.2 E-11
RP-T21	Relay E4	Proper Operation	None	None	Monthly	ε	5.2 E-11
RP-T22	Relay F2	Proper Operation	None	None	Monthly	ε	5.2 E-11
RP-T23	Relay F3	Proper Operation	None	None	Monthly	ε	5.2 E-11
RP-T24	Relay F4	Proper Operation	None	None	Monthly	ε	5.2 E-11
RP-T25	Relay KA	Proper Operation	None	None	Monthly	ε	1.0 E-12
RP-T26	Relay KA1	Proper Operation	None	None	Monthly	ε	1.0 E-12
RP-T27	Relay KA2	Proper Operation	None	None	Monthly	ε	1.0 E-12
RP-T28	Relay KB1	Proper Operation	None	None	Monthly	ε	1.0 E-12
RP-T29	Relay KB2	Proper Operation	None	None	Monthly	ε	1.0 E-12
RP-T30	Relay KC1	Proper Operation	None	None	Monthly	ε	1.0 E-12
RP-T31	Relay KD1	Proper Operation	None	None	Monthly	ε	1.0 E-12
RP-T32	Relay KD2	Proper Operation	None	None	Monthly	ε	1.0 E-12
RP-T33	Relay KA3	Proper Operation	None	None	Monthly	ε	5.0 E-13
RP-T34	Relay KA4	Proper Operation	None	None	Monthly	ε	5.0 E-13
RP-T35	Relay KB3	Proper Operation	None	None	Monthly	ε	5.0 E-13
RP-T36	Relay KB4	Proper Operation	None	None	Monthly	ε	5.0 E-13
RP-T37	Relay KC3	Proper Operation	None	None	Monthly	ε	5.0 E-13
RP-T38	Relay KC4	Proper Operation	None	None	Monthly	ε	5.0 E-13
RP-T39	Relay KD3	Proper Operation	None	None	Monthly	ε	5.0 E-13
RP-T40	Relay KD4	Proper Operation	None	None	Monthly	ε	5.0 E-13

Table D.8 Risk Impact of Surveillance Test Requirements in Engineered Safeguards Actuation

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
ES-T1	Logic L1-1 Channel 1	Proper Operation	None	None	Monthly	None	8.3 E-7
ES-T2	Logic L2-1 Channel 2	Proper Operation	None	None	Monthly	None	3.7 E-7
ES-T3	Bistable A108	Calibration & Proper Operation	None	None	Monthly	None	1.8 E-7
ES-T4	Bistable A208	Calibration & Proper Operation	None	None	Monthly	None	1.8 E-7
ES-T5	Bistable A308	Calibration & Proper Operation	None	None	Monthly	None	1.8 E-7
ES-T6	Pressure Sensor 1020	Calibration & Proper Operation	Buff.Amp.A1-6	None	Each Shift	None	1.2 E-7
ES-T7	Pressure Sensor 1022	Calibration & Proper Operation	Buff.Amp.A206	None	Each Shift	None	1.2 E-7
ES-T8	Pressure Sensor 1040	Calibration & Proper Operation	Buff.Amp.A306	None	Each Shift	None	1.2 E-7
ES-T9	Channel	Open Circuit	None	None	Shift	None	1.1 E-7
ES-T10	Logic Buffer A110	Proper Operation	None	None	Monthly	None	5.0 E-8
ES-T11	Logic Buffer A210	Proper Operation	None	None	Monthly	None	5.0 E-8
ES-T12	Logic Buffer A310	Proper Operation	None	None	Monthly	None	5.0 E-8
ES-T13	Bistable A119	Calibration & Proper Operation	Bistable A120	None	Monthly	None	4.5 E-8
ES-T14	Bistable A219	Calibration & Proper Operation	Bistable A220	None	Monthly	None	4.5 E-8
ES-T15	Bistable A319	Calibration & Proper Operation	Bistable A320	None	Monthly	None	4.5 E-8

Table D.8 Risk Impact of Surveillance Test Requirements in Engineered Safeguards Actuation

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
ES-T16	Channel 2	Open Circuit	None	None	Each Shift	None	4.8 E-8
ES-T17	Logic L2-12 Channel 4	Proper Operation	None	None	Monthly	None	3.6 E-8
ES-T18	Logic L1-13 Channel 3	Proper Operation	None	None	Monthly	None	3.4 E-8
ES-T19	Power Supply	Calibration	Channels 1,3 5,7	None	Monthly	None	2.6 E-8
ES-T20		Calibration	Channels 2,4 6,8	None	Monthly	None	1.2 E-8
ES-T21	Channel 4	Open Circuit	None	None	Each Shift	None	4.7 E-9
ES-T22	Channel 3		None	None	Each Shift	None	4.5 E-9
ES-T23	Logic Buffer A116	Proper Operation	None	None	Monthly	None	2.8 E-9
ES-T26	Logic Buffer A216	Proper Operation	None	None	Monthly	None	2.8 E-9
ES-T25	Logic Buffer A316	Proper Operation	None	None	Monthly	None	2.8 E-9
ES-T26	Pressure Sensor	Calibration and	None	None	Each Shift	None	8.8
ES-T27	Pressure Sensor PT2406	Calibration and Proper Operation	Buff.Amp.A117	None	Each Shift	None	8.8 E-10
ES-T28	Pressure Sensor PT2407	Calibration and Proper Operation	Buff.Amp.A217	None	Each Shift	None	8.8 E-10
ES-T29	Logic Buffer A122	Proper Operation	Buff.Amp.A317	None	Monthly	None	3.7 E-10
ES-T30	Logic Buffer A222	Proper Operation	None	None	Monthly	None	3.7 E-10
ES-T31	Logic Buffer A322	Proper Operation	None	None	Monthly	None	3.7 E-10
ES-T32	Logic Buffer A123	Proper Operation	None	None	Monthly	None	3.7 E-10
ES-T33	Logic Buffer A322	Proper Operation	None	None	Monthly	None	3.7 E-10
ES-T34	Logic Buffer A323	Proper Operation	None	None	Monthly	None	3.7 E-10

Table D.9 Risk Impact of Surveillance Test Requirements in Service Water Systems

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
SW-T1	Pump P4C	Vibration and Temperature	None	None	None	None	2.5 E-5
SW-T2	Pump P4B	Vibration and Temperature	None	None	None	None	1.3 E-5

Table D.10 Risk Impact of Surveillance Test Requirements in Class IE AC Power System

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
EP-T1	Diesel Generator 1	Start	SW CV3806 SW 019A	DG1	Monthly	5 min.	1.72 E-5
EP-T2	Diesel Generator 2	Start	SW CV3807 SW 019B	DG2	Monthly	5 min.	8.35 E-6

Table D.11 Risk Impact of Surveillance Test Requirements in 125V DC System

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
DC-T1	Battery D06	Measure of Individual Cell	None	None	Quarterly	None	2.4 E-6
DC-T2	Battery D07	Measure of Individual Cell	None	None	Quarterly	None	2.3 E-6

Table D.12 Risk Impact of Surveillance Test Requirements in Battery and Switchgear Emergency Cooling System

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
BS-T1	Room Cooler Unit	Functional	VCH4A VUC2D VUC14A AC209A AC41D AC44D AC45D AC202A AC203A AC204A	None	Monthly	Not Known	9.1 E-5
BS-T2	Room Cooler Unit	Functional	VCH4B VUC2B VUC14D AC209B AC41B AC44B AC45B AC202B AC203B AC204B	None	Monthly	Not Known	4.3 E-5

Table D.13 Risk Impact of Surveillance Test Requirements in Emergency Feedwater Initiation ControlSystem

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
E1-T1	Path D_1D_2	Proper Operation	Logic 14D, 15D, 18D,19D,22D,25D	None	Monthly	None	4.7 E-5
E1-T2	Path AC04-BD04	Proper Operation	Logics on Paths	None	Monthly	None	2.2 E-5
E1-T3	Path VCD2	Proper Operation	Logic 17D, 21D, 24D,28D, 34D	None	Monthly	None	1.4 E-5
E1-T4	Path AC6-BD6	Proper Operation	Logic 4AC,48D	None	Monthly	None	9.6 E-6
E1-T5	Path AB04-CD04	Proper Operation	Logics on Path	None	Monthly	None	8.3 E-6
E1-T6	Path CSY2	Proper Operation	Logic DC1B	None	Monthly	None	7.5 E-6
E1-T7	Path D_1D_2	Proper Operation	Bistable 10D,11D, Buff,Amp 6D,7D Sensor 2D,3D	None	Shift	None	2.9 E-6

Table D.13 Cont'd

Test Designator	Component Undergoing Test	Type of Test	Additional Component Tested	Component Aligned Away from ES Position	Expected Test Frequency	Expected Test Duration	Risk Impact of Test
E1-T24	Path A009	Proper Operation	Logic 0A,1A,2A	None	Monthly	None	7.4 E-8
E1-T25	Path B009	Proper Operation	Logic 0B,1B,2B	None	Monthly	None	1.6 E-8
E1-T26	Path C009	Proper Operation	Logic 0C,1C,2C	None	Monthly	None	1.6 E-8
E1-T27	Path VC51	Proper Operation	Bistable 9C, Buff. Amp.5C, Sensor 1C	None	Shift	None	1.4 E-8
E1-T28	Path A009	Proper Operation	Buff.Amp.A5, A6, Pressure Sensor APA, APB	None	Shift	None	9.1 E-9
E1-T29	Path B009	Proper Operation	Buff.Amp. B5, B6, Pressure Sensor BPA, BPB	None	Shift	None	9.1 E-9
E1-T30	Path C009	Proper Operation	Buff.Amp. 15, 16, Pressure Sensor CPA, CPB	None	Shift	None	9.1 E-9
E1-T31	Path VC61	Proper Operation	Bistable 12C Sensor 6C	None	Shift	None	8.4 E-9

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This report presents an evaluation of the core-melt frequency contributions associated with Allowed Outage Times (AOTs) and Surveillance Test Intervals (STIs) at Arkansas Nuclear One - Unit 1 (ANO-1).

The results show that the core-melt frequency contributions from present AOTs and STIs vary by more than four orders of magnitude (a factor of 10,000). This wide range of variation indicates the wide range of the risk importance of present AOTs and STIs. The core-melt contributions from specific AOTs and STIs can be used to prioritize those components which should be focused on for inspection activities, personnel training, and reliability program activities that are involved with surveillance testing and corrective maintenance.

14. DOCUMENT ANALYSIS – a. KEYWORDS/DESCRIPTORS
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