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MEMORANDUM FOR: Thomas E. Murley, Director
Office of Nuclear Reactor Regulation

FROM: Eric S. Beckjord, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NUMBER 173, RISK-BASED METHODS TO EVALUATE REQUIREMENTS IN TECHNICAL SPECIFICATIONS

As requested in several NRR user-need memoranda (References 2-5 in the enclosure), we have developed risk-based methods to evaluate and improve the technical basis for requirements in technical specifications.

These methods are implemented in the form of reliability analysis tools to supplement PRA. These tools evaluate the impact of technical specification requirements on PRA input parameters, such as unavailability and initiating event frequency. Used in conjunction with PRA, these tools can analyze the risk impact of technical specification issues such as:

- Surveillance test intervals, including effects of test-caused transients
- Allowed outage times
- Action statements requiring shutdown
- Preventive maintenance schedules

The research to develop these tools is largely completed. The results are being documented in the reports listed in Table 1, on Page 7 of the enclosure. Half of these reports have been completed. Reports remaining to be completed are listed in Table 1 with the date the draft will be completed.

NRR has used some of these tools to evaluate proposed changes in individual technical specifications. Also, these tools are being used to evaluate technical specifications for the South Texas plant and for the Advanced Boiling Water Reactor.

The availability of these tools at the same time PRAs for many plants are being completed under the IPE Program, will help facilitate their wide use in the evaluation of the risk implications of technical specifications requirements. Also, these tools can be applied to other operational safety issues. For example, the results of this research formed much of the technical basis for the New York Power Authority's 1992 Commission briefing on a pilot project to develop risk-based regulation.

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The capability of these tools is illustrated with examples in the enclosure.

Applying these tools to other issues could be the objective of follow-on research. For example, we are discussing with the NRR staff possible needs for follow-on research to provide:

- Risk assessment of preventive maintenance strategies (to improve NRC guidelines for inspecting or auditing the "balance" between beneficial and adverse aspects of maintenance, as outlined in the maintenance rule).
- Guidelines for auditing dependent failures (to supplement NRC guidelines for risk-based inspection).
- Simplified methods to evaluate the risk impact of technical specification action statements (to facilitate staff review).

The RES staff contact for this research is Carl Johnson, (301) 492-3548.

Eric S. Beckjord, Director
Office of Nuclear Regulatory Research

Enclosure:
Risk-Based Methods to Evaluate Requirements in Technical Specifications

JAN 0 6 1994

Enclosure to Research Information Letter on
Risk-Based Methods to Evaluate Requirements in Technical Specifications

RISK-BASED METHODS TO EVALUATE REQUIREMENTS IN TECHNICAL SPECIFICATIONS

Research performed by:
BNL, SNL, INEL, SAIC, & Avaplan Oy

RISK-BASED METHODS TO EVALUATE REQUIREMENTS IN TECHNICAL SPECIFICATIONS

A. Regulatory Issues

In 1990, when NRR reported to the Commission on progress toward improving technical specifications, the Commission encouraged the staff "to move forward aggressively with the risk-based technical specifications program...." [1]

To support this effort, NRR requested RES to develop methods to evaluate the risk implications of the following issues [2, 3, 4, 5]:

- Risk impact of allowed outage times (AOTs) and surveillance test intervals (STIs)
  - At power
  - During shutdown
  - Effects of test-caused transients on optimum test intervals
- Action statements that require shutting down the reactor if equipment needed during shutdown fails (for example, failure of residual heat removal or standby service water)
- Risk implications of taking equipment out-of-service for maintenance
  - Rolling maintenance schedule
  - Optimizing the frequency of scheduled maintenance
  - Emergency diesel generators (EDGs)
- Improved technical specification defenses against dependent failures
- Configuration management
  - Conceptual framework for risk-based configuration management

B. Approach Using Reliability Methods to Supplement PRA

We have developed the requested methods for analyzing the risk impact of requirements in technical specifications. The approach has been to develop reliability engineering methods to assess the impact of these requirements in terms of PRA input parameters, e.g, unavailability of safety systems and frequency of initiating events. Thus, these reliability engineering tools can be used with existing PRAs to evaluate the risk implications of technical specification issues. This conceptual approach is illustrated in Figure 1.

The capabilities of these tools are illustrated in the following examples.

C. Examples and Capabilities of Tools

1. Risk Impact of Surveillance Test Intervals, Including Test-Caused Transients

In evaluating the risk impact of surveillance test intervals, these tools can evaluate the balance between the beneficial effects of testing (e.g., limiting fault-exposure time) and adverse effects (e.g., test errors that cause transients). For example, Figure 2 illustrates the beneficial and adverse effects of testing main steam isolation valves at a particular plant as the test interval varies between 1 week and 6 months. In this example, the optimum test interval, from a risk perspective, is about 2 months, with little penalty for slightly longer test intervals [6]. This example of quantitative analysis is consistent with the 3-month test interval recommended on the basis of qualitative judgements [7].

2. Risk impact of Action Statements That Require Shutdown

Another example of the capability of these tools is to evaluate the risk impact of action statements that require shutting the plant down, if an allowed outage time is exceeded. Of particular interest are systems that are needed during shutdown. For example, Figure 3 compares the risk of shutting down vs. continuing to operate if one or more trains of standby service water (SSW) fail. The main insights from Figure 3 are as follows. The risk of continued operation is comparable with the risk of shutdown. Also, if all three SSW trains fail, the level of risk is high. The action involving the least risk is to remain at power and repair at least one train promptly.

These insights suggest consideration of a possible modification of the limiting conditions for operation, as illustrated in Figure 4. In this example, the first part of the AOT (up to 1 day) would be used to diagnose whether at least one SSW train can be repaired promptly, and if so, to complete the repair. If it is estimated that repair of at least 1 train will take longer than 2 days, the plant would be shut down. Thus the AOT for multiple trains out-of-service would be 2 days (whereas the current AOT for double train failure is 8 hours). The AOT for a single train failure would remain 3 days. Additional information on this method, and examples for SSW and RHR, are described in reference 8. (BNL is applying a similar approach to an example of a PWR auxiliary feedwater system, and will report the results in March 1994.)

3. Scheduling EDG Maintenance During Power Operation vs. During Shutdown

An example of the risk impact of taking an EDG out of service for maintenance during reactor power operation and during shutdown is illustrated in Figures 5 & 6 [9]. The main insights are that, for this example BWR, the risk impact of taking an EDG out of service during the first few days of hot and cold shutdown is comparable with power operation. However, the risk impact is substantially reduced during refueling when the decay heat is low and the water level is high. These results provide the following insights regarding scheduling EDG preventive maintenance:

- In general, preventive maintenances of short duration (e.g., less than an AOT) can be scheduled during power operation. Shutting the reactor down specifically to perform short-duration maintenances does not appear to reduce the risk, if other important systems are not degraded.

- On the other hand, preventive maintenances of long or uncertain duration (e.g., overhauls) should in general be scheduled during refueling when the decay heat is low and the water level is high.

These insights are illustrated in more detail in Figure 7. These results are based on analysis of only two plants [9, 10]. Analysis of additional plants is not planned.

4. Rolling Maintenance Schedule

Figure 8 illustrates the capability of risk analysis to aid in evaluating a "rolling maintenance schedule." [11] In this example, the risk increases substantially during the first 3 weeks of the 12 week rolling schedule that was analyzed. A modified schedule that moves EDG maintenance from the first 3 weeks, when the risk is high, to a later period, when the risk is low, would reduce the average risk.

5. Optimizing Maintenance Intervals

The maintenance rule requires licensees to ensure that the objective of preventing failures through maintenance is appropriately balanced against the objective of minimizing unavailability due to preventive maintenance. This research has developed a Markov approach to analyze and adjust the frequency of preventive maintenance in order to minimize system unavailability. This approach balances the adverse effect of preventive maintenance (e.g., increase the unavailability contribution due to time out-of-service for maintenance) *vs.* the risk benefit of preventive maintenance (e.g., reduced unavailability contribution due to failures). The potential of this Markov analysis method to help optimize preventive maintenance intervals is illustrated in Figure 9 [11]. However, this method needs to be tested with plant data.

D. Regulatory Applications

NRR has used some of these tools to evaluate proposed changes in individual technical specification applications, and to evaluate Technical Specifications for the South Texas plant and for the Advanced Boiling Water Reactor.

Application of these methods to evaluate the risk impact of technical specification requirements involves the following resources. For generic evaluation, such as evaluation of requirements in the standard technical specifications, the analyst needs a PRA program, such as IRRAS and its data base, to analyze a sample of several plants. For plant-specific analysis, the analyst needs the plant-specific PRA on a computer program such as IRRAS. Evaluation of an individual requirement would take on the order of a staff week. The analyst could be an NRC staff member or a contractor.

Although technical specification improvements are voluntary, the potential for enhanced safety and reduced cost appear to interest the industry. For example, the New York Power Authority integrated many of these tools into their 1992 Commission briefing on a pilot project to develop risk-based regulation. [13]

The availability of these methods, at the same time that PRAs for many plants are being completed under the IPE Program, will provide a capability for widespread use of risk-based methods to improve technical specifications.

Another potential application of these methods involves maintenance. For example, these risk-based methods can help to evaluate both the optimum frequency of scheduled maintenance, and also the balance between scheduling maintenance during plant operation *vs.* during shutdown.

E. Restrictions on Applications

These tools share the strengths and weaknesses of PRA. They are useful to evaluate technical specification requirements that can be quantified in terms of equipment availability and initiating events. Thus, the tools are directly useful to develop a risk-basis for setting AOTs, STIs, and action statements for electro-mechanical components in front-line safety systems and support systems. However, in setting test requirements for much of the routine instrumentation in these safety systems, these tools are only useful to help develop qualitative engineering judgements regarding the relative importance of the instruments and reasonable STIs.

In addition, these methods do not incorporate uncertainty analysis as a built-in feature. The user should include uncertainty analysis where uncertainties are important, as for example when the results are to be compared to safety goals, or when comparing alternative courses of action where the alternatives differ in uncertainty. One approach, for example, is to estimate the uncertainties and use mean values.

In summary, these tools can provide a risk perspective to aid engineering judgement in setting requirements in technical specifications.

F. References

1. Staff requirements memorandum from S. J. Chilk to J. M. Taylor, regarding "Briefing on Risk-Based Technical Specifications Program" May 14, 1990.

2. User need memorandum from F. P. Gillespie to B. W. Sheron, "Research to Support Improvements in Technical Specifications," November 6, 1990.

3. User need memorandum from F. P. Gillespie to B. W. Sheron, "Reliability Assessment Research Needs," November 20, 1990.

4. User need memorandum from T. E. Murley to E. S. Beckjord, "Regulatory Needs for Reliability Assessment Research," June 3, 1991.

5. User need memorandum from T. E. Murley to E. S. Beckjord, "NRR User Needs for RES Support," December 19, 1991.

6. NUREG/CR-5775, "Quantitative Evaluation of Surveillance Test Intervals Including Test-Caused Risks," December 1992.

7. NUREG-1366, "Improvements to Technical Specifications Surveillance Requirements," by R. M. Lobel and T. R. Tjader, December 1992.

8. NUREG/CR-5995. Mankamo et al., "Risk-Based Improvements of Technical Specifications Action Statements Requiring Shutdown: Pilot Applications to the RHR/SSW Systems of a BWR," by T. Mankamo, I. S. Kim, and P. K. Samanta, December, 1993.

9. Letter Report, "The Risk Impact of Diesel Generator Unavailabilities for a BWR During Low Power and Shutdown," by B. D. Staple et al., March 1993.

10. NUREG/CR-5994, "Analysis of EDG Unavailability Due to Maintenance, Testing, And Failures," by P. K. Samanta et al., to be published.

11. NUREG/CR-6002, "Risk Impacts and Effects of Maintenance Scheduling," by W. E. Vesely and P. K. Samanta, to be published.

12. New York Power Authority and NUMARC briefing to the Commission, "Risk-Based Regulation Transition Strategy, March 10, 1992.

Table 1

PRODUCTS: METHODS FOR EVALUATING TECHNICAL SPECIFICATION REQUIREMENTS

TOPICS	REPORTS DESCRIBING ANALYSIS METHODS
Surveillance Test Intervals • Risk impact of surveillance requirements, including effects of test-caused risks	NUREG/CR-5775
Allowed Outage Times • Risk impact of allowed outage times	NUREG/CR-5425
Action Statements Requiring Shutdown • Comparison of risk of shutdown *vs.* continued power operation, if RHR or SSW is inoperable at a BWR • Similar comparison for AFW at a PWR	NUREG/CR-5995 BNL letter report (3/94)
Maintenance • Risk impact of scheduled maintenance • Risk impact of EDG unavailability due to maintenance. (Results used as input to SECY-93-044)	NUREG/CR-6002 (draft 1/94) BNL & SNL Letter Reports NUREG/CR-5994 (draft 1/94)
Common-Cause Failures • Technical specification defenses against dependent failures	NUREG/CR-6140 (draft 1/94)
Technical Specification Requirements During Shutdown • PWR • BWR	NUREG/CR- (draft 2/94) NUREG/CR- (draft 4/94)
Integrated Surveillance • Potential risk-benefits of integrating selected surveillances and preventive maintenances	INEL Letter report
Configuration Management • Conceptual outline of risk-based, operational configuration control	NUREG/CR-5641
Handbook • Summary of principles & methods to assess risk impact of requirements in technical specifications	NUREG/CR-5141 (draft 3/94)

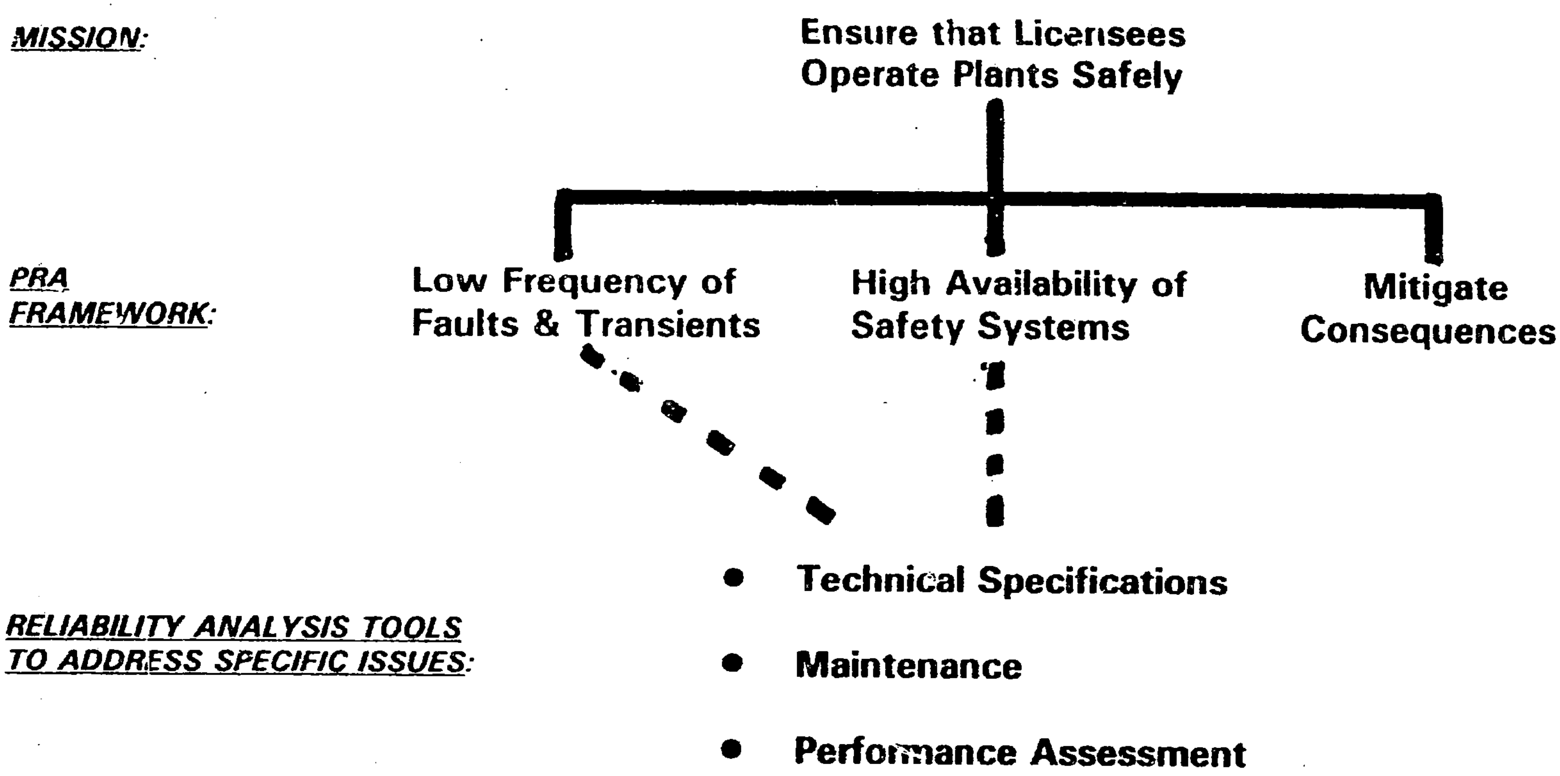

Figure 1. Conceptual approach to develop methods to evaluate the risk impact of requirements in technical specifications

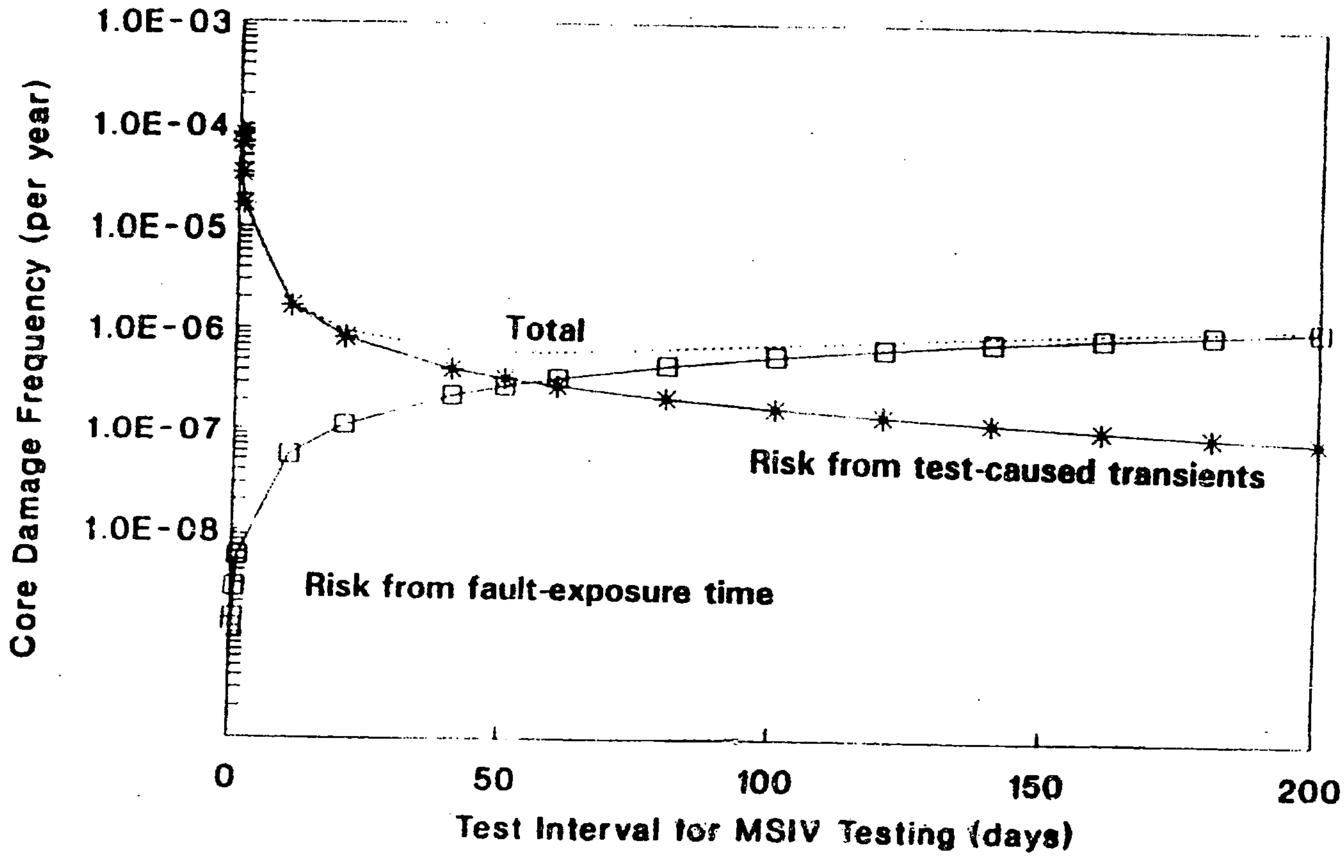

Figure 2. Example of method to analyze the risk impact of the surveillance test interval (for main steam isolation valve at a BWR), including the effects of test-caused transients.

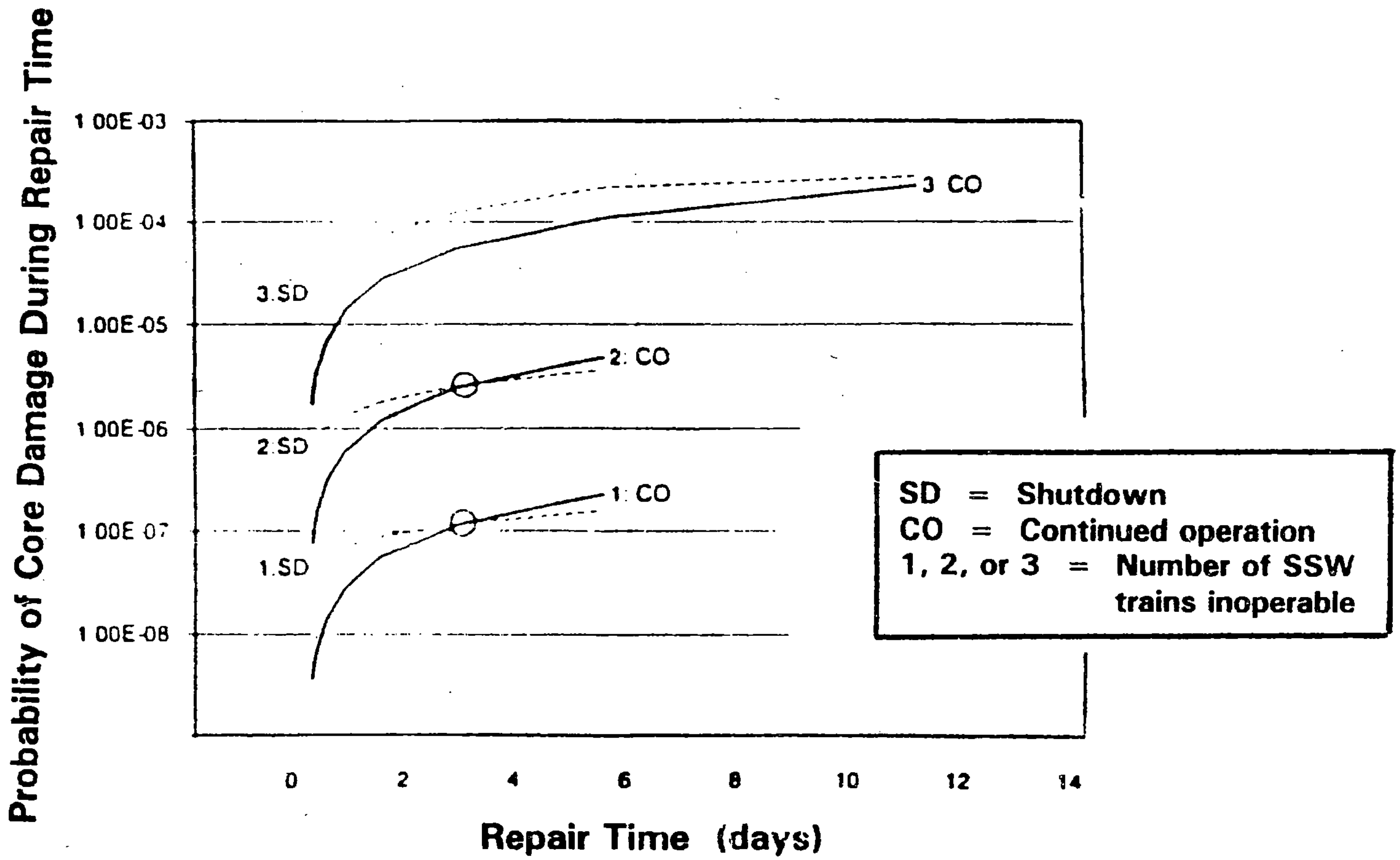

Figure 3. Example of method to analyze the risk impact of action statements requiring plant shutdown. In this example of a BWR with 1, 2, or 3 trains of standby service water inoperable, the risk of continued operation is comparable with the risk of shutting down.

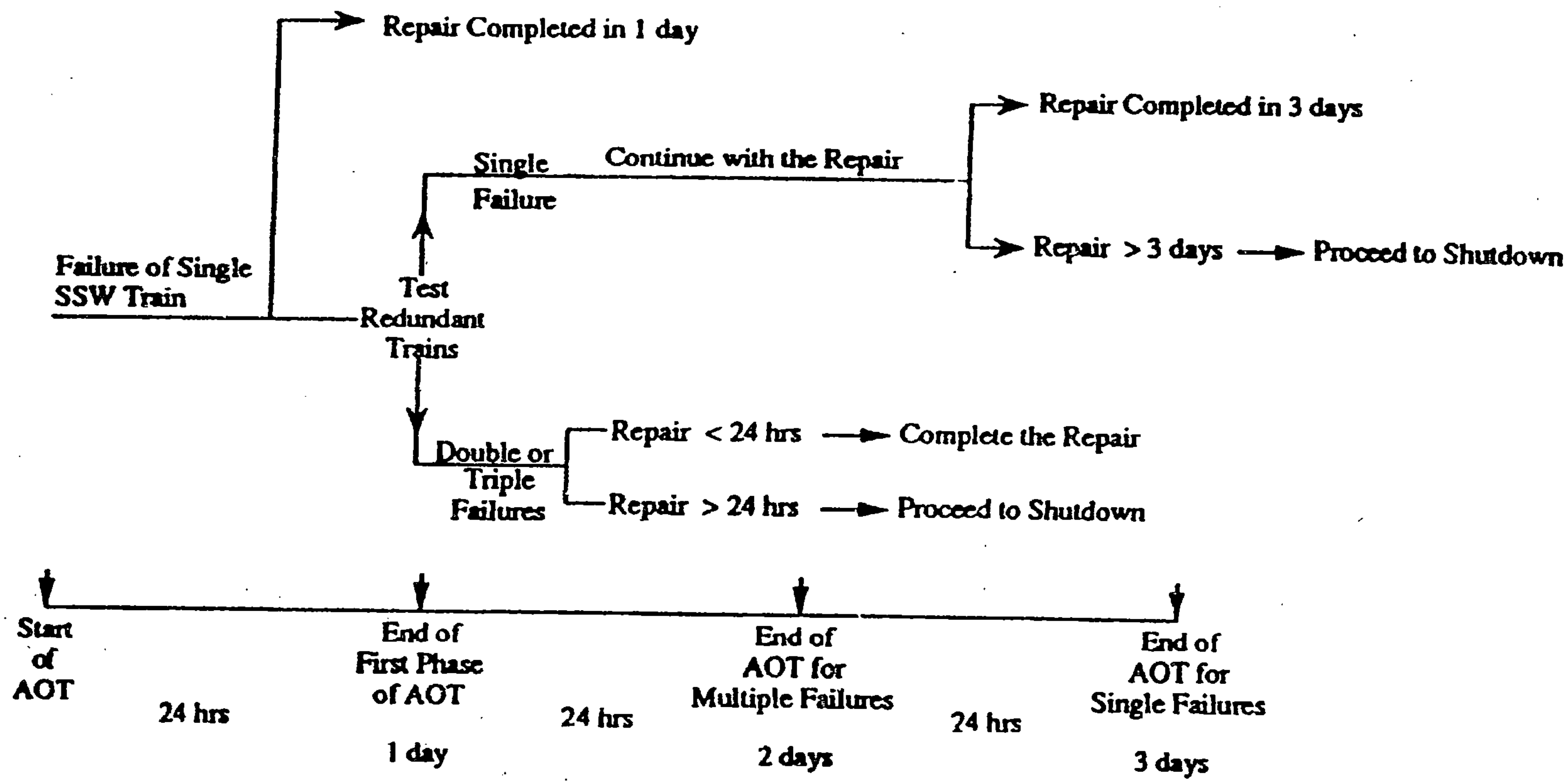

Figure 4. Example of SSW LCO modified to reflect insights from Figure 3

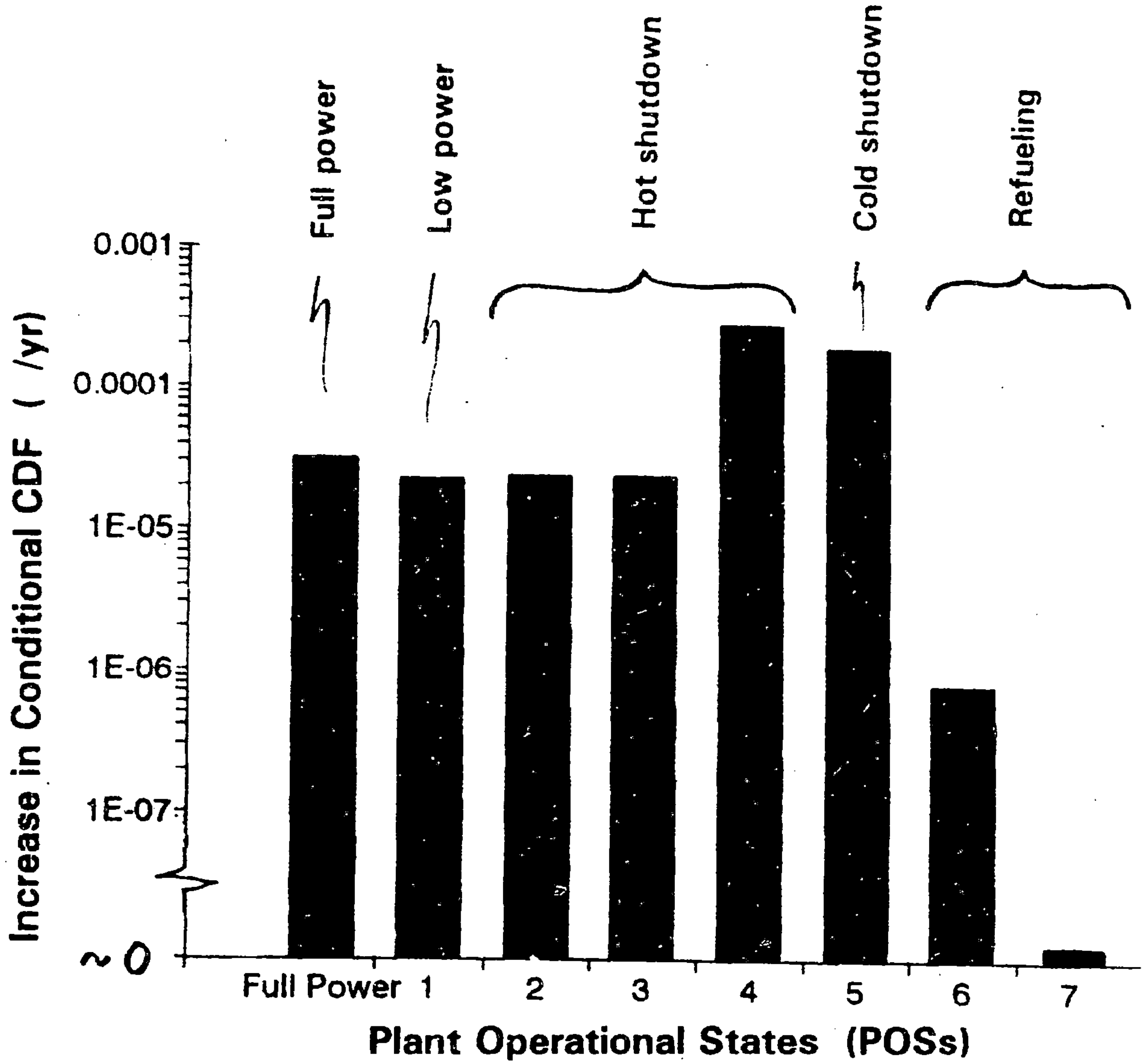

Figure 5. Example (from a BWR) comparing the risk impact of taking an EDG out-of-service during power operation *vs*. during shutdown. (IPE analysis indicates the risk impact during power operation and hot and cold shutdown may be even closer together than shown here.)

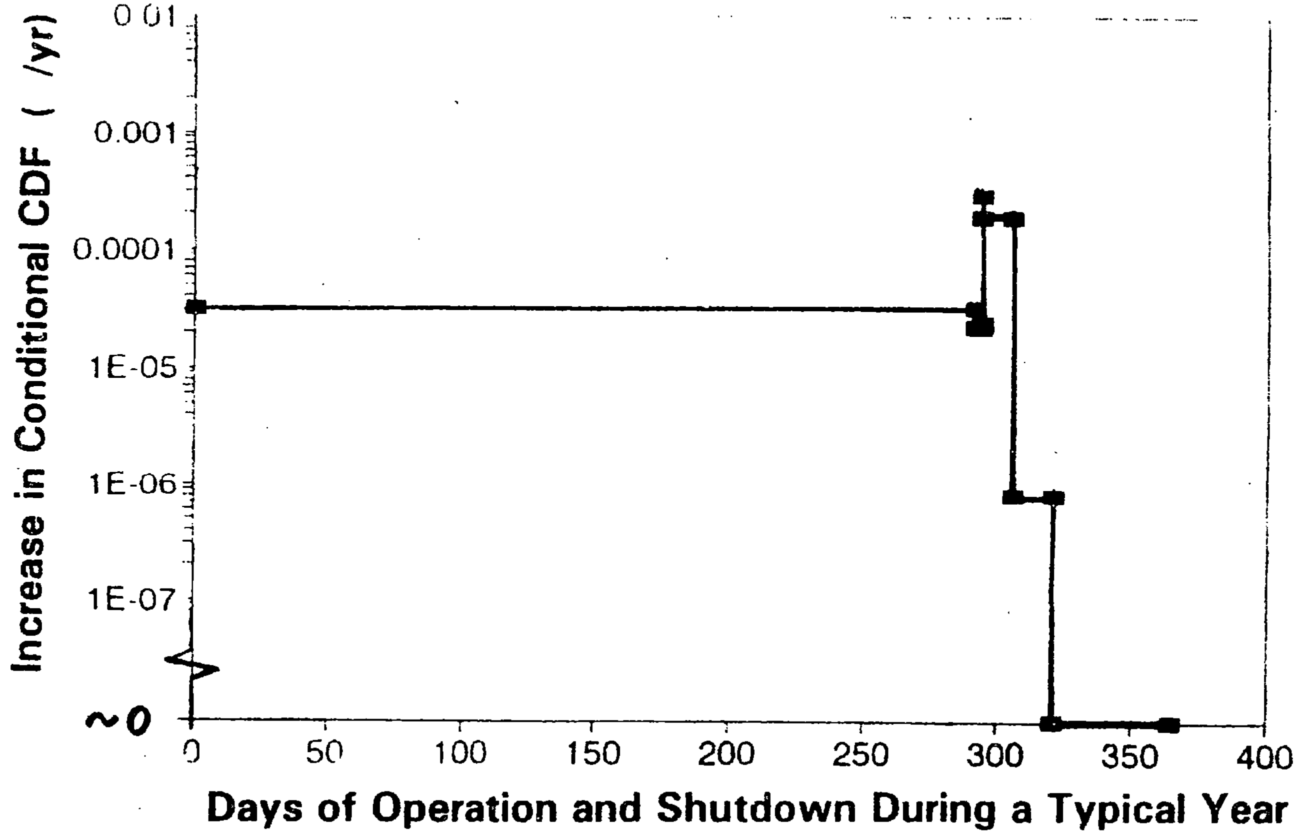

Figure 6. Example (from a BWR) comparing the risk impact of taking an EDG out-of-service during power operation *vs*. during shutdown. (Information in Figure 5 replotted on time scale)

Type of Maintenance and Frequency	Maintenance Duration	Concern for Scheduling Maintenance During Power Operation	Concern for Scheduling Maintenance During Shutdown	Insights
1. Scheduled PMs Fixed frequency PMs that need to be performed every 1½ to 2 yrs (or longer)	a) Longer than AOT*	• risk impact may be unacceptable • uncertainty that PM can be completed and the component can be returned to service	• risk impact during certain shutdown periods significant	• schedule during shutdown • define allowable plant configuration and state for such maintenance • allow sufficient time to complete maintenance uninterrupted.
	b) ~AOT	• uncertainty that PM can be completed and the component can be returned to service within an AOT. • repeated use of LCOs for such maintenance imposes unacceptable risk	• risk impact during certain shutdown periods may be significant	• schedule during shutdown • define allowable states during plant shutdown, e.g., avoid early stages of shutdown.
	c) <<AOT	• none	• plant outage duration can be lengthened	• schedule during power operation or shutdown • optimize PM program between power operation and shutdown
2. Scheduled PMs Fixed frequency PMs that need to be performed between a refueling outage (less than 18 months)	a) Longer than AOT	• risk impact may be unacceptable	• unreliable EDG during power operation	• may be performed during power operation with extended AOT in order to assure EDG reliability during this period. • could involve exemption to AOT
	b) ≤AOT	• repeated use imposes unacceptable risk • repeated use prior to testing masks EDG failure, unreliable EDG failure data	• unreliable EDG during power operation • plant outage duration can be lengthened	• schedule during power operation • optimize PM during power operation and shutdown • control EDG unavailability due to PM (set limit for allowable PM duration and frequency during power operation).
3. Condition - Directed PMs As needed to correct degradation of equipment (choices include scheduling maintenance during power operations, waiting until the next shutdown, or immediately proceeding to shutdown)	a) Longer than AOT	• uncertainty that PM can be completed and the component can be returned to service	• increased risk of shutting down with unreliable EDG. • long wait to perform maintenance if a preferable state in shutdown mode is to be chosen	• depends on a number of factors, e.g., severity of degradation, time from next scheduled outage, potential for common cause failure • may involve changes to TS
	b) ~AOT	• uncertainty that PM can be completed and the component may be returned to service within an AOT.	• larger relative risk to perform maintenance	• schedule during power operation • may involve additional test requirements
	c) <AOT	• repeated use increases risk from EDG downtimes	• unnecessary risk from shutting down • increased risk during power operation	• schedule during power operation • control or monitor frequency to avoid misuse

*AOT: Allowed Outage time, PM: Preventive Maintenance, EDG Emergency Diesel Generator, TS, Technical Specification.

Figure 7 Example of Using PRA Results, Such as Figure 6, to Develop Insights on Scheduling EDG Preventive Maintenance During Power Operation vs. During Shutdown.

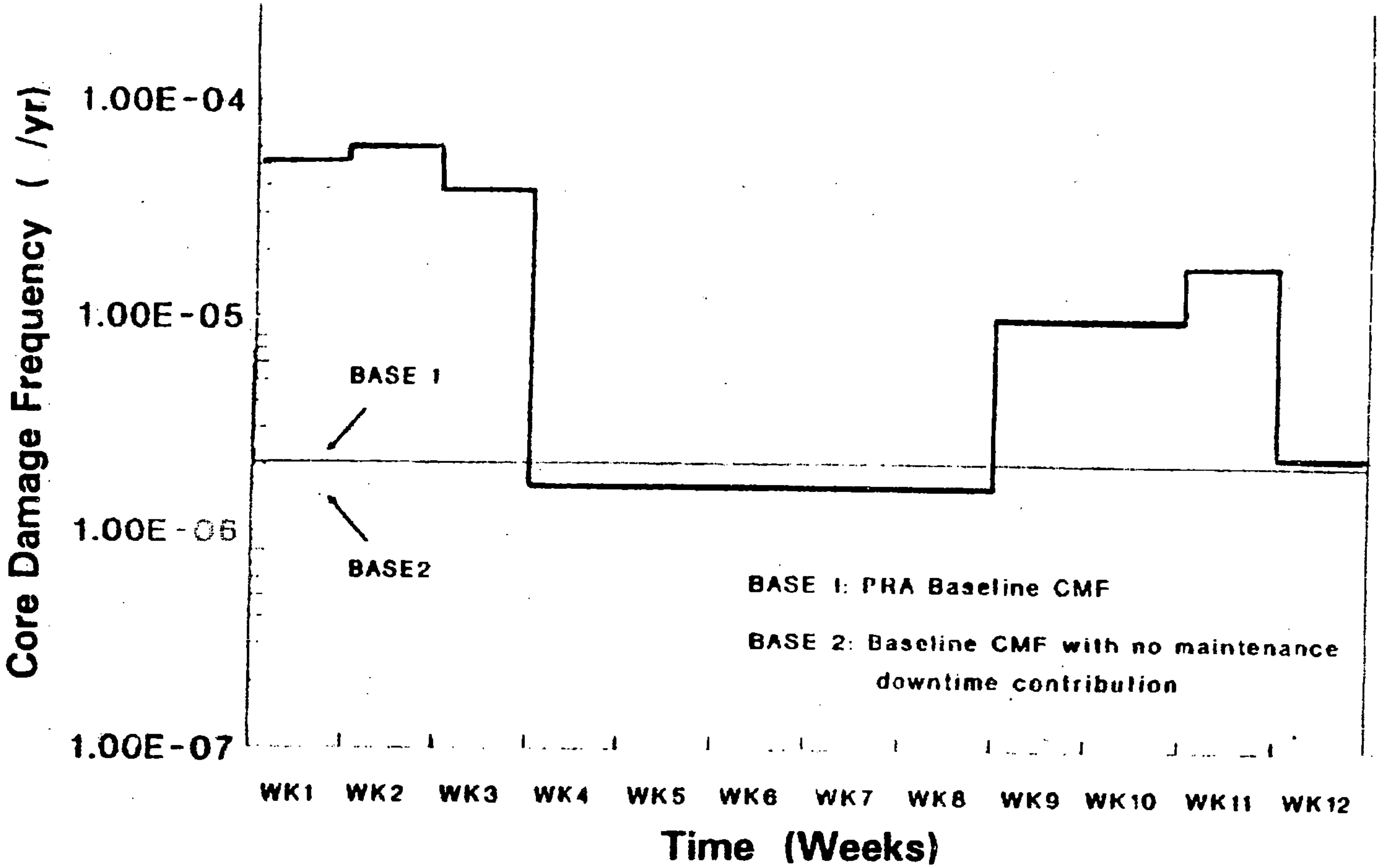

Figure 8. **Example of analysis of risk impact of rolling maintenance schedule. (This bounding analysis assumes that all equipment scheduled for maintenance during a week is out-of-service all week.)**

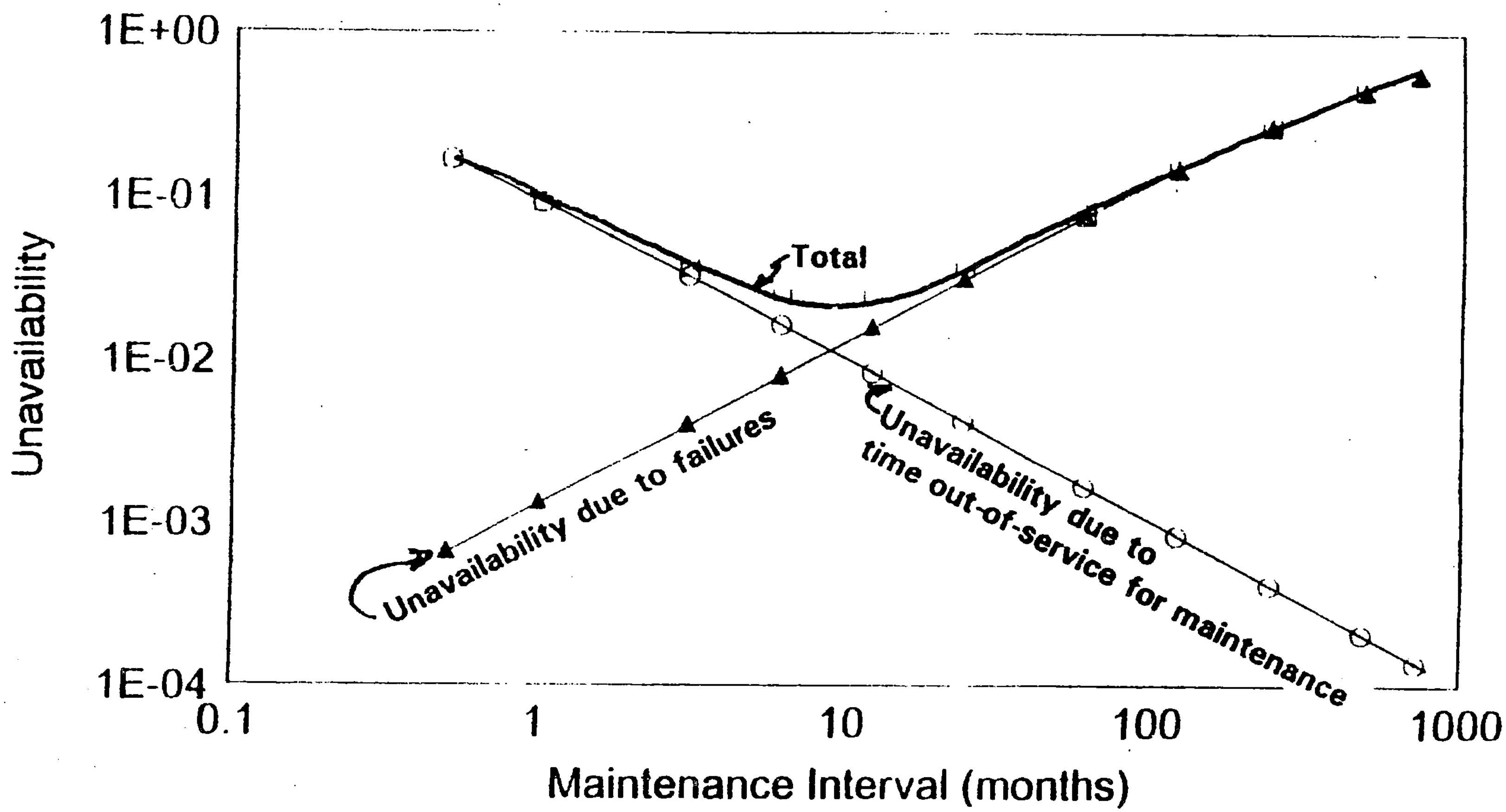

Figure 9. Example of method for exploring the risk impact of preventive-maintenance interval.

In this example, λ_{od} = Degradation rate ≈ incipient failure rate = 10^{-4}/hr
λ_{dl} = Failure rate, given component is degraded = 10^{-4}/hr