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SUBJECT: SELECTED TOPICS IN GUIDANCE FOR COLLECTION AND SCREENING OF COMPONENT RELIABILITY DATA

Dear Dr. Apostolakis:

During the 23rd meeting of the Technical Advisory Committee of the Nuclear Risk Research Center (NRRC), November 17-21, 2025, we met with representatives of the NRRC staff to discuss the guidance for collection of Japanese industry data and quantification of equipment reliability parameters that are used in the industry probabilistic risk assessment (PRA) models. The research team requested our input on three specific topics in the guidance. This letter report documents our recommendations on those topics.

CONCLUSIONS AND RECOMMENDATIONS

1. Based on the practices that are currently used to compile equipment operating experience and to quantify reliability parameters for component demand failure modes, the guidance should recommend that all plants should collect data for the number of component failures and the number of component demands. The failure on demand model should be used to quantify the industry reliability parameters for failures to actuate on demand.

2. The guidance should clarify the considerations for screening out or retaining component failure events that involve personnel errors. Human-induced failures should be excluded from component failure data unless specific, justified conditions indicate that the human action is inseparable from the component's functional reliability. The guidance should recommend that the data analysts should consult with human reliability analysis experts to determine how specific personnel errors are included in the current industry PRAs.

3. The guidance should contain an industry-endorsed "master list" of BWR and PWR systems, components, and failure modes that are included in a full-scope Level 2 PRA. All plants should collect data for the equipment in that list. The

scope of the data should not be restricted to only the specific components and failure modes that are included in each plant's current PRA models.

BACKGROUND

The NRRC has published guidance for the collection and screening of Japanese nuclear power plant equipment performance data (Report NR22006), and quantification of industry-wide component reliability parameters for use in PRAs (Report NR21002). The utilities have collected data according to that guidance, and preliminary values of the reliability parameters have been quantified. Based on the experience from those efforts and other interim review comments, the NRRC is currently revising and updating the guidance in both reports.

During this meeting, we were briefed on the current status of the updated guidance. The research team requested our input on three specific topics that are very important for the data collection and screening guidance. Those topics are:

(1) Data and models that are used to quantify parameters for component failures to actuate on demand

(2) Treatment of personnel errors that contribute to equipment failures

(3) Scope of systems, components, and failure modes for which data are collected

DISCUSSION

The following sections summarize our comments and the technical bases for each item in our Conclusions and Recommendations.

Data and Models for Component Failures to Actuate on Demand

Japanese utilities currently use two different models to quantity the probability[1] that a component fails to actuate when a demand occurs (e.g., a pump fails to start, a valve fails to open, etc.). Some utilities use the "failure on demand" model; other utilities use the "standby failure rate model". The applied model affects the types of data that are collected and the methods that are used to quantify the corresponding reliability parameter values for the industry PRAs.

To provide some perspective on these models, we have included an Appendix that summarizes their basic formulations. The Appendix also contains an example of

[1] In this is report, we use the normal public understanding of the term "probability". In risk assessment, "probability" is used to account for the state of knowledge or uncertainty about the value of a parameter. For example, there is uncertainty about whether the estimated parameter value is the "true" value that would result from an extremely large amount of data. That uncertainty is measured by probabilities that account for limitations in the current amount of data. (This footnote is primarily for the benefit of risk assessment experts, who are very careful about how they use the term "probability".)

how the data are collected, how the failure parameters are quantified in the database for each formulation, and how those parameters are used in the PRA models.

We are aware of some concerns that the failure on demand formulation may over-estimate the demand failure probabilities. We are also aware of other concerns that the standby failure rate formulation may under-estimate the probabilities. Discussions of the conceptual differences and history of these models are too lengthy and esoteric for this letter report. In practice, the maximum difference is a factor of two. It is likely that the "true" failure probability lies somewhere between those limits. However, experience has shown that it is often very difficult to conclusively determine whether a specific failure event was caused entirely by incipient degradation, or if it was caused by a failure mechanism that is related directly to mechanical stresses or electrical surges which occurred during the demand[2].

Data references such as NUREG/CR-6928 and its periodic updates publish estimates of probabilities for actuation failures that are derived from the failure on demand formulation of the data. Those parameter values are used in U.S. nuclear power plant PRAs.

It is very important that all Japanese utilities should collect consistent data for the derivation of industry-wide component demand failure probabilities. It is very inefficient for utility data analysts at each plant to compile two sets of data to support both parameter estimates.

The standby failure rate model is based on several assumptions. The most important assumptions are that all component failures are caused by incipient degradation mechanisms which accumulate over time while a component is in standby, and the standby failure rate is constant. For example, if the causes for equipment failures are a combination of incipient degradation mechanisms and demand-related stresses, the standby failure rate model will under-estimate the probability that a component will fail during a random demand. In the context of the standby failure rate model assumptions, the failure on demand model will over-estimate the failure probability. The difference between each of those estimates and the "true" failure probability requires information about the relative contributions from incipient and demand-related failure causes. That information can be obtained only from comprehensive analyses of extensive data from numerous plants, including detailed forensic examinations of the specific causes for each recorded failure. Furthermore, the applicability of each model may be affected by the specific type of component and how it is operated, maintained, and tested at each plant. The standby failure rate model assumptions may not be supported by industry operating experience, which contains plant-to-plant differences in equipment operating and maintenance practices, and testing intervals. Those differences introduce uncertainty about the industry-wide applicability of the estimated standby failure rates.

When data are collected from several plants, the failure on demand model generally provides better estimates for the expected equipment performance during a random

[2] The demand-related failure causes are often called "shock" failure mechanisms.

demand. Variability and uncertainty in the plant-specific component standby times, testing intervals, and other reasons for non-periodic demands (e.g., routine operational demands, tests to confirm operability during Technical Specifications Allowed Outage Times, plant transients, etc.) affect the underlying assumptions that are used for the standby failure rate formulation. For example, data that have been compiled from several U.S. and European plants have confirmed that some equipment is actually subjected to many more demands than are predicted by only a periodic testing assumption[3].

The NRRC guidance should recommend that all plants should collect data for the number of component failures and the number of component demands. The failure on demand formulation should be used to quantify the industry reliability parameters for failures to actuate on demand.

Some utilities may have important reasons to use the standby failure rate model as the basis for the component demand failure probabilities in their plant-specific PRA. In that case, the industry-wide estimates from the failure on demand formulation can be easily converted to an equivalent standby failure rate that applies for the plant-specific testing interval for each component.

Treatment of Personnel Errors that Contribute to Equipment Failures

The guidance for screening Criterion (b) in Report NR22006 discusses considerations for the treatment of personnel errors that contribute to equipment failures. These considerations apply primarily to "pre-initiator" errors which occur during routine operations, testing, and maintenance activities. Examples include errors during maintenance that functionally disable a component (e.g., use of improper parts, improper re-assembly, etc.), and restoration errors that leave the component unable to perform its intended function after the maintenance is completed (e.g., misalignments of valves, electric power supplies, or signals).

The data that are collected according to this guidance are intended to quantify the probabilities for equipment failures due to hardware malfunctions. In that context, equipment failures which are caused by personnel errors are not relevant to these data and PRA parameters. As a general principle, human-caused failures should be excluded from the hardware failure database unless there is a strong, technically supported justification that the personnel error is inseparable from the component's functional reliability. However, in practice, the failure event screening decisions are often not that simple. In particular, they are strongly influenced by the scope and types of pre-initiator errors that are included in the industry PRA models, according to the currently-applied human reliability analysis (HRA) methods and guidance.

The screening decisions are also influenced by the types of functional testing that are performed to confirm that a component is operable before it is restored to normal service. For example, if the post-maintenance testing is sufficiently rigorous to discover all types of maintenance errors and re-alignment errors that can leave a component disabled, that testing can typically be used as a reason to screen out

[3] This was a very important conclusion from the plant-specific data collection efforts during the Zion and Indian Point PRA studies in the early 1980's.

most failure events which involve these types of errors. This consideration is also typically used as a reason to exclude explicit human failure events (HFEs) from the PRA models for pre-initiator errors that are discovered by effective post-maintenance testing.

Contemporary state-of-the-practice HRA models do not typically include explicit HFEs to quantify the effects from certain types of errors which are not discovered by the applied post-maintenance testing. Examples include errors like the use of sub-standard parts, improper torquing, inadequate internal lubrication, etc. For example, the equipment may function properly during the post-maintenance test. However, the test may not operate the equipment for a long enough time, or it may not apply the loading, pressure, or flow conditions that would occur during an actual demand. Equipment failures due to these types of errors are typically discovered at a later time, after the equipment is returned to service and is operated under different conditions, or it is disassembled for a comprehensive inspection. In principle, the PRA could define and quantify specific HFEs for these types of errors, which are "potentially discoverable, but not discovered". However, in our experience, contemporary PRAs do not typically define or quantify those types of HFEs. Therefore, if a data analyst identifies a component failure which was caused by this particular type of error, and it was not discovered during the normal post-maintenance testing, the event is typically retained in the database as a hardware-related failure.

According to this perspective, some very general considerations for screening Criterion (b) are:

- Do not include the event as a hardware failure if industry practices require post-maintenance functional testing at every plant, and the error can be discovered by that testing.

- Do not include the event as a hardware failure if the industry's currently-applied HRA methods define an explicit pre-initiator HFE for this type of error.

These are only general considerations to illustrate the basic decision process. They should not be applied as absolute "rules". The screening decisions must be made on a case-by-case basis.

The data analysts face a difficult decision if the neither of the above conditions applies. In other words, the analysts identify an event which involves an error that would not be discovered by post-maintenance testing, ***and*** the current HRA methods do not model that type of error as a pre-initiator HFE. In those cases, the event essentially identifies a deficiency in the HRA. In particular, a good quality state-of-the-practice HRA should define an HFE for this error, but the current PRA model does not include those types of HFEs.

In this situation, the records of these events should not be lost, because a full-scope PRA must account for this operating experience. The data analysts should screen out these events from the hardware failure database according to Criterion (b). However, the records should be retained for further evaluation by the HRA experts to determine why they are not included in the PRA as distinct HFEs. Unless there is clear technical justification for screening out these pre-initiator errors from the scope of the HRA, the PRA models should be revised to include the relevant HFEs, and the events should provide input to the quantification of human error probabilities (HEPs) for those HFEs.

In summary, the guidance for screening Criterion (b) should be expanded to better describe these considerations. The screening decisions must be made on a case-by-case basis. If the data analysts screen out an event according to Criterion (b), they must fully document the specific reasons for their decision. Events which identify a potential deficiency in the applied HRA methods or models should not be retained in the hardware failure database. However, they should be "flagged" for evaluation by the HRA experts to determine whether the scope of the pre-initiator HFEs should be expanded to account for the observed operating experience.

Scope of Systems, Components, and Failure Modes

The guidance for screening Criterion (a) and Criterion (e) in Report NR22006 have a very significant effect on the scope of the systems, components, and failure modes for which data are compiled and events are retained for quantification of the reliability parameters. The guidance recommends that a plant should collect data and retain failure events only for the specific components and failure modes that are included in its PRA model. This guidance can result in significant inconsistencies and deficiencies in the scope of the industry-wide data. The following illustrative examples show how this could occur, depending on how the utility data analysts interpret and apply the guidance.

- The PRA models for Plant X include ventilation and room cooling systems for locations that contain PRA equipment. The data analysts for Plant X collect data for the ventilation fans, dampers, and chillers that are included in their PRA. The PRA models for Plant Y do not include ventilation systems. Therefore, the data analysts for Plant Y do not collect data for any ventilation equipment. All plants have ventilation systems. The industry database should contain data for all fans, dampers, and chillers in ventilation systems that are typically included in full-scope PRAs for many plants (i.e., ventilation systems for rooms and building areas that contain PRA equipment). Therefore, to support a comprehensive industry-wide database, Plant Y should collect data for fans, dampers, and chillers in those ventilation systems.

- The current PRA for Plant X is a Level 2 (or "Level 1.5") PRA. The data analysts for Plant X collect data for the containment isolation valves that are included in their PRA, and other equipment that may prevent containment failures or mitigate offsite releases. The current PRA for Plant Y is a Level 1 PRA. Therefore, the data analysts for Plant Y do not collect data for the containment isolation valves and other equipment. Data for those components will certainly be relevant for Plant Y when that PRA model is extended to Level 2. The operating experience for that equipment at Plant Y is also relevant to the industry-wide data for all plants. Therefore, Plant Y should collect data for those components.

- The PRA model for Plant X contains two motor-operated valves, V1 and V2. The PRA success criteria require that Valve V1 must open, and Valve V2 must close.

Therefore, the data analysts retain only events which involve the "fail to open" failure mode for Valve V1, and only events which involve the "fail to close" failure mode for Valve V2. Events which involve Valve V1 failures to close and events which involve Valve V2 failures to open are screened out, because the PRA model does not include those specific failure modes for those particular valves. The data for those failure modes are relevant for other similar motor-operated valves in the Plant X PRA, and for other similar motor-operated valves at other plants. Therefore, Plant X should retain the data for both failure modes for these valves.

The NRRC guidance should contain an industry-endorsed "master list" of BWR and PWR systems, components, and failure modes that are included in a full-scope Level 2 PRA. The guidance for screening Criterion (a) and Criterion (e) should recommend that all plants should collect data for the equipment in that list. The scope of the data should not be restricted to only the specific components and failure modes that are included in each plant's current PRA models. The lists of specific component types and failure modes in Appendix A of Report NR22006 should also be reviewed to confirm that they provide a comprehensive reference.

Summary

We look forward to continuing our discussions with the NRRC research team as they work to complete the updates to this important guidance.

Sincerely,

John W. Stetkar
Chairman

REFERENCES

1. Nuclear Risk Research Center, CRIEPI Report NR21002, "Estimation of the Generic Component Reliability Parameters for Probabilistic Risk Assessment of the Japanese Nuclear Power Plants," September 2021.

2. Nuclear Risk Research Center, CRIEPI Report NR22006, "Component Reliability Data Collection Guide for Probabilistic Risk Assessment," May 2023.

3. Nuclear Risk Research Center, Summary of the Nuclear Regulation Authority comments on the CRIEPI Report "Component Reliability Data Collection Guide for Probabilistic Risk Assessment," received September 7, 2023.

4. Nuclear Risk Research Center, "Briefing on Collection of Japanese Industry Equipment Failure Data and Quantification of Generic Equipment Failure

Rates," Presentation to NRRC Technical Advisory Committee, May 28, 2024, Proprietary.

5. Nuclear Risk Research Center, "Collection of Japanese Industry Equipment Failure Data and Quantification of Generic Equipment Failure Rates," Presentation to NRRC Technical Advisory Committee, November 18, 2025, Proprietary.

6. United States Nuclear Regulatory Commission, NUREG/CR-6823, "Handbook of Parameter Estimation for Probabilistic Risk Assessment," September 2003.

7. United States Nuclear Regulatory Commission, NUREG/CR-6928, "Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants," February 2007.

8. Idaho National Laboratory, INL/EXT-21-65055, "Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants: 2020 Update," November 2021.

9. Stetkar, J. W., "Comments on Standby Failure Rate Model," May 8, 2023, Confidential.

10. Stetkar, J. W., "Comments and Questions on Component Reliability Data Collection Guide for Probabilistic Risk Assessment CRIEPI Report NR22006," September 8, 2023, Confidential.

11. Stetkar, J. W., Personal Comments on "NRA's Comments on the CRIEPI Report 'Component Reliability Data Collection Guide for Probabilistic Risk Assessment'," September 9, 2023, Confidential.

12. Stetkar, J. W., "Comments and Questions on Estimation of the Generic Component Reliability Parameters for Probabilistic Risk Assessment of the Japanese Nuclear Power Plants, CRIEPI Report NR21002," September 16, 2023, Confidential.

13. Stetkar, J. W., Personal Comments on "Japanese Industry's Draft Response to NRA's Comments on the CRIEPI Report 'Component Reliability Data Collection Guide for Probabilistic Risk Assessment'," September 25, 2023, Confidential.

14. Stetkar, J. W., "Comments and Questions on Component Reliability Data Collection Guide for Probabilistic Risk Assessment CRIEPI Report NR22006," November 10, 2023 Confidential.

15. Stetkar, J. W., "Comments and Questions on Estimation of the Generic Component Reliability Parameters for Probabilistic Risk Assessment of the Japanese Nuclear Power Plants, CRIEPI Report NR21002," November 11, 2023, Confidential.

APPENDIX

"Failure on Demand Model" and "Standby Failure Rate Model"

This appendix summarizes the basic formulations of the failure on demand model and the standby failure rate model. It also contains an example of how the data are collected, how the failure parameters are quantified in the database for each formulation, and how those parameters are used in the PRA models.

Failure on Demand Model

The failure on demand model is based on the assumption that the probability for a component's failure to actuate when a random demand occurs is estimated by the historical operating experience for the number of recorded failures (N) and the number of recorded demands (D).

In this formulation, the demand failure probability (Q) is estimated by the following equation:

$$Q = N / D \tag{1}$$

When plant operating experience is compiled for this formulation, the analysts collect the following data.

N = Total number of component failures during the database period

D = Total number of component demands during the database period

The database quantifies the value for parameter Q, according to Equation (1). Parameter Q is then used to quantify the failure probability for the component basic events in the PRA model.

Standby Failure Rate Model

The standby failure rate model is based on the following assumptions.

(1) All component failures are caused by incipient degradation mechanisms which accumulate over time while a component is in standby. The effects from those causes are manifested when a component demand occurs. The rate at which the incipient causes occur is called the standby failure rate, λ_S. It is assumed that a single failure rate accounts for the effects from all incipient causes, and it is constant. In particular, for typical nuclear power plant equipment standby times, it is assumed that λ_S does not depend on the length of time that the component is in standby.

(2) Standby components are functionally tested according to a fixed periodic schedule with a testing interval T. The only normal demands for a component occur during the periodic tests.

(3) All incipient causes for component failures are discovered during the periodic tests. Those conditions are corrected before the component is returned to its normal standby status. Incipient causes do not continue to accumulate into the next standby interval after the test is successfully completed. In other words, the process of accumulating incipient degradations is "reset" to zero when the test is completed. (This is sometimes called an "accumulation and renewal" model or a "perfect renewal" assumption.)

In this formulation, the probability that a component fails when a random demand occurs during the standby test interval T is estimated by the following equation:

$$Q = (1 / T) * \int [1 - \exp(-\lambda_S t)] \, dt \qquad (2)$$

where

λ_S = Standby failure rate, failure per hour

T = Component test interval, hours

The integral is evaluated from time t = 0 to the end of the component test interval at time t = T.

If the values of λ_S and T are relatively small, the integral formulation can be approximated by:

$$Q \sim \lambda_S * (T / 2) \qquad (3)$$

Equation (2) quantifies the probability that the incipient failure causes will functionally disable the component before a random demand occurs. It is sometimes useful to understand the linear approximation in Equation (3) as follows. On average, a random demand will occur halfway through the standby time T. At that time, the incipient causes will have accumulated one-half of the failures that are discovered when the test is performed at time t = T. Therefore, the average probability for failure when a random demand occurs is one-half of the probability which would be observed from the testing results at the end of the interval, which can be estimated by $\lambda_S * T$.

When plant operating experience is compiled for this formulation, the analysts collect the following data.

N = Total number of component failures during the database period

T_{SB} = Total component standby time during the database period

The database quantifies the value for the standby failure rate parameter λ_S, according to the following equation.

$$\lambda_S = N / T_{SB} \qquad (4)$$

Parameter λ_S and the plant-specific testing interval T are then used to quantify the failure probability Q for the component basic events in the PRA model, according to Equation (3).

Data Collection and PRA Quantification Example

For this example, we use hypothetical data to illustrate how the applied model determines the types of data that are collected, how the reliability parameters are quantified, and how those parameters are used in a PRA model.

Suppose that a hypothetical plant collects data for standby Component X, which is tested once per month. The data collection period is 10 years. The operating experience is:

N = 2 failures during the database period

D = 120 demands during the database period

T_{SB} = 87,600 total component standby hours during the database period[4]

Based on these data, the database quantifies the following parameter values:

Q = 2 / 120 = 1.67E-02 failure per demand

λ_S = 2 / 87,600 = 2.28E-05 failure per hour

If the plant uses the failure on demand model to quantify failure of Component X in the PRA, the basic event has a value of:

Q = 1.67E-02

If the plant uses the standby failure rate model to quantify failure of Component X in the PRA, the testing interval is T = 730 hours (one month), and the basic event has a value of:

$Q = \lambda_S * (T / 2) = 8.33E\text{-}03$

Thus, for the same plant operating experience, the estimated probability for failure of Component X in the PRA differs by a factor of 2, depending on which failure model is used.

[4] In this example, it is assumed that one year contains 8,760 hours, ignoring the effects from leap years. That also provides a simple estimate of 730 hours in each month.