COMBUSTION ENGINEERING

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(Project No. 675)

Mr. Frank J. Miraglia
Associate Director for Projects
Office of Nuclear Reactor Regulation
Attn: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Subject: Advanced Reactor Severe Accident Program (ARSAP) - Topic Paper Set 4

Dear Mr. Miraglia:

This letter provides the proposed resolution for the single issue of ARSAP Topic Paper Set 4: "Essential Equipment Performance." Combustion Engineering plans to adopt, in the development of the System 80+™ design, the resolution to this issue. We request, therefore, your early review.

If you have any questions or comments, please call me or Mr. S. E. Ritterbusch of my staff at (203) 285-5206.

Very truly yours,

COMBUSTION ENGINEERING, INC.

A. E. Scherer
Director
Nuclear Licensing

AES:dmb

Attachment: As Stated

cc: Mr. Frank Ross (DOE-Germantown)
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ARSAP SEVERE ACCIDENT ISSUE TOPIC PAPER

4.1 ESSENTIAL EQUIPMENT PERFORMANCE

Issue Definition

The Nuclear Regulatory Commission's (NRC's) Severe Accident Policy Statement[1] addresses means of demonstrating that a new design for a nuclear power plant is acceptable for severe accident concerns. In particular, the NRC Staff is to review the design to determine "acceptability using an approach that stresses deterministic engineering analysis and judgment complemented by PRA." One aspect of that review is the assurance that essential equipment will be capable of performing its safety functions, given the harsh environmental conditions associated with severe accidents.

This paper deals with the issue of establishing a process to ensure the capability of the essential equipment in an advanced pressurized water reactor (PWR) to perform its safety functions during a severe accident. In this regard, the following are applicable:

- "Essential equipment" is the minimum set of equipment necessary to implement the intended design capability for mitigation and management of a severe accident, leading to recovery and the establishment of a safe stable state, and for monitoring of the facility response to a severe accident.

- "Ensuring the capability" involves assuring, either by deterministic engineering analysis and judgment or by physical demonstration, that the subject equipment can survive a severe accident and perform acceptably, despite the projected severe accident environment(s).

- "Severe accident environment(s)" of concern are those that result from risk-significant severe accident sequences which are outside the plant design basis and entail core damage; these environments include the effects of high temperature, pressure, and humidity; hydrogen combustion; and high radiation level and aerosol loadings.

- The "advanced" PWRs currently being reviewed by the NRC are evolutionary designs, based on current generation light water reactors, modified to comply with the requirements of the NRC's Severe Accident Policy Statement and the Electric Power Research Institute (EPRI) Requirements Document.[2] EPRI's document encompasses conclusions from the cumulative industry experience with light water reactor (LWR) technology.

- Because it is not subjected to severe accident environment(s) in performing its prevention function, equipment necessary for prevention of a severe accident is not addressed as essential equipment, unless the same equipment also performs a function in mitigating, managing, or monitoring the accident.

ARSAP Topic Papers 6.1 and 6.2 will define the potential safe stable states and the approaches taken for accident management.

Much of the equipment involved is required by existing regulations (10CFR50.49 and General Design Criteria 4 of Appendix A[3]) to be qualified to the environmental envelope defined by the most severe design basis accidents (including large-break LOCA conditions evaluated in accordance with NUREG-0588[4]). In many ways, the environments for qualification and from a severe accident perspective are similar; thus, the qualified equipment is typically capable of surviving and performing in a severe accident environment. For essential equipment, the determination of severe accident survivability will be based on the design basis qualification experience considering:

- The significant phenomena unique to severe accident conditions and their associated containment response

- The environmental conditions to which the equipment has been qualified, as distinct from the severe accident environments

- The survivability criteria for equipment exposed to conditions more severe than those to which it has been qualified and the logic and rationale for such criteria

- The potential for improving the survivability (e.g., by relocating, shielding, or replacing) of equipment that can not be shown as likely to survive the applicable severe accident environment(s).

In summary, ensuring the capability of essential equipment to perform its safety functions during severe accidents involves: (a) identifying the equipment essential to mitigate, manage, and monitor the severe accident; (b) identifying representative degraded core environment(s) to which the equipment may be exposed; (c) reviewing the designs of the equipment for survivability; (d) determining whether the essential equipment can survive the identified adverse environment(s) by using best-estimate techniques based on existing information; and (e) identifying a means for resolving uncertainties that may result from equipment survivability evaluations.

Historical Perspective

The Industry Degraded Core Rulemaking Program (IDCOR) examined 28 pieces of equipment from four reference plants to determine whether the equipment could perform its safety functions when subjected to severe accident environments.[5] Most of the selected equipment contained components that were sensitive to the severe accident environments. The conclusion of the survivability evaluation conducted by IDCOR was that all equipment could withstand the effects of most degraded core accident environments. Only extended station blackout accident sequences in which no equipment was operational at any time resulted in environments so harsh that equipment might not survive; timely recovery or delayed and controlled releases were projected in these cases. The overall IDCOR conclusion was that the installed equipment would perform acceptably in a severe accident environment for the reference plants.

The limiting environmental parameter in the IDCOR evaluations was typically temperature, including the effects of temperature due to hydrogen combustion. Other parameters were also addressed, however. For example, aerosols and particulates were assessed qualitatively by IDCOR (see Reference 5) in Task 17 for their effect on equipment survivability. Most equipment that IDCOR evaluated for survivability performed its function prior to vessel failure and hence prior to most aerosol generation. The remaining pieces of equipment that were required to survive after vessel failure were protected from aerosol depositions by enclosures, seals, and the effects of relatively higher temperatures that limit the deposition of fission product aerosols in critical locations.

Radiation affords another example of an environmental parameter found not to be limiting. In lieu of performing detailed calculations to determine the localized radiation doses, IDCOR (see Reference 5) used estimated doses. These doses were based on the design basis accident release extended to account for the potentially greater release of particulate fission products and solid material during degraded core events, but reduced to account for the shorter time period during which the equipment was needed. The resulting integrated dose to equipment was less than for the design basis accident and, therefore, the design basis qualification demonstrated radiation survivability for the essential equipment.

The NRC Staff did not prepare a position paper on this issue, but included the demonstration of equipment survivability as an item to be addressed in their review of the IDCOR individual plant evaluation methodology.[6] Utilities were to search for and address potential environmental vulnerabilities for equipment that is needed in a severe accident, with particular emphasis on the identification of potential risk increases due to "severe-accident-environment-created failure modes." The Staff thus did not invoke existing equipment qualification requirements, but neither did they define separate criteria or methods.

Technical Approach to Resolve the Issue for Advanced PWRs

The technical approach to resolve the issue of essential equipment survivability for the advanced PWR employs the following steps to provide a best-estimate methodology appropriate for severe accident evaluation:

1. Identify and list the equipment necessary to mitigate, manage, and monitor severe accidents, based on its role in either significant accident sequences in the PRA or recovery (accident management).

2. Establish the severe accident environmental conditions for which the identified equipment will be evaluated over the specific duration for which the equipment is required to function.

3. Review the designs for the identified equipment and its installation to ensure that the equipment is engineered for survivability.

4. Define best-estimate methodology, procedures, and acceptance criteria for a survivability evaluation of the identified equipment; base the methodology on the approach demonstrated by IDCOR for technical evaluation of existing information on equipment capability, on selection of representative equipment for enveloping evaluations, and on the planned equipment qualification program for the subject advanced PWR; complete the methodology by documenting the basis for a survivability conclusion for each piece of essential equipment on the list.

5. Provide means to resolve any areas of uncertainty in the equipment survivability that may arise either during design review (3 above)

or when the enveloping evaluations are performed (4 above); physical survivability demonstrations or design modifications will be required in such instances to assure that the equipment can perform its safety function.

Each of these five actions is discussed in detail below.

Identify and List Essential Equipment

The determination of equipment that is necessary to mitigate, manage, or monitor severe accidents begins with the probabilistic risk assessment (PRA) for the advanced PWR and the dominant severe accident sequences identified with it. A set of dominant severe accident sequences will be identified as necessary to characterize the risks that are significant in the best-estimate analyses that are required to demonstrate compliance with the radiological release goal defined in the EPRI Requirements Document (see Reference 2). While the PRA affords the principal source for this significant sequence set, related references such as NUREG-1150[7] and studies for similar plants will also be considered.

Given this set of significant sequences, the important systems in them are those that perform safety functions important to minimizing public risk. Such functions may be significant in maintaining core integrity (e.g., reactor shutdown and core inventory makeup) or in determining containment performance (e.g., containment heat removal and combustible gas control). Systems whose failure interrupts these functions and systems that maintain or recover those functions are the important systems for the identified set of accident sequences. Similarly, the specific equipment within these systems that governs failure or success of the functions is the essential equipment; monitoring equipment necessary to determine the status of the functions and to promote recovery of interrupted functions, within the inherent capability of the design for mitigation of the accident consequences, is also essential.

The list of essential equipment developed through the preceding steps will be supplemented to include any additional equipment included in the outlines being developed to document recovery actions for accident management (to be addressed in ARSAP Topic Set 6). The essential equipment list will be submitted to the NRC with the PRA supporting certification of the design for an advanced PWR.

Determine Environmental Conditions

The environmental conditions to which the selected equipment should be evaluated will be dependent upon the proposed equipment location inside containment, the time at which the equipment needs to perform its function, and a specific severe accident sequence. The risk-significant sequences will be analyzed using best-estimate models to determine these area- and time-dependent environmental parameters: temperature, pressure, hydrogen burn temperature and number of burns, aerosol loading, humidity, superheated steam jetting effects (if any), and level of radioactivity.

For example, the MAAP code will be used to determine temperature, pressure, and the number and duration of hydrogen burns for the identified sequences at the time and location for each piece of equipment to be evaluated. This involves running the MAAP code for each sequence and developing time-dependent temperature and pressure curves for representative locations inside containment, including the reactor cavity, the lower compartment, the upper containment, and the primary systems. The key times for core uncovery, vessel failure, and containment failure will be identified. The sequence specific results will be consolidated into curves representing bounding envelopes of pressure and temperature for each of the compartments for those sequences involving either containment failure or no containment failure. This will allow the reduction of the voluminous MAAP data to a more manageable level. The distinction between the two bounding envelopes recognizes the significant differences in containment conditions between the two types of sequences.

The MAAP code will also be used to identify the number, location, and duration of hydrogen burns that may occur for the selected sequences in containment. From this information, calculations will be made that approximate local temperature increases due to hydrogen burns on key equipment. These spikes will be added to the transient envelopes at the times of significant hydrogen combustion.

Since all degraded core sequences include the release of coolant to the containment, the use of 100% relative humidity is acceptable as an enveloping assumption, applicable for all accident sequences.

Similarly MAAP code analyses will be used to establish best-estimate aerosol and radiation environments for in-containment locations where equipment and instrumentation could be subject to adverse effects of aerosols (such as plugging of small instrument lines or localized radiation accumulation) or total radiation doses in excess of design basis qualification values.

The proposed best-estimate analyses of the risk significant sequences will establish environmental envelopes for all relevant parameters sufficient to support the evaluation of survivability for listed equipment. Bounding envelopes (and hence more conservative analyses) may be employed by the designer to facilitate the analysis; however, a best-estimate evaluation, as proposed, is appropriate and sufficient for severe accident evaluation of survivability. The environmental conditions will be submitted with the equipment list and the PRA supporting a design certification application.

Review Designs of Listed Equipment for Survivability

When the essential equipment and the severe accident environments have been identified, the equipment design and installation (or specifications governing future vendor designs) will be reviewed to assure that the equipment has been engineered appropriately for survivability. This review will focus on the suitability of materials, the availability of design basis qualification experience for selected equipment, and the need for relocation or sheltering. The IDCOR conclusions regarding more vulnerable equipment (see Reference 5) and the equipment survival experience from Three Mile Island[8,9] will be considered during these reviews. The reviews are expected to detect vulnerabilities, if there are any, and to provide substantial assurance of the adequacy of the submitted design. Detected vulnerabilities will be addressed as discussed in step five of the resolution approach.

<u>Define Methodology for Evaluation of Equipment Survivability</u>

To demonstrate that the identified equipment is capable of performing its required functions during a severe accident, an evaluation will be performed of the survivability of the equipment in the defined environment. The approach will begin with the selection of representative equipment for enveloping evaluations of survivability. For this equipment, a technical evaluation of survivability will be performed, using best-estimate survivability criteria with emphasis on any potentially significant differences between severe accident and design basis qualification environments for the equipment. Applicable prior survivability evaluations will be referenced. Finally, to ensure complete coverage by the enveloping evaluations, a verification step will be performed to provide documented confirmation of the survivability of each piece of listed equipment.

Several hundred pieces of essential equipment are anticipated for each advanced PWR. To focus the survivability evaluation, the following selection criteria will be applied for the advanced PWR to identify representative equipment for enveloping evaluations:

1. Equipment of representative types, e.g., a pressure transmitter, a cable, a valve, that the designers can use to draw conclusions about the survivability of other pieces of equipment will be chosen.

2. Equipment that faces severe environmental challenge during a degraded core accident and that is judged to be sensitive to a degraded core environment will be selected.

3. Equipment that is required for several sequences in the significant sequence set will be preferred for selection.

The environmental conditions for which the selected equipment is to be evaluated will be specific for the plant zone and may be specific to a particular sequence. Furthermore, the evaluation will extend for the type of accidents and for the time duration during which each piece of equipment is required to function. Considering these factors, additional equipment will be selected if necessary to assure that the enveloping evaluations address survivability for all essential equipment.

The survivability evaluations for the selected equipment will address the necessary equipment performance and the appropriate degree of assurance for survivability. The approach applies to a direct comparison with existing qualification data or a prior survivability evaluation. The survivability criteria are focused on the equipment function. The function of the equipment for mitigating, managing, or monitoring the severe accident will be defined in sufficient detail that a determination can be made as to whether the equipment will perform as intended, for the required duration, for the specific accident sequence, and for the limiting environment(s) to which the equipment will be exposed. If the equipment maintains functional operability in the accident sequence for the duration required, then it will have survived the degraded core accident environment.

Thus, the acceptance criteria does not require equipment performance to meet design basis specifications such as allowable instrument accuracy or valve opening/closing times. Instead, to the extent that a degraded core accident environment exceeds the qualification environment, the potential performance degradation must be estimated and compared with the tolerance for degradation in the severe accident sequence for the required functions in order to determine functional operability. For example, a transmitter may be qualified to operate with +/-2% accuracy in design basis accidents. If it is exposed to a more severe environment during degraded core accidents, the accuracy may be estimated to decrease to +/-3%. If such a change does not impact the primary function of the transmitter to provide signals for mitigating the accident or monitoring the plant status, it will be considered acceptable.

To perform the survivability evaluations, the limiting severe accident environment(s) for each piece of equipment will be compared with the design basis qualification environmental data for that piece of equipment. Each advanced PWR design will generate design basis accident qualification environmental data for safety-related electrical equipment, as this is required by NUREG-0588 (see Reference 4), IE Bulletin 79-01B,[10] and 10CFR Part 50, Section 50.49 (see Reference 3). Further, recent regulatory practice has required qualification data for mechanical equipment, based on General Design Criteria 4 (see Reference 3). Qualification data packages will be prepared for each piece of equipment, based on the applicable environmental requirements whenever the certified design is applied and specific vendor equipment is selected. Listed equipment, if any, that is not required to be qualified (i.e. equipment that is not safety related) is likely to be similar to equipment that has been addressed for this design or for a similar facility for a comparable environmental envelope. These packages, when prepared, will identify sensitive components for the equipment function and document the qualification basis in detail. Seismic and aging considerations will also be addressed by qualification.

If a comparison with the qualification data for the applicable duration indicates that the limiting degraded core accident environment is less severe than the qualification environment or the environmental design criteria, it can be concluded directly that the equipment will survive the severe accident environment. If, however, the limiting severe accident environment is more severe than the qualification or design environment, two alternative courses of action will be pursued in an attempt to complete a survivability demonstration based on existing information: a literature review will be conducted to determine if any prior survivability evaluations have been performed for the specific piece of equipment and analyses will be performed to evaluate the effects of the difference in environments on the equipment performance.

While the examples that follow emphasize temperature as the environmental parameter found to be limiting in most instances by IDCOR, all environmental parameters such as radiation, pressure, humidity, and aerosols will be addressed in the survivability evaluations for the advanced PWR.

Analyses of temperature effects take two forms. First, an analysis of the thermal response of the equipment is conducted to determine the equipment response to the limiting environmental parameters, including hydrogen burn, using a general purpose thermal model such as HEATING-5.[11] The calculated maximum temperature response at the external equipment surface is then compared with an existing design basis qualification temperature. If the equipment temperature in the transient does not exceed the qualification or prior evaluation values, then the equipment has been shown to survive the degraded core accident environment. Second, if the first analysis does not demonstrate operability, the calculated differences between the severe accident and the qualification basis equipment temperature will be evaluated to predict incremental damage to sensitive materials or components (e.g., by using Arrhenius data). A brief excursion to higher temperatures, particularly if partially offset by less total time at high temperature, can be shown acceptable with such techniques.

Upon completion of the survivability evaluations for the selected pieces of equipment, a review will be performed for each piece of equipment on the essential equipment list to verify that its survivability is demonstrated by the evaluations performed and to document the basis for the conclusion.

The advanced PWR applicant will submit the methods, procedures, and acceptance criteria for survivability evaluations with the design to the NRC at the time of the PRA submittal. The evaluations will be performed and documented whenever the design is applied and specific vendor equipment is selected.

Provide Means to Resolve Uncertainties in Survivability

If concerns regarding the design of equipment for survivability are identified in step 3 above or if the equipment cannot be shown to survive by using the techniques listed above in step 4, then physical demonstrations of survivability under degraded core environments or design modification to ensure or to obviate the need for survivability will be pursued. The range of modifications considered can include replacement, shielding, and relocation of affected equipment.

The analytical uncertainties in the defined approach for addressing equipment survivability result primarily from the calculation of the degraded core environments used for the evaluation. ARSAP Topic Paper 5.2 will address these uncertainties and the sensitivity studies that will be conducted. In general, survivability evaluations will be based on the best-estimate analyses of phenomena and the progression of the dominant accident sequences. If the sensitivity studies identify alternative, more severe environments that are likely to be significant to the risk of operating the facility, they will be included in the qualification envelopes or separately evaluated to determine whether additional evaluations, demonstrations, or modifications will be required for specific pieces of affected equipment.

Summary and Conclusion

In summary, to ensure the capability of essential equipment to perform its safety functions during a severe accident, the resolution approach will: (a) identify and list the equipment essential to mitigate, manage, and monitor the severe accident; (b) determine representative degraded core environment(s) to which the equipment may be exposed; (c) review the designs for essential equipment and its installation to ensure that the equipment is engineered for survivability in the severe accident environments; (d) define methodology to evaluate and to demonstrate the survivability of the essential equipment in the identified adverse environment(s); and (e) provide means to resolve any areas of uncertainty in survivability that may be identified through design review or subsequent survivability evaluations.

The defined resolution approach is an appropriate one to assure that essential equipment will be capable of performing its safety functions, given the harsh environmental conditions associated with severe accidents.

References

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4. USNRC, Interim Staff Position on Environmental Qualification of Safety-Related Electrical Equipment, For Comment, NUREG-0588, January 1980, and Rev. 1. July 1981.

5. Industry Degraded Core Rulemaking Program (IDCOR), Equipment Survivability in a Degraded Core Environment, IDCOR Technical Report 17, August 1984.

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7. USNRC, Reactor Risk Reference Document, Draft for Comment, NUREG-1150, February 1987.

8. S. T. Soberano, "Final Report on In Situ Testing of Electrical Components and Devices at TMI-2," JEND-040, EG&G Idaho, June 1984.

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