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# PERSPECTIVES ON PLANT VULNERABILITIES & OTHER PLANT AND CONTAINMENT IMPROVEMENTS

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The primary goal of the Individual Plant Examination (IPE) Program was for licensees to identify plant-unique vulnerabilities and actions to address these vulnerabilities. A review of these vulnerabilities and plant improvements that were identified in the IPEs was performed as part of the IPE Insights Program sponsored by the U.S. Nuclear Regulatory Commission (NRC). The main purpose of this effort was to characterize the identified vulnerabilities and the impact of suggested plant improvements.

No specific definition for "vulnerability" was provided in NRC Generic Letter 88-20[1] or in the subsequent NRC IPE submittal guidance documented in NUREG-1335[2]. Thus licensees were left to use their own definitions. Only 20% of the plants explicitly stated that they had vulnerabilities. However, most licensees identified other plant improvements to address issues not explicitly classified as vulnerabilities, but pertaining to areas in which overall plant safety could potentially be increased.

The various definitions of "vulnerability" used by the licensees, explicitly identified vulnerabilities, proposed plant improvements to address these vulnerabilities, and other plant improvements are summarized and discussed.

## Plant Vulnerabilities

One of the reporting guidelines presented in the IPE submittal guidance document, NUREG-1335, is that each IPE present "a list of any vulnerabilities identified by the review process, a concise discussion of the criteria used by the utility to define vulnerabilities, and the fundamental causes of each vulnerability." As discussed below, most of the licensees clearly identified their criteria for identifying vulnerabilities. However, only 20% of the licensees *clearly stated they had vulnerabilities* and identified potential improvements in equipment, procedures, or training programs to address these vulnerabilities.

## Vulnerability Definitions

The guidance in NUREG-1335 pertaining to the identification of vulnerabilities leaves the licensees to use their own definitions of the term "vulnerability." The definitions for vulnerability used in many of the IPE submittals were based on one of two sets of quantitative criteria: (1) the criteria provided in the NUMARC Severe Accident Issue Closure Guidelines Document 91-04[3], and (2) NRC's Safety Goal Policy Statement defining a core damage frequency objective of 1E-4/ry and a large release objective of 1E-6/ry. A third criteria utilized in some IPE submittals was based on using importance measures or the results of sensitivity studies to determine which components or systems were the most vital to the plant. Several variations and combinations of these criteria were identified in the submittals and are discussed below. No specific definition of vulnerability could be identified for approximately 29% of the plants. However, for a significant number of these plants, some sort of criteria was utilized to identify areas for improving the plant safety. The criteria used to identify vulnerabilities, as well as to identify other areas warranting plant improvements, are discussed in subsequent paragraphs.

The most commonly applied quantitative criteria for identifying plant vulnerabilities are contained in the NUMARC guidelines. Twenty-three percent of the plants reported using some variation of the NUMARC guidelines for identifying what they explicitly called vulnerabilities. The NUMARC guidelines constitute a graded review process to identify areas warranting additional scrutiny. Accident sequences are grouped into functional groupings suggested by the guidelines, and the quantitative results are compared against four criteria levels consisting of values for core damage frequencies (CDFs) or with percent contribution values to the total plant CDF that decrease at each level. A parallel set of criteria levels exist in the NUMARC guidelines for specifically addressing containment bypass accident sequences. Some licensees defined a vulnerability as a functional sequence exceeding 1E-4/ry CDF or contributing greater than 50% to the total plant CDF; i.e., the top evaluation criteria level in the NUMARC guidelines. Additionally, some licensees defined a containment bypass vulnerability as any such functional sequence of this type with a CDF greater than the NUMARC top criteria of 1E-5/ry or contributing greater than 20% to the total CDF. Some licensees, when using the NUMARC guidelines, identified vulnerabilities associated with sequences meeting any of the graded NUMARC criteria (not just the top criteria). In many of these cases, resolution of a vulnerability meeting the lower tier NUMARC criteria is addressed simply by incorporating the issue into future accident management strategies. Other licensees modified the NUMARC top criteria definition of vulnerability slightly. When this was done, the modification was usually that the percent contribution forms of the criteria were not used on the basis that a large percentage of a small absolute frequency should not be used to identify a vulnerability. Yet other licensees used the NUMARC guidelines in combination with additional criteria for identifying vulnerabilities. For example, some licensees added a Level 2 criteria related to the frequency of a source term bin exceeding 1E-5/ry. One plant, Waterford, explicitly added criteria related to single failures, common cause failures, support system failures, and operator errors that had a significant impact on the core damage frequency in their vulnerability screening. The vulnerability screening criteria for WNP-2 also required the total CDF be within the NRC safety goal of 1E-4/ry and included a search for sequences that are outliers when compared to similar plants due to a plant specific feature.

The core damage frequency and large release objectives from the NRC Safety Goal Policy Statement were used by 22% of the licensees to define "vulnerability." These approaches are nearly equivalent to some of the NUMARC criteria in that they focus on just the absolute frequencies for CDF (but in this case the total plant CDF instead of an accident grouping frequency) and a large significant release. Any sequences contributing significantly to exceeding either or both criteria were examined by licensees to determine which design or operational aspects caused such a vulnerability, and resolutions were investigated to lessen the potential for such a vulnerability. Some plants chose to use modified safety goal frequencies in their definitions (e.g. 5E-4/ry for CDF and 5E-5/ry for an early release frequency). One plant (Oyster Creek) applied the criteria at the systemic sequence level instead of for the total plant CDF. Another plant (Palisades) changed the large release criteria from 1E-6/ry to 10% of the plant CDF. Some licensees that used the NRC Safety Goals in their vulnerability screening also used additional criteria. The most common criteria was a comparison to similar plants for the purpose of identifying any new or unusual core damage or containment failure mechanisms specific to their plant. Others also included a criteria that required that any systems, components, or operator actions that significantly impact the core damage frequency be listed as vulnerabilities. One plant (Davis-Besse) considered that a vulnerability might exist if the frequency of core damage is sensitive to a highly uncertain aspect of the plant response but indicated that further evaluation to reduce the uncertainty would be a more appropriate response than a change to the plant. Finally, several plants added Level 2 vulnerability criteria that addressed the performance of containment mitigating systems and the containment itself during severe accidents.

For 26% of the plants, the percent contribution to CDF was used as the base criteria for screening vulnerabilities. Some plants also included the percent contribution to containment failure in their vulnerability screening. The licensees usually relied on the relative contribution of systemic sequences, plant damage states, containment failure modes, and release categories to identify the important contributors to the plant risk. These important contributors were equated to areas where vulnerabilities may exist. Importance measures and sensitivity studies were also generally utilized to identify the fundamental causes or plant features contributing to these potential vulnerabilities. Generally, quantitative thresholds, as exist in the NUMARC guidelines, were not established for screening vulnerabilities based on the percent contribution to CDF or containment failure. Instead, the licensees applied qualitative thresholds using terms such as "significant" or "disproportionately high." Some licensees indicated that a plant feature would only be considered a vulnerability if it was a proportionately higher contributor or outlier when compared to similar plants. Thus, a 50% contributor to CDF might not be a vulnerability if it has a similar contribution at similar plants. One licensee (Turkey Point 3/4) indicated that vulnerabilities would only be considered for issues where they had the highest confidence in the results of their IPE.

For the remaining 29% of the plants, no vulnerability screening criteria could be explicitly identified. However, all of these plants used their IPE results to help identify other plant improvements. Fifteen percent used the NUMARC criteria to help identify areas for plant improvements, but did not explicitly state that the NUMARC criteria were being used to identify vulnerabilities. Fourteen percent appeared to use the percent contribution to CDF and sensitivity studies to help identify and evaluate the impact of other plant improvements.

**Identified Vulnerabilities and Associated Plant Improvements**

Using the various definitions of vulnerability discussed above, about 20% of the plants explicitly identified vulnerabilities in their IPE submittals. The vulnerabilities for Boiling Water Reactors (BWRs), which are discussed first in this section, exhibited no commonality based on plant type or initiator, nor did the vulnerabilities focus on a particular plant design aspect (e.g., support systems). Pressurized Water Reactor (PWR) vulnerabilities are discussed next. The same vulnerability issues, pertaining to particular plant design aspects, were identified for several PWR plants. Other PWR vulnerabilities tended to be plant-unique.

Only four BWR plants (11% of all BWRs) identified vulnerabilities. Millstone 1 identified both hardware and operational/procedure issues as vulnerabilities. These involved failure of the water supplies to the isolation condensers, failure of the operator to initiate the isolation condensers in time to prevent safety relief valves from lifting and subsequently sticking open and requiring coolant makeup, failure of the operator to restore or maintain the reactor vessel level in some accident scenarios, and drywell steel liner melt-through (a generic Mark I containment issue). The only resolution to the vulnerabilities identified in the IPE involved procurement of a portable diesel pump and corresponding procedural changes for it's use in supplying water to the isolation condenser. Fitzpatrick identified a vulnerability in the plant electrical configuration that results in loss of three Residual Heat Removal (RHR) loops (either directly or through the RHR service water system) when either one of two 4.16 kV buses is lost. Fitzpatrick was considering procedure modifications and training for using firewater as a backup to RHR service water and installation of a cross-tie between RHR service water trains. Hope Creek identified a ventilation system vulnerability that would result in loss of essential electrical switchgear. During the IPE analysis process, the utility developed a recovery procedure to address this vulnerability by aligning alternate means of cooling. Credit for this recovery procedure was taken in the final IPE results. Susquehanna identified several vulnerabilities in various areas some of which could be considered generic to most BWRs. The first involved the need for manual actions to bypass the High

Pressure Coolant Injection (HPCI) pump suction transfer and to bypass the high exhaust pressure trips for the HPCI and Reactor Core Isolation Cooling (RCIC) systems. To address this vulnerability, consideration was being given to revising the control strategy for HPCI suction transfer; in addition, the HPCI/RCIC backpressure trip setpoints were raised. Another vulnerability identified at Susquehanna related to the need for manual flow control to avoid severe power excursions upon failure of HPCI and condensate during an anticipated transient without scram (ATWS) scenario. Revision of the control logic to allow immediate operator control of injection from the Low Pressure Coolant Injection (LPCI) and Core Spray (CS) systems is being reviewed; also, a bypass switch on the isolation valve permissives for both systems was installed. Yet another identified vulnerability at Susquehanna involves a potential waterhammer when the Condensate Transfer System keepfull function is lost after a loss of offsite power or station blackout; a potential resolution under review is to provide an alternate, independent power supply for the condensate transfer pumps.

Among the 17 PWRs (23% of all PWRs) that identified vulnerabilities, identification of the same vulnerability issues was evident among some of these plants. For instance, concerns related to loss of coolant accidents (LOCAs) caused by failure of reactor coolant pump seals, particularly when induced by loss of seal cooling, were identified by Calvert Cliffs, Turkey Point, Fort Calhoun, D.C. Cook, Summer, and Beaver Valley. In these cases, resolution of the issue involved implementation or consideration of alternate cooling capabilities, inclusion in severe accident management guidelines, or consideration of new pump seal materials. Loss of critical switchgear ventilation equipment concerns were raised as vulnerabilities at Calvert Cliffs and Beaver Valley with implementation or consideration of alternate cooling capabilities as the resolution. Auxiliary Feedwater System turbine-driven pump reliability issues were identified at Calvert Cliffs, Summer, Millstone 3, and Kewaunee with corresponding equipment modifications or enhanced operator training identified to resolve these issues. Surry, Kewaunee, and Salem identified significant internal flooding issues as vulnerabilities. These flooding issues were addressed by incorporation of a number of procedural and hardware improvements. Interfacing system LOCA issues were identified at Salem, Kewaunee, Millstone 3, and Beaver Valley with corresponding procedure improvements made or under consideration to address improved valve testing or LOCA identification and isolation. The need to enhance depressurization guidance for the operators during steam generator tube ruptures was identified at Beaver Valley and Calvert Cliffs. Switchover from the injection phase to the recirculation phase of coolant injection was identified as a vulnerability at Summer, Haddam Neck, and Millstone 3. Procedural improvements to give operators more time to perform the switchover and improved operator training were being considered.

The other vulnerabilities among the PWRs tended to be plant-unique and involved such things as inadequate surveillance of specific valves, effects of losses of specific electrical buses, compressed air system failures, battery depletion and the inability to cross-tie buses during loss of power conditions, among other examples. Two IPEs also identified external event related vulnerabilities. Millstone 3 identified a seismic-induced station blackout scenario that is dominated by diesel generator oil cooler anchor bolt failure (subsequently replaced) and Turkey Point was considering revising the procedure for preparing the plant to weather a hurricane.

In summary, 20% of the plants identified vulnerabilities, including 11% of the BWRs and 23% of the PWRs. The identified vulnerabilities at the BWRs showed no commonality but for at least one plant, the identified vulnerabilities could be generic to many BWRs. For the PWR plants, there were some common vulnerabilities identified that focused on particular design aspects. It should be noted that while only a fraction of the submittals actually identified vulnerabilities using their respective definitions, nearly all the plants went on to identify other areas warranting investigation for additional improvements. These other improvements are discussed in the subsequent sections.

## Other Plant Improvements

As previously discussed, the major goal of the IPE process was to identify any unique plant vulnerabilities and make any improvements necessary to address these vulnerabilities. It is clear from the submittals, however, that most licensees went beyond this limited intent and identified other improvements (over 500 were identified by the plants) worthy of consideration or implementation, even though no specifically associated vulnerabilities were identified.

Recognizing this fact, a logical question to ask is "what are these other improvements and what are the impacts of the changes that have been implemented or the potential impacts of those improvements being considered for implementation?" To answer this question, the IPE submittals were reviewed to identify and categorize plant improvements explicitly mentioned in the submittals. Based on the submittal documentation, the plant improvements were categorized, to the extent possible, as to two types of information: (1) whether the improvements were already credited in the submittal and implemented, and so are already reflected in the results and insights previously summarized in this paper, and (2) whether the improvement is operational, maintenance-related, or involves design changes. Additionally, the reduction in core damage frequency estimated by the licensee as a result of implementing the improvement was also noted, if available.

The potentially generic (versus plant-unique) nature of the improvements means that they have implications and potential significance for all the plants. For instance, some improvements may be worthy of industry-wide consideration; others may be important to a select group of plants, etc. Hence, as part of the improvement assessments discussed later, the extent to which similar improvements were identified at numerous plants was also identified.

The following discussions summarize the other plant improvements documented in the IPE submittals. In many cases, a few years have past since the submittal date. Hence, some of the planned improvements or those under evaluation may have been implemented (or dropped from consideration) as of the date of this paper.

## Assessment of Other Plant Improvements In BWRs

Nearly all the BWR plants made or are evaluating changes to improve AC reliability, improve DC reliability and add to battery operable life under an extended blackout, as well as address other system weaknesses. While the area of improvement was the same, the specific improvements varied considerably. This suggests that there is no *one* specific fix that is right for all plants to lessen the core damage potential due to loss of power. For instance, AC system changes took the form of added or replaced diesel generators, redundant offsite power capabilities and improved recovery potential, and better proceduralized bus cross-tie capabilities. Unique to the BWR 5s and 6s in this area, but not explicitly identified for every BWR 5 or 6, were identified improvements to add flexibility in the use of the High Pressure Core Spray (HPCS) Division III diesel for operating Division I and II loads. A few plants identified specific diesel cooling improvements. One plant identified a service water valve change while a few others indicated that the use of firewater as a backup to diesel cooling was planned or being evaluated. All of these changes were clearly attempting to lessen the potential for AC power loss and so were generally preventive in nature. Likewise, DC system improvements took many different forms and included alternate battery charging capabilities, battery upgrades, additional load shedding, and improving cross-tie capabilities. These changes generally addressed the ability to maintain at least one train of DC power during loss of AC conditions, which is necessary to operate AC-independent systems and to power instrumentation/indications for providing plant status information to the operator.

Other changes were identified in the IPE submittals which also lessen the vulnerability to station blackout but reduce the core damage potential from other types of accidents as well. Generally, these all provide more reliable core cooling and/or improve the successful use of the AC-independent core cooling systems during prolonged operation. For instance, various isolation condenser improvements were identified for most of the earlier BWR designs. These improvements included better valve reliability, adding procedural guidance for isolation condenser use during an extended blackout, and providing prolonged firewater capability for the shell-side of the isolation condenser during a long station blackout condition. Note that the focus of these improvements was on the cooling system common to all early vintage BWRs that is independent of AC power for operation.

Similarly, improvement considerations were indicated at some plants to ensure better overall reliability and availability of the AC-independent coolant injection systems in the BWR 3s and 4s (HPCI and RCIC). For example, some plants indicated improvements to ensure that these systems were, indeed, AC-independent (e.g., changing a RCIC room exhaust fan from AC-powered to DC-powered). Yet other plants were evaluating further procedural guidance regarding emergency depressurization so that the operator will be less likely to inadvertently lose HPCI and RCIC due to low primary system pressure. A few plants were evaluating improvements so that the operators would be better prepared to replenish the Condensate Storage Tank (CST), the preferred source of water for HPCI and RCIC, if necessary. Some plants also identified improvements regarding the ability to use firewater as a backup to HPCI and RCIC for core injection. All of these improvements address more reliable coolant injection capability and as such, provide better prevention of core damage for a variety of accident classes. While these types of changes were identified in a number of the BWR 3 and 4 design submittals, many were under evaluation and so the extent that these improvements have been implemented can not be determined by simply examining the IPE submittals.

The BWR 5 and 6 designs also identified improvements targeted at the one AC-independent core cooling system in their design; RCIC. In at least two cases, implementation of a bypass of the RCIC high steam tunnel trips was identified as a useful change.

While not prevalent, ventilation improvements were indicated in some IPE submittals. This suggests that the sensitivity to the potential effects of loss of ventilation to rooms containing electrical switchgear, DC system equipment, and core cooling pump systems may be different among plants and is thus more of a plant-specific issue.

Only a few submittals specifically identified improvements for dealing with loss of RHR or ATWS-type scenarios. These involved ensuring the use of the CST for coolant injection pump suction whenever the suppression pool temperature is very high (to avoid loss of pump net positive suction head), automatic inhibiting of the Automatic Depressurization System (ADS) during an ATWS, and the use of an alternate boron injection capability. Such changes clearly are targeting different issues related to either loss of RHR or ATWS accidents. Procedural guidance to use the CST for pump suction improves the long-term operability of coolant injection systems even when the suppression pool temperature is above pump design basis limits. Automatically inhibiting ADS during an ATWS reduces the potential for failing to perform this action when the operator is attempting to respond to a variety of fast-acting symptoms during this class of accident. Use of an alternate boron injection capability is an attempt to further increase the probability of successful boron injection when it is required. These changes are also preventive in nature in that they are designed to reduce the potential for core damage.

As can be observed from the descriptions provided above, most BWR improvements can be classified as procedure/operation changes (approximately 40%), design/hardware changes (approximately 50%), or both. Few improvements appeared to be maintenance-related changes. Typically, the design or procedural changes indicated an element of revised training in order to properly implement the actual change. Approximately 50% of the BWR improvements were implemented, with about 20% implemented and credited in the IPEs, but many were planned or were under evaluation It should be noted that some of the identified improvements (18% of all the identified BWR improvements and 38% of the ones actually implemented) may have been initiated by other requirements (primarily the station blackout rule) while the remainder was initiated due to the IPE process.

Quantitative values for specific improvements were generally not explicitly reported in the BWR IPE submittals but for some implemented (and IPE credited) changes, specific estimates of reductions in CDFs were provided. Installation of a hardened vent brought about widely varying reductions in CDFs at five plants, ranging from "minor" to 15%. At River Bend, the addition of a portable diesel generator backup for station batteries, together with certain firewater modifications, accomplished an 87% decrease in CDF. AC power improvements that were quantitatively analyzed include adding a gas turbine generator (37% reduction in CDF) and establishing alternate offsite power sources at two different plants (17% and 50% reductions). Aligning a portable diesel generator to supply battery chargers during a station blackout was calculated to reduce the CDF at one plant by 31%. The use of firewater as a vessel injection source was also identified as a possible plant improvement and was evaluated at one plant to reduce the CDF by 13%. A change in the ADS logic to automatically inhibit depressurization during an ATWS was found to reduce the CDF at one plant by 23%. As for maintenance improvements, the addition of a procedure to test the HPCS suction line to the suppression pool was reported at one plant to reduce the CDF by 13%. Operational improvements at BWRs that were quantitatively evaluated included aligning LPCI or CS pumps to the CST (80% reduction in the CDF), load shedding on DC buses during a station blackout (13%), and removal of the ADS inhibit requirement during non-ATWS scenarios (19%). An exceptional CDF reduction of two orders of magnitude was calculated at Hope Creek, due to implementation of a switchgear ventilation recovery procedure. These quantitative impacts clearly indicate the extent to which safety has been improved by making improvements to the plants in response to the IPE requirements.

**Assessment of Other Plant Improvements In PWRs**

Station blackout and related power issues were addressed by improvements in all types of PWRs; i.e. all vendor plants. The AC system-related improvements took many forms indicating that no *one* single fix was the best for all PWRs. These improvements included the addition or replacement of diesels with emphasis on the addition of swing diesels among units. Many PWRs also highlighted the addition or upgrading of gas turbines to their plants, and cited improved cross-tie capabilities and bus loading changes. There also appeared to be an emphasis on AC equipment room cooling improvements. These included such changes as the addition of temperature alarms, more redundancy in the ventilation systems, and procedural improvements for dealing with loss of ventilation. These improvements generally focused on lessening the chance of a total loss of AC power and so were preventive in nature. Many of the PWR IPEs also cited DC system improvements as beneficial to their plants. These improvements took the form of

DC bus load shedding, battery upgrades, alternate battery charging features, and improved DC bus cross-tie capabilities. Higher DC system reliability and prolonged battery life provide a better ability to cope with a loss of AC power condition by providing power to continue to operate the AC-independent steam-driven Auxiliary Feedwater System (AFWS) pump train and by providing power to instrumentation and indications of plant status to the operator.

A prevalent PWR improvement area involved reactor coolant pump seal LOCAs and related loss of seal cooling issues. These were addressed by identified improvements in the B&W and Westinghouse plants; but notably were *not* identified among the CE plants. The reason for this, based solely on the submittals, is uncertain. These identified improvements typically dealt with alternate seal flow capability, sometimes even under loss of power conditions. The addition of high temperature seals was notably documented in a number of Westinghouse IPE submittals. Hence, dealing with this potential source of primary coolant loss during station blackout as well as during other loss of seal cooling scenarios was generally of importance to PWR plants.

AFWS improvements were identified for many PWRs and most commonly for the Westinghouse plants. These typically included additional backup water supplies such as the firewater system and redundant pump cooling capability. Other reliability and diversity improvements were identified in a few of the plants, including the ability to operate AFWS manually even under loss of DC power. These improvements address the ability to use the one AC-independent core cooling system in PWRs even during loss of DC power, thereby increasing the chances of preventing core damage due to loss of secondary cooling.

Other examples of PWR improvements include procedural and some design improvements for many of the PWRs, particularly the Westinghouse plants, to deal with internal flooding. Specific improvements varied, indicating the plant-specific nature of dealing with flooding issues. Across all the PWRs, there was a scattering of identified changes to deal with steam generator tube ruptures, interfacing system LOCAs, and other miscellaneous system weaknesses. In particular, better procedural guidance for dealing with steam generator tube ruptures and improved testing and valve status checking were cited for lessening the potential for interfacing system LOCAs.

As can be observed from the descriptions above, most PWR improvements can be classified as procedure/operation changes (approximately 50%), design/hardware changes (about 40%), or both. Few improvements appeared to be maintenance-related changes. Typically, the design or procedural changes indicated an element of revised training in order to properly implement the actual change. Forty-five percent of the PWR improvements were identified as implemented, with 30% implemented and credited in the IPEs, but many were planned or were under evaluation Most of the improvements were identified as a result of the IPE process with only a small percentage (12% of all planned or actually implemented improvements) associated with other requirements (primarily the station blackout rule).

Quantitative values for specific improvements were generally not explicitly reported in the PWR IPE submittals but for some implemented (and IPE credited) changes, specific estimates of reductions in CDFs were provided. The addition of one or more diesel generators at five different plants brought about calculated CDF reductions ranging from 21% to 43%. The addition of two gas turbine generators at two different plants resulted in calculated CDF reductions of 43% and 51%. Reactor coolant pump seal cooling improvements at three plants were calculated to reduce CDF by between 14% and 59%. The addition of high temperature seal materials for the reactor coolant pumps was calculated to reduce the CDF by between 2% and 20% by several plants. The addition of an AFWS pump was identified as potential plant improvements by two plants that resulted in CDF reductions of 7% and 24%. Operational improvements at PWRs included refilling the Reactor Water Storage Tank (83% reduction in the CDF), procedural changes to arrange for alternate cooling sources for charging pumps (25% reduction), and modify an emergency procedure to align the city water supply to the AFWS pumps upon failure of the CST supply (32% reduction). Maintenance improvements included staggering safety injection system pump testing (3% reduction in CDF) and revised maintenance practices on switchgear room ventilation system chillers (11% reduction). Even considering typical uncertainties of PRA results, reductions of this magnitude represent quantitatively important reductions in the potential for plant damage. The largest such reductions were not in any one single area; but instead involved improvements in the areas of internal flooding, loss of ventilation to AFWS, and reactor coolant pump seal cooling for particular plants.

## Summary

Using various definitions for "vulnerability," about 20% of the licensees explicitly identified vulnerabilities in the IPE submittals. Note that, while only a fraction of the submittals actually identified vulnerabilities, nearly all of the plants went on to identify other areas warranting investigation for potential improvements. The IPE program served as a catalyst for further improving the overall safety of nuclear power plants, as a result of numerous other improvements either implemented, planned, or under evaluation. This additional product of the IPE Program is a very important element in measuring the success of the IPE program. Meaningful and cost-effective equipment and procedural changes to the plants have been a benefit to the overall safety of the industry and may not have occurred without implementation of the IPE process, with its inherent, systematic analysis of plant safety.

The licensees of 11% of the BWRs explicitly stated that their plants had vulnerabilities. Although no common vulnerabilities were identified, some of the vulnerabilities could be considered generic to many BWRs. These vulnerabilities involved HPCI suction transfer, HPCI and RCIC high turbine exhaust pressure trips, low pressure injection system valve permissives and control logic, and potential waterhammer issues following a loss of offsite power.

Among the 23% of PWRs that identified vulnerabilities, certain vulnerability issues were common among more than one plant. These included concerns related to reactor coolant pump seal LOCAs, AFWS turbine-driven pump reliability issues, interfacing system LOCA issues, internal flooding issues, switchover from the coolant injection phase to the coolant recirculation phase, loss of critical switchgear ventilation equipment, and the need to enhance operator guidance for depressurization during steam generator tube ruptures. Other vulnerabilities among the PWRs tended to be plant-unique, involving such things as inadequate surveillance of specific valves, losses of specific electrical buses, compressed air system failures, battery depletion, and the inability to cross-tie buses during loss-of-power conditions, among others, some of which were quite unique.

As for other plant improvements not specifically associated with explicitly identified plant vulnerabilities, many were generic in nature with the most often-cited plant improvements for BWRs involving station blackout and the PWR improvements tending to address both loss of power and loss of reactor coolant pump seal cooling. Both types of plants often identified changes aimed at improving core cooling or injection reliability, particularly for those systems or portions thereof that can operate during loss of AC power. PWRs notably more often identified improvements to address internal flooding and interfacing system LOCAs, than did the BWRs. Other less-cited and plant-specific improvements were identified to address a number of other accident class issues at individual plants. Most improvements tended to be procedural or hardware-oriented (as opposed to maintenance-related) and a few appear to have quantifiably significant effects on the CDF for particular plants. Based on the number and variety of other plant improvements implemented, planned, or under evaluation at the time of the submittals, it is apparent that the level of awareness of the potential for severe accidents has increased at many of the nuclear utilities. The extent and specificity of the improvements shows an understanding of plant design and operational characteristics where specific improvements may be warranted.

## References

[1]"Individual Plant Examination for Severe Accident Vulnerabilities," Generic Letter 88-20, U.S. Nuclear Regulatory Commission, Washington, DC, November 23, 1988.

[2]"Individual Plant Examination: Submittal Guidance," NUREG-1335, U.S. Nuclear Regulatory Commission, Washington, DC, August, 1989.

[3]"Severe Accident Issue Closure Guidelines," NUMARC 91-04, January 1992.

[4]"Safety Goals for the Operations of Nuclear Power Plants: Policy Statement," Title 10 CFR, Federal Register, August 4, 1988.

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