NUCLEAR ENERGY INSTITUTE

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September 17, 2004

Mr. Luis A. Reyes
Executive Director for Operations
U.S. Nuclear Regulatory Commission
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Dear Mr. Reyes:

I want to thank you for attending and participating in the August 26, 2004 meeting of NEI's Nuclear Strategic Issues Advisory Committee (NSIAC). Your comments during the meeting were timely and well received by all of the Chief Nuclear Officers in attendance.

As part of your comments on Commission efforts to risk-inform large break loss of coolant accident design requirements, you requested industry's perspective on the potential safety benefits that could arise from this rulemaking. The attached discussion paper was prepared in response to this request and highlights some of the safety beneficial changes that we believe are possible with a risk-informed revision to design requirements.

A secondary objective of this paper is to stimulate additional thoughts and ideas from NRC, industry and other stakeholders. We firmly believe that we have only begun to identify the safety-focused beneficial changes that will naturally arise from the disciplined and informed review of design requirements that the rule change would promote. To this end, we look forward to participation in the 10 CFR 50.46 rulemaking process.

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Again, thank you for taking the time to participate in the NSIAC meeting. If you have any questions, don't hesitate to call me.

Sincerely,

Marvin S. Fertel

Attachment

Safety Benefits of Risk-Informed Changes To LOCA Design Basis Requirements

September 2004
Nuclear Energy Institute

Outline

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1 Introduction

The Nuclear Regulatory Commission (NRC) is on the verge of releasing an important set of changes to the regulations that have guided the safety design and operation of U.S. nuclear power plants for over 30 years. A proposed rule-change package that modifies the Emergency Core Cooling System (ECCS) design requirements is scheduled for release early in 2005. The release will initiate a process of public review and comment leading to a revision to 10 CFR 50.46. When final, the regulation will establish a framework for ECCS design that incorporates risk-informed principles. This change will provide an opportunity for NRC and the nuclear power industry to utilize the results and insights of over 30 years of reactor safety research and plant operation in a manner that refocuses attention on areas of safety importance. In an era when many different issues compete for both industry and NRC management attention and resources, a revised rule that sharpens the overall safety focus could not be more timely.

2 Discussion

Risk studies have clearly demonstrated the positive safety impact that can result from many of the plant changes that could be considered under a revised rule. Changes as simple as extension of Emergency Diesel Generator (EDG) fast-start requirements can result in reliability improvements that directly impact a broad range of event scenarios that improve both safety and operation. The current starting requirements for EDGs are based on deterministic analyses that assume a Loss of Offsite Power (LOOP) coincident with the design basis Loss of Coolant Accident (LOCA) and many other bounding assumptions. This highly-improbable combination of assumptions results in design requirements that can adversely impact more risk significant scenarios. A risk-informed process will allow risk considerations to guide the design process and facilitate a review of design requirements and their impacts on a broad spectrum of events.

Similarly, a simple modification of the pressure setpoint for containment building spray can prevent unnecessary spray actuation for a broad spectrum of small LOCA events. This would act to improve safety for the more risk-significant small LOCA scenarios by preserving emergency water sources for their use by the ECCS system and also increase the reliability of ECCS recirculation operation. These changes are restricted under current regulatory requirements that apply rigid design criteria to the full range of break sizes, with little consideration of their individual risk contributions and the risk contributions of other design basis events.

The traditional deterministic treatment of design basis events does provide for adequate protection, but safety can be further improved by risk-informed regulation. To some, this would appear to be counter-intuitive. It has been a long-standing premise of nuclear power plant safety that by designing a plant to address the most demanding events, safety is maximized. What has been generally overlooked is that actions taken in response to one postulated event can have adverse effects across a wide range of event scenarios.

For example, actuation of containment sprays clearly has a positive impact on the outcome of the design basis large break LOCA. To provide this protection, containment sprays in pressurized water reactors (PWR) are actuated on an increase in containment pressure. In order to accommodate the design basis LOCA event, the pressure setpoint is set relatively low and, as a result, is easily reached by the containment pressurization resulting from relatively small LOCA events. The majority of these less demanding events do not need containment spray to meet design acceptance criteria.

Because the occurrence of these less demanding events is much more likely than the design basis LOCA, the adverse impact of containment spray actuation is magnified. When the combined effect is examined, containment spray operation in the current design configuration can be shown to increase risk.

As part of a sensitivity study performed by a PWR plant, the reliability of containment spray operation was set to zero in their probabilistic risk assessment (PRA) (i.e., all containment sprays fail to operate). They then examined the impact on calculated core damage frequency (CDF) of the additional time operators would have to complete the manual transfer of ECCS injection from the refueling water storage tank (RWST) to containment recirculation. Because the additional time for manual transfer increases the reliability of operator actions, the results showed a decrease in total CDF.

Identification of effects such as this are not always straightforward and require looking at event scenarios in a different manner. The traditional method starts with the current design and operational characteristics and postulates deviations from the expected. The original building blocks of the plant design, established by the limiting design basis events, are not always questioned.

The Commission, in directing the staff to develop a risk-informed revision to 10 CFR 50.46, has clearly recognized the safety benefits that would accrue from a reexamination of the building blocks that comprise the current design basis of nuclear power plants. In doing this, the Commission has indicated that the new risk-informed process also needs to maintain a capability to mitigate a full range of break sizes. This preserves the original building blocks in a manner that maintains the defense-in-depth protection that is a cornerstone of nuclear safety.

As the new rule is being developed, it will be important for all parties to maintain a focus on the risk-significant spectrum of breaks. An undue focus on the least likely spectrum of breaks defeats the entire purpose of the endeavor.

The following section begins this process by targeting areas that have the potential to benefit from a risk-informed revision of LOCA design basis criteria. The discussion focuses primarily on design characteristics of Westinghouse design PWR plants and will not apply equally to other PWR plant designs or boiling water reactors. However, it serves as an illustration of the types of considerations that the revised regulation can encourage.

3 Areas of Potential Safety Benefit

3.1 Emergency Diesel Generator Start Time Requirements

3.1.1 Discussion

The EDGs and associated systems, structures and components (SSC) are designed to provide sufficient capacity, capability, redundancy, and reliability to ensure the availability of necessary power to engineered safety features (ESF) so that the fuel, reactor coolant system (RCS) and containment design limits are not exceeded. These limits must be shown to be met in the event of an assumed loss of all offsite power and a worst case single failure.

To meet the design basis requirements for fast moving design basis accidents (e.g., large break LOCA), an EDG must be capable of starting, accelerating to rated speed and voltage, and connecting to its ESF bus on detection of bus undervoltage in typically 10 seconds or less.

3.1.2 Design/Operational Considerations

Changes to the design basis requirements for Large Break LOCA analyses have the potential to extend the fast start requirements for EDGs. Extension of the 10 second start time requirement would have the effect of reducing wear and tear on diesels from required tests, resulting in an increase in diesel reliability. There would also be an expected reduction in need for invasive troubleshooting following a failure to meet fast start requirements and an associated reduction in the potential for maintenance errors that could result in challenges to the plant's safety systems.

The length of extension is largely dependent on the types of analysis modifications that are allowed. Retention of the coincident LOOP for all large break LOCA analyses would, for example, significantly constrain the potential changes in this area.

3.2 Load Sequencing and Electrical Distribution Systems

3.2.1 Discussion

The design of the AC electrical power systems provides independence and redundancy to ensure an available source of power to the ESF systems. The onsite Class 1E AC distribution system is divided into redundant load groups so that the loss of one group does not prevent the minimum safety functions from being performed. Each train has connections to two preferred offsite power sources and a single EDG.

An EDG starts automatically on a safety injection (SI) signal or on an ESF degraded voltage or undervoltage signal. After the EDG has started, it will automatically tie to its respective bus after offsite power is tripped as a consequence of ESF bus undervoltage or degraded voltage, independent of or coincident with an SI signal. The EDGs will also start and operate in the standby mode without tying to the ESF bus on an SI signal alone. Following the trip of offsite power, nonpermanent loads are stripped from the ESF bus. When the EDG is tied to the ESF bus, loads are then sequentially connected to its ESF bus by the load sequencer. The sequencer logic controls the permissive and starting signals to motor breakers to prevent overloading the EDG by automatic load application.

The competing effects of reliably transferring and sequencing of AC power loads and ensuring adequate AC power is available in the required time span has been an ongoing concern. The potential for "double sequencing" of ESF loads and the impacts of delayed LOOP events are areas of continuing interest.

3.2.2 Design/Operational Considerations

A more realistic treatment of design basis analysis requirements for large break LOCA has the potential to promote modifications to the load sequencing logic that would increase the reliability of the process under a wide range of postulated event scenarios. Safety benefits would be realized in equipment reliability and reduced wear-and tear on equipment. Changes to load sequencing logic and timing would also minimize the potential for grid disturbances following reactor trip and reduce the potential for double sequencing following LOOP.

Changes in the loads that are added to the ESF buses could also be investigated. Each plant design has limits in the total load that can be added to the ESF buses. In some cases, risk-significant equipment (but not designated ESF) could be added to the bus to replace less risk-significant equipment. In other cases it may be possible to remove loads that provide little risk benefit for the purpose of providing additional margin to ESF buses that are currently loaded close to their limit. Changes such as these have the potential to increase the reliability of AC power sources and the reliability of associated equipment loads. The beneficial impact would be reflected in a wide range of event scenarios.

3.3 ECCS Flow Issues

3.3.1 Discussion

The design and operation of the ECCS is defined to a significant degree by relatively few limiting design basis event scenarios. In general, requirements for the low pressure injection pumps and accumulators are defined by the limiting large break LOCA event, high head safety injection is defined by small and medium break LOCAs, and charging pumps are defined by small breaks and transients.

3.3.2 Design/Operational Considerations

An examination of ECCS design requirements that is focused on more risk-significant LOCA scenarios could identify a number of risk-beneficial changes. These changes include modifications to ECCS flow balancing and system resistances to improve operation for smaller breaks and transients.

Changes could also be considered in the actuation logic to improve system reliability or response to small break LOCA events. One example is modification of the actuation logic for low pressure injection pumps (lower setpoint or manual actuation) so that they would not automatically start during events in which RCS pressure remains too high for them to inject. This reduces unnecessary loads to the ESF bus and reduces the potential problems that can occur with pump operation in mini-flow mode.

Consideration could also be given to modifying or possibly eliminating requirements for realignment (i.e., hot-leg switchover) to prevent boron precipitation. Changes in this process may help reduce the frequency of equipment failure or human error.

3.4 Accumulator Design Requirements

3.4.1 Discussion

The functions of the ECCS accumulators are to supply water to the reactor vessel during the blowdown phase of a large break LOCA, and to provide inventory to help accomplish the refill phase that follows. The accumulators also provide a source of makeup inventory for small break LOCAs.

The accumulator size, water volume, and nitrogen cover pressure are selected so that N-1 accumulators are sufficient to partially cover the core following a large break LOCA. The need to ensure that N-1 accumulators are adequate for this function is consistent with the LOCA assumption that the entire contents of one accumulator will be lost via the RCS pipe break during the blowdown phase of the LOCA.

In performing the LOCA calculations, conservative assumptions are made concerning the availability of pumped ECCS flow. These include initiation delays that conservatively address signal generation and pump startup following a LOOP; and conservative reductions in pumped ECCS flow addressing a single-failure loss of one or more pumps.

The role and importance of ECCS accumulators decreases as the postulated break size decreases and would also decrease with more realistic modeling of pumped ECCS flow.

3.4.2 Design/Operational Considerations

Due to the cost of physical changes, the need to maintain defense-in-depth, and need to preserve a capability for reversal of changes, it is highly unlikely that plants would physically remove accumulators from service. A number of changes could, however, be considered.

Revisions of Technical Specification shutdown requirements associated with accumulators would reduce the likelihood of forced shutdown and resulting thermal cycle on the plant. More realistic Technical Specification treatment eases operational burdens enabling operators to better focus on safety significant activities. Wider accumulator parameter bands (e.g., boron concentration, water volume, cover pressure) would reduce periodic adjustments and thus the chances for ECCS valve misalignment.

The operating setpoints of the accumulators could be revised to improve system response to more risk-significant events (e.g., small break LOCA, steamline break). For some events it may be possible to show that delaying one or more accumulators provides a safety benefit. One or more of the available accumulators could be held in reserve (isolated) with remaining accumulators able to respond immediately. The isolated accumulators could then be actuated manually, if needed, to provide a reserve source of cooling flow.

Currently, all accumulators are required to be operable in Modes 1 and 2, and in Mode 3 with RCS pressure > 1000 psig. A reduction in the number of accumulators required to be operable in these modes would provide an associated increase in operating margin, a reduced likelihood of forced shutdown and resulting thermal cycles on the plant.

3.5 Containment Spray System Operation

3.5.1 Discussion

The Containment Spray and Containment Cooling systems provide containment atmosphere cooling to limit post accident pressure and temperature in containment to less than the design values. Reduction of containment pressure and the iodine removal capability of the spray reduce the release of fission product radioactivity from containment to the environment, in the event of an accident. Many PWR designs include a Spray Additive System that injects NaOH solution into the spray. The alkaline pH of the containment sump water minimizes the evolution of iodine and minimizes the occurrence of chloride and caustic stress corrosion on mechanical systems and components exposed to the fluid.

The Containment Spray System consists of two separate trains of equal capacity, each capable of meeting the design bases. The RWST supplies borated water to the Containment Spray System during the injection phase of operation. In the recirculation mode of operation, containment spray pump suction is transferred from the RWST to the containment sump(s).

The Containment Spray System is actuated either automatically by a high containment pressure signal or manually. The injection phase continues until the RWST level reaches a defined low level alarm. The low level alarm actuates valves to align the Containment Spray System pump suction with the containment sump and/or signals the operator to manually align the system to the recirculation mode.

The Containment Spray System and Containment Cooling System limit the temperature and pressure that could be experienced following a design basis accident (DBA). The limiting DBAs considered are the loss of coolant accident (LOCA) and the steam line break (SLB). The DBAs are analyzed with regard to containment ESF systems, assuming the loss of one ESF bus, which is the worst case single active failure and results in one train of the Containment Spray System and Containment Cooling System being rendered inoperable. The Containment Spray System total response time (typically 60 seconds) includes diesel generator startup (for loss of offsite power), block loading of equipment, containment spray pump startup and spray line filling. The analyses include conservative (limited) credit for passive heat removal mechanisms (e.g., heat sinks).

DBA analysis and evaluation results typically show the highest peak containment pressure results from the large break LOCA event. The highest peak containment temperature is commonly calculated to occur following a steamline break.

As noted above, the design bases for the Containment Spray System involve:

- Minimizing Peak Containment Pressure
- Minimize Peak Containment Temperature
- Controlling/Maintaining Containment Pressure and Temperature
- Radiological Suppression
- pH Control

Minimize Peak Pressure

The Large Break LOCA event is typically shown to provide the highest peak containment pressure. For this analysis, the peak calculated containment pressure must be shown to be below the containment design pressure. However, there is considerable margin (typically a factor of 2 or more) between the design pressure and the ultimate (failure) pressure of containment.

Minimize Peak Containment Temperature

The steam line break event is typically shown to provide the highest peak containment temperature. Containment sprays perform an important function in these events to suppress (de-superheat) the containment temperature and maintains temperatures within the qualification envelopes of key safety equipment. Because of the effectiveness of containment sprays, temperatures are quickly reduced to saturation and the effectiveness of containment sprays in further reducing temperatures is greatly diminished.

Controlling/Maintaining Containment Pressure and Temperature

Following suppression of initial containment pressure and temperature increases resulting from a LOCA or steam line break, the containment sprays work in conjunction with other containment cooling systems to maintain pressures and temperatures at acceptable levels. For many PWR plants, the capacity of the other containment cooling systems (e.g., containment fan coolers) is sufficient to meet heat removal requirements.

Radiological Suppression
The role of containment spray operation as a means of suppressing radiological release is important for events where it is postulated that there is significant core degradation. The impact and importance of sprays is greatly reduced for events where there is minimal or no core damage. Current design basis analysis requirements require the assumption of a radiological source term consistent with significant core damage.

pH Control
For some plants, containment spray operation serves as the means for delivery of Sodium Hydroxide. This buffering agent reduces the pH and avoids problems that can arise from long-term exposure of mechanical systems and components to high pH fluids. It is important to note that this role of containment spray is a longer term requirement and is not an immediate need. Many plants address this design requirement through alternate means.

3.5.2 Design/Operational Considerations

The current design/operational configuration of containment sprays leads to a number of detrimental impacts for LOCA events. These include:

- Reducing RWST inventory available for RCS injection
- Shortening time until switchover to recirculation from containment sump
- Increase in containment debris generation and transport to containment sump
- Increase in containment sump head loss and consequential decrease in net positive suction head (NPSH) margin
- Decreases margin in ESF bus loads

Reduction in RWST inventory
During a LOCA event, the RWST serves as the primary source of water for core cooling and replacement of inventory lost through the break. The RWST is also the source for Containment Spray flow. Under expected conditions for a large break LOCA event with no ESF failures, sufficient RWST inventory is available for approximately 20 minutes of injection before steps are taken to transfer the injection source to the containment sump. Because of the magnitude of spray injection flow, greater than 50% of the RWST is unavailable for RCS injection and core cooling. For smaller break LOCAs,

greater than 80% of RWST inventory is used by containment sprays and is unavailable for RCS injection.

Any modifications to containment spray flow actuation or operation that have the impact of reducing the amount of RWST inventory diverted from RCS injection will have a direct safety benefit of minimizing the potential of core damage.

Shortening Time to Recirculation Switchover

The transfer of the injection source for RCS injection and containment spray flow occurs either automatically or through a series of manual operator actions. While every effort is taken to ensure that the complicated series of automatic or manual actions occur without problem and that there is no interruption of injection flow, it is an opportunity for error.

Any modifications to containment spray actuation or operation that have the impact of lengthening the time to recirculation switchover will have a beneficial safety impact by:

1) Increasing the probability that RCS conditions can be stabilized and placed in a normal residual heat removal (RHR) cooling mode of operation (applicable to many small break LOCA events), avoiding the need for recirculation operation
2) Decreasing the probability of human error by avoiding imposition of a complicated set of manual operations early in an event.

Increase in Debris Generation and Debris Transport

Because of the broad area coverage of containment spray flow, there is the potential for a significant increase in the washdown of debris generated by the initiating RCS break and of resident debris materials. The transport of debris is highly influenced by water flow velocities along containment floors. Operation of containment spray flow, in combination with break flow, significantly increases the potential for transport of debris materials to the lower containment early in the event. The effect of containment spray flow on debris transport is magnified as the event progresses, since break flow decreases in time and containment spray flow remains constant.

Increase in Containment Sump Head Loss

A direct consequence of increased debris transport resulting from containment spray operation is an increase in the head loss due to debris collection on the containment sump screens. The increased head loss results in a decrease in the available NPSH and increases the potential for loss of one or more pumps drawing from the containment sump (e.g., low head safety injection pumps, high head safety injection pumps, containment spray pumps).

The head loss across the screens is proportional to the volumetric flow through the screens. Thus, in addition to increasing the transport of debris to the screens and resultant head loss, the high flow volume of containment spray greatly contributes to the head loss across the screens.

Decreased margin in ESF bus load capacity

As noted earlier in the discussion, the process of transferring (shedding) and sequencing (adding in a controlled and timely manner) AC power loads to the ESF bus during a LOCA event involves tradeoffs. Decisions are made concerning which loads are "shed" and which loads are added. Equipment that is not needed immediately will be sequenced to be loaded after higher priority loads are added. Under current Large Break LOCA analysis assumptions, containment spray pumps are required to be added very early in the sequencing process. The combination of these loads with other essential loads (including ECCS pumps) can lead to small margins to the load limit and increases the potential for a trip (loss) of one or both ESF buses.

Any modifications to containment spray actuation or operation that have the impact of lengthening the time to initiation of one or more pumps will have a beneficial safety impact by increasing the margin to trip of ESF buses.

Potential design/operational modifications

Potential changes to address the detrimental impacts noted above could include a combination of the following:

1) Raising the containment spray setpoint

   Analysis of large break LOCA events with more realistic analysis assumptions along with consideration of the available margin between containment design pressure and the ultimate pressure capability should allow for an increase in the setpoint. This would minimize the potential for containment spray actuation for a range of smaller LOCA events.

2) Staggering the containment spray setpoints for individual trains

   This modification would help prevent unnecessary spray operation.

3) Modifying spray termination criteria to allow earlier termination of spray injection

   Termination of spray operation when no longer needed helps preserve RWST inventory for RCS injection and minimizes containment debris transport issues.

4) Modifying spray actuation logic
Modifications to spray actuation logic, beyond setpoint modification, may provide a more effective means to ensure that sprays operate when needed and, equally important, do not operate when not needed. This could involve incorporation of available instrumentation that is not currently used in spray actuation logic (e.g., containment radiation monitors, steamline pressure)

5) Reduction/throttling of spray flow
This would include any modifications that act to reduce spray flow in excess of that needed to address pressure and temperature.

6) Manual actuation
In general, automatic spray actuation is only needed to address containment pressure and temperature. Manual actuation could be considered to address radiological suppression and pH control needs.

3.6 Fuel Management / Core Peaking Factors

3.6.1 Discussion

Limits on radial and axial peaking factors preclude core power distributions that could potentially violate fuel design criteria. The most limiting criteria of these criteria are:

(i) Peak cladding temperature during a large break LOCA must not exceed 2200 °F.
(ii) during a loss of forced reactor coolant flow accident, there must be at least 95% probability at the 95% confidence level that the hot fuel rod in the core does not experience a departure from nucleate boiling (DNB) condition
(iii) during an ejected rod accident, the energy deposition to the fuel must not exceed 280 cal/gm, and
(iv) the control rods must be capable of shutting down the reactor with a minimum required shutdown margin with the highest worth control rod struck fully withdrawn.

The peaking factor limits assumed in the large break LOCA analyses are typically limiting relative to (i.e., lower than) the limits assumed in safety analyses for other postulated accidents.

3.6.2 Design/Operational Considerations

Consideration of more realistic large break LOCA design basis analysis requirements would potentially allow an increase in peaking factor limits. The extent of any allowed increase would be limited by the peaking factor limits established for other design basis events (e.g., Loss of pumped RCS flow, control rod ejection).

Higher allowed peaking factors provide greater flexibility to fuel designers when attempting to reduce neutron flux at the vessel wall. This can result in a corresponding reduction in risk from pressurized thermal shock.

Wider peaking factor bands would also potentially result in fewer operator reactivity manipulations and potentially fewer adverse excursions.

Increased design margin for fuel may also result in longer allowed fuel cycles that in turn means fewer thermal cycles on the plant. Improved fuel economy will result in fewer spent fuel assemblies that require storage and transport.

Changes in fuel design may also be allowed to address other design issues. Some plants have modified the core baffle to remove or plug baffle holes (LOCA holes). The baffle jetting through the LOCA holes has caused fuel design changes to increase the number of assembly grids. These additional grids lead to less core flow and/or flow diversion that reduces margin to DNB. If the baffle holes are removed, then the additional grids may no longer be needed.