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REDUCTION OF LOW POWER SETPOINT

FOR RIVER BEND STATION

ROD PATTERN CONTROL SYSTEM

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CONTENTS

1. INTRODUCTION

The control rod drop accident has been chosen as the event that encompasses the consequences of a prompt reactivity excursion in a Boiling Water Reactor (BWR). The accident analysis involves calculating the peak fuel enthalpy resulting from the highest worth control rod being dropped out of the core during reactor startup or shutdown. The calculated enthalpy is compared to a design basis value which is established so as to limit internal fuel rod pressure and therefore, prevent fuel dispersal and core damage. In addition, generic analyses have been performed which demonstrate that conformance to the design basis enthalpy value will ensure that the offsite dose consequences due to a control rod drop accident will be within the guidelines of 10 CFR Part 100.

Calculation of the resultant peak fuel enthalpy due to a control rod drop accident is performed with conservative models that bound potential operational occurrences. In addition to the use of conservative analysis techniques, mitigating systems and procedures have been developed to limit the incremental worth of control rods and thus, reduce the consequences of a rod drop accident. These systems and procedures are enforced during reactor startup and shutdown and restrict (by hardwired circuits or computer programs) rod movement to predetermined sequences to limit rod worth. Although these rod pattern control systems and procedures assist to mitigate the consequences of a rod drop accident, they also severely impact plant operations. Affected areas include economic and human factors considerations as well as a potential reduction in plant safety.

This report will provide a detailed description of the control rod drop accident; the methodology used to calculate resultant peak fuel enthalpy; mitigating systems and procedures provided to limit incremental rod worth as well as the operational impact of these mitigating systems on plant performance. In addition, conservatisms in the analysis procedures will be demonstrated by comparison to realistic operational data, and computer models predictions. These conservatisms will then serve as a basis to reduce the analytical low power setpoint (LPSP) of the River Bend Station (RBS) rod pattern control (RPC) system from 20% of rated power currently to 10% of rated power.

The CRDA analyses referenced in this report are the original analyses (References 2 and 3), and the subsequent Banked Position Withdrawal Sequence analyses (Reference 4).

2. SUMMARY AND CONCLUSIONS

The information in this report provides the detailed justification required to support the establishment of the analytical LPSP at 10% of rated power for the RPC system at River Bend Station. The conservatisms inherent in the current analysis methodology provide the technical support required to make this proposed change. Further justification is provided by a nonadiabatic computer model that demonstrates the substantial margins that will still exist after the proposed LPSP setpoint reduction has been incorporated. These intrinsic analytical conservatisms, in conjunction with the economic, safety and human factors benefits of reducing the number of required operator actions, demonstrate that the analytical LPSP setpoint can be established at 10% of rated power (RTP) while maintaining adequate safety margin. As part of this evaluation, GE has reviewed the current RBS technical specifications for the Rod Withdrawal Limiter (RWL) and concurs with the proposed change, e.g. 20(-0,+15).

In other words, the constraints imposed by the RPCS are not required above 10% of rated core thermal power, while the constraints imposed by the RWL are not required below 35% of rated core thermal power.

3. SYSTEM DESCRIPTION

There are many ways of inserting reactivity into a BWR; however, most of them result in a relatively slow rate of reactivity insertion and therefore pose no threat to the system. It is possible, however, that a rapid removal of a high worth control rod could result in a potentially significant excursion; therefore, the accident which has been chosen to encompass the consequences of a reactivity excursion is the control rod drop accident (CRDA).

3.1 CONTROL ROD DROP ACCIDENT DESCRIPTION

The following sequence of events is postulated to occur during the CRDA.

a. A reactor is at a control rod pattern corresponding to maximum incremental rod worth.

b. The control rod that will result in the maximum incremental reactivity worth addition at any time in core life under any operating condition, becomes decoupled from the control rod drive (i.e., a complete rupture, breakage or disconnection of a control rod drive from its control blade at or near the coupling).

c. The decoupled control rod sticks in the fully inserted position as the rod drive is withdrawn.

d. The control rod becomes unstuck and drops at the maximum experimentally determined velocity to the position of the rod drive.

This unlikely set of circumstances results in a high local reactivity insertion in a small region of the core and significant shifts in the spatial power generation during the course of the excursion. Based on currently approved analysis methods, the Doppler reactivity coefficient is the key reactivity feedback mechanism affecting the termination of the initial prompt power burst. Final shutdown is achieved by scramming all but the dropped rod. The analytic methods used to determine the consequences of a CRDA are discussed in Section 5.0

3.2 CRDA DESIGN BASES AND CRITERION

The control rod drop accident is evaluated based on the following design bases and design criterion.

a. The maximum control rod worth will be established by the worst single inadvertent operator error or mechanical malfunction.

b. Technical Specification scram times will be employed.

c. The rod drop velocity will be the worst case measured value plus three standard deviations.

d. The control rod will drop from its fully inserted to its rod drive position.

e. The rod drop accident will be evaluated at the time in the fuel cycle at which the consequences are worst.

The LPSP is set so that the resultant peak fuel enthalpy due to the postulated rod drop accident defined by the design bases stated above, shall be equal to or less than 280 cal/gm. For operation below the LPSP, systems are provided so that the design limit of 280 cal/gm is not exceeded for the design basis accident. Conformance to the 280 cal/gm design limit also ensures that the 10 CFR Part 100 offsite dose criteria will be satisfied for the design basis accident.

3.3 MITIGATING SYSTEMS AND PROCEDURES

To reduce the consequences of the CRDA, systems and procedures have been developed to limit the incremental worth of control rods during reactor startup and shutdown. For RBS, these mitigating systems and procedures include the RWL function; the RPC function; and the Banked Position Withdrawal Sequence (BPWS).

The RPC provides a control rod monitoring function that enforces adherence to established startup, shutdown and low power level control rod movement sequences. These sequences are designed to limit incremental control rod worths. The RPC prevents the operator from establishing control rod patterns that are inconsistent with the predetermined BPWS sequences by initiating rod select, rod withdrawal and rod insert block signals as required. Operation of the RPC is intended from 100% control rod density to the LPSP.

The BPWS enforces adherence to certain constraints applied to control rod movement between 100% control rod density (CRD) and the LPSP in order to limit incremental control rod worth. Below the LPSP, the RPC system is designed to enforce the BPWS which is generically defined in Reference 4. As such, the control rods in a BPWS plant are assigned to specific groups whose sequence of withdrawal (or insertion) is controlled by the rod pattern control systems. As described in Reference 4, the BPWS allows the first 25% of the control rods to be withdrawn continuously from the fully inserted to the fully withdrawn position. The second 25% of the control rods to be withdrawn are banked to axial notch positions with the stipulation that all rods within a group must be withdrawn to their designated banked position before proceeding to the next banked position. Once 50% CRD is attained, the remaining control rods are withdrawn within the restrictions described in Reference 4. The predetermined banked position control rod withdrawal sequences optimize the core power distribution which minimizes control rod worth.

CRDA results from BPWS plants have been statistically analyzed and, in all cases, it was shown that the resultant peak fuel enthalpy is much less than the 280 cal/gm design limit even with a maximum incremental rod worth corresponding to 95% probability at the 95% confidence level. Based on these results, the NRC has found it acceptable to delete analysis of the CRDA from the standard GE-BWR reload licensing package for the BPWS plants for all GE fuel designs, including the most recent fuel type (References 1 and 5). The 280 cal/gm design basis CRDA limit is not fuel cycle or fuel design dependent based upon the Technical Requirements Manual required LPSP Nominal Setpoint, Operable Technical Specification Control Rod Scram times and the RPCS Technical Specification Limiting Condition for Operation.

The radiological effect of a CRDA was evaluated for new GE fuel product lines as part of the GESTAR Amendment 22 licensing process. For all GE fuel designs, including the most recent fuel type (GE12 design), calculations have shown that the relative amount of activity release following a postulated bundle drop accident is well below the guidelines set forth in 10CFR100. Therefore, the radiological effect following a CRDA for all current GE fuel design is demonstrated to be bounded by the licensing requirements.

4. OPERATIONAL IMPACT

Section 3 describes mitigating systems and procedures used to limit the consequences of a postulated control rod drop accident. These systems and procedures prescribe sequences of control rod movement that involve a series of controlled rod moves (steps) intended to limit incremental rod worth and thus the results of a CRDA. The implementation of rod pattern control systems and procedures therefore, has an economic, safety and human factors impact on plant operations. The following subsections describe the impact of these mitigating systems and procedures.

4.1 SAFETY IMPACT

The rod withdrawal and insertion sequences previously described all involve the time consuming process of moving control rod groups in a banked position mode to their prescribed locations. Thus, the ability to rapidly reduce power below the LPSP (without scramming the reactor) is not possible with the current RPC system. A rapid shutdown capability is often advantageous in avoiding challenges to the reactor protection system. There have been times when plants with RPC system, operating at power levels below the LPSP, have experienced minor anomalies (i.e., loss of condenser vacuum, turbine vibration, etc.) but could not avoid scrams due to the constraints of the RPC systems. It is also possible, that in the unlikely event of a partial scram situation or an anticipated transient without scram (ATWS), the reactor power level could be lowered below the LPSP with the resulting rod pattern in violation of the preprogrammed control rod sequence. In this instance, the RPC system may actually prevent the operator from quickly reducing the reactor power level further. These examples illustrate that although the RPC systems and procedures do limit the consequences of a CRDA, they also lead to increased challenges to the reactor scram system and the potential for more frequent vessel cycling.

The BPWS requirements of the RPC impose a flat axial power distribution on the reactor core to limit and reduce incremental control rod worths to meet CRDA requirements during reactor startup and shutdown. Conversely, Reactor Stability criteria impose a middle peaked power distribution requirement for upshift and operation of reactor recirculation pumps on high speed for additional boiling boundary margin (shorter 2 phase boiling length). GE has shown that above 10% power, the RDA cannot exceed 280 cal/gm because of the prompt Doppler feedback in the power range and the impossibility of achieving high rod worth with the relatively low rod density, even with erroneous rod patterns. As a result, the BPWS constraints currently imposed provide no additional protection for the CRDA and unnecessarily limit the stability margin that can be achieved by imposing conflicting rod pattern requirements during upshift and operation of reactor recirculation pumps on high speed.

4.2 ECONOMIC IMPACT

With control rod withdrawals typically on critical path during plant start-up, it is clear that the regimented and time consuming procedures imposed by the RPC systems can significantly impact the plant capacity factor. It is estimated that these practices unnecessarily increase startup times by up to 10 hours and typically decrease plant capacity factor by 0.5% per year. For a typical nuclear unit with replacement power costs of $300,000 per day, this equates to a loss of approximately $500,000 per year. Availability and capacity factor reduction is also caused by the slow controlled shutdown requirements of the rod pattern control systems and the potential increase in plant scrams. Shutdown times can be increased by 10 to 20 hours due to the restrictions of these rod pattern control systems. As discussed in Subsection 4.1, the inability to rapidly reduce power below the LPSP could lead to additional challenges to the reactor protection system. Reducing unnecessary scrams by modifying the CRDA mitigating procedures leads to an increase in plant capacity factor.

4.3 HUMAN FACTORS

The substantial number of operator actions required by the RPC system and procedures during startup and shutdown, places an obvious burden on the plant operator. Increasing the required operator actions also increases the opportunity for operator error which could impact plant safety.

Besides this noticeable human factors impact, there is an additional area of potential confusion caused by the multiple control rod movement philosophy set by the CRDA mitigating systems and procedures. The intent of restricting rod movement below the LPSP is to minimize the incremental worth of any control rod and therefore limit the reactivity excursion in the event of a CRDA. Beyond the LPSP, however, the rod movement philosophy changes to consider axial power shaping for reactor stability requirements. At higher power levels the operational concern is with minimizing total core peaking and establishing the target core axial power distribution. When these varied philosophies regarding rod movement conflict at intermediate power levels associated with the LPSP, increased complexity of the reactor startup process occurs.

5. CRDA ANALYTICAL METHODOLOGY

The currently approved methodology for analyzing a CRDA is described in detail in

5.1 CURRENT CRDA METHODOLOGY

5.1.1 Control Rod Worth

As stated in the CRDA design bases used to determine the LPSP, the maximum worth control rod at the most reactive point in the fuel cycle (established by the worst single operator error) is assumed to drop and thus initiate a prompt reactivity excursion. The worst single operator error that will produce the maximum rod worth involves withdrawing an out-of-sequence rod as described in Reference 2.

5.1.2 Adiabatic Prompt Excursion Model

5.1.3 Accident Reactivity Shape Function

The accident reactivity shape function for a specific rod is calculated to determine the incremental reactivity worth of the chosen rod

5.1.4 Doppler Reactivity Feedback

Subsection 3.1 mentions that the Doppler reactivity coefficient is the key reactivity feedback mechanism affecting the termination of the initial prompt power burst during the CRDA

5.1.5 Scram Reactivity Shape Function

Termination of the rod drop accident is accomplished by a reactor scram initiated by the average power range monitor (APRM) 118% overpower signal. For actual plant startup to approximately 5% power, the APRM scram level is setdown to 15% power (less than or equal to 20% of rated core thermal power allowable value) and the intermediate range monitor (IRM) scram signal is also operational. However, no credit is taken in the CRDA analysis for these scram setpoints. The rate at which negative reactivity is inserted into the core during the scram is controlled by the Technical Specification scram insertion speed and the scram reactivity shape function. The scram shape function is established by performing a

5.1.6 Analysis Conservatisms

The CRDA analysis methodology just described is representative of the physical phenomena occurring during the rod drop event. However, this analytical procedure incorporates many conservatisms to bound different potential applications. Some conservatisms used in the analysis are as follows:

The following inputs assumptions and parameters are used in the CRDA analysis:

The BPWS constraints imposed by the RPC as described in Reference 4 are utilized to develop control rods position inputs parameters for the CRDA analyses. These constraints include the following:

- First 25% of the control rods to be withdrawn are from the full-in to the full-out position.

- Second 25% of the control rods to be withdrawn are banked to axial notch positions, such as 00-04-08-12-48,

- All control rods within a group must be withdrawn to their designated banked position before proceeding to the next banked position.

- All control rods within a group must be completely withdrawn before proceeding to the next control rod group.

5.2 NON-ADIABATIC CRDA MODELS

Continued examination of the CRDA in BWRs has led to the development of realistic computer models that more accurately reflect the moderator void feedback mechanism. Accident tests indicate that substantial voiding occurs during a CRDA near saturated conditions (References 7 and 8). Specifically, Reference 7 presents results of experimental tests that demonstrate that the void reactivity feedback effect generated by prompt moderator heating accounted for approximately 35% of the total prompt reactivity feedback at the time of peak power for hot-standby conditions. The improved models (such as presented in Reference 9) calculate considerable reduction in peak fuel enthalpy when moderator void feedback is included. The calculations performed with these new models has led the NRC to conclude (Reference 5) that the consequences of a CRDA are in reality "... significantly below those of standard General Electric methods..." and that the analysis results "... are artificially high."

6. RESTORATION OF THE 10% CORE THERMAL POWER LPSP

When the CRDA analysis methodology was first developed (Reference 2) the power level above which a CRDA was inconsequential was determined to be 10% of rated. Since this time, the NRC has required that the analytically determined LPSP be conservatively set at 20% of rated power. Justification for restoring the setpoint to 10% of rated power is as follows:

a. The summary of rod drop excursion results presented in References 2 and 3 demonstrate that a CRDA above 10% of rated power will always result in peak fuel enthalpies less than 280 cal/gm (assuming the worst single operator error). These results employed conservative Technical Specification scram times and a 3.11 ft/sec rod drop velocity (the impact of these conservative values on the CRDA analysis is discussed in Subsection 5.1.6). The Reference 2 analysis also included the effect of axial gadolinia distributions. In addition, Reference 2 presents an analysis where the maximum control rod worth at the most reactive point in the operating cycle (mid-cycle) was combined with the worst CRDA conditions from the beginning of cycle. The results indicate, that even for this worst case scenario, the resultant peak fuel enthalpy will always be less than 280 cal/gm (worst single operator error) above 5% power. Thus, it is conservative to bypass the rod pattern control system above 10% of rated power.

b. Further support of the 10% power setpoint is provided by Reference 10. This report states that "Above approximately 10% power, the RDA cannot exceed 280 cal/gm because of the prompt Doppler feedback in the power range and the impossibility of achieving high rod reactivity worth with the relatively low rod density, even with erroneous rod patterns."

c. The new models which include moderator reactivity feedback (Subsection 5.2, Reference 9) provide additional justification for the 10% of rated power LPSP. These methods indicate that the existence of any steam flow (i.e., power) will result in the CRDA results remaining below the design basis limit. Therefore, a LPSP limit of 10% is extremely conservative relative to the new models.

d. An additional justification for the 10% LPSP is the impact on plant operation. The reduction of the LPSP will greatly reduce the number of operator actions required during plant startup and shutdown (Section 4) and therefore, reduce potential operator errors. The decrease in required operator actions will also result in the following:

   (1) Reduced challenges to the reactor protection system by increasing the rapid power reduction capability without scramming (Subsection 4.1). This will lead to reduced reactor vessel cycling and thus increased plant safety.

   (2) Reduced control rod maneuverability restrictions during a partial scram or ATWS event improves the operator's capability to perform an orderly reactor shutdown which results in increased plant safety (Subsection 4.1).

   (3) Increased capacity factor (and cost savings) by reducing startup and shutdown times and lessening required scram recoveries (Subsection 4.2).

   (4) Better capability to optimize target rod patterns and improve operating thermal margin instead of minimizing control rod worth at unnecessarily high power levels (Subsection 4.3).

7. REFERENCES

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