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ON NUCLEAR POWER PLANT UPRATING

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ABSTRACT

Power uprating for commercial nuclear power plants has become increasingly attractive because of pragmatic reasons. It provides quick return on investment and competitive financial benefits, while involving low risks regarding plant safety and public objection. This paper briefly discussed nuclear plant uprating guidelines, scope for design basis analysis and engineering evaluation, and presented the Salem nuclear power plant uprating study for illustration purposes. A cost and benefit evaluation of the Salem power uprating was also included.

1.0 INTRODUCTION

The environment for building new nuclear power plants in the United States has been rather difficult in recent years. The reasons are two-fold: Socio-political and Economical. The reluctance for the anti-nuclear people to accept any risks associated with the potential severe consequences from nuclear power plant mishaps has become a socio-political issue, rather than a technological issue, that needs to be settled. The Not-In-My-Backyard sentiment among some of the pro-nuclear people towards building new nuclear power plants added barriers to new plant construction.

The excessive regulatory burden on nuclear power plants in the U.S. has made nuclear power plants less competitive in certain geographical regions as compared to other power sources such as fossil, combined cycle, gas turbine and cogeneration plants. Therefore, power uprating, the approach to increase the electric output from the existing nuclear power plants, has become very attractive from both the considerations of public acceptance and plant economy, because it requires no new plant site; no impact on plant safety; and the return on investment is economically attractive as well.

For most nuclear power plants, the intent of power uprating is to remove the self-imposed over-conservatism built into the current plant systems and components. For majority of the U. S. built Light Water Reactors (including PWRs and BWRs), the as-built systems and equipment may have as much as 5% overcapacity above the original NRC-approved power rating. In conjunction with analytical tool (i.e., computer models and design methodologies) improvement and accumulated operating experience, a power uprating by approximately 5% would require only limited hardware modifications on certain key components. This means a relatively low capital investment.

This paper will briefly discuss the power uprating guidelines adopted for the Westinghouse PWRs and the General Electric BWRs and the required work scope for power uprating. The findings from the Salem power uprating study are then presented for illustration purposes. The economic benefits from the uprating are compared with other power sources such as fossil and natural gas plants.

2.0 GUIDELINES TO ACHIEVE HIGHER POWER

Due to the differences in design and design philosophy, the power uprating strategies for PWR and BWR are somewhat different. For example, for Salem Generating Station, a 4-loop Westinghouse pressurized water reactor, its premise to achieve a higher power rating is to maintain the plant operating parameters within the allowable operating window as shown in Figure 1. Figure 1 indicates that at different power ratings, the bounding operating parameters vary. The Departure From Nucleate Boiling Ratio (DNBR) limit line, which reflects the core/fuel operating limit, would become more restrictive with increasing core power. However, the secondary side (steam) pressure line and the reactor hot leg temperature line, which reflect the restrictions on steam generators, essentially envelop the upper bound of the operating window. The turbine volumetric flow line, which dictates the lower bound of the operating window, shows the minimum value required for the desired turbine power output.

For Hope Creek Generating Station, a General Electric BWR 4, Mark I Boiling Water Reactor, an extended operating region for the typical Power/Flow Map such as shown in Figure 2 will be justified. An increased power rating will shift the reactor operation towards the expanded power/flow area. Uprated power operation will involve slightly elevated reactor vessel pressure, which is needed to compensate for the larger pressure drop through the steamlines due to increased steam flow and to provide sufficient turbine inlet pressure for higher power generation.

For both PWRs and BWRs, some plant modifications and setpoint changes may be required to offset the physical impacts incurred by the increased power rating and the higher steam flow rate.

3.0 SCOPE FOR DESIGN BASIS ANALYSIS AND ENGINEERING EVALUATION

Although the power uprating approaches for PWRs and BWRs are different (Figure 1 vs. Figure 2), the required design basis analyses are dictated by the same set of regulations - the NRC Standard Review Plan[1]. For plants which were licensed before the current NRC Standard Review Plan was issued, the currently applied design bases may still be applicable.

For either PWR or BWR plants, it appears that adequate core thermal margins could be made readily available through the use of improved computer models or refined analytical methodologies for the ~ 5% core power rating increase. The major efforts to accomplish a power uprating are therefore, placed less on design basis analyses[2,3], but more on the trade-offs between the extent of hardware modifications (the cost) and the optimal power gain. The higher the power stretching from the original power rating, the more hardware modifications or components upgrading will be required. Costly hardware changes are usually deemed unwarranted.

The following two sections discuss the technical aspects of the Salem plant uprating study[4] and its economic evaluation for illustration purposes.

4.0 SALEM STATION POWER UPRATING STUDY - AN EXAMPLE

To explore the feasibility of power uprating, Salem conducted a thorough study regarding its Nuclear Steam Supply Systems (NSSS) safety margins, Balance of Plant (BOP) components capacity adequacy, Turbine/Generator efficiency, and the possible environmental impact.

Salem evaluated the possibility of uprating its NSSS and Turbine/Generator systems for Units 1 and 2 from an operating point of 3423 MWt at a Reactor Coolant System (RCS) average temperature of 577.9 °F (303 °C) to 3600 MWt over a range of RCS average temperature from 565 °F (296 °C) to 583.1 °F (306° C) (Table 1). The possible operating constraints due to various levels of tube plugging during the life of the steam generators were considered. Salem assumed a 10% average tube plugging in its four steam generators and up to 15% peak tube plugging for one steam generator.

The power uprating study were conducted for all key systems and components in the Nuclear Steam Supply Systems and the Balance of Plant Systems. The results are summarized as follows;

4.1 NUCLEAR STEAM SUPPLY SYSTEMS (NSSS)

4.1.1 NSSS ACCIDENT ANALYSES

The Loss of Coolant Accident (LOCA) analyses indicate that at the 3600 MWt rated conditions the Emergency Core Cooling System (ECCS) will continue to meet the 10CFR50.46 criteria. The design transient analyses (or non-LOCA analyses) show that the existing Reactor Protection System is adequate to maintain the core integrity, provided that certain set points be revised to maintain the needed safety margins. The containment integrity analyses demonstrated that at the power level of 3600 MWt, the post accident containment peak pressure is maintained below the containment design limit.

4.1.2 NSSS FLUID SYSTEMS EVALUATION

The fluid systems capabilities were evaluated for the power level of 3600 MWt over a range of RCS temperatures between 565.0 °F (296 °C) and 583.1 °F (306 °C). Three systems, namely, Residual Heat Removal (RHR), Component Cooling Water (CCW), and Service Water Systems, may be significantly impacted by the uprated power level. The RHR cooldown period will need to be extended; Higher CCW temperature may require the plant to install miniature cooling tower or some devices of similar functions to alleviate potential environmental concerns. It is worth noting that the higher CCW temperature is only partially due to the power uprating. A greater proportion of the higher CCW temperature was caused mainly by the higher recorded water temperature at the Delaware River in the past few years. The river water is the ultimate heat sink for the Salem plant operation.

4.1.3 STEAM GENERATOR EVALUATION

In order to achieve a higher power rating, upgrade of the steam generator moisture separators and installation of four sentinel plugs will be required. These modifications are for maintaining the steam quality at a desirable value and to eliminate the potential risk of U-bend vibration respectively.

It was recognized that for RCS T_{hot} above 600 °F (315.6 °C), the steam generator tube material (Alloy 600) would be more prone to corrosion. Thus, operation at the low end of the proposed temperature range is preferred.

4.1.4 TURBINE-GENERATOR EVALUATION

To increase the reliability of the operation of the low pressure turbines, some blading modifications are recommended. Modifications of the high pressure turbines are also suggested, though not required, for more efficient operation at the 3600 MWt rating. There is no need for the electrical generator modifications if operation of the generator at the uprated conditions with a power factor of 0.94 lagging to 0.975 leading is acceptable for the power grid.

4.1.5 REACTOR CORE/FUEL EVALUATION

As a result of improved design methodology, inherent safety margins could be utilized to offset the margin loss due to a higher core power. Therefore, there is no concern relative to the capability of the core to generate thermal power up to 3600 MWt. In summary, no core or fuel modifications are needed.

4.1.6 CONTROL SYSTEMS AND SETPOINTS REVIEW

The NSSS control systems were reviewed and found adequate for the uprated conditions. The review of the margin to the steam generator low-low level reactor trip set point indicated that if the units are expected to experience large load rejections at rates close to 200%/minute, the operation of the steam dump valves may be marginal, therefore, further investigation will be needed.

4.2 BALANCE OF PLANT

Heat balance models were developed to establish the predicted operating conditions for the steam cycle based on thermodynamic parameters of the plant, one at 3423 MWt and the other at 3600 MWt. The results of the evaluations of functional systems and components are as follows:

4.2.1 RADIOLOGICAL DOSE ANALYSIS

Dose will increase for most postulated accidents, however, the doses at the site boundary and the local planning zone will remain within the limits of 10CFR100. The Control Room LOCA doses are within the more limiting criteria of GDC-19. The doses associated with Steamline Break and Steam Generator Tube Rupture are based upon limitations imposed by Tech Specs (not a function of power level) and thus will not be affected by power uprating.

4.2.2 STRUCTURAL/PIPING EVALUATION

Evaluation of the containment structure to withstand pressure loading associated with a LOCA at uprated conditions and the assessment of the current piping systems to support the uprating were conducted. No weakness were identified based on available information.

4.2.3 STEAM AND POWER CONVERSION SYSTEM REVIEW

The steam and power conversion systems were reviewed based on the heat balance analyses to assess margins to accommodate the uprating. It was identified that some shell side relief valves for the feed water heaters and the heater drain system may need to be upgraded to adequately provide the safety margins.

4.2.4 AUXILIARY SYSTEM REVIEW

To ensure sufficient cooling capacity and makeup capability, the auxiliary systems were assessed. The systems include Service Water, Turbine Auxiliary Cooling, Demineralized Water Makeup, and HVAC. The Service Water System may have difficulty to provide sufficient cooling to the plant if the assumed water temperature for the Delaware River was increased from 85 °F (29.5 °C) to 90 °F (32 °C). Alternatives are available to resolve the issue. The turbine Auxiliary Cooling System would need to be upgraded to accommodate the uprating.

4.2.5 I/C AND ELECTRICAL POWER SYSTEMS REVIEW

The reviews indicated that the existing systems will function adequately.

4.2.6 ENVIRONMENTAL IMPACT REVIEW

The environmental impacts as a result of the uprating may have a significant effect. The circulating water conditions resulting from the increased condenser outlet temperature will require a review of associated environmental discharge regulation. System modifications may be required.

Other issues such as Radioactive Waste Management, Radiation Protection, and Environmental Qualifications were reviewed and no impacts were identified as a result of the power uprating.

The summary of the anticipated changes for the Salem power uprating by 5.1% (from 3423 MWt to 3600 MWt) is included in TABLE 2.

5.0 ECONOMIC EVALUATION

Based on the potential changes listed in TABLE 2, which were derived from the Salem feasibility study, and the assumption of in service date of January 1, 1998, the increase in rated capacity results in system operating savings which outweigh both the cost to uprate and the increase in $/MBTU fuel costs for Salem. Assuming a life-time levelized basis, the integrated project cost estimate is $98M. The integrated project includes the uprating required hardware modifications and the high pressure turbine optimization, which is not required by the uprating but will help improve the plant efficiency. For the $98M project cost, the payback period is approximately 7 years. If all potential costs (moderate and high risk items) are included, the overall cost may be up to $150 M. The conceptual project cost of $98M is equivalent to approximately $700/KW. The total cost of the increased capacity is no more than 3 cents/kwh. The generation cost for coal plant and natural gas plant is approximately 5 cents/kwh. The cost advantage of plant uprating is self-evident. In addition to the cost advantage, the power uprating could be accomplished within a relatively short time period. This may be another important factor for the region facing near term power shortage.

6.0 CONCLUSION

The Salem power plant uprating study demonstrated the feasibility, from a safety and economic perspective, to extract more power from the existing plant equipment as do some other Light Water Reactor Plants. No significant licensing issues would be anticipated for power uprating by up to ~5%.

7.0 REFERENCES

1. "Standard Review Plan (LWR Edition)", NUREG-0800, U.S. Nuclear Regulatory Commission, June 1987.

2. "Generic Guidelines for general electric Boiling Water Reactor Power Uprate - Licensing Topical Report", NEDO-31897, February 1992.

3. "A Review Plan For Uprating The Licensed Power of A Pressurized Water Reactor Power Plant", WCAP-10263, January 1983.

4. "Salem Nuclear Generating Station Units 1 & 2 Rerating Feasibility Study", Public Service Electric & Gas, New Jersey, January 1990.

FIGURE 1

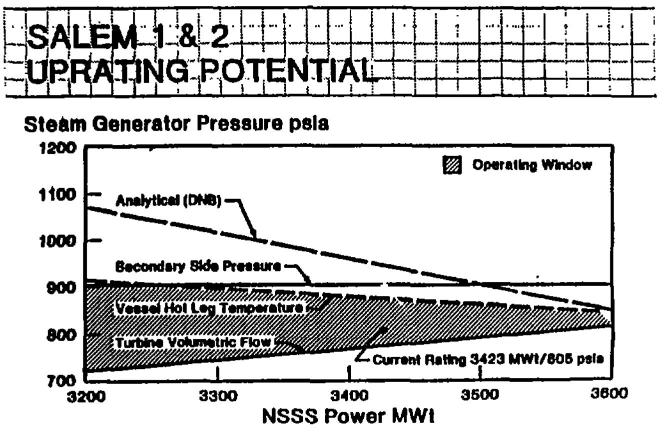

FIGURE 2

Typical General Electric Power/Flow Map

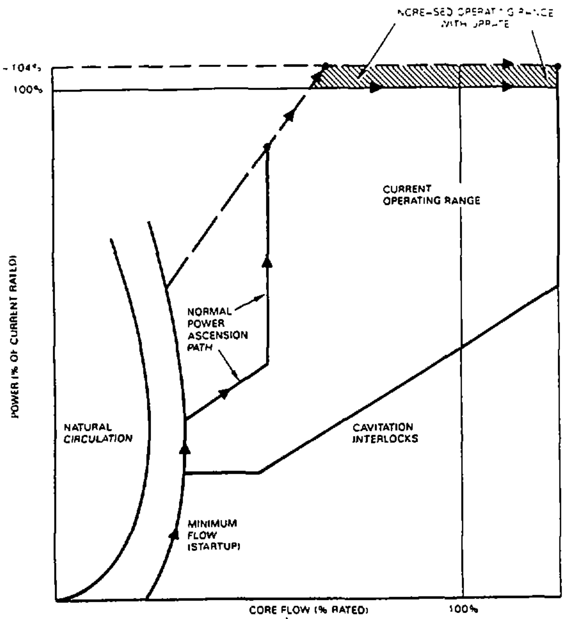

TABLE 1

SALEM UPRATING FEASIBILITY STUDY

NSSS DESIGN BASIS PARAMETERS
3600MWt

Uprating with High and Low Temp. Assumption

	Current	10% Plugging (Average)		15% Plugging (Peak)	
		Low	High	Low	High
NSSS power, (MWt)	3423	3600	3600	3600	3600
Reactor Powr, (MWt)	3411	3588	3588	3588	3588
RCS Pressure, (psia)	2250	2250	2250	2250	2250
Thermal Design Flow, (gpm/loop)	87,300	85,000	85,000	85,000	85,000
Reactor Flow, (10 lb/hr)	132 2	131 3	128 1	131 3	128 1
Core Bypass, (%)	6 5	6 5	6 5	6.5	6 5
RCS Temperatures, (°F)					
Vessel Outlet	610 8	601.0	618 2	601 0	618 2
Core Average	581.8	569 1	587 5	569 1	587 5
Vessel Average	577 9	565 0	583 1	565 0	583 1
Vessel/Core Inlet	545 0	529 0	548 0	529 0	548 0
S/G Outlet	544 8	528 7	547 8	528 7	547 8
Steam Paramaters					
Steam Temperature (°F)	519.0	502 8	522 5	500 7	520 4
Steam Pressure (psia)	805	698	830	685	816
Steam Flow (10 lb/hr)	14 86	15.71	15 78	15 70	15 77
Feedwater Temperauter (°F)	432 8	439 0	439 0	439 0	439 0
Zero Load Temperature (°F)	547	547	547	547	547
S/G Tube Plugging(%)	3 5	10	10	15	15

TABLE 2

SUMMARY OF ANTICIPATED CHANGES

	REASON FOR CHANGE					
POTENTIAL CHANGE	KNOWN MODIFICATIONS	EFFICIENCY / MWe IMPROVEMENT	DESIGN MARGIN IMPROVEMENT	RELIABILITY / AVAILABILITY ENHANCEMENT	SUPPORT ACTIVITIES	*NOTES*
HP TURBINE OPTIMIZATION	●	●				
STEAM GENERATOR MCO MODIFICATIONS	●	●				
POWER SYSTEM STABILIZER			●	●		SALEM UNIT 1 ONLY
THIRD MAIN FEED PUMP			●	●		FOR STARTUP AND TRANSIENTS
MINIATURE COOLING TOWER			●	•		POTENTIAL ENVIRONMENTAL CONCERN
BALANCE OF PLANT VALVE CHANGEOUTS			●			VALVE AND/OR VALVE TRIM CHANGEOUTS
HEATER DRAIN SYSTEM PIPING MODIFICATIONS			●	●		UPGRADES UNITS TO PRESENT DAY STANDARDS
SHUNT CAPACITORS FOR TRANSMISSION/ DISTRIBUTION			●	●		
INSTRUMENT SETPOINT CHANGES	●					
PROCEDURE REVISIONS- OPS, EOPS, etc.	●				●	