General Electric Advanced Technology Manual

Chapter 4.11

Power Uprates

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4.11 POWER UPRATES

Learning Objectives:

1. Define Licensed Thermal Power and recognized how it is measured.

2. Identify the types of power uprates.

3. Recognize the major design considerations that must be reevaluated when applying for a power uprate including reduction in safety and operating margins.

4. Identify the components in a typical BWR design that can limit the amount of a power uprate.

4.11.1 Introduction

The NRC regulates the maximum thermal power level at which a commercial nuclear power plant may operate and is referred to as Rated Thermal Power (RTP). RTP is also referred to as the Licensed Thermal Power and is defined as the maximum allowed total reactor core heat transfer rate to the reactor coolant. This power level is used, with other data, in many of the licensing analyses that demonstrate the safety of the plant. This power level is specified in the license and technical specifications for the plant. The NRC controls any change to a license or technical specification, and the licensee may only change these documents after NRC approves the licensee's application for change. The process of increasing the maximum power level at which a commercial nuclear power plant may operate is called a power uprate.

4.11.2 Background on Power Uprates

Utilities have been using power uprates since the 1970s as a way to increase the power output of their nuclear plants. To increase the power output of a reactor, typically more highly enriched uranium fuel and/or more fresh fuel is used. This enables the reactor to produce more thermal energy and therefore more steam, driving a turbine generator to produce electricity. In order to accomplish this, components such as pipes, valves, pumps, heat exchangers, electrical transformers and generators, must be able to accommodate the conditions that would exist at the higher power level. For example, a higher power level usually involves higher steam and water flow through the systems used in converting the thermal power into electric power. These systems must be capable of accommodating the higher flows.
In some instances, licensees will modify and/or replace components in order to accommodate a higher power level. Depending on the desired increase in power level and original equipment design, this can involve major and costly modifications to the plant such as the replacement of main turbines. All of these factors must be analyzed by the licensee as part of a request for a power uprate, which is accomplished by

amending the plant's operating license. The analyses must demonstrate that the proposed new configuration remains safe and that measures continue to be in place to protect the health and safety of the public. These analyses, which span many technical disciplines and may be complex, are reviewed by the NRC's technical and legal staffs and NRC management before a request for a power uprate is approved.

4.11.3 Types of Power Uprates

The three categories of power uprates are—

- Measurement Uncertainty Recapture power uprates
- Stretch power uprates
- Extended power uprates

Measurement uncertainty recapture power uprates are less than 2 percent and are achieved by implementing enhanced techniques for calculating reactor power. This involves the use of state-of-the-art feedwater flow measurement devices to more precisely measure feedwater flow, which is used to calculate reactor power. More precise measurements reduce the degree of uncertainty in the power level, which is used by analysts to predict the ability of the reactor to be safely shutdown under postulated accident conditions.

Stretch power uprates are typically up to 7 percent and are within the design capacity of the plant. The actual value for percentage increase in power a plant can achieve and stay within the stretch power uprate category is plant-specific and depends on the operating margins included in the design of a particular plant. Stretch power uprates usually involve changes to instrumentation setpoints but do not involve major plant modifications.

Extended power uprates are greater than stretch power uprates and have been approved for increases as high as 20 percent. These uprates require significant modifications to major balance-of-plant equipment such as the high pressure turbines, condensate pumps and motors, main generators, and/or transformers.

4.11.4 Regulatory Process for Submitting/Reviewing Power Uprate Requests

The process for amending commercial nuclear power plant licenses and technical specifications related to power uprates is the same as the process used for other amendments; therefore, power uprate requests are submitted to NRC as license amendment requests. This process is governed by 10 CFR 50.90, 50.91 and 50.92. After a licensee submits an application to change the power level at which it operates its plant, the NRC notifies the public, by issuing a public notice in the ***Federal Register***, that the NRC is considering the application. The public has 30 days to comment on the licensee's request and 60 days to request a hearing. The NRC thoroughly reviews the application, any public comments, and any requests for hearings received from the public. After completing its review and considering and addressing any public comments and requests for hearings related to the application, the NRC issues its findings in a safety evaluation and notifies the public in another ***Federal Register*** notice of the NRC decision related to the application. On the basis of its findings, the NRC may approve or deny the request. Press releases are issued if a power uprate is approved.

4.11.5 Power Uprate Major Design Considerations

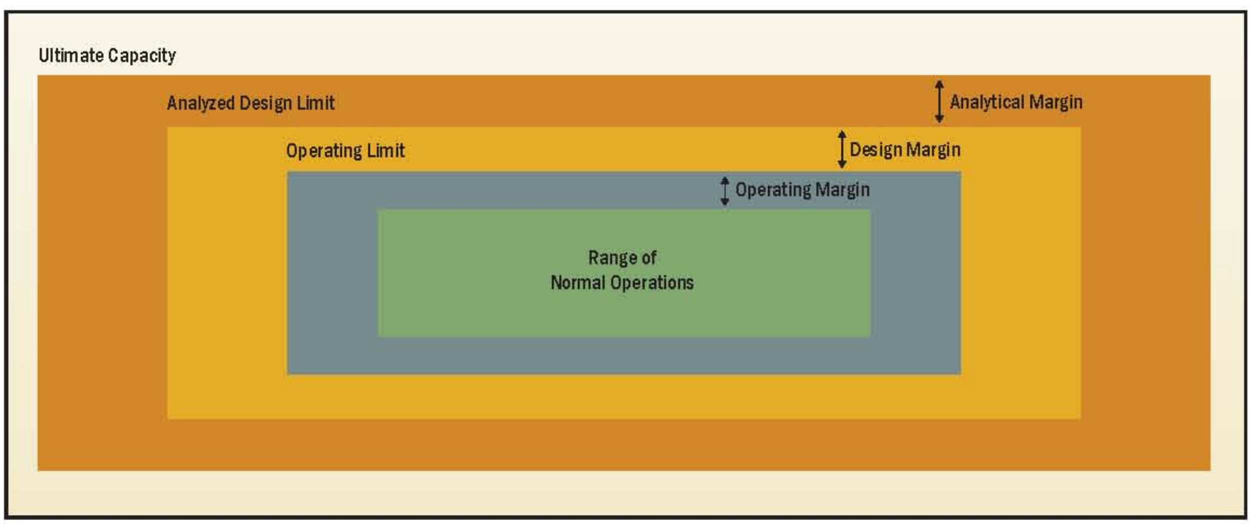
Increased thermal output requires greater thermal input into many of the plant systems and components, potentially reducing required margins through lowered material properties and adding burden on pumps, bearings, and seals. Increased flow accentuates flow accelerated corrosion (FAC) in pipes and other components. Increased mass flow has the potential to raise flow-induced vibration levels in systems and components to unacceptable levels or change the frequency of the exciting forces, causing vibration where it previously did not exist. The Electric Power Research Institute (EPRI) maintains a lessons-learned database that identifies issues observed and resolved in previous power uprates and serves as an excellent information base for future uprates. It is difficult to generalize about the perfect plan to complete an optimum EPU for a given plant. Differences in initial regulatory approaches, past responses to regulatory issues, and previous modifications and equipment change outs to maintain plant operation all combine to make the EPU program for each plant unique. Even side-by-side “identical plants” frequently require separate plans to accomplish an equivalent EPU. Therefore, detailed studies are required for each plant. However, some general trends have been observed. Design duty for overpressure protection and required relief capacity in the reactor coolant pressure boundary from normal operating and transient design conditions typically increase with increased power. This may require that safety-relief valves be modified. Otherwise, reactor coolant pressure boundary modifications have not been a major concern. Industry experience with power uprates to date has shown that the installed capacity of emergency core coolant systems is nearly always sufficient without modification.

Major balance-of-plant (BOP) upgrades have been the focus of most EPUs. The turbine, main generator, main power transformer, and power train pumps often have to be replaced or modified. Components such as feedwater heaters, moisture separator reheaters, and heat exchangers are frequently replaced with larger units. Feedwater, condensate, and heater drain pumps, along with supporting components, typically have to be replaced or modified. This increases the demands of isophase bus duct cooling. Increased steam and feedwater mass flow often require that piping be replaced to accommodate greater mass flow or to counteract the effect of FAC. The design must also consider any increased demand for demineralized water. For each EPU, an HP turbine retrofit (at least) is required, and because throttle margin can be achieved through the retrofit without an attendant increase in operating reactor pressure, the uprate can be analyzed and performed at constant pressure. Depending on the existing margins, the magnitude of the uprate, and the condition of the turbines, it may be necessary to replace, repower, or modify the low-pressure (LP) and/or HP portion of the turbine. In many cases, the condenser is either replaced or retubed. Plants with closed-loop cooling may also have to consider cooling tower upgrades, and plants with open cycles need to evaluate thermal effects from the condenser outfall. Major modifications to the generator and stator (rewinding) are expected. This may also require increased cooling for the generator. Transformers may need to be replaced with larger units. Replacement components are generally larger and heavier, which means that structures supporting these components are challenged and frequently have to be strengthened by modifying the building structure and other foundations.

4.11.6 Margin Management

An EPU is a major undertaking for an operating plant that requires the combined expertise of the plant staff, Nuclear Steam Supply System (NSSS) contractors, turbine contractors, and, in most cases, nuclear Engineering, Procurement, and Construction (EPC) contractors. An initial but important step is to establish a margin management program (if the plant does not already have one) to ensure that adequate margins are available in systems, structures, and components (SSCs). Developing or updating the margin management program may be done in parallel with other EPU preparation steps.

Several "margins" are of interest in a margin management program. The Institute of Nuclear Power Operations (INPO) identifies three different nuclear plant design margins: operating, design, and analytical.



Operating margin is the difference between the operating limit and the range of normal operation. The operating limit is analogous to design values in engineering terms. It accounts for, and envelops, all the potential operating conditions of the plant. Design codes and licensing criteria include a certain margin, or safety factor, beyond the design limit, which addresses uncertainties in design, fabrication durability, reliability, and other issues. The difference between the analyzed design limit and the operating limit is this conservatism, which INPO calls the design margin.

Normal aging and plant operation—which require constant attention by owners—can decrease each of these margins. Increased thermal output from an EPU imposes further demands on the operating limit. Even systems or components not directly affected by the power increases may not function as efficiently as intended following an EPU. For all of these reasons, the margin management program becomes an important tool in performing an EPU.

The margin management program has two basic parts. One is analytical: ensuring that the design documents are current, correct, and consistent with the plant design features. The second part is more complex in that it requires a systemic assessment of the current condition of the physical plant through engineering walkdowns and reviews of condition reports and other operational data. A thorough review of EPRI's generic lessons-learned database is also important for identifying potential future issues.

Assuming that the necessary assessments have been performed and a decision made to consider an EPU, the next step is to conduct a feasibility study. An integrated team consisting of the owner's plant staff, an experienced architectural/engineering firm, the NSSS supplier, and the turbine generator supplier should perform the feasibility study. This approach minimizes interface issues among the aforementioned parties in relation to current operating experience at the nuclear plant and the NSSS, BOP, and turbine generator equipment.

Potential modifications to the NSSS, the nuclear systems, the turbine and cooling system, and the BOP are studied. Initial evaluations are conducted to identify the potential power increases available through modifications of the NSSS, as discussed above. The turbine generator is also evaluated to determine modifications required to meet the proposed uprated power needs. And finally, the potentially affected nuclear and BOP systems and components are evaluated to determine the pinchpoints—those items that have suffered margin erosion due to preexisting factors or would suffer erosion due to the EPU modifications.

A cost-benefit analysis is included in, or prepared in parallel with, the feasibility study. Typically, the greater the uprate, the greater the cost of the last kilowatt added. Most utilities are finding that, compared with other available alternatives, it is cost-effective to implement the greatest amount of added power possible from the EPU, provided that other outside factors demonstrate that the need exists.

The next phase of the feasibility study is to identify modifications necessary to meet the EPU's requirements and ensure that the modifications reestablish required margins. In some cases, margin can be restored solely through more sophisticated analysis. In other cases, hardware changes or plant modifications are required. Next, equipment specifications are prepared and purchase orders are placed for long-lead-time components. Typical components in this category include:

- HP and LP turbines (replacement)

• Main and auxiliary generators (upgrades)
• Transformers (replacement)
• Feedwater heaters (replacement)
• Pumps and motors (feedwater, condensate, heater drains, component cooling water)
• Spent fuel pool cooling heat exchangers
• Moisture Separator Reheaters
• Condenser and/or cooling tower (upgrades)
• Water treatment system (upgrades)

Based on the feasibility study, including the cost-benefit analysis, the owner decides on the final upgrades/modifications required to meet the EPU goals. With this final list, a more detailed evaluation is performed that supports a Licensing Amendment Report (LAR) for NRC review and approval. The LAR requirements are provided in NRC document RS-001, Review Standard for Extended Power Uprates. The LAR incorporates the completed analytical results along with additional detailed evaluations of SSCs directly or indirectly affected.

4.11.7 Power Uprate Issues

The US nuclear power industry has experienced over 60 events related to power uprates since 1997. From the Institute of Nuclear Power Operations (INPO) Significant Event Report (SER) SER-05-02: “Significant aspects of these events include the following:

- An extended, unplanned shutdown was required to retrieve several loose parts as a result of a flow-induced, high-cycle fatigue failure of a steam dryer cover plate.

- Operational transients and equipment damage have occurred as a result of weaknesses in identifying, communicating, and training the plant staff on expected changes to secondary plant operating characteristics.

- Unanticipated operating challenges and degraded equipment performance have resulted from reductions in operating and design margins.

- Some units have operated beyond their licensed power levels for extended periods because of errors in reactor thermal power calculations following uprates that changed secondary plant operating characteristics.”

Some of the more significant events occurred between 2002 and 2004 as a result of EPUs at Quad Cities and Dresden. These events involved the steam dryers:

June 2002: Steam dryer cover plate at QC 2 fails after 90-day EPU operation with pieces found on top of steam separators, and in main steamline flow venturi and turbine stop valve strainer. (Figure 1)

June 2003: Steam dryer hood, internal braces, and tie bars fail at QC 2 after 300-day EPU operation. (Figure 1)

Oct. 2003: During RFO inspection after 700-day EPU operation, Dresden 2 finds 4-inch cracks in steam dryer hood panels and holes in FW sparger from broken sampling probe.

Nov. 2003: At QC 1, steam dryer hood fails with 6x9 inch plate (Figure 3) lost after 330-day EPU operation. Also, damage identified to main steam electromatic relief valve (ERV), steamline supports, and HPCI steam supply MOV.

Dec. 2003: During shutdown inspection after 300-day EPU operation, Dresden 3 finds two 4-inch through-wall cracks in steam dryer hood, and two FW sampling probes in sparger. Also, Dresden 2 identifies lost FW sampling probe.

Mar. 2004: During RFO inspection after 240-day EPU operation, QC 2 finds numerous steam dryer indications including cracking near gussets installed in 2003, tie bar welds, dryer stiffener plate weld, and horizontal-vertical plate intersection.

4.11.8 Uprates - Completed, Under Review, Expected

The NRC has approved 139 uprates as of April 2011 and typically has several applications for power uprates under review at any given time. In addition, licensee responses to a December 2010 NRC survey indicate they plan to submit 35 power uprate applications in the next five years, including 12 extended uprates and 23 measurement uncertainty recapture uprates. If these applications are approved, the resulting uprates would add another 5,254 MWt (1,855 MWe) to the nation's generating capacity. Lists of uprate applications approved, under review, and anticipated can be found in the three tables at the end of this fact sheet, and on the NRC's website at: http://www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps.html

4.11.9 Summary

Power Uprates have been used by the nuclear industry as a means of achieving higher licensed thermal power output since the late 1970s. The three types used have been Measurement Uncertainty Recapture, Stretch, and Extended Power Uprate. Depending upon the size of the uprate the plant may require significant equipment modification as well as margin reductions, therefore careful analysis must be conducted as part of the License Amendment Request.

While experience from power uprate projects is generally favorable, some plants have incurred problems with their implementation (e.g. equipment damage or degraded performance, unanticipated responses to plant conditions). These problems have arisen mainly from an insufficient analysis and/or understanding of the full implications of the proposed power uprate or from insufficient attention to detail during the design and implementation phase. To implement a power uprate, it is strongly recommended that:

- The power uprate project plan should ensure that it accomplishes the power increases in controlled, conservative and well-monitored incremental steps.

- A comprehensive safety analysis should be undertaken, which covers all aspects of plant behavior under normal, abnormal and accident conditions (as was done for the original SAR).

- A rigorous, disciplined approach focusing on multidisciplinary teams, including engineering, licensing, operations, maintenance and test implementation personnel, with appropriate skills is required to ensure success.

- The vulnerability to equipment caused by material degradation and vibration concerns needs to be considered and reflected in the power uprate process.

- Operating staff are adequately trained as it relates to how the plant will operate after the power uprate. It is equally important that maintenance, engineering and radiation protection personnel are provided training on the changes made as a result of the power uprate program.

- All affected documentation, and operating and maintenance procedures should be updated and reflect the new conditions.

- Special attention should be paid to procedure development, training and simulator modeling. This will help to verify actual plant response versus expected plant response in power uprated conditions and avoid the unanticipated problems. The impact of the power uprate on plant life management for long term operation is an important issue. Plant ageing issues may be aggravated by the power uprate due to plant conditions. This may result in a need for more inspections and installation of monitoring systems for certain critical components to ensure extended plant operational life.

4.11.10 References

1. IAEA NUCLEAR ENERGY SERIES No. NP-T-3.9: Power Uprate in Nuclear Power Plants: Guidelines and Experience, Printed by the IAEA in Austria January 2011 STI/PUB/1484

2. Eugene W. Thomas, Bechtel Technology Journal, Nuclear Uprates and Critical Capacity, December 2009

3. IAEA, Implications of power uprates on safety margins of nuclear power plants, Report of a technical meeting organized in cooperation with the OECD/NEA held in Vienna, 13–15 October 2003

4. NRC INSPECTION MANUAL, INSPECTION PROCEDURE 71004

5. U.S. NRC Website,
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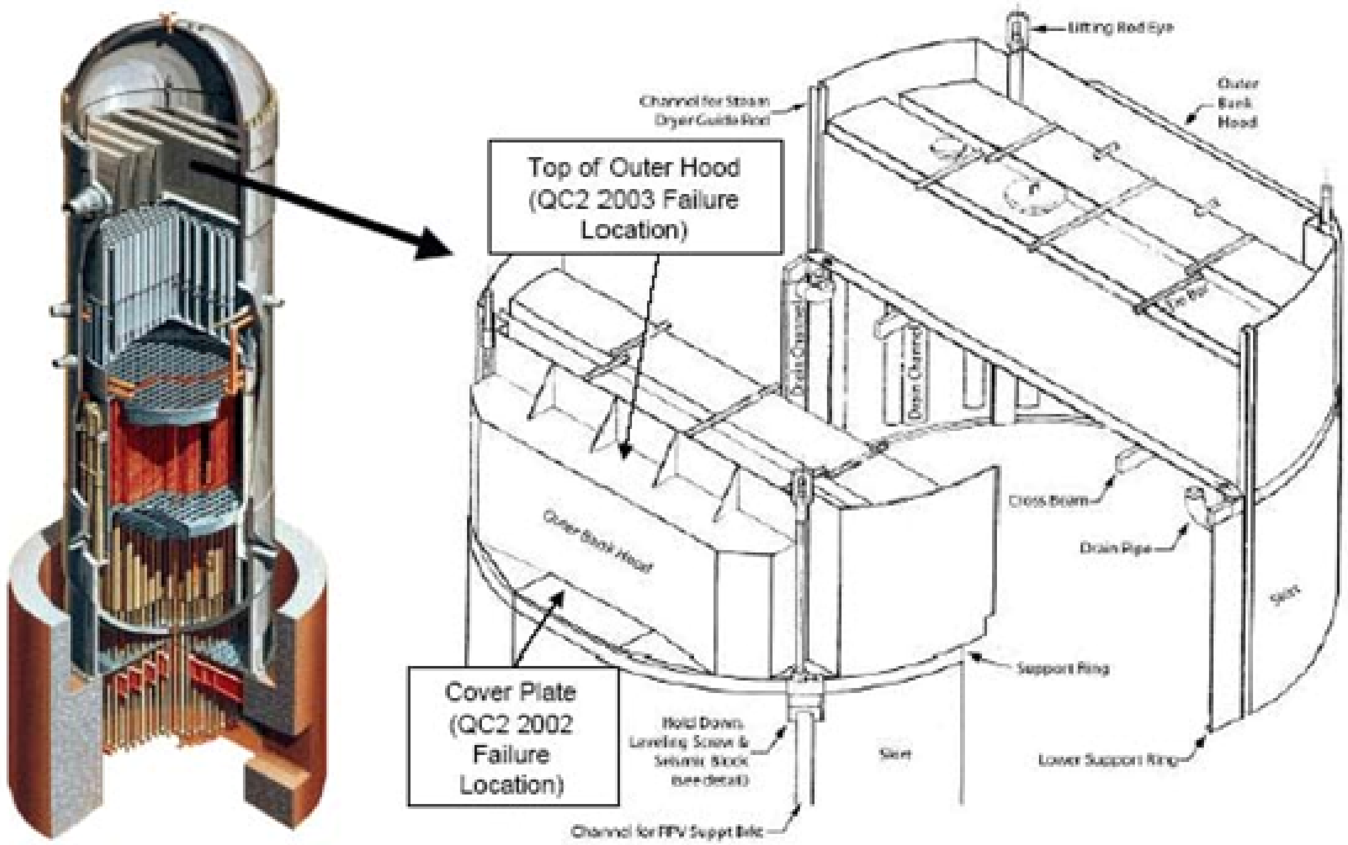
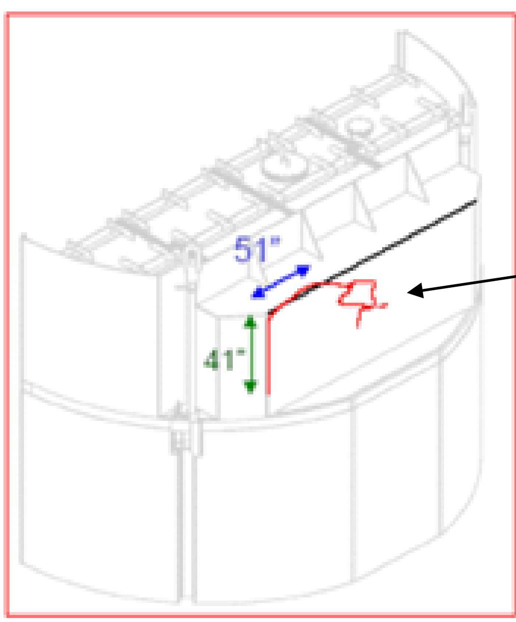
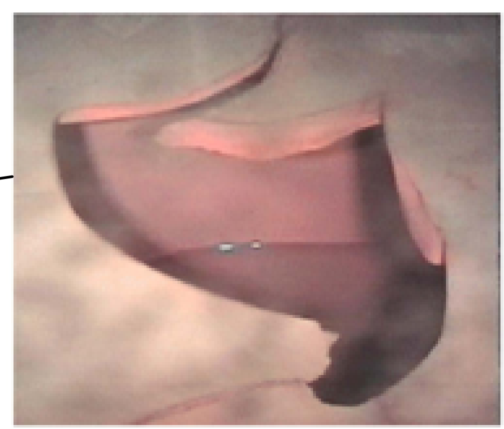




270° Side



Missing portion of outer bank vertical plate, approx 6"X9"

Figure 4.11-1 QC Steam Dryer Damage