



**UNITED STATES
NUCLEAR REGULATORY
COMMISSION**

**MATERIALS DEGRADATION
DUE TO POWER UPRATE**

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INTRODUCTION/ BACKGROUND

- **U.S. power plants have been implementing power uprates to increase electrical output since the 1970s**
- **Power uprates are categorized as:**
 - **Measurement Uncertainty Recapture (increases up to 2%)**
 - **Stretch (increases up to 7%)**
 - **Extended Power Uprate (increases up to 20%)**
- **Cracking of reactor pressure vessel internals is a long-standing issue at Boiling-Water Reactors without power uprates**



Approved Extended Power Upgrades

- **Monticello – 6.3%**
- **Hatch 1 and 2 – 8%**
- **Duane Arnold – 15.3%**
- **Dresden 2 and 3 – 17%**
- **Quad Cities 1 and 2 – 17.8%**
- **Clinton – 20%**
- **ANO-2 – 7.5%**
- **Brunswick 1 and 2 – 15%**



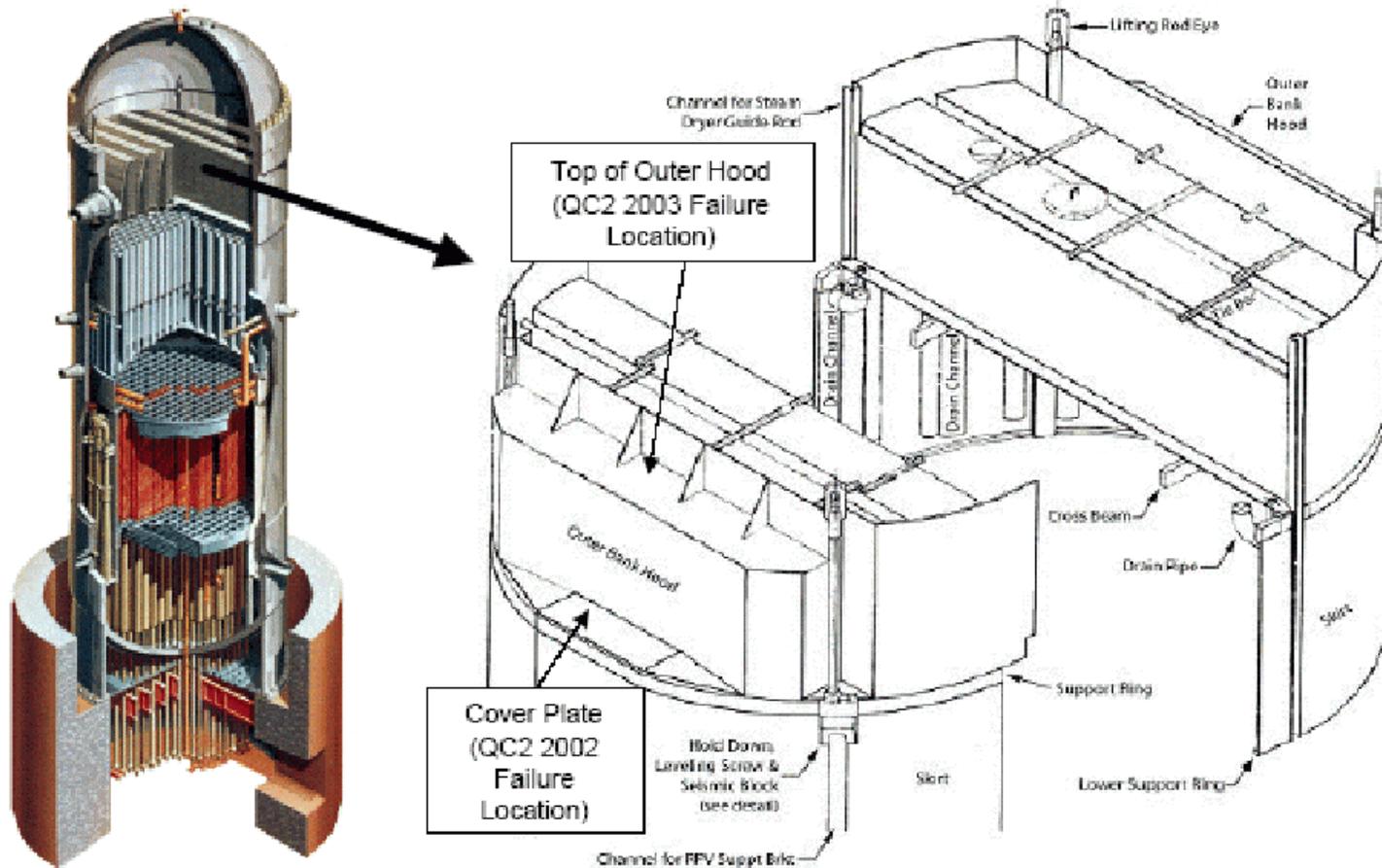
Scope of Material Degradation from Power Uprate

- **Quad Cities Unit 2 – June 2002:**
 - **After 90 days of extended power uprate (EPU) operation, steam dryer cover plate fails with pieces found on steam separators and in main steamline**

- **Quad Cities Unit 2 – June 2003:**
 - **After additional 300 days of EPU operation, steam dryer experiences failure of hood, internal braces, and tie bars**



Quad Cities 2 Steam Dryer Failures 2002 and 2003





Scope of Material Degradation from Power Uprate

- **Dresden Unit 2 - October 2003:**
 - **During refueling outage after two years of EPU operation, 10 centimeter cracks identified in steam dryer hood panels**
 - **Holes found in feedwater sparger from broken feedwater sampling probe**

- **Dresden Unit 2 – December 2003:**
 - **Feedwater sampling probe found missing during shutdown**

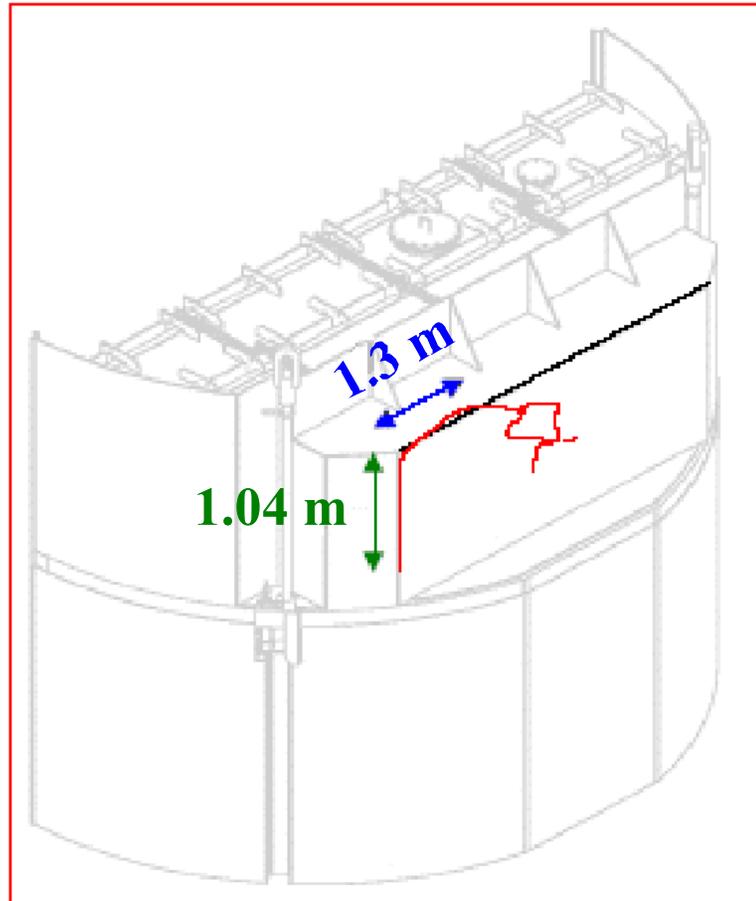


Scope of Material Degradation from Power Uprate

- **Quad Cities Unit 1 - November 2003:**
 - **After approximately one year of EPU operation, significant cracking had occurred on the steam dryer hood and a 16.5X23 centimeter piece of the outer bank vertical plate was missing**
 - **The pilot vent line on a main steam electromatic relief valve (ERV) was sheared off from the pilot assembly and the solenoid actuator for the ERV was significantly damaged. Damage was also discovered on the main steam line supports**



Quad Cities Unit 1 Steam Dryer Failure November 2003



270° Side



Quad Cities Unit 1 Steam Dryer Failure November 2003



**Missing portion of outer bank vertical plate,
approximately 16.5 cm. X 23 cm.**



Scope of Material Degradation from Power Uprate

- **Dresden Unit 3 – December 2003:**
 - **During shutdown inspection after 10 months of EPU operation, two 10 centimeter through-wall cracks were found in the steam dryer hood**
 - **Two feedwater sampling probes were found in the feedwater sparger**

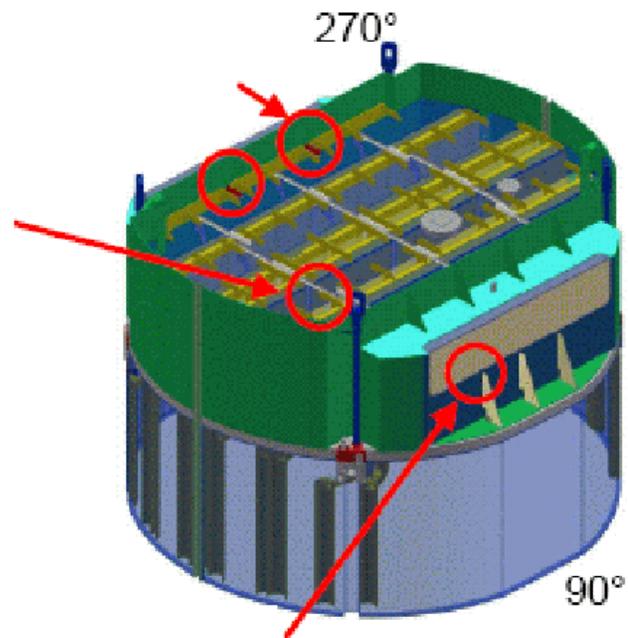
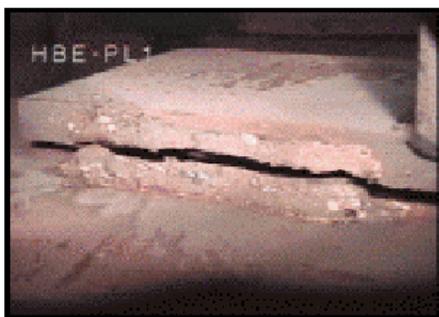


Scope of Material Degradation from Power Uprate

- **Quad Cities Unit 2 – March 2004:**
 - **After approximately 8 months of EPU operation, numerous steam dryer indications were identified during a refueling outage inspection including:**
 - **Cracking near gussets installed in 2003,**
 - **Broken tie bar welds, and a**
 - **Damaged stiffener plate weld**
 - **Damage was identified in areas that had previously been repaired**
 - **A Target Rock safety relief valve tested 6.8% above the nominal safety lift setpoint**



Quad Cities Unit 2 Steam Dryer Failure March 2004





Steam Dryer Cracking Power Uprated Plants

- **Other boiling-water reactor plant inspections in Spring 2004:**
 - **A thin, 46 centimeter crack along a weld was found at Nine Mile Point Unit 2, (Curved Hood Steam Dryer), after several years of operation at 4.3% power uprate**
 - **Minor cracking was found at Brunswick Unit 1, (Slanted Hood Steam Dryer), after two years of operation at 13 % power uprate**



Potential Causes of Material Degradation

- **July 2002 Quad Cities Unit 2 steam dryer cover plate:**
 - **High cycle fatigue due to high frequency resonance (180 Hz) as a result of alignment of cover plate natural frequency, standing acoustic wave frequency, and vortex shedding frequency**

- **July 2003 Quad Cities Unit 2 steam dryer hood:**
 - **High cycle fatigue due to low frequency pressure loading (0 – 50 Hz)**

- **November 2003 Quad Cities Unit 1 steam dryer:**
 - **High cycle fatigue from fluctuating pressure loading with acoustics**



Potential Causes of Material Degradation

- **2003 Dresden Feedwater Isokinetic Probes:**
 - **Resonance frequency vibration**

- **January 2004:**
 - **General Electric identified fluctuating pressure load in the acoustic range as a potential failure cause of the Quad Cities steam dryers**
 - **Exelon's study of the vibration effects determined that Quad Cities electromatic relief valves were unable to withstand EPU vibration for a full operating cycle**



Potential Causes of Material Degradation

- **March 2004 Quad Cities Unit 2 steam dryer:**
 - **Inadequate design of previous gusset repair, movement of high stress point during tie bar repair, and poor installation practice for stiffener plate**

- **Reasons Quad Cities and Dresden are more susceptible to adverse flow effects:**
 - **Units have steam dryers with square hoods. Square hood designs experience greater stress than the slanted or curve hood designs**
 - **The main steam lines are smaller in diameter than at other units and therefore have higher steam velocities**
 - **EPU power uprate results in increased loadings on feedwater and main steam components**



Plant-Specific Corrective Actions

- **July 2002:**
 - **Quad Cities Unit 2 steam dryer cover plate thickness increased from 0.64 cm. to 1.27 cm.**

- **July 2003:**
 - **Quad Cities Unit 2 steam dryer outer hood plates thickness increased from 1.27 cm. to 2.54 cm. with gussets installed and braces removed**

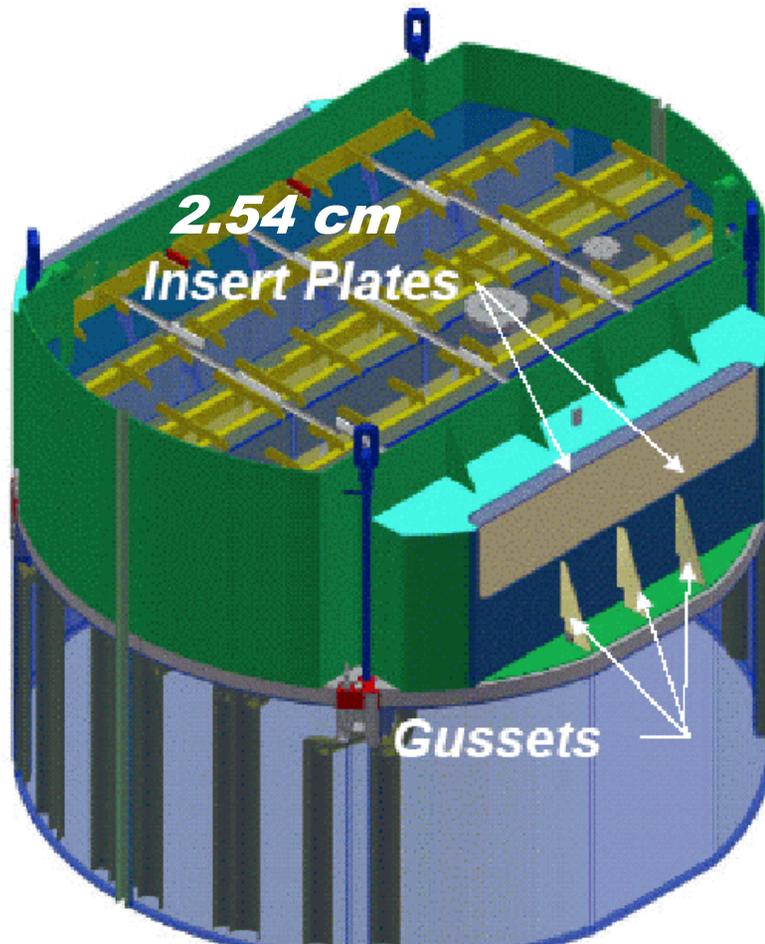
- **October 2003:**
 - **Dresden Unit 2 steam dryer modified similar to Quad Cities Unit 2 (July 2003)**

- **November 2003:**
 - **Quad Cities Unit 1 steam dryer modified similar to Quad Cities Unit 2 (July 2003)**

- **December 2003:**
 - **Dresden Unit 3 steam dryer repair improved over both Quad Cities units**



Quad Cities Unit 1 Steam Dryer Repairs November 2003

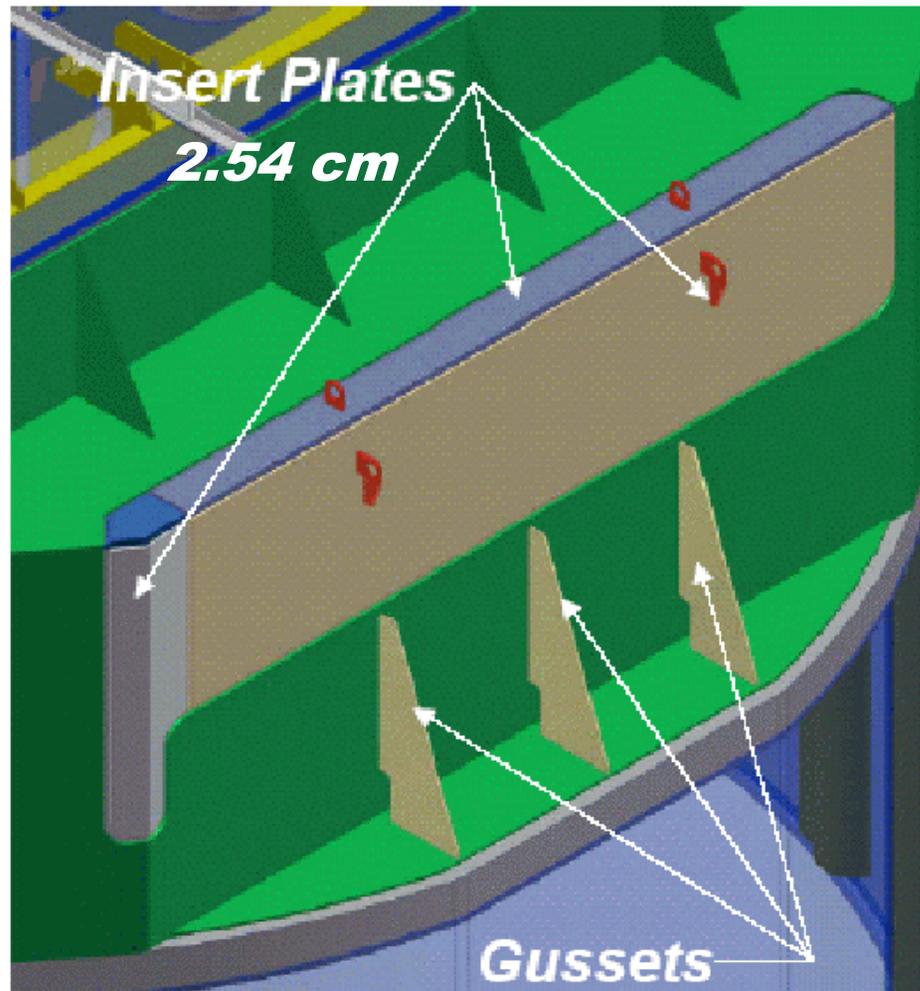


Similar to:

Quad Cities 2 – June 2003
Dresden 2 – October 2003



Quad Cities Unit 1 Steam Dryer Repairs November 2003



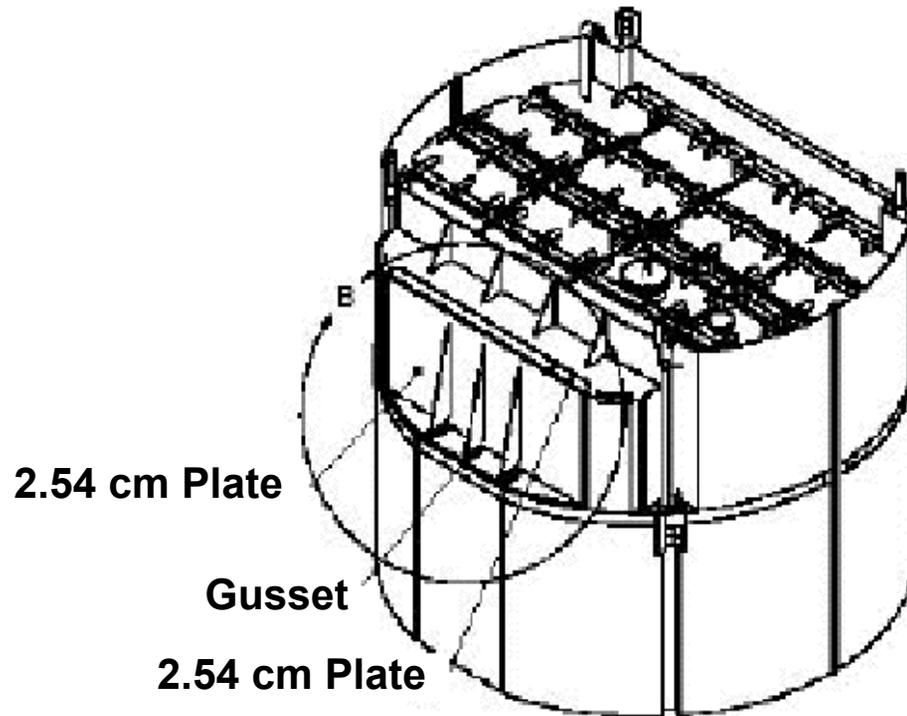


Plant-Specific Corrective Actions

- **Quad Cities Unit 2 – March 2004:**
 - **Replacement of entire vertical plate of steam dryer hood**
 - **Installation of full-length gussets on vertical plate**
 - **Electromatic relief valves strengthened to support two-year operating cycle**



Quad Cities Unit 2 Steam Dryer Repairs March 2004





Industry Action

- **August 2002: General Electric SIL 644 issued for square-hood steam dryers to monitor moisture carryover and refueling outage inspections**
- **September 2003: Supplement 1 to SIL 644 to all boiling-water reactors with power uprates to monitor moisture carryover and refueling outage inspections**
- **February 2004: The Boiling-Water Reactors Owners Group (BWROG) assumes the industry lead for EPU vibration issues**



Industry Action

- **March 2004: Exelon evaluated Dresden EPU operation with refueling outages in November 2004 (Unit 3) and November 2005 (Unit 2)**

- **Exelon Commitments – April 2, 2004:**
 - **Limit Quad Cities units to pre-EPU power except for 72-hour testing period**
 - **Modify Quad Cities Unit 1 electromatic relief valves before long-term EPU operation**
 - **Provide specific commitments on the following:**
 - **NRC acceptance of Quad Cities units EPU operation**
 - **Reevaluation and future monitoring of steam dryers and other components impacted by flow-induced vibrations**
 - **Description of steam dryer loads and future inspection plans and repairs**



Planned Industry Actions

- **June 2004: General Electric plans to complete a review of steam dryers and steam and feedwater components**
- **September 2004: The Boiling-Water Reactors Vessel and Internals Project plans to complete new steam dryer inspection guidance**



NRC Actions

- **September 2002: Information Notice (IN) 2002-26, “Failure of a Steam Dryer Cover Plate After a Recent Power Uprate,” issued documenting cover plate failure at Quad Cities Unit 2**
- **July 2003: Supplement 1 to IN 2002-26, “Additional Failure of Steam Dryer After a Recent Power Uprate,” issued documenting the subsequent failure of the steam dryer at Quad Cities Unit 2. An NRC Special Inspection was performed following the steam dryer failure**



NRC Actions

- **September 2003: NRC issues a letter to the BWROG with comments on the General Electric SIL, Supplement 1**
- **November 2003: NRC holds a public meeting with the BWROG to discuss steam dryer cracking and other flow-induced vibration issues. NRC also has discussions with Exelon regarding the Quad Cities Unit 1 steam dryer repairs and lost parts**



NRC Actions

- **January 2004: Supplement 2 to IN 2002-26, “Additional Flow-Induced Vibration Failures After a Recent Power Uprate” issued documenting steam dryer and other component failures at Quad Cities Unit 1**
- **February and March 2004: The NRC holds additional public meetings with the BWROG to discuss steam dryer cracking and other flow-induced vibration issues**



NRC Actions

- **March 2004: IN 2004-06, “Loss of Feedwater Isokinetic Sampling Probes at Dresden Units 2 and 3” issued**
- **March and April 2004: The NRC holds internal meetings to discuss research support on adverse flow effects from power uprates**



NRC Actions

- **April 2004: The NRC sends an acknowledgement letter to Exelon noting concerns with Exelon's plans to justify long-term EPU operation at Quad Cities and Dresden**



NRC Future Actions

- **NRC Research to establish a program to address the adverse flow effects due to power uprates in boiling-water reactors, including procuring technical consultants in flow-induced vibration**
- **Review Exelon's information supporting Quad Cities and Dresden units EPU operation**
- **Consider issuing additional generic communications**
- **Revise the EPU Review Standard**



Other Technical Challenges

- **Ultrasonic flow instrumentation (MURs)**
- **Transient testing and monitoring of flow-induced vibration (EPU's)**
- **Ancillary effects**



Ultrasonic Flow Instrumentation Problems (MURs)

- **AMAG Ultrasonic Flow Instruments**
 - **NRC evaluating the potential impact of this issue on power uprates**
 - **NRC issued a Morning Report describing issue**
 - **Issue does not pose an immediate safety concern**
 - **NRC rescinded approval of MUR at Fort Calhoun due to problems implementing the power uprate with AMAG**
 - **Currently, no known problems at units that have implemented MUR power uprates**
- **Calton Ultrasonic Flow Instruments**



Transient Testing and Flow-Induced Vibration Monitoring (EPU)

- **Guidance for transient testing is contained in draft Standard Review Plan (SRP) 14.2.1**
 - **Considers original power ascension tests**
 - **Focuses on EPU related modifications**
- **Guidance acknowledges that licensees may propose alternative approaches**
 - **Provides supplemental guidance for evaluation of alternative approaches**
- **Guidance places responsibility on licensees to justify proposed alternative approaches**
- **Licensees should consider instrumenting and monitoring steam and feedwater lines and components for flow-induced vibration changes**



Ancillary Effects

- **Accelerated use of the spent fuel pool**
- **ALARA adjustments**
- **Challenges to equipment performance due to increased temperatures in the plant**



Other Important Focus Areas following Power Upgrades

- **Reduction in time available for operator actions**
- **Irradiation-assisted stress corrosion cracking of reactor internals**
- **Flow-accelerated corrosion**
- **Fatigue of feedwater piping**
- **Containment response**
- **Local power oscillations**
- **ATWS and ATWS recovery**



SUMMARY

- **Some material degradation issues have resulted from power uprates, especially due to flow-induced vibrations**
- **NRC, General Electric, power plant owners and the BWROG are monitoring and evaluating material degradation issues related to power uprates, including the causes and corrective actions for these issues**
- **The NRC has issued several generic communications on material degradation issues related to power uprates and continues to interact with General Electric and the industry to address these issues**
- **The focus of NRC's reviews of these issues is on maintaining safety following implementation of the power uprate**



Power Uprates

- **NRC's Power Uprate Website**

<http://www.nrc.gov/reactors/operating/licensing/power-uprates.html>

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