## BWR/PWR IN-VEssel Inspection Workshop

**International Light Water Reactor Materials Reliability Conference and Exhibition 2016**  
August 1, 2016 • Hyatt Regency McCormick Place, Chicago, Illinois USA  
Room 102A

### AUGUST 1, 2016

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<tr>
<th>TIME</th>
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<tr>
<td>8:00 AM</td>
<td>Introduction and Safety Brief</td>
<td>Kyle Amberge (EPRI)</td>
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<td>8:10 AM</td>
<td>Overview of NEI 03-08, Material Initiative</td>
<td>Chuck Wirtz (EPRI)</td>
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<td>8:30 AM</td>
<td>BWR Aging Management Program Development</td>
<td>Chuck Wirtz (EPRI)</td>
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<td>9:30 AM</td>
<td>PWR Aging Management Program Development</td>
<td>Kyle Amberge (EPRI)</td>
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<td>10:45 AM</td>
<td>Review PWR Reactor Internals Guideline (MRP-227)</td>
<td>Kyle Amberge (EPRI)</td>
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<td>Review PWR Reactor Internals Inspection Standard</td>
<td>Jack Spanner (EPRI)</td>
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<td>Review BWR Vessel Internals (BWRVIP) Guidelines</td>
<td>Chuck Wirtz (EPRI)</td>
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<td>3:30 PM</td>
<td>Inspection Experiences, Results and Lessons Learned</td>
<td>Jack Spanner (EPRI) / Jeff Landrum (EPRI)</td>
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The Materials Initiative and NEI 03-08

Chuck Wirtz
EPRI BWRVIP Integration Task Manager

International LWR Materials Reliability Conference
August 1, 2016
Overview

- Primary system materials integrity is vital to plant performance and reliability
- Reactor components operate in a harsh environment - high temperatures, cyclic stress, vibration, intense neutron fields, etc.
- Numerous materials and alloys exist in a plant’s systems and the aging of these materials is complex and not always fully understood
- Routine surveillances, ISI, and replacements can mitigate some of these factors; however, some failures can be expected
- **Challenge**: To find the next material vulnerability and to address it before any failures occur
Operating Experience

- Reactor Internals components:
  - Core shrouds
  - Core spray piping
  - Jet pump beams
  - Jet pump inlet piping
  - Jet pump restrainer brackets
  - Top guides
  - Steam dryers
  - PWR baffle bolts and split pins

- Pressure boundary items:
  - BWR recirculation piping
  - BWR CRD stub tubes
  - Pressurizer heater sleeves
  - Primary system full penetration butt welds
  - PWR reactor vessel bottom mounted nozzles
  - PWR CRDM head penetrations
Forcing Function

- BWRs had programs dealing with IGSCC
  - Piping covered by GL 88-01 and then BWRVIP-75
  - Reactor internals managed by BWRVIP program

- A series of events in PWRs motivated industry executives to take broad generic action
  - Indian Point steam generator tube
  - V.C. Summer dissimilar metal weld leak
  - Multiple PWR head penetration leaks
  - Davis-Besse RPV head wastage
Indian Point

- February 2000: SG tube leak
  - Hidden by noise in NDE signal
Crack in RCS hot leg, Fall 2000
– A Hot Leg Nozzle to Pipe Weld

Extent of Axial Crack
Extent of Circumferential Crack
Blunts at Carbon Steel
PWR RPV Heads

Leaking PWR CRDM Head Penetrations
Davis-Besse

March 2002

- CRDM penetration and head wastage
BWR Internal Components

Alloy 182/600 304, 304L, or 347SS

Steam Dryer
Core Spray Piping
Core Spray Safe End to Nozzle Weld Butters
SRM Dry Tubes and In-core Housing
Recirc. Inlet Safe End and nozzle welds
CRD Stub Tube to Housing Weld

Access Hole Cover

Core Shroud Welds
Jet Pump Riser Brace
Jet Pump Beams
Recirc. Piping Welds
Shroud-to-Shroud Support Welds
Jet Pump Riser Elbow
Top Guide
PWR PWSCC Potential Impact

- Surge nozzle - pipe welds
- Safety & relief nozzle-pipe welds
- RV nozzle - pipe weld
- CRDM motor housing
- CRDM nozzles to RV head welds
- Head vent pipe
- Monitor tube
- Core support block
- RV nozzle-pipe weld
- Heat transfer tubing
- Tubesheet (TS) cladding
- Tube-TS cladding weld
- Partition plate & welds
- Bottom channel head drain tube & welds

* Represents locations that have experienced cracking and or leakage at other PWRs are highlighted in red.
Impact of Unexpected Operating Experience (OE)

- Unanticipated Impacts
  - Events costly and impact reliability, safety, and performance
    - Davis-Besse – more than $500M
    - Unplanned head replacement ~ $60M to $100M and up
    - Unanticipated RPV penetration repairs ~$65M
    - Lost generation ~$1 million/day replacement power
    - Increased dose exposure
      - Increased regulatory involvement and oversight
      - Quality of life of utility work force
- Something had to be done
The issues and expectation

- What will fail next?
- When will it fail?
- Are replacement materials susceptible?

Industry must anticipate and stay ahead of these problems
In August 2002 NEI Executive Committee directed industry to:
  – Get in front of material issues
  – Perform assessment of materials programs to identify strengths, weaknesses, and make recommendations
  – Scope
    ▪ Primary pressure boundary components in BWRs and PWRs
    ▪ Material issues related to nuclear fuels
    ▪ NDE
    ▪ Chemistry/corrosion control programs

A Materials Assessment Working Group (MAWG) was formed with representatives from all industry groups dealing with materials issues
MAWG Issue Statement

The corrosion of the base metal in the Davis-Besse reactor pressure vessel head, increased occurrences of control rod drive mechanism nozzle cracking in pressurized water reactors (PWRs), and the V. C. Summer hot leg dissimilar metal weld defect represent issues that have threatened nuclear plant asset value and raised questions regarding the ability of the industry to detect degraded conditions in reactor coolant system components and piping. Other plant events over the last three years involving steam generator tubes, boiling water reactor (BWR) vessel internals and other pressure boundary, vessel internals, and fuel materials suggest that the nuclear industry has not been able to consistently anticipate and manage materials problems as well as it could. These events also suggest the need for better integration of existing PWR and BWR materials programs, as well as underlying technical support programs in the areas of plant chemistry, NDE, cracking/corrosion research, etc. Lessons from programs that are working well need to be transferred. Finally, the industry must continue to monitor and manage the impacts of materials issues prevention and mitigation strategies on fuel reliability and performance.
Key Conclusions from MAWG Assessment

- Industry lacked a unified strategic focus and direction
- Limited coordination of industry efforts on materials issues
- Budget and funding challenges
- Unable to enforce and to verify implementation of industry guidance
- Oversight of industry materials efforts was inconsistent
- Industry participation in materials issue programs lacking
- Implementation of materials tools inconsistent

**Recommendation**: Define an NSIAC Initiative to address materials aging management
What is a NSIAC Initiative?

- Formal agreement among the utility Chief Nuclear Officers (CNOs) that form the Nuclear Strategic Issues Advisory Committee (NSIAC) to follow a defined policy
- Requires 80% vote of the NSIAC for approval
- **Binding** industry commitment at CNO level for full implementation
  - Not a formal regulatory commitment
  - Provides regulatory credibility
  - Deviation process involves an informal regulatory commitment
Industry Materials Initiative

- Unanimous NSIAC approval May 2003
- Initiative provides for:
  - Two oversight groups for materials issues
    - MEOG – Materials Executive Oversight Group
    - MTAG – Materials Technical Advisory Group
  - Proactive management of materials aging
  - Integration and coordination of industry work on materials issues
  - Funding provision for high priority, emergent and long term issues
  - Consistent and timely implementation of guidelines
  - Oversight of industry material activities
  - Treated as if it were a regulatory commitment
NEI 03-08 – Guideline for the Management of Materials Issues

- Documents the Materials Initiative
- Defines scope of the Initiative
- Establishes policy
- Identifies Issue Programs within scope
- Defines roles, and responsibilities
  - MTAG and MEOG
  - Issue Programs (IPs)
  - Utilities
- Current version is Revision 2, effective January 1, 2010

Note: Initial version of NEI 03-08 had 10 strategic elements for IPs. It recommended the BWRVIP as the program to be used as a model for 8 of the 10 elements
Materials Initiative

- The objective of this Initiative is to assure safe, reliable and efficient operation of the U.S. nuclear power plants in the management of materials issues.
- **Each licensee will endorse, support and meet the intent of NEI 03-08**, Guideline for the Management of Materials Issues. This initiative is effective January 2, 2004.
- The purpose of this Initiative is to:
  - provide a consistent management process
  - provide for prioritization of materials issues
  - provide for proactive approaches
  - provide for integrated and coordinated approaches to materials issues
- **Utility actions required** by this Initiative include:
  - commitment of executive leadership and technical personnel
  - commitment of funds for materials issues within the scope of this Initiative
  - commitment to implement applicable guidance documents
  - provide for oversight of implementation
Materials Management Policy

Initiative Policy Statement

“… the industry will ensure that its management of materials degradation and aging is **forward-looking and coordinated** to the maximum extent practical. Additionally, the industry will **continue to** rapidly identify, react and **effectively respond to emerging issues**. The associated work will be managed to emphasize safety and operational risk significance as the first priority, appropriately balancing long term aging management and cost as additional considerations. To that end, as issues are identified and as work is planned, the groups involved in funding, managing and providing program oversight will ensure that the **safety and operational risk significance of each issue is fully established prior to final disposition**.”
NEI 03-08 Scope and Issue Programs

- **Scope**
  - Reactor internals
  - Primary system pressure boundary components
  - Related NDE, chemistry and corrosion controls
  - Other as directed by NSIAC

- **Issue Programs (IPs)**
  - EPRI
    - BWRVIP
    - MRP
    - SGMP
    - NDE
    - Corrosion Research (PSCR)
    - Chemistry Control (WCC)
  - PWROG Materials Subcommittee (MSC)
NEI 03-08 Expectations for Owners

- **Utility responsibilities** *(shall)*
  - Maintain a RCS Materials Degradation Management Program
  - Implement “Mandatory” and “Needed” IP guidance (see next slide)
  - Participate in IPs
  - Apply appropriate focus on materials issues
  - Communicate materials OE
NEI 03-08 Implementation Requirements

- NEI 03-08 guidance is classified as follows:
  - “Mandatory” - to be implemented at all plants where applicable
  - “Needed” – to be implemented whenever possible, but alternative approaches are acceptable
  - “Good Practice” – implementation is expected to provide significant operational and reliability benefits, but the extent of use is at the discretion of the individual plant or utility

- In practice, “Mandatory” and “Needed” guidance is required unless a formal deviation disposition is processed (similar to a ASME Code Relief Request). The only difference for a deviation from “Mandatory” guidance versus one from “Needed” guidance is that deviating from “Mandatory” guidance requires independent 3rd party approval.

- BWRVIP guidelines typically include an “Implementation” paragraph in Section 1 of the report that outline the NEI 03-08 implementation requirements of the report.
NEI 03-08 Expectations for Issue Programs

- Materials IP responsibilities
  - Identifying, prioritizing, and resolving issues
  - Communicating
  - Managing regulatory interface
  - Developing guidance
  - Reviewing deviations
  - Self assessments and performance metrics
  - Process for addressing emergent materials issues
2008 Assessment

- Industry performed an assessment of NEI 03-08 effectiveness

- Key conclusions:
  - Overall success in achieving the Initiative’s objectives
  - Broad commitment to the Policy and desired behavior is being obtained
  - Overall guidance is being implemented and programs are being supported
  - Continue management attention to the use of deviations
  - Highest priority issues being addressed by IPs, but improvements could be obtained by prioritizing across IP boundaries
  - Roles of MEOG, MTAG, and APWG should be revisited
2008 Assessment Impact

- MEOG and MTAG will be sunset
- EPRI Materials Action Plan Committee (MAPC) to provide strategic direction for materials issues including:
  - EPRI materials IPs: BWRVIP, MRP, SGMP, PSCR, WCC, NDE
  - PWROG MSC
- NDE APC would be separate but coordinate with MAPC
- BWRVIP and PWR executive committees report to MAPC for strategic coordination
- MAPC members to include:
  - CNO as chair to coordinate with NSIAC
  - Executive and Technical chairs of the IPs
  - At-large members for fleet representation
  - INPO and NEI representatives
- Implement January 1, 2010
Materials Organizational Structure

- **Nuclear Power Council**
  - **Long Term Operations**
  - **NDE Action Plan Committee**
  - **Materials & Aging Action Plan Committee (MAPC)**
    - **Executive Chair:** CNO/VP Level Executive
    - **Technical Chair:** VP/Director Level Executive
  - **Water Chemistry Action Plan Committee**
  - **Other APCs not shown**

- **BWRVIP Executive Committee**
  - **BWR Vessel Internals Program (BWRVIP)**
  - **Primary System Corrosion Research (PSCR)**
  - **Welding & Repair Technology Center (WRTC)**

- **PMMP Executive Committee (EC)**
  - **PMMP (EOC)**
  - **PMMP Executive Committee (EC)**
  - **Material Reliability Program (MRP)**
  - **Steam Generator Mgmt Project (SGMP)**

- **PWR Owners Group Materials Subcommittee (PWROG MSC)**

* NDE APC coordinates with Materials APC and PWR Owners Group
** Materials Subcommittee has a representative on Materials APC
Initiative Accomplishments

- Integrated industry strategic plan for materials
- Achieved a high level of industry integration, coordination, alignment, and communication on material issues
- Established a process for prioritizing projects, budgets, and planning
- Predictable funding for materials R&D
- Engaged INPO as an active participant
- Defined expectations and protocols for industry actions upon discovery of an emergent issue
- Established consistent process for deviations and communication with NRC
- Executive level interactions between industry and senior NRC management
- Successful at closing materials issues and gaps
- Fewer unexpected materials related transients
Together...Shaping the Future of Electricity
Boiling Water Reactor Aging Management Program Development

Chuck Wirtz
EPRI BWRVIP Integration Task Manager

International LWR Materials Reliability Conference
August 1, 2016
Outline

- Intergranular Stress Corrosion Cracking (IGSCC) Background and Timeline
- BWROG and Industry’s Initial Response to BWR Internals IGSCC Issues
- Establishment of the BWRVIP and its Objectives
- Initial Strategic Planning
- Current BWRVIP Strategic Planning Processes (MDM & IMTs)
- BWRVIP Organization & Membership
- Summary
- Regulatory Background
Intergranular Stress Corrosion Cracking (IGSCC) Background and Timeline
IGSCC Background

• Intergranular Stress Corrosion Cracking (IGSCC) in austenitic piping was a major issue for Boiling Water Reactors (BWRs) in the 1980s – susceptibility of reactor internals to IGSCC was also recognized

- Shroud cracking in 1993-1994 confirmed that IGSCC of internals is a significant issue for BWRs
- BWR utility executives formed the BWRVIP in mid-1994 to proactively address BWR reactor vessel and internals material condition issues
- The goal was to lead industry toward proactive generic resolution of vessel and internals material condition issues with generic, cost-effective strategies
IGSCC Background

- The BWR Owners Group (BWROG) for IGSCC research formed in 1979-1980
  - Worked with EPRI to integrate IGSCC research for industry
  - GE led much of the work to understand IGSCC
  - In response to NMP-1 leaking safe-ends, EPRI developed a procedure and protocol for IGSCC UT tests
  - First IGSCC ultrasonic (UT) qualification completed October 8, 1982
  - NRC, EPRI and BWROG developed a 3-party agreement for the qualification of ultrasonic examiners for IGSCC

- From these efforts by BWROG, EPRI and GE came:
  - Fundamental understanding of IGSCC
  - Initial understanding of HWC
  - IGSCC specific UT procedures and personnel qualification

- GE devoted much to the understanding IGSCC
  - Ford and Andresen slip dissolution model
  - Understanding fundamental cause/method of IGSCC initiation and growth allowed mitigation to be developed
IGSCC Timeline 1965-1988

- IGSCC in stainless steel piping started in early 1960s
- 1965 – first occurrence in commercial BWR at Dresden 1 in 6” bypass line in HAZ
- 1974 – Dresden 2 IGSCC detected in 4” bypass line
  - U.S. Atomic Energy Commission orders 15 plants to shut down and inspect 4” piping (Inspection and Enforcement Bulletins (IEB) 74-10, 10A, 10B)
  - Inspections (1974-1975) result 9 plants finding IGSCC in 4” bypass lines or 10” sch. 80 core spray pipe (IEB 75-01)
  - All cracking detected to-date in small diameter and stagnant lines
- 1975 – newly formed NRC orders 23 BWRs shut down for inspection – operational impact
- 1977 – 3 international plants identify IGSCC in recirculation risers (IGSCC in high flow pipe)
- 1982 – Through-wall IGSCC detected by leakage at 2 safe-ends in Nine Mile Point Unit 1
  - Had been examined ultrasonically (UT) 9 months earlier
  - Raised questions about adequacy of UT
  - NRC issues IEB 82-03
- 1983 – NRC issues IEB 83-02 to address mounting concerns on large-bore cracking
- 1984 – NRC issues Generic Letter (GL) 84-07 and GL 84-11
- 1984, May – axial cracking detected in nozzle to safe-end weld
- 1984, June – BWROG approves research program to address IGSCC with NDE and Repairs
- 1988 – NRC issues GL 88-01 and NUREG-0313. It becomes the standard for piping exams for the next decade
IGSCC Timeline 1990 - 1999

- **1989 - 1990 :**
  - BWROG has an Internals Inspection and Repair committee formed
  - Issues with jet pump beams, shroud head bolts, dry tubes, core plate plugs, etc.

- **1990 Shroud cracking is detected at an international BWR-4. GE issues RICSIL 054.**

- **1992 – BWROG meets with NRC in January on potential cracking of BWR internals. NRC encourages BWROG to address internals cracking comprehensively**

- **1993 – Brunswick 1 detects shroud cracks**

- **1993 – GE issues RICSIL 054, Rev 1 in July and includes revised inspections**

- **1993 – In October GE issues SIL-572 to replace RICSIL 054**

- **1994 – BWROG issues inspection criteria**

- **1994 – Spring additional shroud cracking detected at Dresden 3 and Quad Cities 1**

- **1994 – June 10, BWRVIP formed**

- **1994 – June 28, BWROG meets with NRC introducing the BWRVIP and providing justification for continued operation till inspections could be performed**

- **1994 – July 25, NRC issues GL 94-03**

- **1999 – BWRVIP-75 was developed to alter inspection frequencies in GL 88-01. BWRVIP-75-A released October 2005**
BWR Internals Susceptible to IGSCC

- RPV Attachment welds
- Shroud head bolts
- Feedwater nozzle
- Top Guide
- Core Shroud Welds
- Jet Pump Riser Brace
- Jet Pump Beams
- Recirc. Piping Welds
- Shroud-to-Shroud Support Welds
- Jet Pump Riser Elbow
- CRD Stub Tube to Housing Weld
- Access Hole Cover
- Steam Dryer
- Core Spray Piping
- Core Spray Safe End to Nozzle Weld Butters
- SRM Dry Tubes and In-core Housing
- Recirc. Inlet and outlet Safe End and nozzle welds

Alloy 82/182, 600
304, 304L, 316 or 347SS
X-718, X-750
Boiling Water Reactor Owners Group (BWROG) and Industry’s Initial Response to BWR Internals IGSCC Issues
GE and BWROG Addressing IGSCC in BWR Internals

- GE understood possibility of IGSCC affecting reactor internals and shared the information with owners via the BWROG
- GE and BWROG efforts on internals
  - Work by BWROG Internals Inspection and Repair committee
  - Series of Service Information Letters (SILS) and Rapid Information Communication Services Information Letters (RICSILS) recommending inspections
  - KKM first identified shroud cracking – 1990
  - BWROG meets with NRC in January 1992 – NRC encourages action
  - Brunswick 1 was the first U.S. plant to identify shroud cracking 1993
  - NRC issued Information Notice (IN) 93-79
  - April 1994 the BWROG produced “BWR Core Shroud Evaluation” (GE-NE-523-148-1193)
  - More extensive cracking was detected at Dresden 3 and Quad Cities 1 in Spring 1994
  - NRC issued IN 94-42 and IN 94-42, supplement 1 respectively
Initial Shroud Cracking Response

- NRC began questioning plant operability in light of IGSCC in shrouds and its potential to be a common mode of internals failure
- Industry/BWROG and GE began work on:
  - Revised shroud inspection and evaluation criteria - “BWR Shroud Cracking Safety Assessment”
  - Bases for continued operation until examinations could be done
- June 10, 1994 Industry executives met to discuss strategy on BWR internals cracking
  - Believed effort would be too large for a committee within BWROG
  - Decided to work with EPRI – effort to be similar to steam generator program
  - Access to international information and not limited to NSSS vendor
  - Established the BWR Vessel and Internals Project (BWRVIP)
  - 7 executives volunteered to take active lead role
Establishment of the BWRVIP and its Objectives
Establishment of the BWRVIP

- June 28, 1994 industry executives met with NRC senior management on shroud cracking
  - Presented a detailed description justifying continued operation till shroud examinations could be completed
  - Introduced the BWRVIP organization to NRC – including an the executive that would lead each technical area

- July 14, 1994 BWROG submitted a “BWR Shroud Cracking Safety Assessment” (GENE-523-A107P-0794)
  - Provided basis for continued operation presentation of June 28
  - Due to urgent need, issued without BWROG member’s review

- July 25, 1994 NRC Issues Generic Letter (GL) 94-03 requesting:
  - Owners examine their shrouds no later than next refueling outage
  - Owners perform a safety assessment justifying operation till examinations are complete
  - (Note: NRC later reported BWR shroud cracking to Congress as Abnormal Occurrence 94-20 in NUREG-0900, Vol. 17)
Shroud Safety Assessment

- August 5, 1994 BWROG issues Revision 1 to “BWR Shroud Cracking Safety Assessment”
  - Fully endorsed by owners
  - Categorized plants into susceptibility groups
  - Documented shroud flaw tolerance
  - Evaluated the likelihood of a $360^\circ$ through-wall crack in conjunction with a combination of Loss of Coolant Accident (LOCA) and seismic events
  - Justified continued operation till examinations were performed
  - Updated consequence analysis of $360^\circ$ through-wall crack
  - Appendix A documented the safety analysis including
    - All shroud weld locations
    - Normal operations and accident scenarios
    - Operator actions
BWRVIP Objectives

- Lead industry toward proactive generic resolution of vessel and internals material condition issues
- Identify or develop generic, cost-effective strategies from which each operating plant will select the alternative most appropriate to their needs
- Serve as a focal point for the regulatory interface with the industry in BWR vessel and internals material condition issues (including license renewal)
- Share information among members to obtain useful data from many sources
**BWROG Transition to BWRVIP - Final Steps**

- **September 2, 1994** BWRVIP issues BWR Core Shroud Inspection and Evaluations Guidelines (GENE-523-113-0894) to NRC (precursor to BWRVIP-01, published October 1996)

- **December 28, 1994** NRC issued its Safety Evaluation (SE) to the BWRVIP for the:
  - BWROG “BWR Core Shroud Evaluation”, and
  - BWRVIP “BWR Shroud Cracking Safety Assessment”

- **This Safety Evaluation:**
  - Effectively closed out the BWROG role for owners on internals cracking completing the transition to the BWRVIP
  - Identified NRC acceptance of many shroud approaches and categories
  - Identified NRC concerns and limitations (NDE, reinspection, repairs, etc.)

- **This SE combined with the results from BWRVIP-06 set the initial course of the BWRVIP**
Initial Strategic Planning
Initial Strategic Planning

- While the initial focus of the industry efforts was to address shroud cracking, common mode failure of other internals was a concern.
- Parallel to the efforts to answer GL 94-03 and issue shroud safety assessments and inspection criteria a strategic planning team was formed to assess the rest of the internals.
- The strategic planning team included Utility, GE, Structural Integrity and EPRI members.
- Goal of the team:
  - Confirm which internals were safety-related by function – support from GE systems, structural and thermal hydraulics engineers.
  - For safety-related internals understand their relative significance in accident scenarios, such as:
    - Core spray always 1st system credited, supports long-term cooling.
    - Jet pumps critical to maintain 2/3 core height flooded post-LOCA.
  - Develop a basis to prioritize work and component sequence.
- The result was BWRVIP-06, “Safety Assessment of BWR Reactor Internals” was published October 1995.
BWRVIP-06 Scope and Purpose

- Components categorized as “safety-related” are those that can be relied upon to remain functional during and following design basis events to ensure (10CFR50.2):
  - (1) The integrity of the reactor coolant pressure boundary
  - (2) The capability to shut down the reactor and maintain it in a safe shutdown condition; or
  - (3) The capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to 10CFR100

- Purpose
  - Perform deterministic safety assessments of all internals, penetrations and attachments (non-safety received a less rigorous assessment)
    - Consider BWR/2 – BWR/6 components and subcomponents
    - Configurations were “as designed”, did not account for plant modifications
  - Identify short and long term actions to assure safe operation assuming component cracking
  - Provide a tool to assess other cracking that might occur
BWRVIP-06 Approach

- Assume each weld and/or bolted connection fully failed (synergistic or multiple component failures not considered)
- Assess resulting safety consequences based on the component’s function for normal operation and accidents
- Functions considered included:
  - Maintain coolable geometry
  - Maintain rod insertion times
  - Maintain reactivity control
  - Assure core cooling
  - Assure instrumentation availability
- Assumed failures were beyond design basis in some cases
- Evaluate worst case failure impact on accident consequences and plant responses considering:
  - Detectability of failure during operation or by inspection
  - Redundancy of load carrying capability or components
  - Probability of challenging event
BWRVIP-06 Results

- No short-term actions needed (premature shutdowns or other action)
- Long-term actions were defined for components whose function is needed for response to:
  - Design basis LOCA
  - Anticipated transients without scram events (ATWS)
  - Seismic events
- Some component failures combined with low probability events could result in increased core damage frequency
- Based on relative importance to safety BWRVIP-06 provided insights on sequencing work to develop component inspection and repair guidelines for most components (e.g. fuel support casting, no action)
- The results of BWRVIP-06 fed directly into the susceptibility and failure considerations contained in Section 2 of subsequent Inspection and Evaluation (I&E) guidelines for each component
BWRVIP-09 Quantitative Safety Assessment of BWR Reactor Internals

- BWRVIP-06 was a deterministic assessment
- BWRVIP-06 identified eight components whose failures combined with low probability events may result in increased core damage frequency
- To provide additional confidence in BWRVIP-06 and further assess impact of component failure the BWRVIP chose to perform probabilistic risk assessment (PRA) of:
  - Control rod guide tubes, housing and stub tubes
  - Core plate
  - Core spray piping
  - Core spray spargers
  - Jet pump assemblies
  - LPCI coupling
  - Access hole covers
  - Top guide grid
BWRVIP-09 Quantitative Safety Assessment of BWR Reactor Internals

- Approach was to conservatively assume a conditional failure probability of 1.0 for a component
- Perform PRA to calculate core damage frequency (CDF) considering LOCA and seismic events
- Used conservative accident mitigating system alignments, data and modeling assumptions to obtain upper-bound CDF estimates
- Compare results against a screening criteria of 1E-6 per reactor year
  - 1E-6 is two orders of magnitude below NRC safety target of 1E-4
- If component CDF exceeded 1E-6, weld failure probabilities were assessed via Monte Carlo methods using accepted crack growth rates, fluence SCC threshold, crack distributions, etc.
- Results concluded no CDF concerns, no short-term actions were needed, and supported the BWRVIPs prioritization of components for inspection and evaluation guidelines (I&EG) development
- Report was submitted to NRC June 16, 1997
BWRVIP-06 and -09, NRC response

- NRC issued a Safety Evaluation Report (SER) for BWRVIP-06 and-09, dated September 15, 1998
  - Did not consider multiple failures on different components
  - Did treat single failures conservatively in BWRVIP-06
  - Did use a bounding approach to calculate CDF
  - NRC research was performing an independent assessment of cascading failures

- The SER concluded:
  - BWRVIP component prioritization was acceptable
  - While multiple common mode failures were not considered, the industry had implemented effective inspection and repair programs to provide NRC high degree of confidence multiple failures would not occur and to ensure component integrity

Note: NRC’s failure assessment documented in NUREG/CR-6677 supported the BWRVIP conclusions)
Inspection Prioritizations

- Based on the results of the BWRVIP-06 and 09 Assessments, the priorities for developing BWRVIP Inspection & Evaluation Guidelines were established as follows:

  - **High Priority**
    - Shroud
    - Core Spray Piping and Sparger
    - Shroud Support
    - Top Guide
    - Core Plate
    - Standby Liquid Control System

  - **Medium Priority**
    - Jet Pump Assembly

  - **Low Priority**
    - Control Rod Drive Guide Tube and Stub Tubes
    - Incore Housing and Dry Tubes
    - Instrument Penetrations
    - RPV Attachments
    - Low Pressure Coolant Injection (LPCI) Coupling
Summary of Initial Strategy

- Address shroud cracking to maintain fleet safety and operability
- Based off the results of BWRVIP-06 and BWRVIP-09 develop inspection and repair criteria based on prioritized list
- Accelerate work on mitigation – can internals be protected and how
- Develop the supporting tools needed by owners such as NDE methods, crack growth information, fluence models, etc.
- Initiate long-term work to address future needs such as irradiated crack growth and fracture toughness, welding tools
- Develop program structure that gave owners guidance, regulators assurance and engaged INPO
- Review and adjust the program on annual basis based on OE, technical needs to support plants, regulatory needs, etc.
- This was BWRVIP approach until NEI 03-08 was issued – and was effective since BWRVIP was the model for much of NEI 03-08
Current BWRVIP Strategic Planning Processes (MDM & IMTs)
NEI 03-08 Integrated Materials Issues Strategic Plan

- Provides systematic approach to managing materials issues
  - Identify vulnerabilities
  - Assess condition (inspect & evaluate)
  - Mitigate degradation initiation and propagation mechanism
  - Repair or replace as required

- Approach used:
  - Materials Degradation Matrix and Issue Management Tables
    - Materials Degradation Matrix and Issues Management Tables to be maintained as living documents with annual updates
Industry Materials Degradation and Issue Management Table Approach

- Develop a fundamental understanding of the degradation phenomena/mechanisms
- Perform operability and safety assessments
- Develop Inspection and evaluation guideline
- Evaluate available mitigation options
- Develop repair & replace options
- Monitor and assess plant operation experience
- Obtain regulatory acceptance

Materials Degradation Matrix (MDM) and Issue Management Tables (IMT) are effective materials aging management tools in support of industry’s Materials Degradation and Issue Management Initiative.
The Materials Degradation Matrix (MDM)

- Provides a comprehensive listing of potential degradation mechanisms for existing LWR primary system components
- Assesses the extent to which applicable degradation mechanisms are understood
- Incorporates the state of industry knowledge worldwide associated with mitigation of applicable degradation mechanisms
- Document the results of an expert elicitation process
- Proactively identifies potential challenges to avoid surprises
- Is updated on periodic basis
Color Chart Presentation of MDM Results

- **Blue**: lack of data to establish degradation applicability
- **Green**: well characterized, little or no additional research is needed
- **Yellow**: ongoing R&D efforts to resolve uncertainties in near-term time frame
- **Orange**: insufficient R&D to resolve uncertainties in a near-term time frame
# MDM Results Example---- BWR Reactor Internals

## Table 4.2: BWR Reactor Vessel Internals

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>Corrosion</th>
<th>Wear</th>
<th>SCC</th>
<th>Fatigue</th>
<th>Reduction in Fract Properties</th>
<th>Irradiation Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HSG</td>
<td>Pitting</td>
<td>FAC</td>
<td>Foul</td>
<td>Wear</td>
<td>IG/TG</td>
</tr>
<tr>
<td><strong>SS: 300 Series Base Metal &amp; HAZ</strong></td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>b2-6a</td>
<td>Y</td>
</tr>
<tr>
<td><strong>SS: Welds &amp; Clad</strong></td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>b2-4a</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Cast Austenitic Stainless Steel</strong></td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>b2-6a</td>
</tr>
<tr>
<td><strong>Ni-Alloy: A600 Base Metal &amp; HAZ</strong></td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Ni-Alloy: A62 Welds &amp; Clad</strong></td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td><strong>Ni-Alloy: A70 Welds &amp; Clad</strong></td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

## Fasteners & Hardware

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>Corrosion</th>
<th>Wear</th>
<th>SCC</th>
<th>Fatigue</th>
<th>Reduction in Fract Properties</th>
<th>Irradiation Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HSG</td>
<td>Pitting</td>
<td>FAC</td>
<td>Foul</td>
<td>Wear</td>
<td>IG/TG</td>
</tr>
<tr>
<td><strong>SS: 300 Series</strong></td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td><strong>SS: XM-19</strong></td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td><strong>Ni-Alloy: X-750</strong></td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>
BWR Issue Management Tables (IMTs)

- BWRVIP prepares the BWR IMTs
- Initially (IMT Rev 0) utilized BWRVIP-06, Safety Assessment - reflected current state of the BWRVIP Program
- Identified and prioritized “gaps” by reviewing impact at a subcomponent level
- Subsequent revisions included new gaps, gap revisions, gap closures, and gap prioritizations (High, Medium & Low) based on MDM updates, Operating Experience (OE), research results, and BWRVIP member input for the prioritizations
- Latest version published as BWRVIP-167, Revision 3 in 2013 – includes hyperlinks to MDM gaps and EPRI document summaries
BWR Issue Management Tables (IMTs)

- Gaps are categorized as follows:
  - Degradation Mechanism (DM) Understanding Gaps
  - Assessment (AS) Gaps
  - Mitigation (MT) Gaps
  - Inspection and Evaluation (I&E) Gaps
  - Repair/Replacement (RR) Gaps
  - Regulatory Issue (RG) Gaps
### Example IMT – BWR Reactor Vessel Internals

#### Table A-2 Reactor Vessel Internals (Continued)

<table>
<thead>
<tr>
<th>Components &amp; ID No.</th>
<th>Material</th>
<th>Degradation Mechanisms</th>
<th>Conseq. of Failure</th>
<th>Mitigation</th>
<th>Repair / Replace</th>
<th>I &amp; E Guidance</th>
<th>Gaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.9 Shroud</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.9-1 Shroud Cylinders</td>
<td>SS</td>
<td>SCG: Fat, RFP: IE</td>
<td>IG/TG, IA LC-Env Emb</td>
<td>B, E, F</td>
<td>EPRI BWRVIP BWRVIP-190 BWRVIP-225</td>
<td>EPRI BWRVIP BWRVIP-76R1 BWRVIP-158-A</td>
<td>B-DM-06 B-DM-09</td>
</tr>
<tr>
<td></td>
<td>(304, 304L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Example of Gap Description given on next slide
Example Gap Description – B-AS-09

<table>
<thead>
<tr>
<th>R&amp;D Gap Description</th>
<th>Results Data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>B-AS-09 - Assess the Impact of High Fluence on Fracture Toughness</strong></td>
<td><strong>Priority:</strong></td>
</tr>
<tr>
<td>Issue: There is a need for additional data to fully characterize the effect of high neutron fluence on the fracture toughness properties of austenitic stainless steel weld and HAZ materials.</td>
<td>R3 (2013): High</td>
</tr>
<tr>
<td><strong>Description:</strong></td>
<td>R2 (2010): High</td>
</tr>
<tr>
<td>The austenitic stainless steel alloys in BWR core structures experience significant fracture toughness reductions at elevated fluence levels. While the data sets for austenitic stainless steel base metal are considered to be sufficient, the data sets for fracture toughness of highly irradiated stainless steel weld and HAZ materials are more limited for typical BWR 60-year and 80-year end of life fluences. As a result, there is incentive to fill this gap with supplemental data.</td>
<td>R1 (2008): High</td>
</tr>
<tr>
<td>The serviceability of BWR core structures and components is verified periodically through a prescribed program of inspection and evaluation. Evaluations of current serviceability and projections of future serviceability rely on accurate fracture toughness data. Results of these evaluations support run/reap decisions. Resolution of this gap includes development of comprehensive guidance for evaluating fracture toughness through development of sufficient irradiated materials data to address the fluence ranges of interest.</td>
<td>Status: Open</td>
</tr>
<tr>
<td>Current work plans include an international IASGC project to extract material from the reactor pressure vessel of Zorita, a decommissioned plant located in Spain. Stainless steel weld and HAZ materials irradiated to 5-10 dpa are targeted for additional fracture toughness testing. Because lower bound saturation fracture toughness values for weld and HAZ materials cannot be characterized with existing data for either 60 or 80-year operations, this gap is considered an LTO issue.</td>
<td>Responsibility: BWRVIP: Assessment</td>
</tr>
<tr>
<td><strong>References:</strong></td>
<td>Other: P&amp;CR Program</td>
</tr>
<tr>
<td>MDM (Note b2-12a), <a href="#">BWRVIP-100R1</a>, <a href="#">BWRVIP-140</a>, <a href="#">BWRVIP-154R2</a></td>
<td>LTO Impact: Indirect</td>
</tr>
</tbody>
</table>
BWRVIP Strategic Planning Process

- The current IMTs are used as key input to the BWRVIP’s strategic planning, or scope selection, process.
- Currently there are 47 gaps including:
  - 6 Degradation Mechanism Understand gaps
  - 23 Assessment gaps
  - 4 Mitigation gaps
  - 8 Inspection and Evaluation gaps
  - 3 Repair/Replacement gaps
  - 3 Regulatory Issue gaps
- Of the 43 gaps, 17 are ranked High, 18 Medium, and 12 Low.
- Metrics established for NEI 03-08 requirements require that Issue Programs be working on at least 90% of their High Priority gaps in order to stay “Green.”
BWRVIP Organization and Membership
Executive Committee

- Membership consists of one executive of each BWRVIP utility member
- Elects members of the Executive Oversight Committee (EOC)
- Votes on proposed Charter revisions and policy issues
- Meets at least once a year to review the overall direction and progress of the activities of the group
- Reviews and approves the yearly BWRVIP scope, budget and funding approach
- Approves all NEI 03-08 mandatory and needed guidance
- Approves all reports and related transmittals that are submitted to the NRC for review and approval
Executive Oversight Committee (EOC)

- Membership consists of BWRVIP Chairman and Vice Chairman, BWROG Chairman and two other Executive Committee members (as Executive sponsors of the Assessment and Mitigation Committees)
- Reviews the status, direction and progress of ongoing work
- Approves workscope and funding changes within the annual budget approved by the Executive Committee
- Reviews recommendations regarding emerging issues
- Oversees the regulatory interface
Assessment Committee

- What needs to be inspected and at what frequency
- What inspection methods – volumetric or visual
- How to disposition observed degradation considering
  - Examination method
  - Materials
  - Environment both chemical and irradiation state
- Material testing to establish disposition tools such as:
  - Crack growth rates
  - Fracture toughness criteria
- Trending and assessing inspection data
Inspection Committee

- How to inspect including
  - Equipment and techniques available for each component
  - Defining associated limitations and uncertainties
- Maintenance of BWRVIP-03 inspection guidelines and demonstration status
- Assess visual examination reliability (Round Robin tests)
- Work with vendors to develop new techniques/tools
- Support new demonstrations
Repair/Replace Committee

- Define what repair/replacement techniques are available
- Establish what associated requirements that must be met
- Research and development on advanced welding techniques to be used on irradiated materials
- Maintain the various component Repair Design Criteria
- Maintain BWRVIP-84 material selection criteria for repairs and replacements
- Assess surface mitigation techniques
Mitigation Committee

- Find the materials ultimate solution - How can SCC degradation be prevented or reduced?
- Maintain BWR water chemistry guidelines
- Assess fleet data and consider mitigation optimization
- Assess on line NMCA deposition effectiveness
- Investigate means to monitor and assure plant implementation effectiveness, e.g. Electrochemical Potential (ECP) monitoring, Noble Metals Chemical Application (NMCA) durability, etc.
- Coordinate with fuels groups as mitigation options are developed/considered
2016 BWRVIP Member Utilities

**U. S.**
- DTE Energy
- Duke Energy
- Energy Northwest
- Entergy
- Exelon
- FirstEnergy
- NextEra Energy
- NPPD
- PSEG Nuclear
- Southern Nuclear Company
- Talen Energy Corp
- Tennessee Valley Authority
- Xcel Energy

**Intl**
- BKW FMB Energie AG – Switzerland
- Chubu Electric Power Company – Japan
- Chugoku Electric Power Company – Japan
- Comisión Federal de Electricidad – Mexico
- Forsmarks Kraftgrupp AB – Sweden
- Horizon – UK
- Iberdrola Generation – Spain
- JAPC – Japan
- Kernkraftwerk Leibstadt – Switzerland
- Nuclenor – Spain
- OKG Aktiebolag – Sweden
- Ringhals AB – Sweden
- Taiwan Power Company – Taiwan
- Tokyo Electric Power Company – Japan
Summary
Summary

- IGSCC has a long and problematic history in BWRs
- 100’s of millions of dollar have been spent dealing with it
- History shows when proper resources are brought to bear, technical issues can be resolved
- When sound technical bases are developed and used, owners and regulators alike benefit and have confidence
- A firm continued commitment by owners is necessary to effectively manage IGSCC and other materials degradation
  - Participation in the BWRVIP both technically and financially
  - Implementation of the products
  - Reporting of results
Together…Shaping the Future of Electricity
Pressurized Water Reactor Internals Aging Management Program Development

Kyle Amberge
EPRI MRP Assessment Task Manager
International LWR Materials Reliability Conference
August 1, 2016
PWR Internals Description and Function Overview
and
MRP-227 Overview

Kyle Amberge

kamberge@epri.com
PWR Internals Description and MRP-227 Overview

Topics

- Aging Management Program
- Nuclear Energy Institute (NEI) 03-08
  - Implementation elements
- MRP-227
- Internals Inspection Planning
- ASME Section XI Inspections
- Latest Revisions to MRP-227
Reactor Internals Aging Management Program (AMP)  
Why Inspect Internals?

- PWR internal components may be affected by age-related degradation effects
- As the PWR plants age, the likelihood of degradation mechanisms occurring increases
- The long-term safety & reliability of the PWR fleet requires development & implementation of aging management strategy
- The AMP supports utilities in meeting regulatory commitments for license renewal, power uprates, and aging management of internals
NEI 03-08, “Guideline for the Management of Materials Issues”:
Implementation Requirements

- In May, 2003 the NEI Nuclear Strategic Issues Advisory Committee (NSIAC) as a formal Industry Initiative made a commitment for each licensee to endorse, support and meet the intent of NEI 03-08, “Guideline for the Management of Materials Issues” in response to incidents such as VC Summer and Davis Besse leaks.

- Goal is to ensure that the industry’s management of materials degradation and aging is forward-looking, focused on issues commensurate with their safety significance, and coordinated to the maximum extent practical. Additionally, the industry will continue to rapidly identify, react and effectively respond to emerging issues.

- When properly implemented, this should result in fewer unanticipated issues that consume an inordinate level of industry resources, and divert the focus from an orderly approach to managing materials performance. It is expected that every utility will fully participate in the implementation of the materials
NEI 03-08 Deviation Process

- Failure to meet a Mandatory or a Needed requirement is a ‘deviation’ from the guidelines and a written justification for the deviation must be prepared and approved as described in Appendix B of NEI 03-08. A copy of the deviation is sent to the Materials Reliability Program (MRP) to evaluate if improvements to the guidelines need to be developed and the USNRC is notified.

- MRP-227 contains Mandatory and Needed requirements to be implemented in accordance with NEI 03-08

- MRP-228 contains Needed and Good Practice requirements to be implemented in accordance with NEI 03-08
MRP Reactor Internals Aging Management

Key Documents

- NUREG-1801, Revision 2: Generic Aging Lessons Learned (GALL)
- MRP-228: Materials Reliability Program: Inspection Standard for Reactor Internals
- WCAP-17096-NP, Revision 2: Reactor Internals Acceptance Criteria and Data Requirements
- LR-IGS-2011-04: License Renewal Interim Staff Guidance, Updated Aging Management Criteria for PWR Reactor Vessel Internal Components
The function of PWR Internals are to:

- Provide support, guidance and protection for the reactor core;

- Provide a passageway for the distribution of the reactor coolant flow to the reactor core;

- Provide a passageway for support, guidance, and protection for control elements and in-vessel/core instrumentation; and

- Provide gamma and neutron shielding for the reactor vessel
MRP-227 OVERVIEW

- NEI-03-08 Implementation Requirements
  - Mandatory category requirement
  - Needed category requirements

- MRP-227 Component Categorization
  - Likelihood and severity of safety
  - Economic consequences

- Primary and Expansion
  - Examination method
  - Coverage
  - Examination frequency
  - Acceptance criteria
  - Primary-Expansion link
MRP-227 GUIDELINE OVERVIEW

Component List

Screening Criteria

Below Screening

Initial Screening

Above Screening

No Credible Damage Issue

Likelihood & Severity Analysis

Moderate

High

Category A
No Adverse Effects

Category B

Category C

Resolved by Analysis

Functionality Analysis

No Additional Measures

Aging Management Strategy

Existing
Expansion
Primary

Existing Programs

New Requirements

Aging Management Program
I&E Guidelines - Rev. 0

Links between categorization, functionality analysis, aging management strategy development (MRP-227)
MRP-227 Plant Specific Aging Management Programs Implementation

- Issue Resolution Classifications
  - Mandatory – to be implemented at all plants where applicable
  - Needed – to be implemented whenever possible but alternative approaches are acceptable

- MRP-227-Rev 1 Mandatory Element
  - Each commercial U.S. PWR unit shall develop and document and maintain an engineering program for management of aging of reactor internal components.
MRP-227 Plant Specific Aging Management Programs Implementation – Needed Elements

- MRP-227 Rev 1 has 4 Needed Elements
  - **Needed:** Each commercial U.S. PWR unit shall implement the requirements of Tables 4-1 through 4-9 and Tables 5-1 through 5-3 for the applicable design.
  - **Implementation means performance of examinations** of applicable components within the timeframe specified in the applicable tables.
MRP-227 Plant Specific Aging Management Programs Implementation – Needed Elements

- **Needed**: Examinations specified in these guidelines shall comply with the **Needed** requirements in the MRP-228 Inspection Standard.

- **Needed**: Examination results that do not meet the examination acceptance criteria defined in Section 5 of these guidelines shall be recorded and entered in the owner’s plant corrective action program and dispositioned. Engineering evaluations used to disposition an examination result that does not meet the examination acceptance criteria in Section 5, shall be conducted in accordance with NRC approved evaluation methods (i.e., ASME Code Section XI, WCAP-17096-NP or equivalent method).
MRP-227 Plant Specific Aging Management Programs Implementation – Needed Element (cont’d)

- **Needed**: Each commercial U.S. PWR unit shall provide a summary report of all inspections and monitoring (including coverage(s) achieved and inspection limitations), items requiring evaluation, and new repairs to the MRP Program Manager within six (6) months of the completion of an outage during which PWR internals within the scope of MRP-227 are examined.
  
  • This summary of the results will be compiled into an overall industry report and will be updated biennially
  
  • MRP sends internals summary report to USNRC every 2 years.
MRP-227 Development

• Need to demonstrate that the effects of aging degradation in PWR internals are adequately managed is essential for maintaining a healthy fleet and assuring continued functionality of the reactor internals.

  ▪ The goal of the development of MRP-227 was primarily to support license renewal, but the guidelines are intended to apply to the current license period as well.
    – As a part of license renewal, many utility owners made commitments to participate in and follow industry guidance for managing the effects of age-related degradation mechanisms applicable to the PWR Internals components
    – Program under development for over a decade and ongoing
    – Worldwide input /R&D into its development
    – Numerous industry/NRC meetings on PWR internals over the years

  ▪ The objective of MRP-227 is to provide generic I&E guidelines for each PWR design for use by individual plant owners in preparing and executing their PWR internals AMPs.
MRP-228 Rev 2 Implementation Requirements
Examination Systems Needed Elements

- Examinations performed according to prior versions of MRP-228 are acceptable. However, the needed requirements of MRP-228, Rev. 2, shall be implemented for all examinations occurring 12 months after publication of this report.
  - **Needed**: Technical Justifications are required for the examination systems specified in 2.1.1 and examination systems shall meet the qualification requirements of Section 2.1.
  - **Needed**: All examination personnel, equipment, examinations, classification and measurement of indications, and documentation associated with **visual examinations** shall meet the requirements of Sections 2.3.4, 2.3.5, 2.3.6, 2.3.7, 2.3.8, and 2.3.9, respectively.
  - **Needed**: All examination personnel, examinations, classification of indications, and documentation associated with **UT** shall meet the requirements of Sections 2.4.4, 2.4.6, 2.4.7, and 2.4.8, respectively.
  - **Needed**: Personnel performing NDE methods other than visual and UT of bolting shall meet the requirements of Section 2.5.
Measurement Uncertainty

- **Needed**: Technical justifications are required for determining the measurement uncertainty and shall meet the requirements of Sections 2.1.1 and 3.3.

Evaluation Factors for Measurements

- **Good Practice**: When measuring flaw indications by visual examinations, the guidance given in Section 3 for application of evaluation factors to length measurements should be considered.

Inspection Planning

- **Good Practice**: Planning for inspections should consider the optimum sequence and combination for inspections, such as combining visual examinations with UT of bolting in the same area of the vessel in order to minimize radiation dose to the examination personnel and reduce examination task durations (see Section 2.3).
Industry Program Overview

Document descriptions

Focus: Safety, Dose, Reliability

Approach: Define a proactive strategy using a systematic approach aligned with the USNRC’s generic license renewal elements for internals

- MRP-227 I&E Guideline provides what and when is to be inspected
- MRP-228 is an inspection standard that describes how to inspect
- WCAP-17096-NP is a guideline for acceptance criteria methodology
- MRP-318 gives the prioritization and contingency planning options for PWR internals
- WCAP-17436 gives the results for the reactor internals risk ranking and response planning
- WCAP-17451-P Revision 1 provides Control Rod Guide Tube (CRGT) guide card inspection frequencies

Note: These guidelines do not reduce, alter, or otherwise affect current American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code Section XI or plant-specific licensing inservice inspection requirements.
ASME Section XI periodic inspections

- Section XI specifies the following:
  - Components and items to be inspected
  - Method of inspection
  - Area or volume of component to be inspected
  - Standards for acceptance of relevant indications
  - Frequency of examinations

- Inspections are required on the basis of periods and intervals
  - One interval is 10 years total duration
  - An interval is divided into 3 periods of ~3 years each
  - Inspection of some components can be deferred until end of interval, but not into the next interval
Basis for Aging Management Program

- Basic Principles
  - Inspection: confirm material conditions consistent with original functional requirements using leading component indicators
  - Monitoring/Trending: based on sampling

- Comply with utility’s licensing requirements

- Materials Aging Assessment
  - Establish thresholds for degradation mechanisms affecting internals (EPRI technical report MRP-175)
Relevant Aging Mechanisms and Effects

- Stress Corrosion Cracking (Cracking) (SCC)
- Irradiation-Assisted Stress Corrosion Cracking (Cracking) (IASCC)
- Wear (Loss of Material)
- Fatigue (Cracking)
- Thermal Aging Embrittlement (Loss of Toughness > Cracking) (TE)
- Irradiation Embrittlement (Loss of Toughness > Cracking) (IE)
- Thermal and Irradiation-Enhanced Stress Relaxation (ISR) and Creep (Loss of Preload > Wear/Cracking)
- Void Swelling and Irradiation Growth (Dimensional Change or Distortion > Cracking) (VS)
Screening Process for MRP-227

- **Primary Component:**
  - PWR internals that are highly susceptible to the effects of at least one of the eight aging mechanisms
  - The aging management requirements provide reasonable assurance of the continued functionality of the primary components and predict future performance of expansion components
  - Also includes components which have shown a degree of tolerance to a specific aging degradation effect, but for which no highly susceptible component exists or for which no highly susceptible component is accessible

*Note: Disassembly of components and assemblies not required for inspections.*
Screening Process for MRP-227

- **Expansion Component:** PWR internals that are highly or moderately susceptible to the effects of at least one of the eight aging mechanisms, but for which engineering evaluations and safety assessments have shown a degree of tolerance to those effects

- **Existing Programs:** PWR internals that are susceptible to the effects of at least one of the eight aging mechanisms and for which generic and plant-specific existing AMP elements are capable of managing those effects

- **No Additional Measures:**
  - PWR internals for which effects of all eight aging mechanisms are below screening criteria
  - No further action required for managing these components.
Plant Specific Aging Management Programs

- I&E Guidelines define ‘generic’ inspection strategy for the program
- Plant specific program should address:
  - Variations in plant design
  - Plant specific operating history
  - Schedule of refueling, ISI and plant modifications
  - Plant specific commitments
  - Demonstrate license renewal commitment alignment

Technical Basis Documents
- MRP-189 Rev 2: Screening, Categorization, and Ranking of B&W-Designed PWR Internals
- MRP-191: Screening, Categorization and Ranking of Reactor Internals of Westinghouse and CE PWR Designs
- MRP-231 Rev 3: Aging Management Strategies for B&W PWR Internals
- MRP-232 Rev 1: Aging Management Strategies for Westinghouse and Combustion Engineering PWR Internals
PWR Reactor Internals Inspection Planning
4-Step Engineering Program Process

1. Scope Definition
2. Development
3. Program Development and Implementation
   – Pre-Inspection Engineering
   – Field Inspection
4. Industry Reporting, Response, and Follow-Up
Step 1 and Step 2: Engineering Program Plan

- **Scope Definition**
  - Must meet the requirements of the inspection and evaluation guidance while considering plant-specific situations and preferences.

- **Development**
  - Couples the plant-specific scope definition with regulatory plan requirements as defined in the ten GALL elements, MRP-227 conditions and applicant/licensee action items, and utility owner’s plant-specific commitments and preferences.
Aging Management Program Plan

- An AMP is a tool to support effective management of critical components as plants age
- Required for License Renewal / Life Extension by GALL, Revision 2
- Only NEI 03-08 “Mandatory” Requirement in I&E Guidelines (MRP-227)
Aging Management Program Plan
Summary of NUREG-1801 (GALL)

- Aging Management Program Elements
  - Scope Definition
  - Preventive Actions
  - Parameters to be Monitored or Inspected
  - Inspection (Detection of Aging Effects)
  - Monitoring or Trending
  - Acceptance Criteria (Action Levels)
  - Corrective Actions
  - Confirmation
  - Administrative Controls
  - Operating Experience Review

Aging Management Strategy Input

I&E Guidelines (MRP-227)

Implementation
Pre-Inspection Engineering Package

- Pre-Inspection Engineering Package consists of:
  - Component Inspection Details
  - Acceptance Criteria
  - Inspection Response Plan

- Alignment with:
  - MRP-227 (I&E Guideline)
  - MRP-228 (Inspection Standard)
  - WCAP-17096-NP Revision 2 (Acceptance Criteria)
  - WCAP-17451-P (Guide Card wear evaluation)

- Nuclear safety related
- Plant-specific requirements
Component Inspection Details (CIDs)

- Provide a visual reference for the location of components to be inspected
- Indicate specific area of the component to be inspected
- Show surrounding area to provide perspective of clearances and potential obstacles
- Provide naming conventions for the component and any observed flaws

From a MRP-227A IVI
Acceptance Criteria

- MRP-227
  - Provides examination acceptance and expansion criteria
- WCAP-17096-NP, Revision 2
  - Provides a methodology for the analysis process
- WCAP-17451-P
  - Provides assessment and projection tools for guide card wear
WCAP-17096-NP Acceptance Criteria

- **Philosophy**
  - Determine the allowable criteria (e.g., maximum crack length) that will permit the customer to return to service for the entire inspection cycle (typically 10 years)
  - An alternate approach would be to provide acceptance criteria to allow a return to power for 1 fuel cycle
    - This prevents an impact to the current outage and allows the utility time to decide how to disposition the inspection finding
Contingency Planning

- To identify options to respond to observed material degradation
- To manage impacts on existing plant activities
- Limit or bound risk of outage extension
- Utility-specific risk
- Bring together key stakeholders to ensure consensus

Utility stakeholder direction is critical!
Together…Shaping the Future of Electricity
Review PWR Reactor Internals Inspection Standard (MRP-228)

Jack Spanner
EPRI

BWR/PWR In-Vessel Inspection Workshop
EPRI International BWR & PWR MRP Conference
August 1, 2016
Chicago, IL
MRP-228 GUIDELINE OVERVIEW
Inspection Standard for PWR Internals

- NDE System Qualification: Technical Justification Overview
- Visual Examinations
  - VT-1 and VT-3 use ASME Section XI requirements
  - Enhanced VT-1 (EVT-1) requirements provided
- Ultrasonic Examination of Bolting in Reactor Pressure Vessel Internals
  - Technical Justification (TJ) based on ASME Section V, Article 14
  - MRP provided protocol for future bolting demonstrations (MRP Letter 2013-011)
- Nondestructive Examination (NDE) Requirements
  - Personnel Training/Experience
  - Equipment Requirements
  - Examination Requirements
  - Documentation of Results
  - Measurement of Relevant Indications
  - Use of MRP Mockups
- NEI-03-08 Implementation Requirements
MRP-228 General Procedures
Technical Justification Overview

- Technical Justifications for NDE System Qualification
  - Required for qualification of NDE systems (including measurement uncertainty) other than VT exams
  - TJ Elements
    - Description of the component(s) and degradation mechanism(s)
    - General description of the NDE system
    - Influential parameters and procedure essential variables
    - Description of the examination technique
    - Description of procedure experience
      - Prior examinations
      - Laboratory
      - Demonstration tests
MRP-228 VT GENERAL PROCEDURES

- Generic Standards for VT - Purpose and Scope
  - Describes requirements and recommendations for performance of underwater remote visual examination of PWR internals, components and associated repairs.

  - Used by PWR utilities when performing visual examination (EVT-1/VT-1/VT-3) of PWR Internals, components and associated repairs to meet the recommendations set forth in MRP documents.

- Visual Methods
  - EVT-1 techniques are used for detecting surface imperfections and flaws such as cracks
  - VT-1 techniques are used for detecting gaps
  - VT-3 is used for detecting general degradation conditions.
    - Wear
    - Distortion
    - Missing, protruding or broken bolts and damaged or distorted locking devices
    - Missing or degraded components
    - Cracking
    - Vertical displacement
Background discussion on VT examinations

- In the fall of 2004, a report titled NUREG/CR, “An Assessment of Visual Testing” was issued by Pacific Northwest National Laboratory (PNNL) for the USNRC detailing work performed to assess the effectiveness of VT examinations as currently performed in the industry.
- The conclusions reached as a result of the work reported that as currently performed, VT examinations could not reliably detect cracks in nuclear components until a rather large Crack opening Displacement (COD) (> 40 µm; .00157 in./0.040mm)) was present.
  - Lighting
  - Speed
  - Pixel size versus crack opening
- Eventually, EVT-1 in the Boiling Water Reactor Vessel Inspection Program (BWRVIP) revised from a .0005 in. (0.0127mm) wire to the .044 in. (1.1mm) VT-1 characters and +/- 30° viewing angle perpendicular to the surface.
Remote VT Round Robin
Conducted by USNRC and Industry

- Objective of task is to assist in providing input into the specifics of performing an industry round robin for remote VT, monitoring the progress of the round robin, and assist in interpreting and reporting the round robin result.

- Support USNRC Research (RES) staff in an assessment of Remote VT technology
  - Implementation of a round robin
  - Performed in three phases.

- Determine an effective approach for performing an industry round robin designed to more accurately assess capabilities.
  - Work with PNNL to design an appropriate round robin strategy.
  - Provide independent reporting of round robin results.

- Status
  - Three phase study conducted over 5 years
    - Recently completed 3rd phase of testing
    - 3rd phase included field procedures, SS cracked samples, independent analysis and relooks
    - EPRI report will be published in 2016
Examination system can adequately resolve the 0.044-in. (1.1mm) characters.

Primary purpose is to find surface breaking flaws (cracking).

Surfaces to be inspected shall be sufficiently free from extraneous materials, such as crud and other deposits so that relevant conditions will not be masked. Prior to EVT-1 examination, a cleaning assessment must be performed. This applies to surfaces in the as-found condition and in the post-cleaned condition.

Camera motion should not exceed 0.5”/second (12-mm/sec).

Overlap examination scans in a manner that ensures complete coverage of the area of interest.

Camera angle should not exceed 30º to perpendicular from the examination surface or that demonstrated during Resolution Demonstration Check (RDC).

- Inspection TAC included this in MRP-228, Rev 1 2012 revision
- Obtaining coverage may be more difficult

Examination shall be performed within the distance and zoom parameters established during the RDC.
The proper application of EVT-1 techniques reveals very fine details of small flaws.
Examination system can adequately resolve the 0.044-in. Characters.

Primary purpose is to find surface conditions such as gaps.

Surfaces to be inspected shall be sufficiently free from extraneous materials, such as crud and other deposits so that relevant conditions will not be masked.

Camera angle should not be less than 30° from the examination surface or that demonstrated during RDC.

Examination shall be performed within the distance and zoom parameters established during the RDC.
MRP-228 VT Viewing Angles

EVT-1 Maximum Angle

Perpendicular

MRP & BWRVIP EVT-1

VT-1, VT-3 & Direct Minimum Angle from Surface

30°  30°  120°
MRP-228 VT-3 Technique

‐ VT-3
  ‐ Examination system can adequately resolve the 0.105-in. (2.7-mm) Characters.
  
  ‐ Looking for general mechanical and structural condition of components and to detect discontinuities (cracking) and imperfections.
  
  ‐ No cleaning required.
  
  ‐ Camera angle should not be less than 30° from the examination surface or that demonstrated during RDC.
  
  ‐ Examination shall be performed within the distance and zoom parameters established during the RDC.
MRP-228 Non-Relevant Indication

 Scratch and discoloration

Illustration of non-relevant indication
MRP-228 Relevant Indication

- Cracking

Illustration of relevant indication: Cracking
MRP-228 VT Definitions (Continued)

- Inspection Standard for VT
  - Essential variable
    - Any element, component, or combination of the equipment used for the examination that, if changed, could affect the ability of the examination equipment to detect indications or an evaluator’s ability to evaluate indications. The specific essential variables will be as described in the examination procedure. These include the camera, camera tube or board, and camera lens; video processor, monitor, and recording device (if evaluations will be performed from recordings, i.e. resolution); and examination conditions, such as lens-to-subject distance.

  - Resolution demonstration
    - The process of demonstrating the ability of the remote visual examination equipment, equipment setup, inspection area environment, and examination technique to resolve the required characters on the resolution card.
MRP-228 Resolution Card

A card bearing the characters described in Paragraphs 2.3.6.3.b.1 and 2.3.6.3.b.2 of MRP-228 used to verify the adequacy of lighting and/or remote camera resolution for EVT-1/VT-1 and VT-3

Lower Case Vision Card DB#14357
(ASME Section XI, Table IWA-2210)

VT-1
aceorsuvwnz

VT-3
w a v c x e z o s r u

Example resolution card.
MRP-228
VT Personnel 2.3.4

- Personnel Training/Experience
  - Personnel evaluating examination data shall be certified as a Level II or Level III examiner in the VT-1 and/or VT-3 method, as appropriate, to a written practice meeting the requirements of ASME, Section XI
  
  - Employer training: In addition, personnel evaluating examination data shall receive a minimum of four hours of indoctrination training on examination requirements, operation of examination equipment, overview of MRP-228 requirements, and specific information related to the component(s) being examined.

  - Personnel evaluating examination data shall have a minimum of 10 hours of work time experience performing remote VT of internals. Experience to perform EVT-1, VT-1 or VT-3 can be accumulated separately or in combination with the other techniques.
Utilities shall also conduct **site-specific training** for all personnel evaluating examination data

- Topics to be included
  - Utility-specific procedural requirements
  - Configuration details
  - Previous examination results
  - Specific outage scope
  - Evaluation and Reporting

- Document prior to each MRP-227 examination
- MRP provides a standardized training package for utilities to provide to personnel responsible for evaluating remote visual inspection data
  - Materials Reliability Program: Site Specific Remote Visual Training for In-Vessel Inspections (MRP-382 Rev 1) Product ID: 3002005387
MRP-228 VT Personnel

- Personnel Training/Experience (Continued)

- Utilities shall ensure that all personnel involved in the evaluation of examination data meet the requirements of MRP-228.

- Personnel who have had previously documented PWR internals remote visual examination evaluation experience (which includes crack detection and characterization) are considered to have satisfied the training and work experience requirements as described of MRP-228; however, the items outlined in Paragraphs 2.3.4.2 a, b, and c (Review videos, non-relevant indications and areas prone to cracking) of MRP-228 must have been included in the prior training for those individuals or shall be included in the site-specific training specified in MRP-228. The time required for this specific training is at the discretion of the utility.
Resolution standards for demonstrating system performance

- For purposes of demonstrating system performance, the resolution card shall include, as a minimum, the 0.044-inch characters as described in Paragraph 2.3.6.3.b.1 of MRP-228.
- An alternative resolution standard may be used if it can demonstrate sensitivity equal to or higher than that demonstrated by the 0.044-inch characters as described in Paragraph 2.3.6.3.b.1 of MRP-228.
- Where the examinations to be performed are limited to VT-3, a resolution card including VT-3 0.105-inch characters, as described in Paragraph 2.3.6.3.b.2 of MRP-228 may be used.

Underwater Cameras

- Black and white or color may be used if the entire system meets the requirements of Section 2.3.6.3 of MRP-228.
- Camera resolution and auxiliary features have significant impact on the ability to perform quality examinations and evaluate examination results.
- Resistance to radiation fields (both magnitude and duration) should be considered in the selection of camera and related equipment.
MRP-228 Color vs. Black & White Cameras

- Black & White cameras are more radiation resistant and with more light can perform as well as color.
- Color cameras are affected less by motion and useful for characterization.

Examination photo taken with Black&White camera

Examination photo taken with color camera
MRP-228 GENERAL PROCEDURES
Equipment Requirements (Continued)

- Cameras
  - Example High Rad Underwater Cameras

Example underwater camera #1.
Example underwater camera #2.
MRP-228 GENERAL PROCEDURES
Equipment Requirements (Continued)

- Pan/Tilt/Zoom Cameras

Example Pan/Tilt/Zoom (PTZ) Underwater Cameras.
MRP-228 GENERAL PROCEDURES
Equipment Requirements (Continued)

- Cameras
  - Camera lenses

- Lens selection and use are at the discretion of the utility as long as the entire system meets the demonstration requirements described in Section 2.3.6.3 of MRP-228.

- Industry experience has shown that narrow angle-of-view lenses (for example, 25 mm) produce higher levels of magnification than wide angle-of-view lenses (for example, 9 mm) at a given camera-to-subject distance. This increases their ability to detect fine flaws at a given distance. However, narrow angle-of-view lenses reduce the depth of field and the effective size of the examination area, increasing the scanning and examination time.

- Lenses with zoom features capable of variable magnification and depth of field may be used if the resolution requirements of Section 2.3.6.3 of MRP-228 are met for the entire range of the lens and examinations can be performed in a timely manner.
Lighting

- Lighting must be controlled to avoid shadows and excessive glare. An improper angle of lighting during examination can cast shadows into the area of interest, interfering with the ability to detect indications. Saturating the area of interest with light can create a glare, which can also interfere with detection of indications. When additional lighting is needed, excessive glare can often be avoided by using a supplemental light source rather than relying on increasing the intensity of integral camera lighting for illumination.

- Lighting sources should be equipped with a control that permits varying the intensity. The ability to vary the degree of illumination and the angle of lighting and the use of supplemental lighting are useful techniques for evaluating indications.

  Note: Diffuse lighting is a useful technique.
MRP-228 Effect of Lighting
Test Plate with crack barely visible with glare

Ambient light

Excess light
MRP-228 GENERAL PROCEDURES
Equipment Requirements (Continued)

- Viewing Monitors

- Monitors used for viewing can have a direct impact on the ability to discern indications. Monitors should have a horizontal line resolution equal to or greater than the camera to be used in the examination.

- Although adjusting the brightness and contrast controls on the monitor can better enable examination personnel to discern indications, adjustments to the monitor do not alter the images being recorded. Therefore, when recording devices are being used, these controls should be set to the neutral position. The contrast and brightness adjustments should first be made by adjusting the lighting and camera iris. Adjustments made to the contrast and brightness for other devices and features, such as for online image capturing or hard copy video processors (if used), should be made subsequently. Adjusting the picture as described will help to ensure that the recorded image will closely match that being viewed live by examination personnel.
Video data recording

- Video data recording of PWR internal component inspections is not required by MRP-228, but is recommended as a way to increase examination reliability by enabling independent data review and the ability to compare the data with those of previous and subsequent inspections.

- When the examinations are recorded, the ability of the recording media at the settings used during the examination should be sufficient to verify that the equipment resolution demonstration meets the requirements described in Section 2.3.6.3 of MRP-228. This is typically accomplished by reviewing the recorded system resolution demonstration check performed prior to and after each examination or series of examinations.

- Where the equipment settings allow for adjusting the recording levels (for example, standard play versus extended play), the settings for examination shall be consistent with those used for recording the demonstration to ensure the quality of the video record.
MRP-228 GENERAL PROCEDURES
Examination Requirements 2.3.6

- **Surface conditions**

  - Surfaces to be inspected shall be free extraneous materials, such as crud and or other deposits, so that relevant conditions will not be masked. For VT-3 examinations, the as-found condition is sufficient without further cleaning.

  - Prior to EVT-1 examination (for example, to detect evidence of cracking), industry experience has shown that a cleaning assessment must be performed.
    1. Surfaces shall be considered suitable for examination when surface texture identifiers such as grinding and machining marks, weld beads and ripples, undercut, and arc strikes are readily visible
    2. If the suitability of a surface for examination is indeterminate, the following technique may be used: perform a pre-cleaning inspection of a worst-case area that includes the identifiers listed in 1) above; then clean the area and perform a post-cleaning inspection. If the identifiers seen in the post-cleaning inspection are significantly clearer or sharper than those in the pre-cleaning inspection or if previously undetected landmarks are identified, the existing surface conditions have the potential for masking crack indications, and cleaning shall be performed prior to inspecting.
Surface conditions (Continued)

3) A cleaning assessment may determine that pre-inspection cleaning is needed but that it cannot be performed due to physical restraints that prevent access for cleaning equipment. When this is the case, a utility should perform a “Best effort” inspection of the area and document the reason(s) that no cleaning was performed.

Note: Cleaning may momentarily decrease clarity

− Cleaning methods shall not smear surface sediment, which could mask or hinder the detection of indications. Cleaning methods also shall not produce a polished surface finish that could contribute to excessive glare during examination that could interfere with the detection of indications.

− Cleaning methods must comply with site Foreign Material Exclusion (FME) requirements

− Industry experience has shown that abrasive pads can smear sediments and hinder the detection and evaluation of indications. Nylon bristle brushes and hydro-lazing have been shown to be effective in removing these materials without producing a shiny, reflective surface.
MRP-228 GENERAL PROCEDURES
Color Cleaning Assessment

Surface needs cleaning

Fine detail is visible but surface crud may mask very small indications

Surface needing cleaning for examination.

Surface with crud masking indications
MRP-228 GENERAL PROCEDURES
Surface condition

This surface condition meets the requirements for an EVT-1 examination.

Surface meeting EVT-1 cleanliness requirements.
Environmental/Water Clarity

- Water clarity, throughout the examination, should remain equal to or better than that used during the resolution demonstration. If water clarity becomes suspect, examinations should be discontinued and a resolution demonstration performed per Section 2.3.6.3 of MRP-228.

- Lighting of the examination area should be controlled using integral camera lights and supplemental lighting as needed to maintain examination sensitivity.
Water Clarity

- Water quality (Turbidity) can have a noticeable impact on the image presented

Example of water quality impact on image quality during foreign object search
MRP-228 GENERAL PROCEDURES
Examination Requirements (Continued)

- Equipment Resolution Demonstration Requirements

- a. The resolution capabilities of the examination equipment and technique shall be demonstrated using a resolution card (as described in Section 2.3.5.1 of MRP-228) under environmental conditions representative of the examination area, before performing examinations, and whenever components of the equipment that have been identified in the procedure as essential variables are changed. Also, an RDC shall be performed at the beginning and end of each examination or series of examinations.

- b. The RDC shall be sufficient for EVT-1 or VT-1 provided that the system is capable of resolving the 0.044-in. characters as described in item 1. The RDC shall be sufficient for VT-3 provided that the system is capable of resolving the 0.105-in. characters. The lens-to-object distance and zoom required to resolve the required characters becomes the maximum distance of the lens to the surface of the item to be examined and minimum zoom that may be used during the examination.
Equipment Resolution Demonstration Requirements (Continued)

- 1) Remote EVT-1 or VT-1 examination processes shall be demonstrated as capable of resolving lower case characters without ascenders or descenders (for example, a, c, e, and o) with character heights no greater than 0.044-in. (1.1 mm) at the maximum examination distance.

- 2) Remote VT-3 examination processes shall be demonstrated as capable of resolving lower case characters without ascenders or descenders (for example, a, c, e, and o) with character heights no greater than 0.105-in. at the maximum examination distance.

- 3) Although not required, it is recommended that the RDC be recorded if examinations are to be recorded. Whenever an RDC is recorded, a review of the video recording should be performed prior to continuing examinations to ensure that the required characters are visible on the recorded image.
MRP-228 GENERAL PROCEDURES
Examination Requirements (Continued)

- Equipment Resolution Demonstration Requirements (Continued)

- c. Except for the circumstances described in the next paragraph, if an RDC fails to meet the requirements previously described, all examinations performed since the last valid RDC shall be considered void and the areas reinspected.

- 1) In cases where a camera fails (for example, electronic failure or mechanical breakage) or where degraded camera performance has been identified and the examination was video recorded, an evaluation may be performed to determine the need for re-examination. Such evaluations shall include, as a minimum, a comparison of the recorded image made immediately after the last acceptable RDC and those made just prior to the camera failure or performance degradation by a Level II (or III) remote visual examiner qualified to this standard. This review shall focus on examination landmarks to determine whether resolution just prior to the failure was equivalent to that experienced immediately after the last acceptable RDC. All such evaluations shall be independently reviewed by a Level III remote visual examiner qualified to this standard and shall be approved by the utility.
d. To avoid the potential for extensive re-examination, consideration should be given to performing an RDC more frequently when examinations are performed in excessively high radiation fields.

It has been observed that cameras may burn out in high radiation fields. In black-and-white cameras, this is indicated by foggy or hazy areas or spots on the monitor; for color cameras, white spots, “snowy” images, or complete white-out may occur. This condition can be temporary or permanent. If it occurs, the camera should be moved to a lower radiation field and an RDC performed. If the required characters on the resolution card can be resolved, the camera may continue to be used; however, consideration should be given to using a more radiation-tolerant camera in the area that produced the condition. If, however, the required characters cannot be resolved, the camera shall be repaired or replaced, and all areas inspected since the last acceptable RDC shall be reinspected except as noted in item c.
MRP-228 GENERAL PROCEDURES
Examination Requirements (Continued)

- **Area(s) of interest**

  - For EVT-1 or VT-1 examination of components, the area of interest shall consist of all accessible surfaces of the component. For welds, the area of interest is generally considered the entire width of the weld and ¾ in. (19-mm) of the adjacent base material on each side of the weld. However, for small welds such as the control rod guide tube upper flange welds, the entire weld and 0.25 in. (6 mm) of the adjacent base material is the area of interest. To determine the adequacy of coverage, the area of interest may be further refined based on the damage mechanism for the items identified in MRP-227. Such refined determinations of coverage adequacy shall be documented in the inspection report, as prepared or reviewed by a Level III remote visual examiner qualified to this standard, and shall be approved by the utility.

  - For VT-3 examinations, specific coverage determinations are not required. The VT-3 consists of a general condition examination of the accessible portions of the item, and the area of interest is dependent on the damage mechanisms for the item as identified in the applicable examination requirement of MRP-227.
Air Bubbles on Lenses
Air Bubbles on Lenses Causing System to Focus on Bubbles
Mini-Sub Cable Interference
Resolving False Indications

- During VT-3 examination of the control rod guide tube (CRGT) spacer castings, potential crack-like indications were seen in the C-tubes at the intersection of the C-tube and spacer castings. These locations were not part of the MRP-227A reactor internals inspection scope (they were adjacent to the examination area).

- Deployed a different (higher resolution, closer & better angle to area of concern) camera to obtain a better view of the anomalies.

- The video obtained by the supplemental camera of the area of interest revealed no suspect conditions. The previously identified questionable areas were considered acceptable.
Radiation Effects

- Black & White camera Example of foggy or hazy image due to high radiation field
- Color camera Example of snowy image due to high radiation field (will be discussed later in the course)
Camera Effects of High Radiation Fields
Camera Effects of High Radiation Fields
MRP-228 GENERAL PROCEDURES

Summary

- Examination Technique
  1. Maximum and proper examination distance and zoom
  2. Use audio commentary to describe the component, examination and findings
  3. Character generators are also useful
  4. Avoid shadows in the area of interest
  5. Camera speed should not exceed 0.5 in/sec (EVT-1).
  6. Overlap to ensure complete coverage
  7. To the extent permitted by accessibility and component geometry, the camera should be positioned such that the angle view is not more than 30 degrees from perpendicular to the surface of the item being inspected for EVT-1. Larger angles may be used if demonstrated during the RDC.
Examination Requirements (Continued)

- Inspection planning

  - In order to optimize inspection time, consideration should be given to organizing the examinations to be performed in specific areas of the vessel coincidentally, such as performing a VT-3 of the locking devices while performing the ultrasonic examination of the associated bolt.

  - Good inspection planning will also:
    - Reduce dose to personnel
    - Reduce dose to equipment
    - Allow for inspecting most likely to fail items first
    - Ensure that examinations will not interfere with other activities
    - Consider reactor and component configurations which facilitate proper examination conditions
MRP-228 GENERAL PROCEDURES
Classification

- Examination Requirements (Continued)

  - Classification of indications
    - Indications and conditions shall be classified as either relevant or non-relevant.
    - Initial interpretation and evaluation of indications should be performed during the examination (real time).
    - Processes such as digital image enhancement may be used for evaluation provided that they produce the required resolution sensitivity.
    - Review of recorded evaluations is recommended. Industry experience has shown that an independent review of the examination, performed by a second qualified individual, significantly increases the level of confidence that indications and conditions have been properly identified and evaluated. Recording of the examination provides a way for this review to be accomplished separate from the critical path.
Sizing

Examination Requirements (Continued)

– Measurement of relevant Indications

- Determining indication length (that is, linear indications) on vessel internal components can be challenging if remote operation of measuring tools is necessary. However, rulers and specially made or improved measuring tools and techniques have been used to measure indication lengths with acceptable accuracy and repeatability.

- Where known measurement accuracy is needed to support condition assessment of components within the scope of the Guidelines (MRP-227), measurements may be taken by any technique, provided that it can be shown to have a repeatable accuracy under the conditions in which it will be used.

- There are various types of software and hardware available that use pixel count, laser grid patterns, image comparison or other techniques to give highly accurate measurements.

Note: Length measurements may be difficult because crack opening displacement (COD) may vary along length of crack, particularly at ends.
MRP-228 GENERAL PROCEDURES

Sizing

- Examination Requirements (Continued)
  - Measurement of relevant Indications

Pixilation – digital measurement

Ruler

Measurement of relevant indications: Pixilation

Measurement of relevant indications: Ruler
Flaw length

Flaw Length Measurement by Visual Examination

- Background

- Although MRP-228 does not restrict the flaw measurement techniques that may be used
  - Techniques not using rulers or landmarks must be supported by the Technical Justification for the NDE system
- Previous studies by other industry programs and the NRC have identified the limitations of remote visual examination systems used for underwater visual examinations, including flaw length sizing.

- Techniques

- Two techniques have generally been used for flaw length measurement during remote visual examinations: direct measurement with a ruler or comparison of flaw indications with adjacent items or features of known dimensions. Variations on these techniques can be used to improve their accuracy and repeatability.
Flaw Length Measurement by Visual Examination (Continued)

- Determining Uncertainty (Continued)

- As an alternative to developing a TJ for different measurement uncertainty, an evaluation factor may be used.
- Where measurement uncertainty must be considered, the following evaluation factor may be added to each end of a flaw in lieu of demonstrating measurement uncertainty.

<table>
<thead>
<tr>
<th>Measurement technique</th>
<th>Evaluation factor (inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimation by landmarks</td>
<td>0.82 (20.8-mm)</td>
</tr>
<tr>
<td>Ruler measurements</td>
<td>0.2 in. (5-mm)</td>
</tr>
</tbody>
</table>
MRP-228 UT GENERAL PROCEDURES

- UT Examination of Bolting in PWR Internals
  - MRP-227 Primary and Expansion Bolting
  - B&W has more bolting types than others
  - Most CE units have very little bolting
  - Reliability of transducer contact with the surface of the head varies by design
  - Bolting has experienced failures
  - These examinations require a Technical Justification (TJ) to be written and have been tested in open and blind demonstrations
MRP-228 GENERAL PROCEDURES

Definitions

- UT Examination of Bolting in PWR Internals (Continued)
  - Definitions (Continued)
    - Essential variables – Any element, setting, component, or combination of the equipment used for the examination that, if changed, could affect either the ability of the examination equipment to detect indications or an evaluator's ability to evaluate indications. The specific essential variables will be as described in the examination procedure. For ultrasonic examinations, this includes the transducer size, transducer frequency, transducer arrangement, transducer shape, cable length, number of intermediate connectors, UT scope/system, UT scope/system settings, pulse repetition rate, calibration, and data analysis software. Changes in the essential variables of the procedure require revision to the Technical Justification.
MRP-228 UT GENERAL PROCEDURES
Personnel 2.4.4

- UT Examination of Bolting in PWR Internals (Continued)
  
  - Personnel training/experience
    
    - Personnel evaluating or analyzing examination data shall be certified as a Level II or III examiner in the UT method to a written practice meeting the requirements of the utility’s program.

  
  - In addition, personnel analyzing examination data shall receive a minimum of 2 hours of training on the UT bolting procedure, examination requirements, overview of MRP-228 requirements, and specific information related to the bolting being examined.

  
  - As a minimum, this training shall include:
    
    - Review of actual UT bolting data, if available, showing the types of flaws or relevant indications to which the components are susceptible. Recorded data or manual scanning of vessel internal bolts with reflectors representative of cracking, relevant indications, and non-relevant indications should be used.
    
    - Areas prone to cracking
    
    - Effect of surfaces on detection and evaluation
    
    - Techniques that maximize the reliability of the UT
MRP-228 GENERAL PROCEDURES

Cracks

• Bolting UT flaws
  • Core Barrel Bolts (B&W)
    ▪ Crack at position 5
    ▪ Primarily caused by IASCC
  
  • Baffle Bolts
    ▪ Failures have been attributed to a combination of IASCC, loss of pre-load, and fatigue
    ▪ From Tihange
MRP-228 GENERAL PROCEDURES
Equipment Requirements 2.4.5

- UT Examination of Bolting in PWR Internals
  - Equipment requirements
    - The equipment included in the UT procedure as an essential variable or range of variables as described in MRP-228 must be used for the examinations and be included in the Technical Justification and demonstration, as applicable.

ROV for Baffle Bolt examination

ROV Performing Baffle Bolt examination in 2-loop Mock-Up
MRP-228 UT GENERAL PROCEDURES
Examination Requirements 2.4.6

- UT Examination of Bolting in PWR Internals (Continued)

  ▪ Surface conditions
    - The surfaces of the bolts on which the transducers are placed shall be sufficiently free of extraneous materials and surface conditions so as not to interfere with the transmission of ultrasound into the bolt.

  ▪ Volume(s) of interest
    - For UT examination of baffle-former bolts, the area of interest shall consist of the head to shank region (excluding the head).
      ▪ Inquiry to MRP revised volume to head to shank region and incorporated into MRP-228 Rev 2.
    - For UT examination of all other bolts, the area of interest shall consist of the length of the bolt excluding the head. A TJ may be used to provide an alternative volume.
MRP-228 UT Essential Variables

- UT Examination of Bolting in PWR Internals (Continued)
  - Examination requirements (Continued)
    - Procedure essential variable content:
      - **Instrument/system** including manufacturer (model or series) of pulser, receiver and amplifier
      - **Search units** including manufacturer (model or series) and the nominal frequency, mode of propagation, nominal angles, number, shape size and quantities of active elements
      - **Search unit cable(s)** including type, maximum length and maximum number of intermediate connectors
      - **Detection** and sizing technique including scan pattern, beam direction(s), min and max pulse repetition rate, minimum sampling rate, extent of examination, action to be taken for access restriction, surface from which examinations are performed
MRP-228 UT Essential Variables

- UT Examination of Bolting in PWR Internals (Continued)
  - Examination requirements (Continued)
    - Procedure essential variable content: (Continued)
      - Calibration techniques
      - Calibration and examination data to be recorded
      - Method of data recording and recording equipment used
      - Method and criteria for the analysis and discrimination of indications
      - Surface preparation requirements
      - The procedure shall specify a single value or range of values for the items listed above
MRP-228 GENERAL PROCEDURES
Recording Flaws

▪ UT Examination of Bolting in PWR Internals (Continued)
  – Classification of Indications
    ▪ Indications shall be classified as either relevant or non-relevant. If an indication cannot be classified during initial examinations, additional re-looks shall be performed. The UT procedure shall contain instructions describing how the data will be interpreted and analyzed. All relevant indications shall be reviewed by another UT Level II or Level III examiner.
  – Documentation of Results
    ▪ Documentation should, as a minimum, include the following: 1) the examination procedure number and revision, date(s) of examination(s) and evaluation(s) and names of personnel performing the examinations, and data review and analysis, 2) the location and extent of the bolts examined, 3) a calculation of the percentage or number of bolts that were successfully examined compared to the number scheduled for examination, and 4) the number and location of bolts with flaw indications, including their unique identification, if available.
UT Examination of Bolting in PWR Internals (Continued)

- Technical Justifications and Capability Studies
  - Ultrasonic examination systems are required to be qualified by a Technical Justification as described in Section 2.1 of MRP-228. The organization that prepared the procedure will also be responsible for preparing the Technical Justification. The utilities are responsible for approving the Technical Justification and may request that the MRP assist by reviewing the Technical Justification.
  - TJ requirements based on guidance of ASME B&PV Code, Section V, Article 14, not including Appendix II
  - Capability study to support TJ is required that meets the guidance of intermediate rigor using blind testing similar to ASME Section XI, Appendix VIII
  - MRP Inspection TAC provides guidance for conducting capability studies on MRP website (MRP Letter 2013-011).
Personnel Qualification

- To examine internals personnel shall be certified to at least a Level II examiner in the applicable method in accordance with an employer’s written practice.

- Utilities shall conduct site-specific training on utility-specific procedural requirements, configuration details, previous examination results, operation of examination equipment, specific outage inspection scope, and any other pertinent information related to examination, evaluation and reporting, as applicable. The training is to be conducted prior to inspections for each refueling outage. The training shall be documented by the utility with the actual training time required to be determined based on the outage inspection scope, the inspection history, and the familiarity of data evaluators with the site.
Personnel Qualification (Cont’d)

– Utilities shall ensure that all personnel involved in the evaluation of examination data meet the requirements of this document.

Procedure Qualification

– Utilities are responsible for approving the Technical Justification prepared in accordance with Section 2.1 and they may request that the MRP assist in this review.

– TJs are required for all NDE procedures other than VT-1, VT-3 and EVT-1
### A.3 Checklist for Other NDE Methods and Techniques

<table>
<thead>
<tr>
<th>Paragraph</th>
<th>Item description</th>
<th>Confirmation (Y or N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1.1.1</td>
<td>Was a technical justifications provided for qualification of the NDE system?</td>
<td></td>
</tr>
<tr>
<td>2.1.2.2</td>
<td>Is the technical justification report for 2.1.1.1 approved by a Level III examiner in the applicable NDE method?</td>
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<td>2.1.2.3</td>
<td>Is the technical justification report for 2.1.1.1 reviewed and approved by the utility?</td>
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<td>2.1.3</td>
<td>Does the technical justification for 2.1.1.1 include the contents of 2.1.4?</td>
<td></td>
</tr>
<tr>
<td>2.5.1</td>
<td>Are personnel evaluating or analyzing examination data certified as a Level II or Level III examiner in the applicable NDE method to the employer’s written practice?</td>
<td></td>
</tr>
<tr>
<td>2.5.2</td>
<td>Did the utility conduct and document site-specific training for all personnel evaluating examination data, including utility-specific procedural requirements, configuration details, previous inspection results, operation of examination equipment, specific outage inspection scope, and any other pertinent information related to inspection, evaluation, and reporting?</td>
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</tr>
<tr>
<td>3.3</td>
<td>When measurement uncertainty determinations are necessary, is the effectiveness of the technique provided in a technical justification by the organization performing the inspection measurements?</td>
<td></td>
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</table>
Mockups

- Use of MRP Mockups
  - Mockups developed by the MRP
  - MRP-228, Section 2.2 is a guide for the use of MRP developed mockups
  - Mockups are used primarily for training
MRP-228 GENERAL PROCEDURES
EPRI B&W Mockups

- Example B&W Design Mockups

- Baffle Bolts
- Thermal Shield Bolts
- Lower Core Barrel Bolts
- Locking Devices
MRP-228 Westinghouse Design Mockups

- Westinghouse Design Mockups (Thermal shield flexure)
Questions, Discussion
Boiling Water Reactor
Vessel and Internals
(BWRVIP) Guidelines

Chuck Wirtz
EPRI BWRVIP Integration Task Manager

International LWR Materials Reliability Conference
August 1, 2016
BWRVIP Guidelines

BWRVIP Guidelines can be grouped into the following categories:

- Safety Assessments
- Administrative Guidelines
- Inspection and Flaw Evaluation (I&E) Guidelines
- Reports that Support Flaw Evaluations
- Nondestructive Examination (NDE) Guidelines
- Repair Guidelines
- Integrated Surveillance Program
- Water Chemistry Guidelines
## BWRVIP Guidelines to Manage Degradation

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<th>Assessment</th>
<th>Inspection</th>
<th>Repair/Replace</th>
<th>Mitigation</th>
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<td>Component</td>
<td>(I&amp;E) Guidelines</td>
<td>Guidelines</td>
<td>Design Criteria</td>
<td>Recommendations</td>
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<td>Core shroud</td>
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<td>BWRVIP-02-A/-04-A</td>
<td>BWRVIP-62, Rev. 1/-190, Rev. 1</td>
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Safety Assessments

  - **Purpose:**
    - Perform deterministic safety assessments of all internals, penetrations and attachments (non-safety received a less rigorous assessment)
      - Consider BWR/2 – BWR/6 components and subcomponents
      - Configurations were “as designed”, did not account for plant modifications
    - Identify short and long term actions to assure safe operation assuming component cracking
    - Provide a tool to assess other cracking that might occur
  - **Scope:** Components categorized as “safety-related” are those that can be relied upon to remain functional during and following design basis events to ensure (10CFR50.2):
    - (1) The integrity of the reactor coolant pressure boundary
    - (2) The capability to shut down the reactor and maintain it in a safe shutdown condition; or
    - (3) The capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to 10CFR100
Safety Assessments

- Inspection Prioritizations resulting from the BWRVIP-06 Ground Work:
  - High Priority
    - Shroud
    - Core Spray Piping and Sparger
    - Shroud Support
    - Top Guide
    - Core Plate
    - Standby Liquid Control System
  - Medium Priority
    - Jet Pump Assembly
  - Low Priority
    - Control Rod Drive Guide Tube and Stub Tubes
    - Incore Housing and Dry Tubes
    - Instrument Penetrations
    - RPV Attachments
    - Low Pressure Coolant Injection (LPCI) Coupling

- **Purpose**: To provide additional confidence in BWRVIP-06 and further assess impact of component failure, the BWRVIP perform probabilistic risk assessment (PRA) of components whose failures could result increased core damage frequency.

- **Scope**: The eight components identified by BWRVIP-06 whose failures, combined with low probability events, may result in increased core damage frequency:
  1. Control rod guide tubes, housing and stub tubes
  2. Core plate
  3. Core spray piping
  4. Core spray spargers
  5. Jet pump assemblies
  6. LPCI coupling
  7. Access hole covers
  8. Top guide grid

- **Results**: Concluded no CDF concerns, no short-term actions were needed, and supported the BWRVIPs prioritization of components for inspection and evaluation guidelines (I&EG) development.
Administrative Guideline

BWRVIP-94: BWR Vessel and Internals Project, Program Implementation Guide, is the overall program guidance document for the BWRVIP program:

- Specifies having a BWRVIP Program is “Mandatory” under the implementation requirements of NEI 03-08 while other elements of BWRVIP-94 are “needed”
- Provides guidance to ensure owners consistently implement BWRVIP guidelines
- Incorporates the relevant guidance from NEI Initiative 03-08, “Guidelines for the Management of Materials Issues” (NEI 03-08), including
  - Roles and Responsibilities of the BWRVIP
  - Roles and Responsibilities of Individual Utilities
- Defines
  - BWRVIP Member’s responsibilities
  - Utility requirements
  - What constitutes a BWRVIP Program
  - Support elements of a program
  - Regulatory commitments
- Provides
  - Guidance on deviation dispositions
  - expectations regarding emergent issues
BWRVIP-94 Utility Responsibilities

- Have a BWRVIP Program
- Have a Water Chemistry Control Program
- Maintain the Program in a current condition
  - Revise the program to comply with Executive Committee approved documents
  - Implement the new guidance within 2 refueling outages, unless otherwise specified by the BWRVIP
    - Update the program, and
    - Perform initial examinations, but
    - Cannot implement less conservative criteria when previous version is NRC-approved (e.g., previous version is a “-A” version)
- Conduct BWRVIP activities under 10CFR50 Appendix B QA Program
BWRVIP-94 Utility Responsibilities, cont’d

- Report Inspection/Repair results
- Conduct self-assessments of their BWRVIP program
- Communicate new “emerging” materials issues promptly
- Process a Deviation Disposition (DD) when deviating from “Mandatory” or Needed” criteria
  - Includes inspection strategies, frequencies, techniques and evaluation of results
  - DD shall include technical basis assessing impact and acceptability of the deviation
BWRVIP-94 BWRVIP responsibilities

- Developing and maintaining a strategic work plan
- Maintain an up-to-date listing of BWRVIP documents and their NEI 03-08 classification
  - Listing is in BWRVIP Cockpit
- Develop and maintain/revise guidelines as warranted
  - Incorporate new OE
  - Incorporate new research or technical information
- Interpret BWRVIP guidelines
  - Will interpret requirements
  - Will not use interpretation to change guidelines
- Resolving materials issues that fall within the scope of the BWRVIP
- Regulatory interface for major materials issues
Inspection and Evaluation Guidelines (I&EG)

- There is an I&EG document for each internal component addressed by BWRVIP
- There are also I&EGs for the reactor vessel attachments, penetrations, and pressure boundary piping
  - In some instances, e.g., small bore penetrations, the BWRVIP Guidelines simply refer to ASME for the inspection requirements
- These documents are the practical core of materials management for the internals and primary pressure boundary
- They tell you what to inspect, when to inspect it, and how to evaluate the results
## Inspection and Evaluation Guidelines

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Contents of I&E Guidelines

- Description of component
- Discussion of susceptibility to IGSCC
- Discussion of consequences of failure of each location
- Inspection history
- Inspection requirements
- Evaluation methods
- Reporting requirements (now addressed in BWRVIP-94)

(Note: Format differs somewhat among I&E Guidelines)
Component Descriptions include:
- Sketches show location of welds, bolted joints, etc.
- Locations labeled for identification purposes
- General plant variations shown (BWR/2 vs. BWR/6)
  - In some cases, plant specific configurations shown
- Configuration information is based on best available design information (BWRVIP-15)
- As-built configuration may be significantly different

Susceptibility Discussion includes:
- Which locations are likely to experience degradation through IGSCC or other mechanisms, and which are not
- Susceptibility is an input to inspection requirements
- Non-susceptible locations do not normally require inspection
Contents of I&E Guidelines

- Safety Consequence
  - Safety consequences of failure for each location discussed
  - Safety consequence is an input to inspection requirements
  - Locations with higher safety impact generally have more stringent and/or more frequent examinations
    - Jet pump locations below inlet mixer more critical to preserve 2/3 core height flooded during a LOCA
  - Locations not having adverse safety consequences are generally not required to be inspected
  - Guidelines recommend that there may be economic reasons to inspect additional locations

- Inspection History
  - Review of inspections performed at the time of report preparation
  - List of indications observed
  - Secondary input to inspection requirements
Contents of I&E Guidelines

- Inspection requirements include:
  - List of locations to inspect
  - Schedule for “baseline” inspection
  - Inspection methods allowed or required for each location
    - EVT-1: enhanced visual with cleaning requirements
    - VT-1: close visual examination
    - VT-3: general visual examination
    - UT: ultrasonic examination
    - ET: eddy current examination
  - Reinspection criteria
    - Frequency – based on inspection method used
    - Sample size
  - Scope expansion
    - Additional inspections if cracks are found
  - Alternatives to inspection
    - Specific repairs or analyses to eliminate inspections
Contents of I&E Guidelines

- Flaw evaluation guidance describes acceptable procedures for evaluation of flaws
  - Structural analysis techniques, in some cases, equations
    - Limit load
    - Linear elastic fracture mechanics
    - Elastic plastic fracture mechanics
  - Loads to be considered
  - Effects of environment (e.g. water chemistry, fluence, etc.)
  - Assumptions regarding cracking in un-inspected regions
  - Consideration of NDE uncertainty (if applicable)
  - Leakage calculations (if applicable)
- Refer to appropriate BWRVIP guidelines to be used for crack growth rates and fracture toughness
Reports that Support Flaw Evaluations

- Crack Growth Reports:
  - BWRVIP-14-A, Evaluation of Crack Growth in BWR Stainless Steel RPV Internals
  - BWRVIP-59-A, Evaluation of Crack Growth in BWR Nickel Base Austenitic Alloys in RPV Internals
  - BWRVP-60-A, Evaluation of Stress Corrosion Crack Growth in Low Alloy Steel Vessel Materials in the BWR Environment
  - BWRVIP-80-A, Evaluation of Crack Growth in BWR Shroud Vertical Welds

- Irradiated materials:
  - BWRVIP-99-A, Crack Growth Rates in Irradiated Stainless Steels in BWR Internal Components
  - BWRVIP-100-A, Assessment of the Fracture Toughness of Irradiated Stainless Steel for BWR Core Shrouds
Nondestructive Examination (NDE) Guidelines

BWRVIP-03: BWR Vessel and Internals Project, Reactor Pressure Vessel and Internals Examination Guidelines, is the BWRVIP’s guidance document for NDE used to perform BWRVIP inspections

- Contains the generic procedure requirements for enhanced visual examinations (EVT-1), ultrasonic (UT), and Eddy Current of BWR vessel internals
- Provides guidelines for the use of BWRVIP mockups and the protocol for NDE Technique Demonstrations on the mockups
- Provides guidelines for determining NDE Technique Uncertainty and Inspection Tool Positioning Uncertainty
- Documents vendor technique demonstrations (mostly UT) for the different BWR vessel internal components (over 270 demonstrations to date)
- Revised annually to incorporate new technique demonstrations and any other updates (currently at Revision 18)
### Component

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Repair Guidelines

- **Repair Design Criteria Guidelines**
  - Individual BWRVIP reports that provide general design guidance and acceptance criteria for permanent and temporary repair for various BWR vessel internal components (see next slide)

- **Supporting Repair Guidelines**
  - BWRVIP-84, Revision 2-A, Guidelines for Selection and Use of Materials for Repairs to BWR Internal Components
  - BWRVIP-95-A, Guide for Format and Content of BWRVIP Repair Submittals
  - BWRVIP-97-A, Guidelines for Performing Weld Repairs to Irradiated BWR Internals
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Water Chemistry Guidelines

- **BWRVIP-190, Revision 1, BWR Water Chemistry Guidelines**
  - Volume 1: Mandatory, Needed, and Good Practice Guidance
  - Volume 2: Technical Basis

- **BWRVIP-62, Technical Basis for Inspection Relief for BWR Internal Components with Hydrogen Injection**
  - BWRVIP-62-A, currently the NRC approved version, does not include current practice of online noble metals chemical addition (OLNC)
  - BWRVIP-62, Revision 1, includes OLNC and is currently under NRC review
## Mitigation/Water Chemistry

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## Mitigation Recommendations

- BWRVIP-62, Rev. 1/-190, Rev. 1
- N/A
- BWRVIP-62, Rev. 1/-190, Rev. 1
- N/A
Integrated Surveillance Program

- The Integrated Surveillance Program (ISP) was developed by the BWRVIP and is used by all U.S. BWRs to meet 10CFR50, Appendix H, RPV material surveillance program requirements

- BWRVIP-86, Revision 1-A, Updated BWR Integrated Surveillance Program (ISP) Implementation Plan
  - Provides the ISP test matrix and schedule
  - Provides ISP administration and implementation guidelines
  - Revision 1 extended the ISP for License Renewal

- BWRVIP-135, Integrated Surveillance Program (ISP) Data Source Book and Plant Evaluations
  - Documents plant-specific ISP data evaluations
  - Provides guidelines for use of ISP data
Together...Shaping the Future of Electricity
PWR Inspection Experiences, Results and Lessons Learned

Jack Spanner
EPRI

BWR/PWR In-Vessel Inspection Workshop
International Light Water Reactors Material Reliability Conference

Chicago, IL
August 1, 2016
MRP-227 Inspection Results

- Ginna
- Surry Unit 1 & 2
- Kewaunee (Guide card only)
- HB Robinson
- Oconee 1, 2 & 3
- Point Beach 1 & 2
- North Anna Unit 1 & 2
- Prairie Island 1 & 2
- Palisades
- Millstone 3
- Three Mile Island 1
- Turkey Point 3 & 4
- Indian Point 2
- Salem 1
- Catawba 2
Contact Information

- EPRI MRP Project Manager: Jack Spanner
  - Phone: +1-704-595-2565
  - E-Mail: jspanner@epri.com

- EPRI MRP Project Manager: Kyle Amberge
  - Email: kamberge@epri.com
  - Phone: +1-650-855-2039
Recent Baffle-Former-Bolting Inspection Findings

- DC Cook 2, 4-loop Westinghouse plant, 2010, visual only (Ref. TB-12-5)
  - 18 bolts with visual indications with visual clustering
  - UT not performed
  - 40 bolts were replaced
Recent Baffle-Former-Bolting Inspection Findings

- Indian Point 2, 4-loop Westinghouse plant, 3/2016, VT-3/UT (Ref. MRP-2016-007)
  - Markings on periphery of neighboring fuel assembly identified (no fuel failure).
  - Inspections identified 227 with visual degradation or UT indications
    - Includes 14 that were not inspectable
  - Total number of baffle-former bolts 832
  - Number of bolts inspected UT 787
  - Number with no UT indications 605
  - Number of bolts with UT indications 182
  - Number with head-shank indications 182
  - Number of bolts not inspected due to Confirmed Visual Indications 31
  - Number of bolts not inspected due to surface or lock-bar weld condition 14

- Replaced 276 bolts
Recent Baffle-Former-Bolting Inspection Findings

- Salem 1, 4-loop Westinghouse plant, 4/2016, UT/VT-3, 182 indications with visible clustering
  - 18 visually missing or protruding
  - 8 visually cracked locking bar welds
  - 18 UT un-inspectable
  - Loose or protruding bolt heads resulted in fuel fretting and a leaker at one fuel assembly
Other Recent Baffle-Former-Bolting Inspection Findings

- Surry 1, 3-loop Westinghouse plant, 2010, UT (Ref. MRP-219)
  1 indication, none replaced

- Surry 2, 3-loop Westinghouse plant, 2011, UT
  2 indications, none replaced

- HB Robinson, 3-loop Westinghouse plant, 2013, UT
  8 indications, none replaced

- Turkey Point 3, 3-loop Westinghouse plant, 2015, UT
  zero indications out of 305 inspected to date

- Oconee 3, B&W plant, 2014, UT
  1 indication out of 863 inspected, 1 un-inspectable, none replaced

Actions for BFBs are being addressed by BFB Focus Group

- Alert letter issued by PMMP-MRP 2016-014 for US plants
By the Numbers*
Through Fall of 2014

- 15  Units begun or completed MRP inspections
- 959  W guide tube flange welds inspected
- 2427  Inches of irradiated welds inspected (approx.)
- 9125  Inches of non-irradiated welds inspected (approx.)
- 2226  CASS items inspected
- 8887  Baffle bolts inspected**
- 1306  B&W high strength bolts inspected
- 108  B&W baffle plates inspected

* All numbers approximate. Includes reported inspections through Fall 2014; some data includes retired plant; additional data may affect results slightly

** Includes retired unit
By the Numbers (Cont’d)

- Zero Guide Tube Flange weld indications
- Zero irradiated girth weld indications
- One non-irradiated weld indication
- One CASS VT-3 indication
- 619 baffle bolt indications (4.9% of total)
- 20 B&W high strength bolt indications (1.5% of total)

{ All numbers approximate }
Trends and Observations

- Except for baffle-former bolts initial inspections at W and B&W and partial CE NSSS designs have not identified any major issues of concern
- No macroscopic effects of void swelling
  - No distortions, cracking, or excessive bolting failure
- High-strength nickel alloy clevis insert bolting failures
  - However, not in safety function load path
- Baffle-Former Bolts are being actively addressed
  - 4-Loop down-flow plants
- Guide card wear will require monitoring
  - MRP Interim guidance MRP-2014-006 issued (WCAP-17451-P)
- Current results reduce uncertainty of damage mechanism predictions
- Issues of greatest concern not seen
  - SCC of austenitic welded components not observed
    - Cracking currently limited to high strength bolting
  - IASCC of welds not observed, indications limited to bolts
  - Macroscopic effect of void swelling not observed
- Some adjustments and efficiencies are needed, as expected with a ‘living’ program
  - Lessons learned incorporated into MRP-227 Rev. 1 and MRP-228 Rev. 2
Ginna RV Internals MRP-227 Primary Item Exam Results
Summary of First Full MRP-227 Inspection

- Guide Card Wear –100% VT-3 Inspection; no appreciable wear seen
- CRGT Flange Welds –100% EVT-1 Inspection; no relevant indications identified
- Core Barrel Upper Flange Weld –100% EVT-1 Inspection; no relevant indications identified
- Thermal Shield Flexures –100% VT-3; no relevant conditions
- Core Barrel Baffle Edge Bolts & Seams –100% VT-3 (all 16 high fluence seams for full length); no relevant conditions
- Baffle Former Assembly –100% VT-3; no relevant conditions
- Baffle Former Bolts –Replace or UT of plant specific minimum bolt pattern or alternate bolts as selected by analysis; 1 bolt (or 1%) identified with a relevant UT indication
Surry Unit 1 MRP-227 Inspection Results

- Only one UT indication detection of a likely flaw in one bolt, identified as “C113”.
- VT-3 identified two bolts deformed at the hex head points.
- VT-3 also identified one baffle former bolt and one edge bolt with one missing locking bar weld.
Surry Unit 1

Baffle Bolt Inspections – Deformed Hex Head Points

Missing Locking Bar Weld
Surry Unit 2 Spring 2011 Baffle Bolt Inspections

- Bolting material is Type 347 with external hex head with lock bar slot.
- All 1088 baffle to former bolts were UT and VT-3 examined. All accessible 936 baffle edge bolts were VT-3 examined.
- Baffle former bolt UT detected indications in two bolts, identified as “A125” and “G63” located at the head to shank region of the bolt.
- With only two assumed failed bolts out of 1088, there is significant margin above the industry evaluation guideline for reactor internals, WCAP-17096 Revision 2.
HB Robinson 2

- No relevant indications
- Circumferential indication identified at weld centerline around 345°, this was determined to be a Non-relevant fabrication anomaly.
- 1076/1088 BF bolts UT’d: 8 possible defects and 1 confirmed head-shank defect
- Comments:
  - RNP Core Barrel protrudes out of Containment Vessel cavity water approximately 18” while in the stand.
  - A portion of this exam was done in the vessel, then in the stand.
  - Specialized vendor tool with the capability to traverse the circumference of the Core Barrel was used for this inspection except when the Vessel Head Alignment Keys became an obstruction
  - Another tool was utilized to inspect the remaining sections that were obstructed from view while the Core Barrel was in its stand
Oconee Unit 1

- Performed all MRP-227-A inspections in one outage
- UT – 5 lower core barrel (LCB) with crack like indications
- VT – 1 LCB locking device with a missing weld on one side and a small weld on the other.
  - The coverage for the VT-3 examination of 7 of the LCB bolts and their locking devices was 40% to 50% due to the partial obstruction from the stand, although 100% of the accessible surfaces were examined.
- UT – 1 flow distributor bolt (#49) with crack like indication.

- 860 out of 864 baffle-to-former bolts
  - 4 baffle-to-former bolts were un-inspectable due to large welds on locking bars.
Oconee 1
Vent Valve Jack Screws
Point Beach 1

- Completed all examinations during Spring 2013
- Guide Card Wear
  - 93 of 297 guide cards with recordable indications (wear) were identified
- CRGT Flange Welds
  - 110 of 118 (93%) accessible welds in 24 Peripheral CRGTs
  - Note: Missed welds attributed to interference from RV Flange Protector Ring
- CB Lower Girth Weld
  - (Covered by thermal shield)
  - 78% of exterior surface
  - Weld features not visible
- CB Lower Flange Weld
  - 92% of exterior surface (RV Flange Protector Ring interference)
  - Weld features not visible
Point Beach 1

- **Baffle Former Bolts**
  - 100% of 728 bolts examined by phased array UT
  - 92% of bolts (670) provided relevant exam results
  - **Findings**
  - No failures found for 670 bolts with relevant exam results

**Note:** Non-relevant exam results attributed to bolt head geometry
North Anna 1 and 2 and Millstone 3

- **Flux Thimble Tubes**
  - **North Anna 1:** No tubes required repositioning in 2012
    - 50 of 50 tubes examined by eddy current
  - **North Anna 2:** Two tubes required repositioning 3” in 2011
    - 50 of 50 tubes examined by eddy current
  - **Millstone 3:** No tubes required corrective action in 2013
    - 58 of 58 tubes examined by eddy current
Prairie Island 2

- Baffle Former Bolts
  - 100% of 728 bolts examined by phased array UT
  - 75 bolts had indications
  - 21 of these were in the head-shank
  - 54 of these were in the shank (Unique)
  - 653 bolts had no indications

Note: Bolt failures bounded by minimum pattern analysis per WCAP-17096

- Only B-F bolts were examined in 2013
Prairie Island 1

- Baffle Former Bolts
  - 100% of 728 bolts examined by phased array UT
  - 40 bolts had UT indications
  - 24 of these were in the head-shank
  - 15 of these were in the shank (Unique)
  - 1 of these was in a thread
  - 728 bolts had no VT-3 indications

Note: Bolt failures bounded by minimum pattern analysis per WCAP-17096

- Only B-F bolts were examined in 2014
Oconee 2

- **Lower Core Barrel Bolts**
  - UT of 108 out of 108 with one crack like indication
  - VT-3 of 106 out of 108 bolts and locking devices due to stand obstruction

- **Baffle former bolts**
  - 863 out of 864 UT’d – one was un-inspectable

- **Flow Distributor bolts**
  - 96/96 bolts UT’d
  - 2 bolts with crack like indications

- The jack screw locking devices are not currently in MRP-227 but were identified as needing to be screened in A/LAI #2. Additional parts of the Vent Valves, including the jack screw locking devices, receive a ASME Section XI, Category B-N-3 VT-3 examination. 3 of 4 components were damaged or deformed
Oconee 3

- **Lower Core Barrel Bolts**
  - UT of 108 out of 108 with three crack like indications - Seen in 1984
  - VT-3 of 108 out of 108 bolts and locking devices

- **Upper Core Barrel Bolts**
  - UT of 120 out of 120 with two without back wall signal - Seen in 1984
  - VT-3 of 120 out of 120 bolts and locking devices

- **Baffle former bolts**
  - 863 out of 864 UT’d – one had a crack like indication and one was un-inspectable

- **Flow Distributor bolts**
  - 96/96 bolts UT’d
  - One bolt with crack like indication

- **IMI Guide tube spiders & spider to rib sections weld**
  - Two linear indications adjacent to guide tube spider casting weld
Three Mile Island 1

- Flow Distributor bolts
  - 100% of 96 bolts were examined by UT and VT-3
  - One bolt with crack like UT indication
  - VT-3 detected no relevant indications
Palisades (CE Design)

- Core Shroud Assembly (Bolted)
  - Palisades detected slight 46 mil gap in shroud plate but verified from fabrication
  - Core Shroud Assembly Bolts
    - One core shroud bolt seated differently with locking bar bent and opening on the right side
- Lower Cylinder Girth Welds
  - Upper GW – 100% coverage from inside
  - Middle GW – 86.7% coverage from outside
  - Upper GW – 76.7% coverage from outside
- Instrument Guide Tubes
  - 15 locations, 8 welds each, 100% coverage
Lessons Learned

- Plants need to consider their internals stand design and its possible impact on examinations
  - Consider exam challenges caused by close proximity of cavity walls, stand components, floor, etc. that might interfere with examination access
  - Recognize that accessibility to lower components may be limited
  - Consider performing some examinations while internals suspended
  - Shallow reactor cavities may also result in the internals extending above the water level when placed in the stand
    - ALARA considerations may warrant the use of shielding
  - Some examinations may best be performed before placing internals in stand
  - Consider use of 3D modeling to evaluate impacts
Lessons Learned
Shallow Cavities

- Lower Girth Weld Tool employed for challenging conditions
  - Core barrel exposed 4 feet above water
  - Very high dose
  - No access due to shield tanks

Tooling approach driven by extreme circumstances –
Dose rates in excess of 400 mR
Lessons Learned

• Some inspections performed with core barrel in vessel
  – Core Barrel: Upper Flange Weld and Upper Girth Weld from ID
• Others require core barrel removal from OD
• Common to split inspections over two or more outages
• Typically integrated with ASME Section XI examinations
• Special tooling often required
• Vendor crew of roughly 20 specialists required 24/7
• Vendor crew typically experienced on both PWRs and BWRs
• Owner oversight is important
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