



ELECTRIC POWER
RESEARCH INSTITUTE

Welding & Repair Technology Center

Highlights

Dan Patten, Energy Harbor
Greg Frederick, EPRI

NRC Technology Exchange
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via Webex



EPRI - WRTC Point of Contacts

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 - gfrederick@epri.com

WRTC

Research Focus Areas

- WRTC is primary focus is tactical, with a mix of strategic focus.
- RFAs highlight WRTC's Core research activities
- WRTC currently have 10 RFA's – to help define scope of research
- Each RFA will not be discussed. Just some key highlights from a couple RFAs



RFA
1

Nickel-Base Filler Metal Weldability and New Alloy development; Steve McCracken, smccracken@epri.com

RFA
2

Irradiated Materials Welding Solutions; Jon Tatman, jtatman@epri.com

RFA
3

Identify, Research, Develop, and Mature Advanced Welding Processes; Steve McCracken, smccracken@epri.com

RFA
4

Optimize Joining, Fabrication, and Repair Processes (including WRS) ; Jon Tatman, jtatman@epri.com

RFA
5

Small Bore Piping Issues; Stephen Tate, state@epri.com

RFA
6

Transfer and Promote Fabrication and Joining Technologies into Codes, Standards, and Regulations; Steve McCracken, smccracken@epri.com

RFA
8

Repair Solutions for Structures: Containment, Fuel Pool Asset Management, and Spent Fuel Storage

RFA
9

Tactical Implementation of Repair Methods; Nick Mohr, nmohr@epri.com

RFA
10

Document and Evaluate Operating Experience for Welding and Repair Programs; Nick Mohr, nmohr@epri.com

RFA
11

Material Development and Evaluation (Powder Metallurgy, Advance Manufacturing, Coatings, and Hardfacing Application); Stephen Tate, state@epri.com

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Research Focus Areas

- High level review of RFA 1, 2, 4, 5, 6, and 9



RFA
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Research Focus Areas



RFA 1

Nickel-Base Filler Metal Weldability and New Alloy development; [Steve McCracken, smccracken@epri.com](mailto:smccracken@epri.com)

RFA 1: Nickel-based Filler Metal Weldability and New Alloy Development

General Description

- Research and understand high-chromium nickel-base weld metal (82, 52i, 52, 52M, 52MSS) cracking mechanisms and weldability
- Develop solutions for improved weldability and resistance to solidification cracking and ductility-dip cracking
- Advanced NiCrFe filler metal development for improved weldability and performance
- Support mockup fabrication for CGR testing and characterization

Select Completed Deliverables

- 3002015845, *High-Cr Ni-base Filler with Improved Weldability for Nuclear Applications*, June 2019
- 3002010760, *Hot Cracking of NiCrFe Weld Metal Diluted with Austenitic Stainless Steel*, Dec 2017
- 3002007909, *Weldability Testing of NiCrFe Weld Metals – Resistance to Solidification Cracking*, Dec 2016
- 3002005527, *Screening Test for NiCrFe Weld Metals – Preliminary Studies*, Sep 2015

Current Projects and Milestones

- 52XL large scale mockups, mechanical testing and SCC testing
- Transverse varestraint test optimization with IHI
- NiCrFe screening test with Framatome
- 2020 – Guidelines for procurement of NiCrFe filler metals
- 2020 – Magnetic stir welding studies



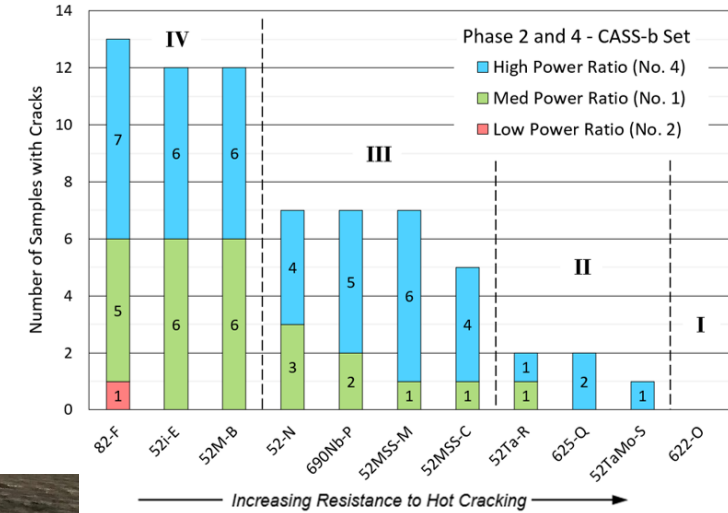
Weld Puddle Stirring



Oxides Without Wire Cleaning



New 52XL (52TaMo) Wire



Performance Comparisons Between NiCrFe Variants



Screening Collaboration with Framatome

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Research Focus Areas



RFA 2

Irradiated Materials Welding Solutions; Jon Tatman,
jtatman@epri.com

RFA 2: Irradiated Materials Welding Solutions

General Description

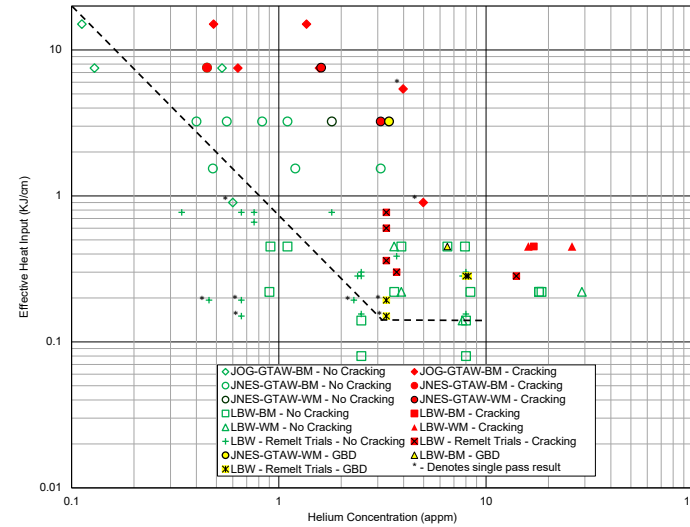
- Development of repair processes and weldability thresholds for highly irradiated materials (repair challenges due to helium)

Current Projects and Milestones

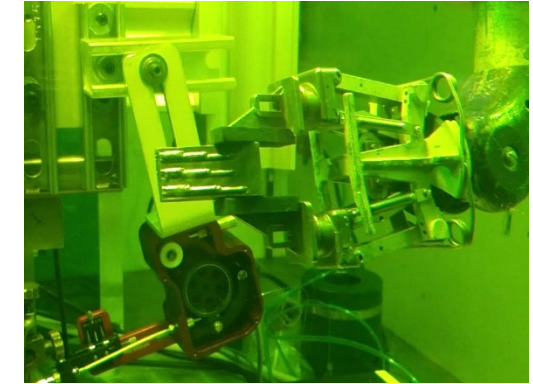
- Several welding campaigns have recently been completed at Oak Ridge National Laboratory (ORNL) and Westinghouse (on characterized materials)
- Code case development for repair of irradiated austenitic materials
- Development of field-deployable welding system

Notable Deliverables

- 3002005568 (BWRVIP-97 Revision 1): Guidelines for Performing Weld Repairs to Irradiated BWR Internals
- 3002002954 (MRP-379): Irradiated Material Guidelines
- 3002015849: Status Report for Collaborative Research Program on Irradiated Materials Weldability



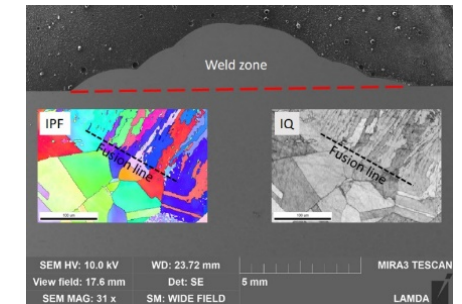
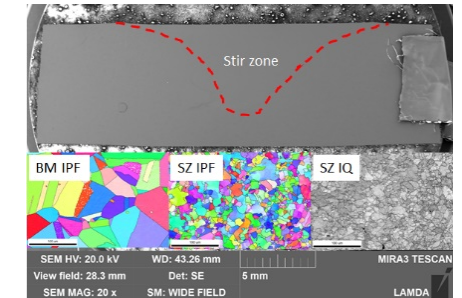
He-Induced Cracking Threshold Plot: 304 SS



Welded irradiated sample within WEC hot cell



Welds performed at WEC on irradiated sample with ~3 appm He



Cross-sections of laser (left) and friction stir (right) welds performed at ORNL on irradiated samples within hot cell cubicle

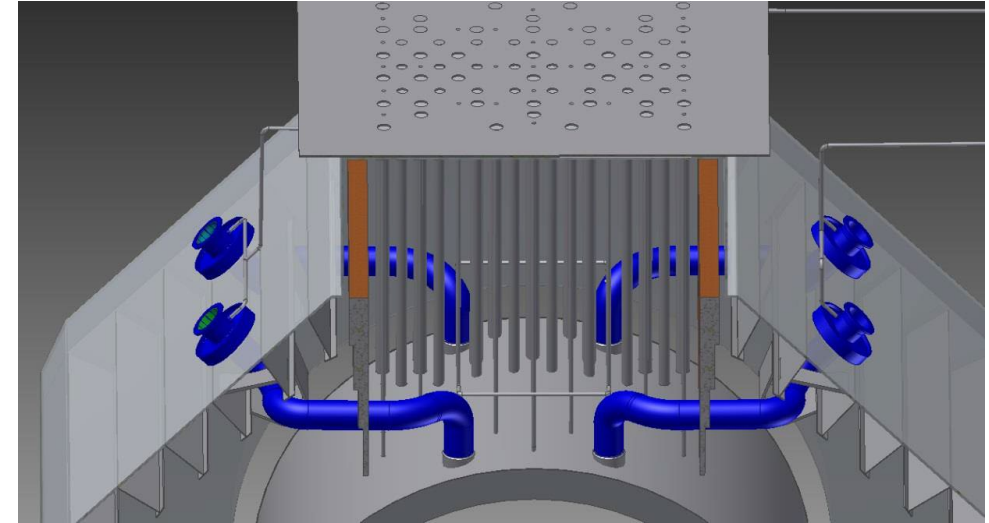
RFA 2: Irradiated Materials Welding Solutions - Recent Plant OE

■ Bruce Unit 7 Calandria Relief Duct

- Volumetric inspection performed in 2016 revealed significant degradation of highly irradiated CRD [1]
- Bruce Power currently seeking potential repair methods (including welding)

■ Ginna Clevis Insert

- Visual inspection revealed Alloy 600 clevis separated from clevis insert
- Weld repair would have been ideal, however, lack of weldability data for Inconel material excluded this option



Bruce Unit 7 Calandria Relief Duct [1]



Ginna Clevis Insert

[1] A. Brooks, S. Gupta, "Continued Fitness for Service of the Bruce B Unit 7 Calandria Relief Ducts," 1st International Conference of Materials, Chemistry and Fitness-for-Service Solutions for Nuclear Systems May 15-17, 2019, Markham, Ontario, Canada.

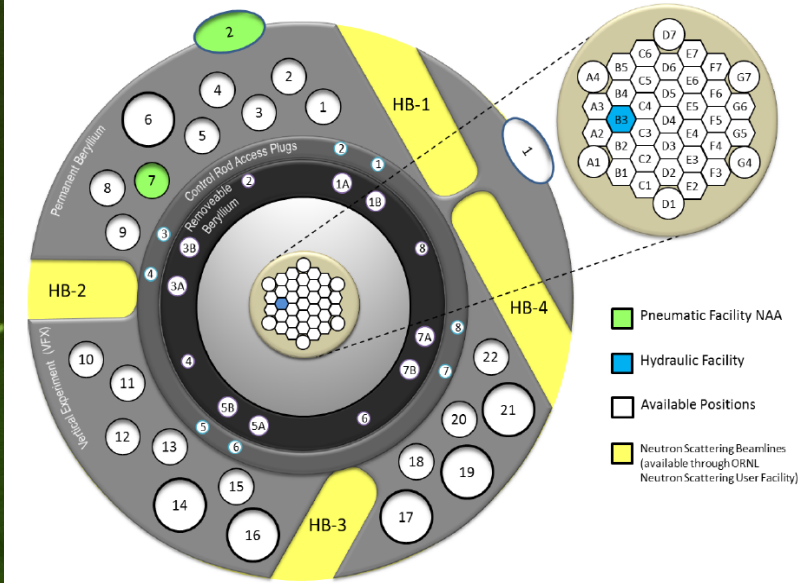
What is needed to weld repair reactor internals?

1. **Weldability data for common alloys (stainless steel, and Ni-alloys)**
 - Supporting ASME Code Case development
 - 80 fabricated samples (304, 316, and Alloy 182)
 - Helium ranges between 1 and 30 appm
 - Vintage Samples – Westinghouse (304 “hex block” material)
 - Helium ranges 0.1 – 8 appm, damage up to 30 dpa
 - Welding and characterization completed at ORNL & Westinghouse
2. **Field-deployable underwater repair capabilities**
 - Focus on common repair processes (to include GTAW)
3. **ASME Section XI Code Case to support repairs**
 - components greater than 0.1 appm He

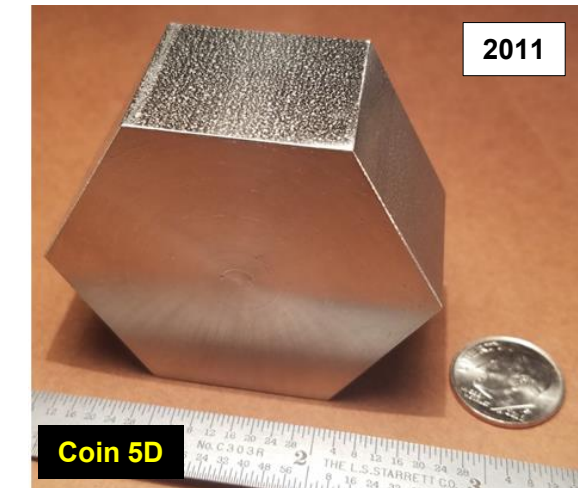
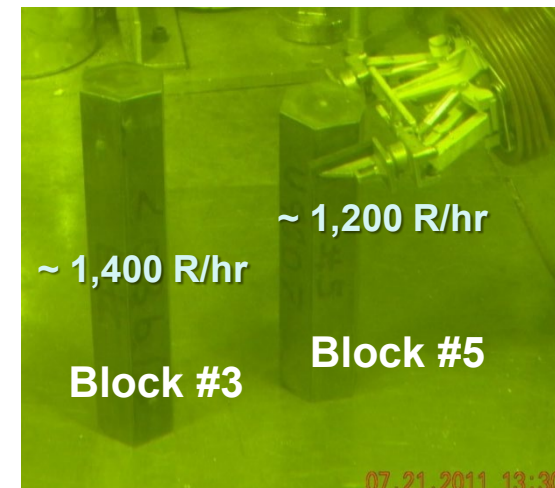
ORNL Irradiated Samples



High Flux Isotope Reactor (HFIR)



Westinghouse Vintage 304 “Hex Block” Irradiated Materials



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Research Focus Areas



RFA 4

Optimize Joining, Fabrication, and Repair Processes (including WRS) ; Jon Tatman, jtatman@epri.com

RFA 4: Optimize Joining, Fabrication, and Repair Processes

General Description

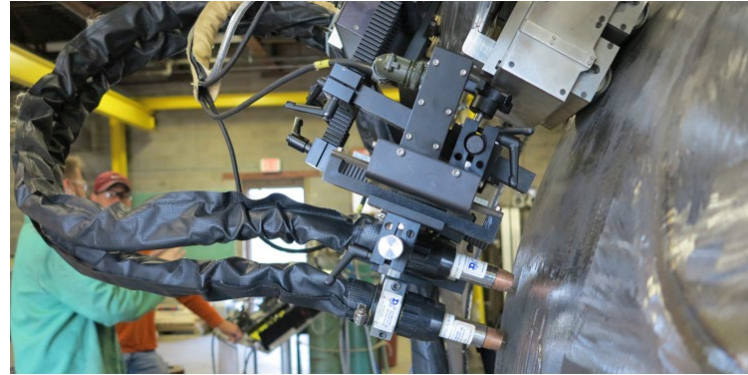
- Opportunity to optimize and improve established welding processes and procedures
- Optimize residual stresses through surface conditioning and other techniques

Legacy documents

- 3002000413: Repair Technology for Degraded Pressure Vessel and Heat Exchanger Shells (GMAW)
- 3002013028: Evaluation of New Stress Mitigation Techniques
- 3002010747: Improved Calculation Methods for Weld Heat Input and Dilution Control

Current projects and Milestones

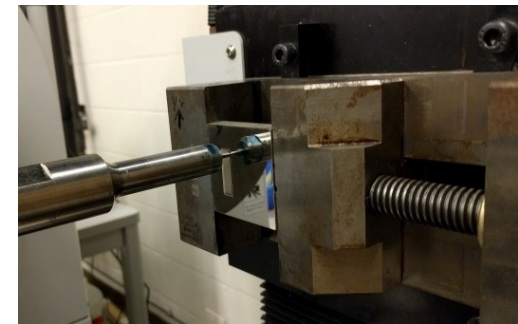
- Development of high deposition repair processes for safety components (including GMAW)
- Development and code acceptance of advanced surface stress improvement techniques
- Development and validation of effective heat input formulas for improved process control



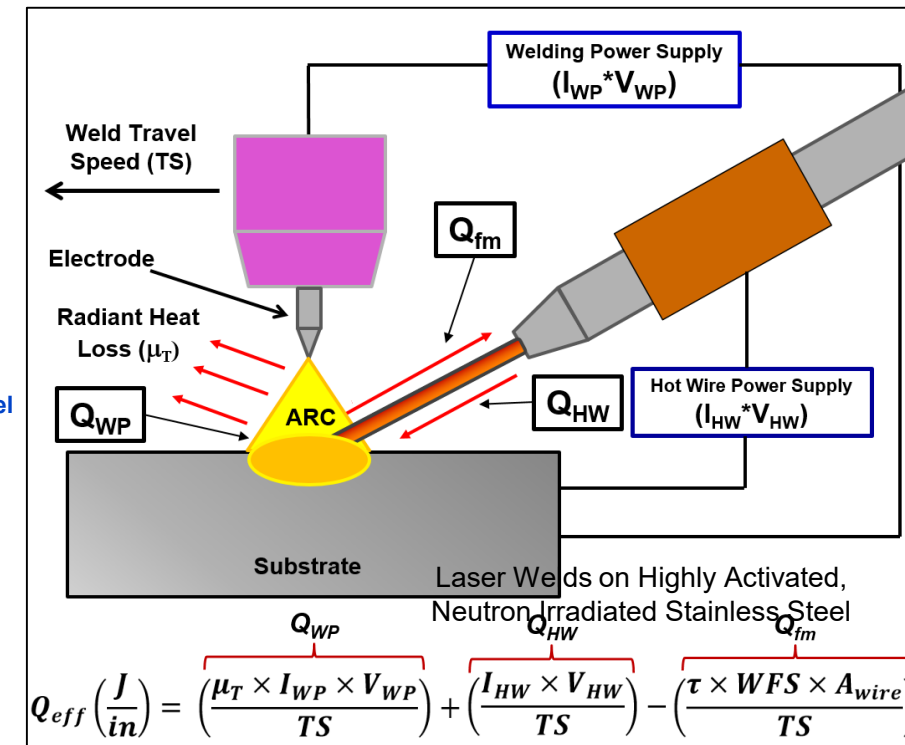
Dual GMAW for Large-Scale Heat Exchanger Overlay Repair



Low Plasticity Burnishing of Containment Vessel



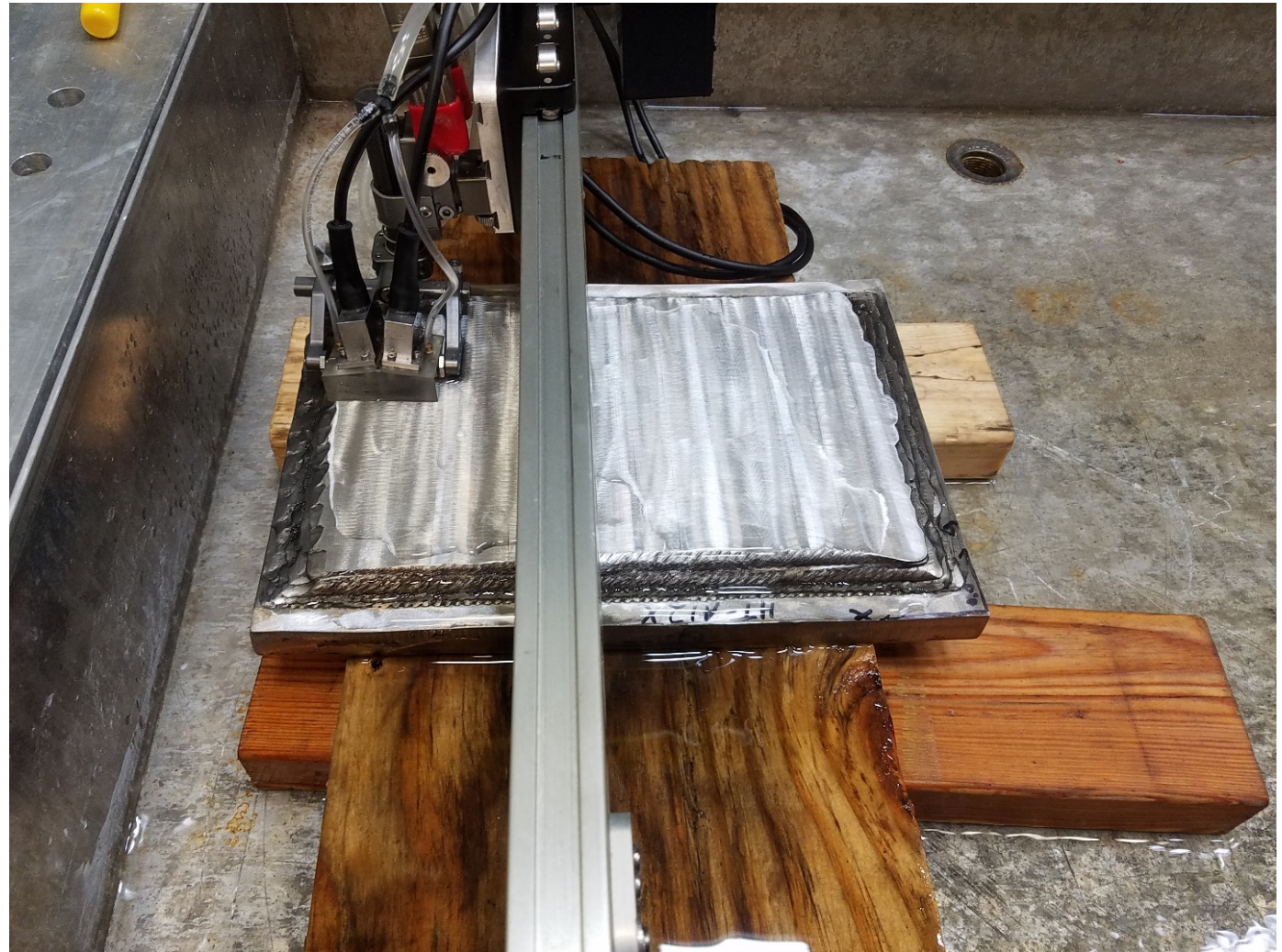
UNSM of Alloy 600



Effective Weld Heat Input Formula

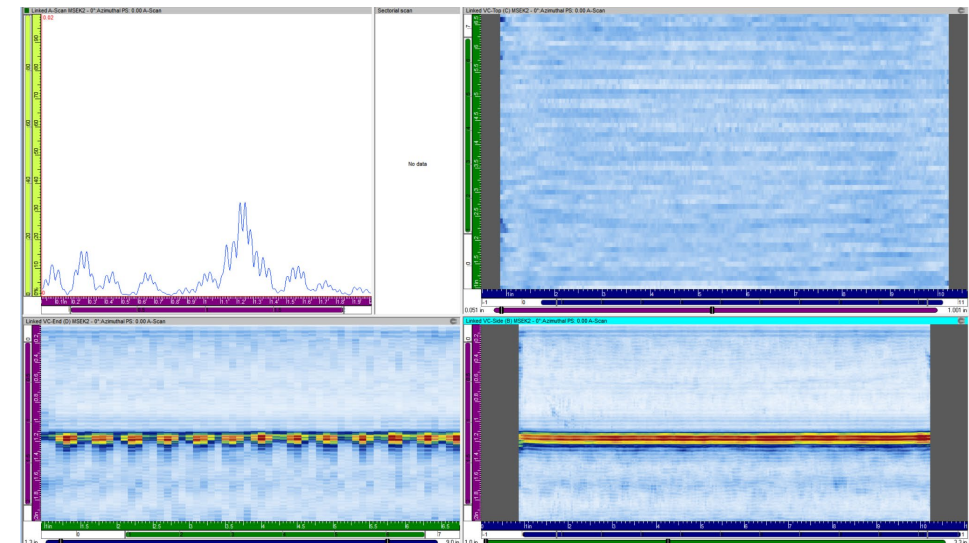
GMAW for Emergent Repairs

- Efforts to assess capability of using GMAW for emergent safety-related repairs continues to gain traction
 - Ability to significantly reduce welding time during emergent repairs
- EPRI-WRTC, Exelon, and Framatome are collaborating to fabricate additional weld pad specimens for NDE
- Recent results indicate significant improvements in both weld quality and inspectability in stainless steel and Inconel GMAW pads



GMAW for Emergent Repairs: Summary

- NDE specimens being welded by multiple organizations and equipment manufacturers.
 - Different weld equipment (e.g., Miller, Fronius), shielding gas mixtures and waveform parameter programs being tested
- UT inspectability of EPRI WRTC Inconel pad “better” than initial EPRI stainless steel plates
 - Inconel was found to be less inspectable than stainless steel in previous EPRI investigations
 - Inspectability of recent pads for both material-types found to be acceptable
 - Improved inspectability may be attributed to updated advanced waveforms programs for Inconel
- Inspection of Framatome stainless steel weld pad revealed yet another significant improvement
 - Additional stainless steel pads to be fabricated by Framatome in all welding positions, inspected by EPRI



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Research Focus Areas



RFA 5

Small Bore Piping Issues; [Stephen Tate, state@epri.com](mailto:state@epri.com)

RFA 5: Small Bore Piping Asset Management

■ General Description

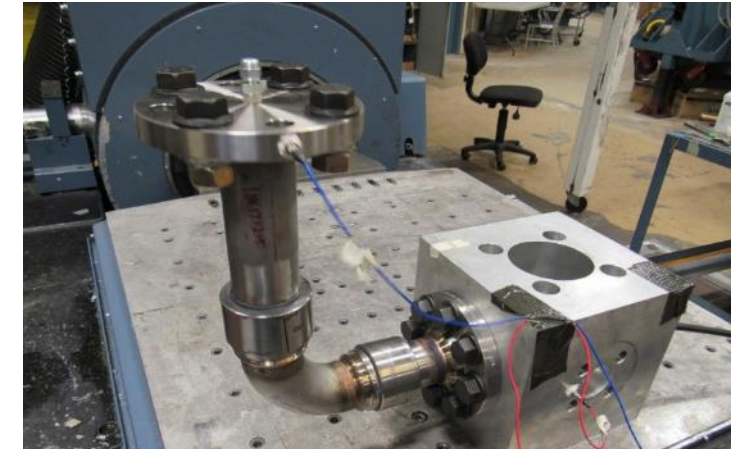
- Understanding small bore (NPS 2 or 50 mm and under) piping issues and maximizing small bore piping reliability
- Socket welds, butt welds, and overlays
- Mechanical joints

■ Current Projects and Milestones

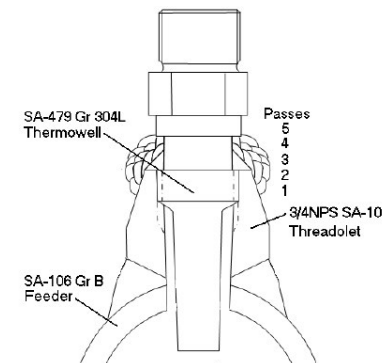
- High cycle fatigue testing of mechanical fittings for small bore piping and Code acceptance of mechanical fittings
- Socket Weld Workshop
- Implementation Guidelines for mand Implementation Guideline for small bore mechanical fittings.

■ Select Completed Deliverables

- 3002010753: Practical Guideline to Socket Welding
- 3002015848: Evaluation of Small Bore Mechanical Fittings – High Cycle Fatigue



High cycle fatigue testing - mechanical fitting



Socket weld overlay

RFA 5: Small Bore Piping Asset Management

- Socket Weld Workshop

- **Value**
 - Provide resources to improve unit reliability and reduce maintenance related to small bore piping
- **Current Industry Need**
 - Education related to vibration and small bore piping failures: weld quality is not the single solution



ASME - Code Acceptance

- Code Cases to allow use of Lokring fittings up to NPS 2 in Sect. III Class 1, 2, or 3 applications:
 - N-878: Allows alternative to Section XI, IWA-4142.1(b), procurement requirements for non-welded fittings.
 - N-879: Approves Micro-Alloyed Steel (i.e., MAS) material for fabrication of fittings for use in CS applications.
 - N-880: Allows alternative to Section XI, IWA-4143, procurement requirements for small nonstandard welded fittings.
 - N-893: Approves LTCS-333 FAC resistant material for fabrication of forged (instead of welded) fittings for use in CS/Chromoly applications
- Exelon submitted two relief requests to the NRC for:
 - Review and approval of ASME Section XI Code Cases N-878, N-879 & N-880
 - Exelon has NRC approval of all relief requests as of Spring 2020



Lokring Fatigue Testing – NPS 4 (100 mm)

Implementation Guide Approach – Mechanical Fittings

1

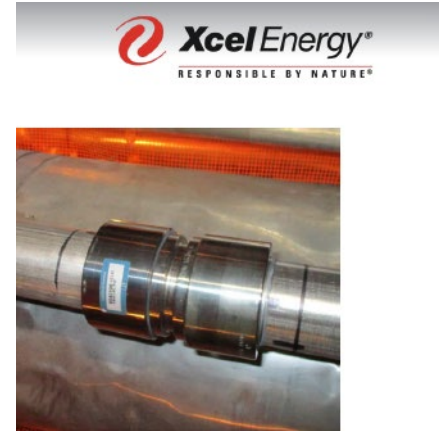
- Previous deliverables technically focused but included current status of code changes on mechanical fittings
- Still confusion from some members on where fittings could be used

2

- What do members need to reduce barriers for use of mechanical fittings?

3

- Development of Implementation Guide for Small Bore Mechanical Fittings; Background and installation
 - Application requirements and limitations
 - Procurement
 - Code/Regulatory acceptance
 - Operating Experience
 - Sample Relief Requests



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Research Focus Areas



RFA 6

Transfer and Promote Fabrication and Joining Technologies into Codes, Standards, and Regulations; [Steve McCracken, smccracken@epri.com](mailto:smccracken@epri.com)

RFA 6: Transfer and Promote Fabrication and Joining Technologies into Codes, Standards, and Regulations

- **General Description**
 - Promote and support Code and Regulatory adoption of code cases, code revisions and guidance documents that provide resolution for industry issues
- **Select Completed Deliverables**
 - Report 3002013123, 2018 Code Issues Report
 - Reviews current status if Code actions related to repair. 2019 Code Issues Report (published in July)
- **Key Projects and Milestones**
 - Risk-informed approach for repair & replacement activities (N-752)
 - Guidelines and requirements for welding on irradiated material (N-638-10)
 - Hardness protocol for temper bead qualification
 - Expand socket weld overlay case for SCC and DMW joints (N-666-1)
 - Weld overlay for repair & mitigation of base metal fatigue (N-894)



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Research Focus Areas



RFA 9

Tactical Implementation of Repair Methods;

Nick Mohr, nmohr@epri.com

RFA 9: Tactical Implementation of Repair Methods

Description: Development and implementation of specific repair solutions, primarily in the form of guidance for assisting members in implementing new and innovative repairs and mitigation methods.

Objectives: Develop deliverables that help members address the “How”

- Guideline documents based on research, operating experience, and lessons learned

Current Research and Activities

• Reports

- Use of Non-Metallic Repairs (e.g. carbon fiber wraps) - expected 2020
- Weld Overlay Handbook: review of areas for revision in 2019/2020 and revision in 2020 or 2021
- Secondary Water Chemistry Issues with Repair Welding Phase 3: Goal reduce sodium excursions from welded repairs, 2-yr project starting in 2019 with report in 2020 to provide guidance on implementation of data from Phase 1 and 2

• Application/Tools

- Repair Guidance Tool: Electronic tool (Events Management Response Tool) to assist members in determining which repairs can be used, relevant EPRI information, lessons learned, etc.- Scoping in 2019 and initial trial in 2020
- IAEA Temper Bead Welding Report – International Code comparison, equivalency, limitations, and requirements by country, will be accumulated in one document
 - Goal to improve implementation of TB welding

RFA 9: Tactical Implementation of Repair Methods

Completed Deliverables

- *Welding and Repair Technology Center: Guideline for Sleeve and Pad Reinforcement Repairs: Code Cases N-786-3, N-789-3, and N-865.* EPRI, Palo Alto, CA: 2018. 3002013125
- *Welding and Repair Technology Center: Evaluation of Welding Process Effects on Secondary Water Chemistry—Phase 2.* EPRI, Palo Alto, CA: 2016. 3002007906.
- *Welding and Repair Technology Center: Evaluation of Welding Process Effects on Secondary Water Chemistry.* EPRI, Palo Alto, CA: 2014. 3002003111
- *Welding and Repair Technology Center: Essential and Emergency Service Water Issues-Update: Erosion, Leakage Operability, and Repair.* EPRI, Palo Alto, CA: 2015. 3002005539
- *Welding and Repair Technology Center: Repairs to Leaking American Society of Mechanical Engineers (ASME) Class Systems—Update.* EPRI, Palo Alto, CA: 2015. 3002005537.

Purpose and Objective of Event Management Response Tool (EMRT)

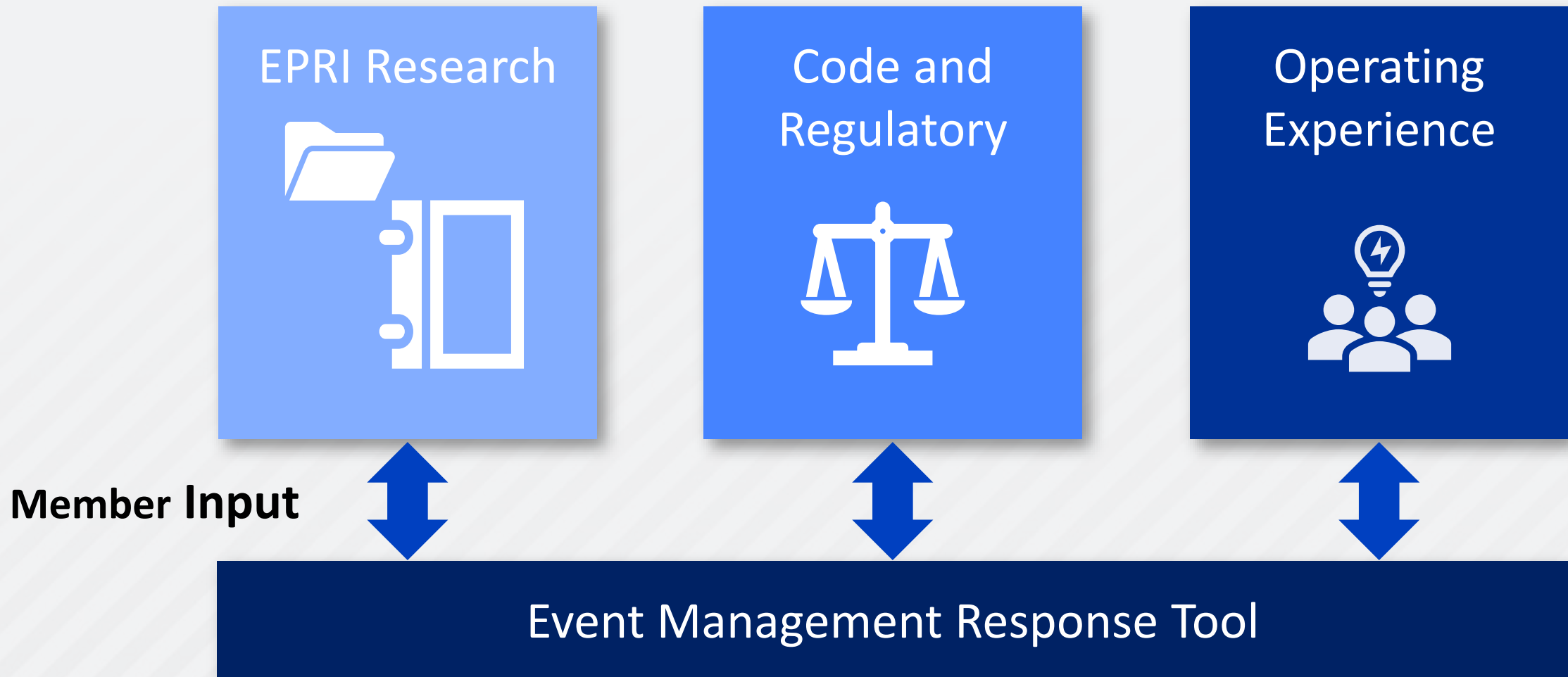
- Goal to increase EPRI Member productivity by:
 - Reduction of time associated with finding the needed research products
 - Display the first attempt at determining the pertinent information from each of the research products
 - Reduction of time associated with finding Code and Regulatory information (e.g. approved Code Cases, Relief Request)
 - Currently, discussing capturing ADAMS documents w/NRC for ingestion into EMRT
 - Reduction of time associated with find operating experience and lessons learned from other EPRI members related to event

All three pieces of information are necessary for members to make the best decision



Value/Objective:
Provide EPRI members the needed information to make informed decisions in one location in reduced time

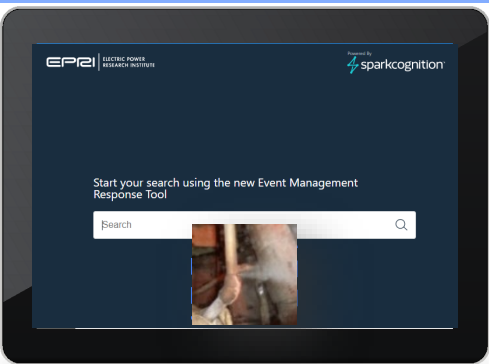
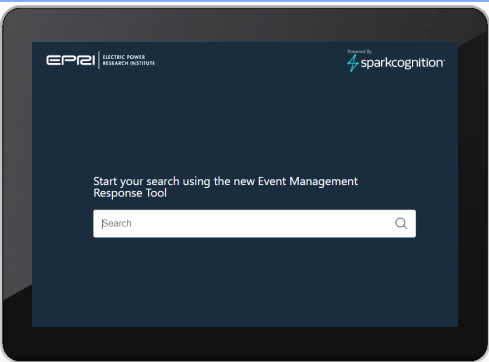
Event Management Response Tool (EMRT)



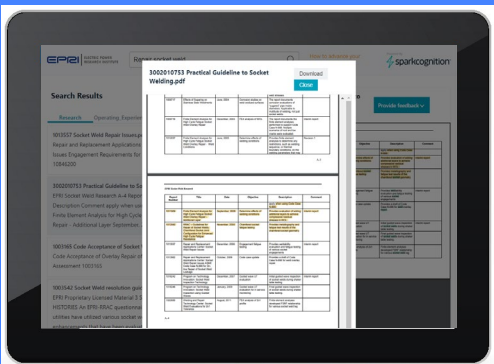
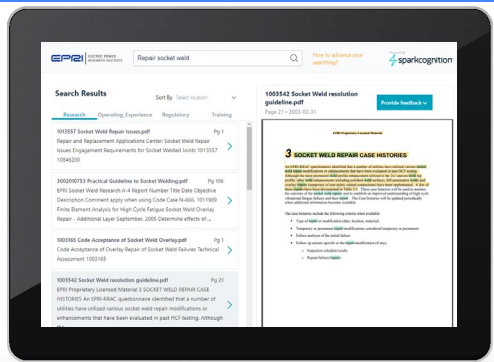
Member inputs a search and relevant information across all three buckets is presented based on relevancy

EMRT: Natural Language Processing & Access Full Data Library

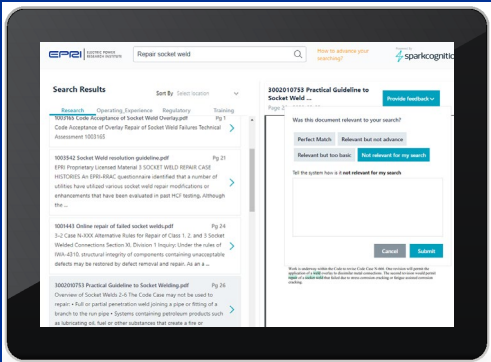
Input



Display of Output



Feedback Loop

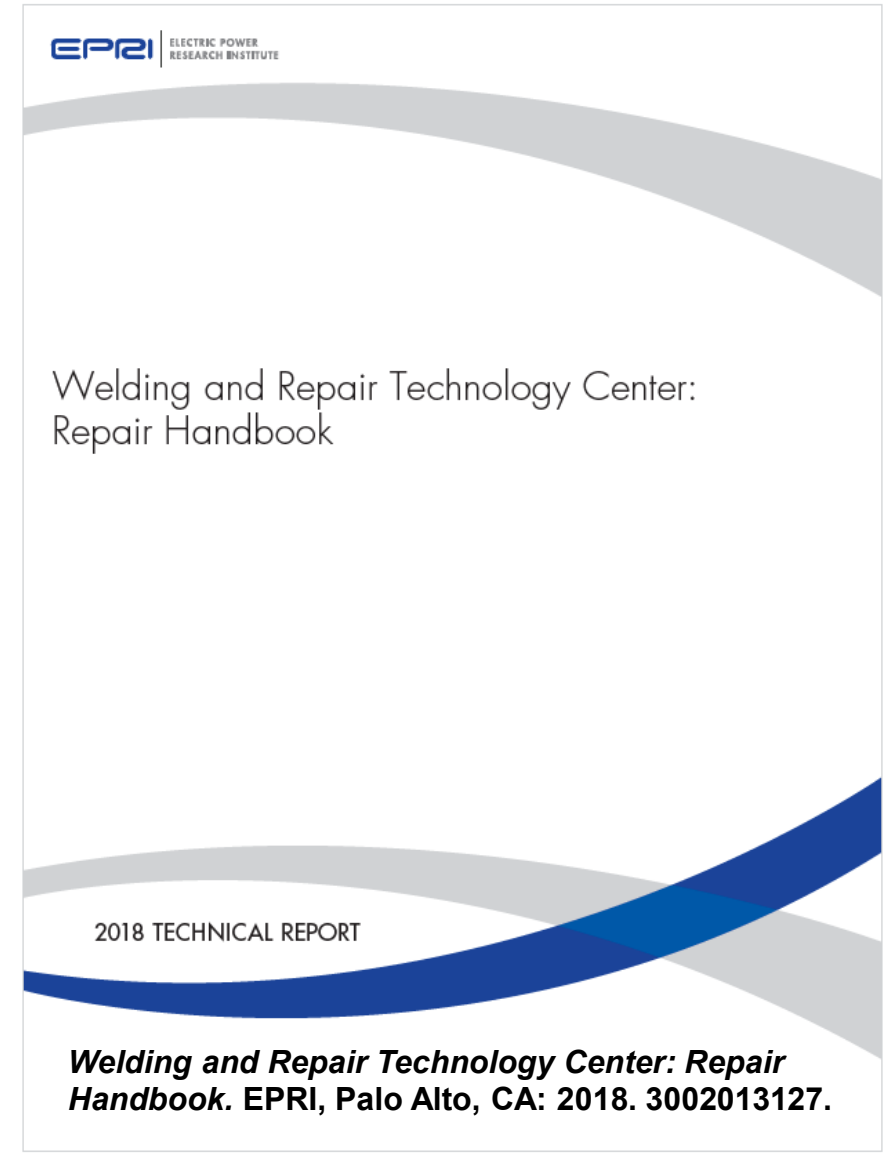


Machine Learning & Refinement of Output

Key goal is to find relevant primary and supplementary information

Repair Handbook Update-2020

- **Value: Find information about repair options and background information quickly while providing operating experience and lessons learned**
- Reference WRTC Repair Handbook 3002013127 (Nov 2018)
- In 2020 the 2018 report will review and update all existing content against current governing Code provisions and Regulatory requirements:
 - ASME Section XI through 2019 Edition
 - ASME approved Repair/Replacement Code Cases through 2020
 - Regulatory Guides 1.147 and 1.193 issued March 2020
 - 10CFR50.55a effective June 3, 2020



Repair Handbook Update-2020

▪ Updates for 2020

- a) Code Cases reflecting latest revisions, new Code Cases and latest NRC conditions
- b) International Country Appendices
- c) Input received from Canada, Czech Republic, Japan, U.S.
- d) Non-Metallic Repair/Replacement (HDPE, CFRC)
- e) Sleeve-Coupled Proprietary Fittings (Mechanical Fittings) (N-878, 879, 880, 893)

▪ New Topics for 2020 Update:

- a) Risk-Informed Repair/ Replacement (Code Cases N-660, N-662 and N-752)
- b) Regulatory Guides 1.147, 1.84 & 1,193
- c) RPV Bottom-Mounted Instrument Nozzle Repairs (Code Case N-733-1)
- d) New 10CFR50.55a rule adding requirements for VT-2 testing of bolted connections
- e) Section XI Division 2 – Reliability and Integrity Management Program
- f) Recent changes to IWA-4143, off-site fabrication (Record 19-2731)
- g) IWA-4340, Mitigation of Defects by Modification.

Repair Handbook Flowcharts

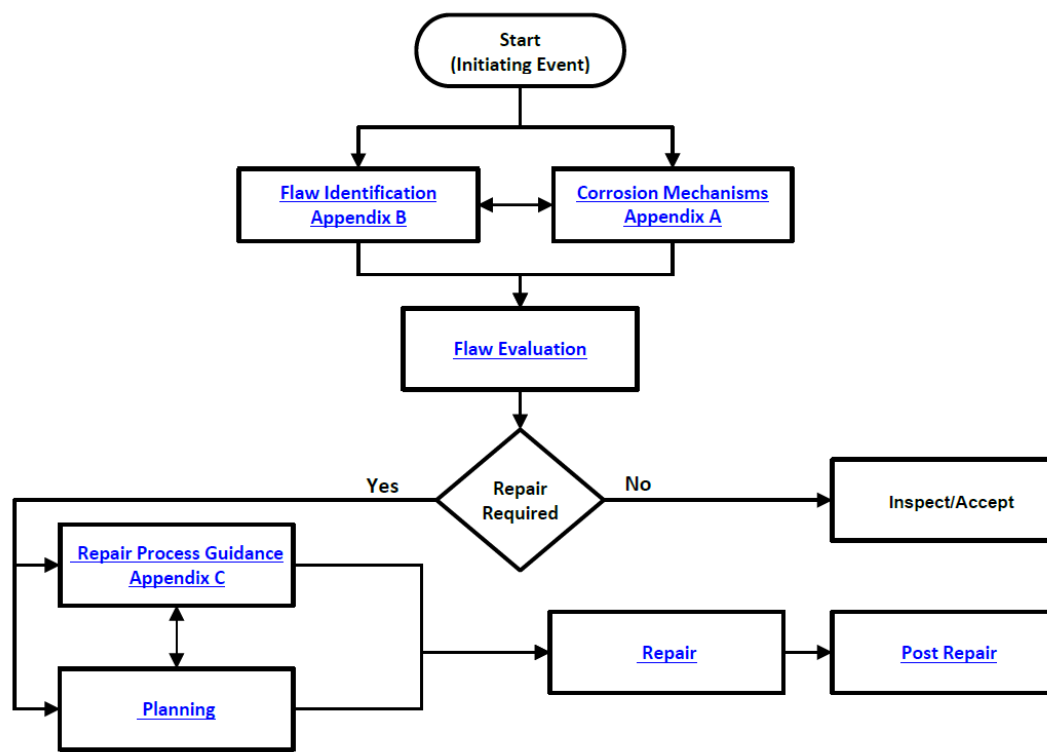
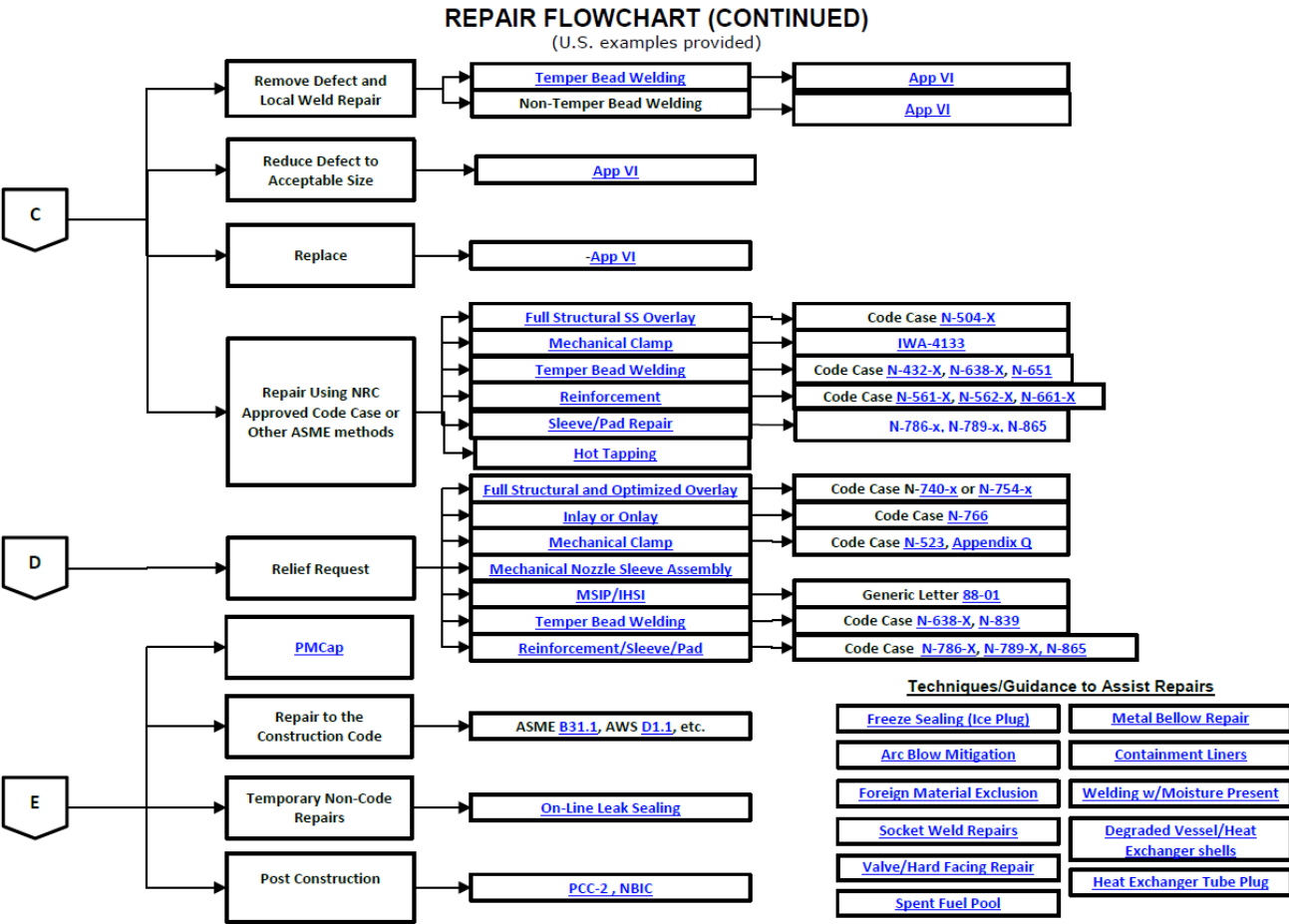


Figure 1-1
Repair handbook flowchart



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