Welding & Repair Technology Center

Highlights

Dan Patten, Energy Harbor
Greg Frederick, EPRI

NRC Technology Exchange
July 14, 2020
via Webex

EPRI - WRTC Point of Contacts

- Dan Patten, Energy Harbor, WRTC Program Chair
  - dpatten@energyharbor.com
- Greg Frederick, WRTC Program Manager
  - 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

WRTC

Research Focus Areas

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

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

WRTC

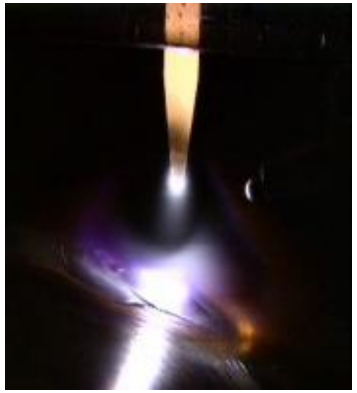
Research Focus Areas

RFA 1

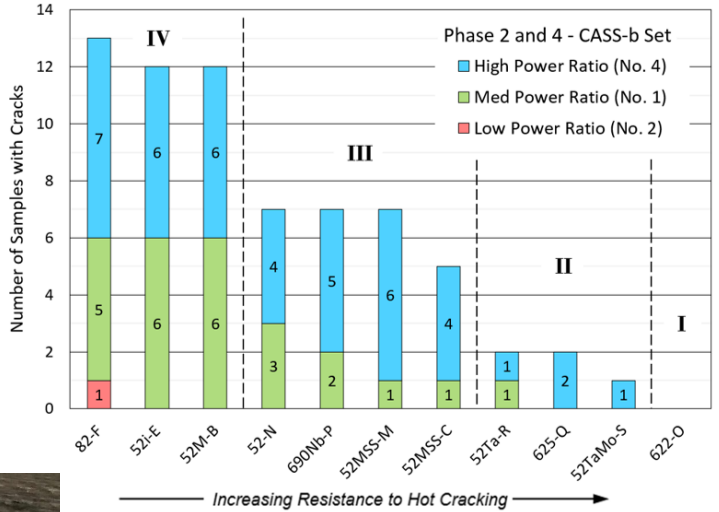
Nickel-Base Filler Metal Weldability and New Alloy development; Steve McCracken, smccracken@epri.com

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



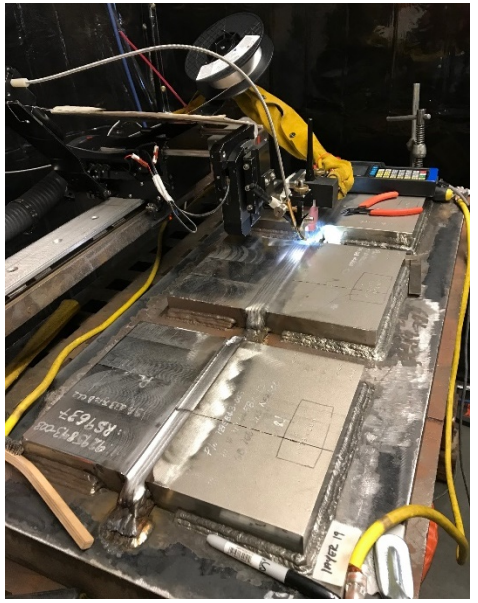
Weld Puddle Stirring



Performance Comparisons Between NiCrFe Variants

Oxides Without Wire Cleaning

New 52XL (52TaMo) Wire



Screening Collaboration with Framatome

WRTC

Research Focus Areas

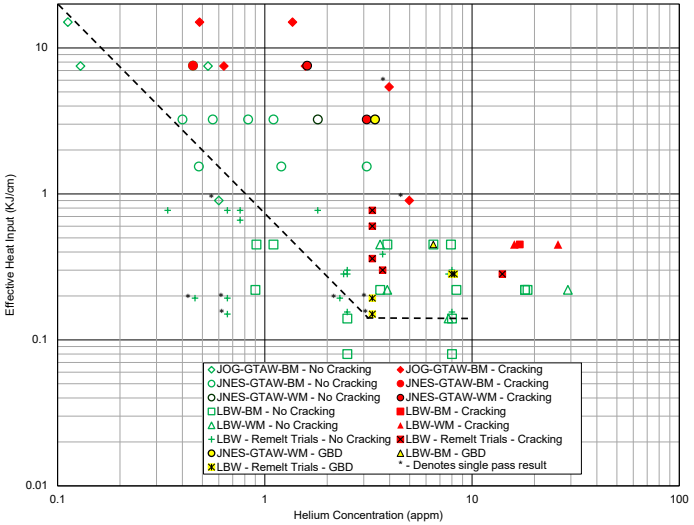
RFA 2

Irradiated Materials Welding Solutions;

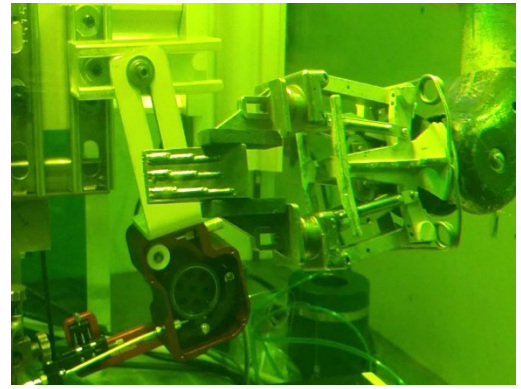
Jon Tatman,
jtatman@epri.com

RFA 2: Irradiated Materials Welding Solutions

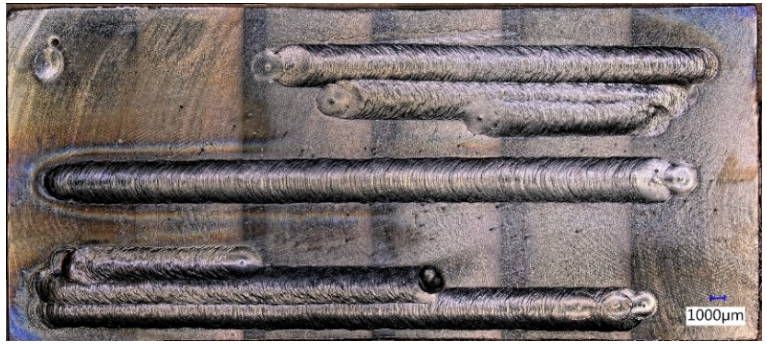
- **General Description**
  - Development of repair processes and weldability thresholds for highly irradiated materials (repair challenges due to helium)
- **Current Projects and Milestones**
  - Several welding campaigns have recently been completed at Oak Ridge National Laboratory (ORNL) and Westinghouse (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



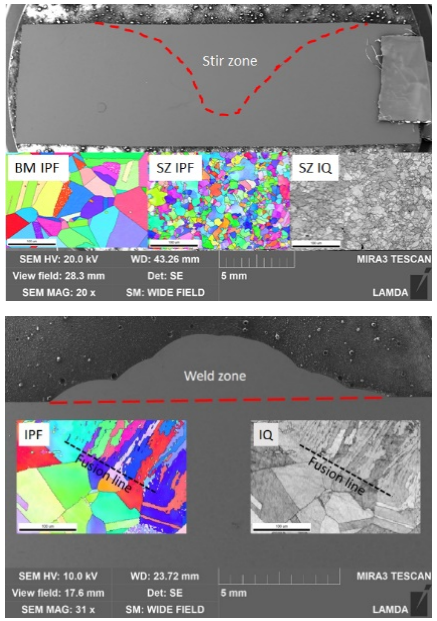
He-Induced Cracking Threshold Plot: 304 SS



Welded irradiated sample within WEC hot cell



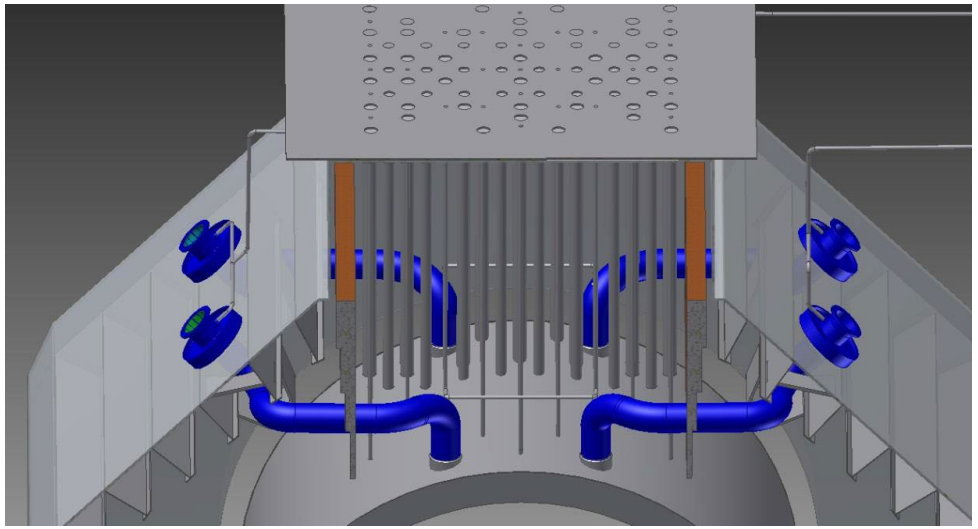
Welds performed at WEC on irradiated sample with ~3 appm He



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]

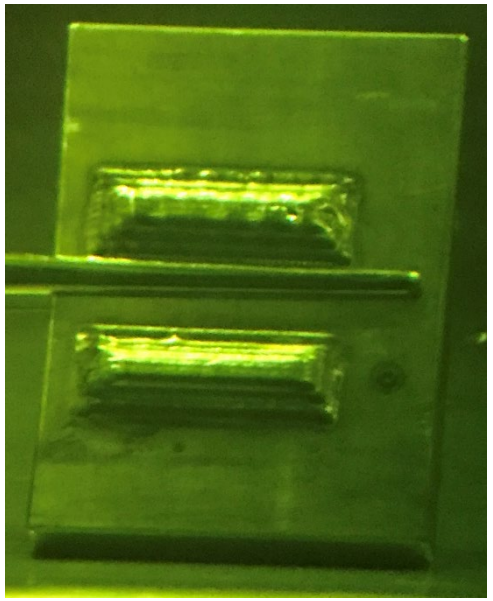
Ginna Clevis Insert

[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.

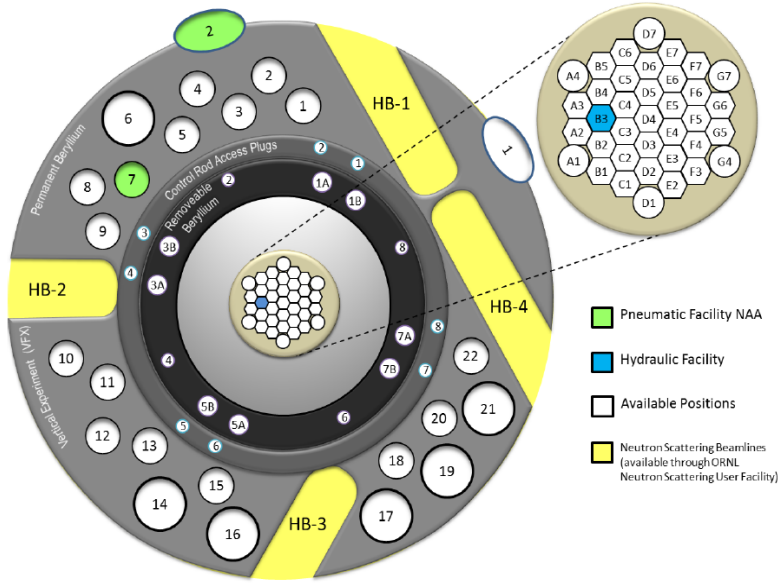
What is needed to weld repair reactor internals?

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

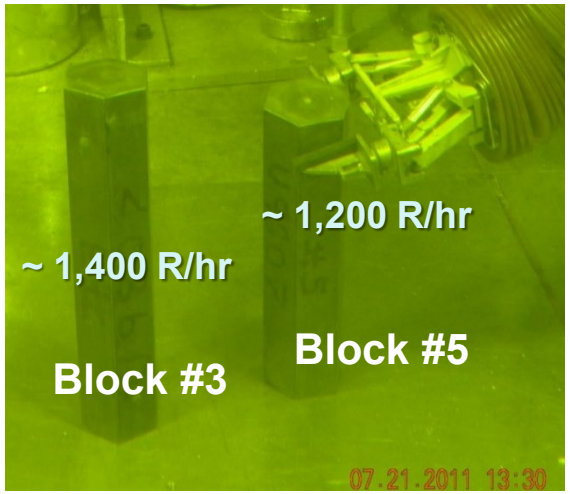
ORNL Irradiated Samples

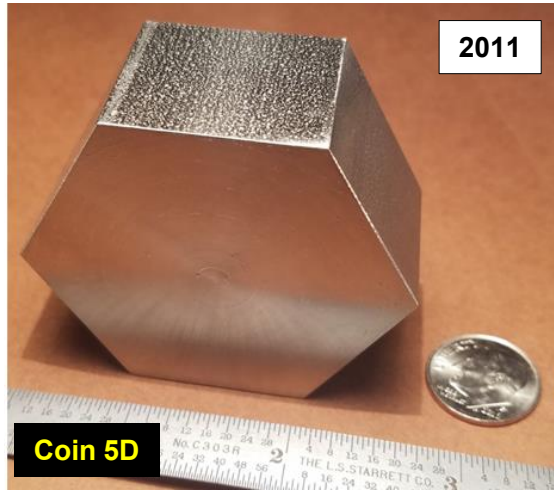


High Flux Isotope Reactor (HFIR)



Westinghouse Vintage 304 “Hex Block” Irradiated Materials





WRTC

Research Focus Areas

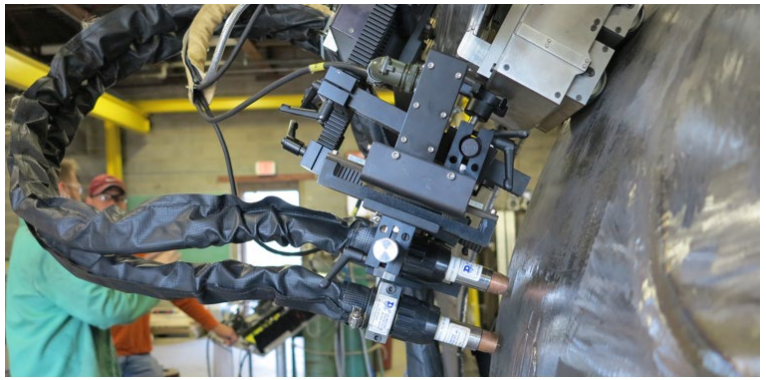
RFA 4

Optimize Joining, Fabrication, and Repair Processes (including WRS)

; Jon Tatman, jtatman@epri.com

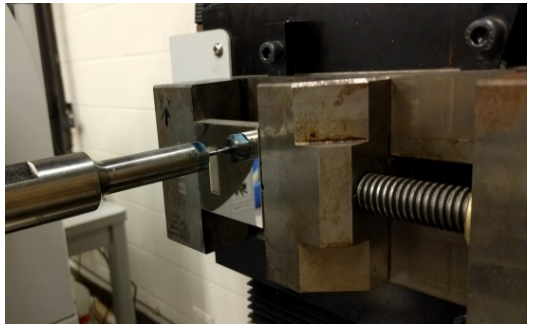
RFA 4: Optimize Joining, Fabrication, and Repair Processes

- **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

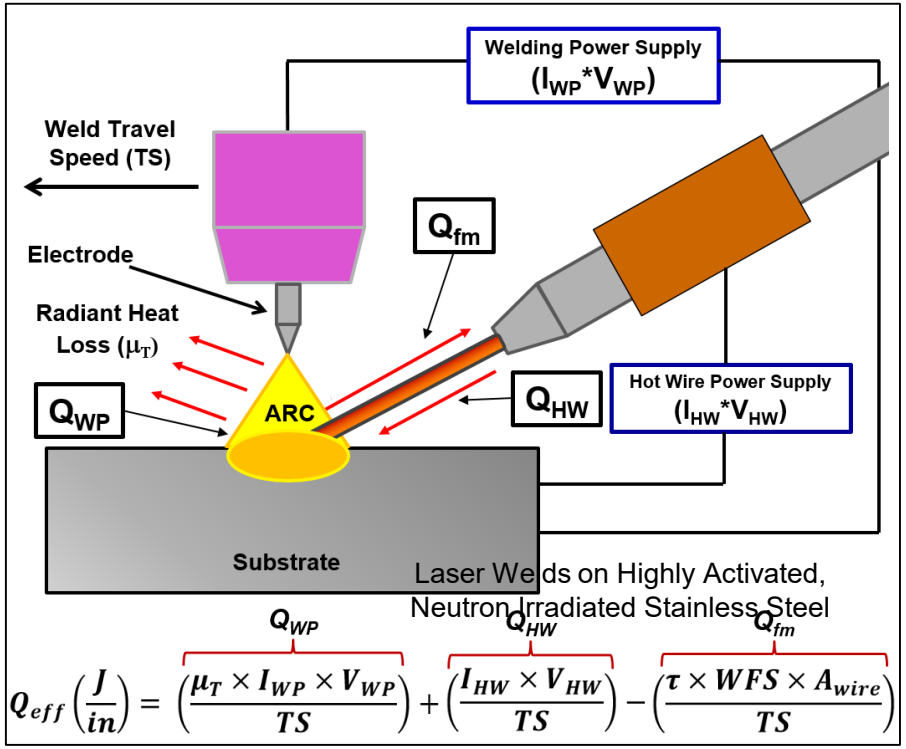


Dual GMAW for Large-Scale Heat Exchanger Overlay Repair

Low Plasticity Burnishing of Containment Vessel



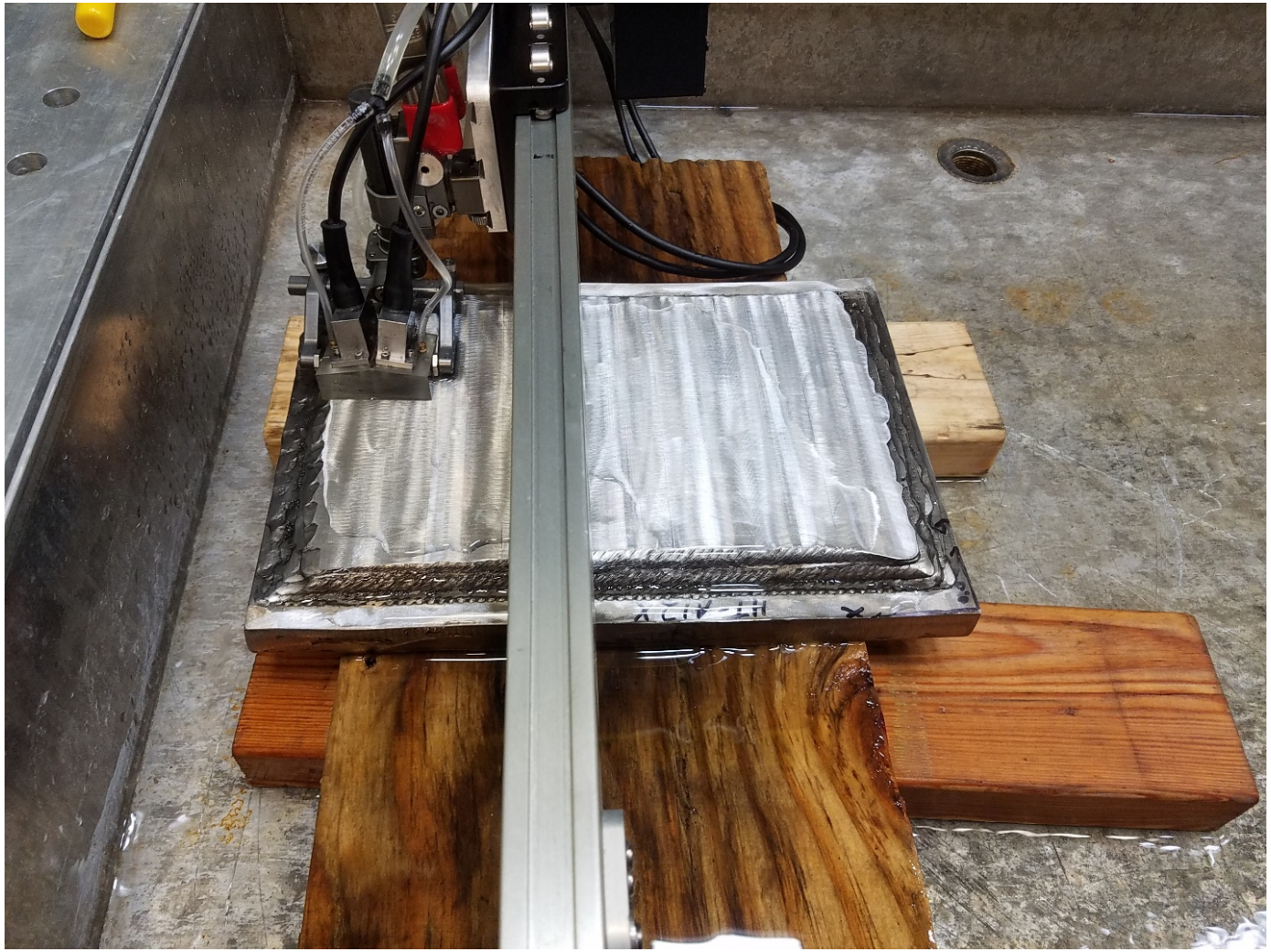
UNSM of Alloy 600



Effective Weld Heat Input Formula

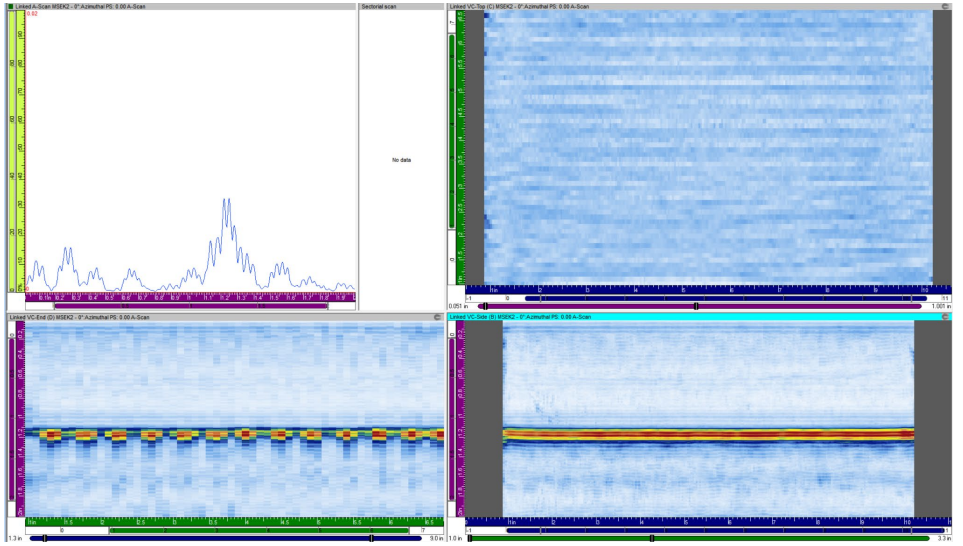
GMAW for Emergent Repairs

- 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



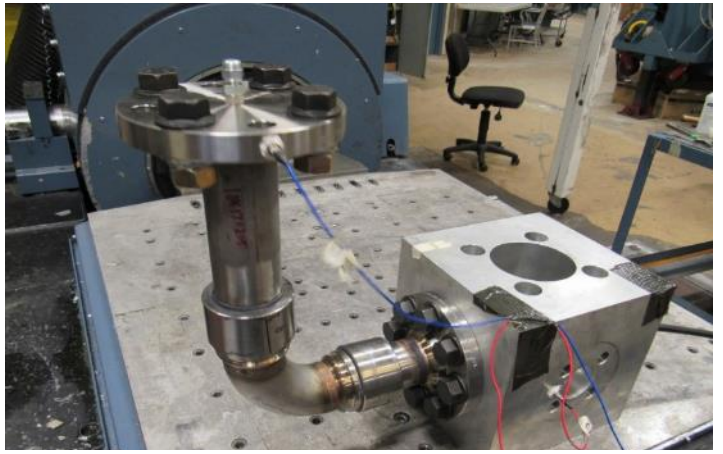
WRTC

Research Focus Areas

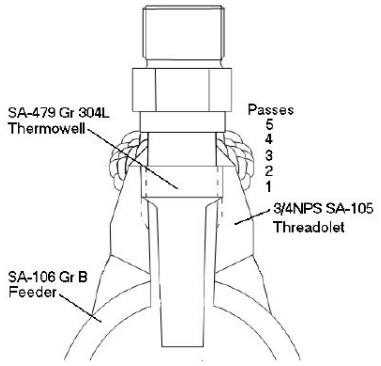
RFA 5 **Small Bore Piping Issues;** Stephen Tate, state@epri.com

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



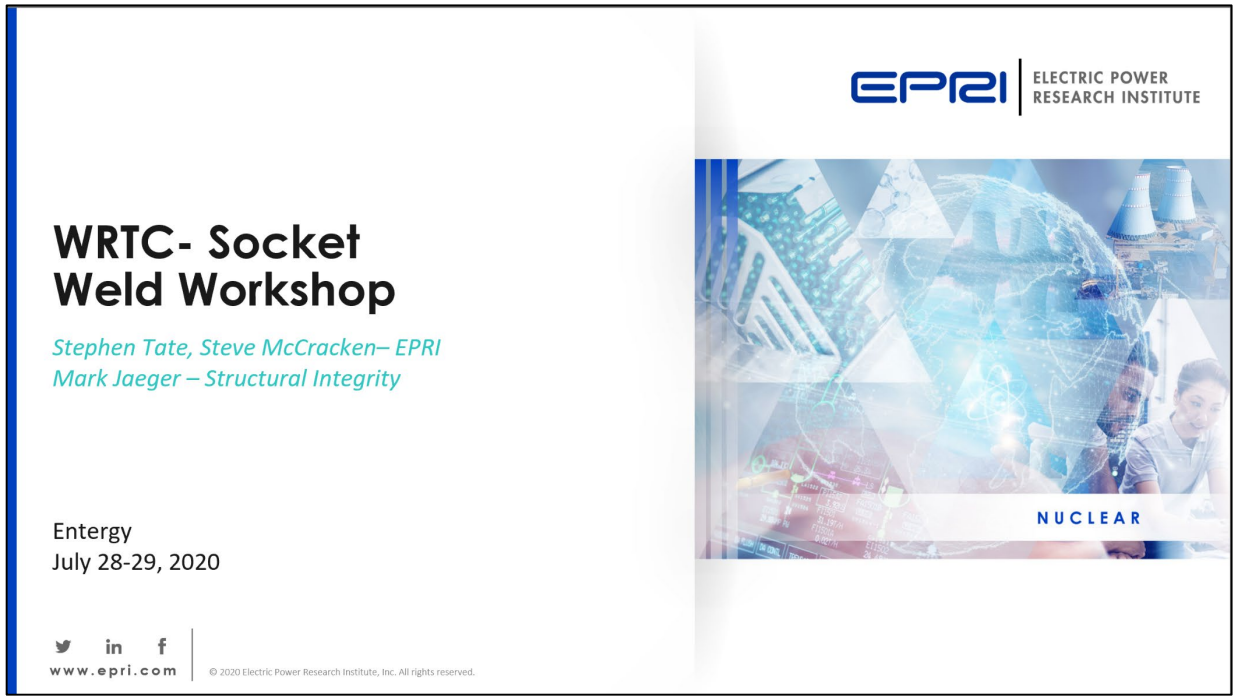
High cycle fatigue testing - mechanical fitting



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

WRTC

Research Focus Areas

RFA 6

Transfer and Promote Fabrication and Joining Technologies into Codes, Standards, and Regulations; Steve McCracken, 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)

WRTC

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

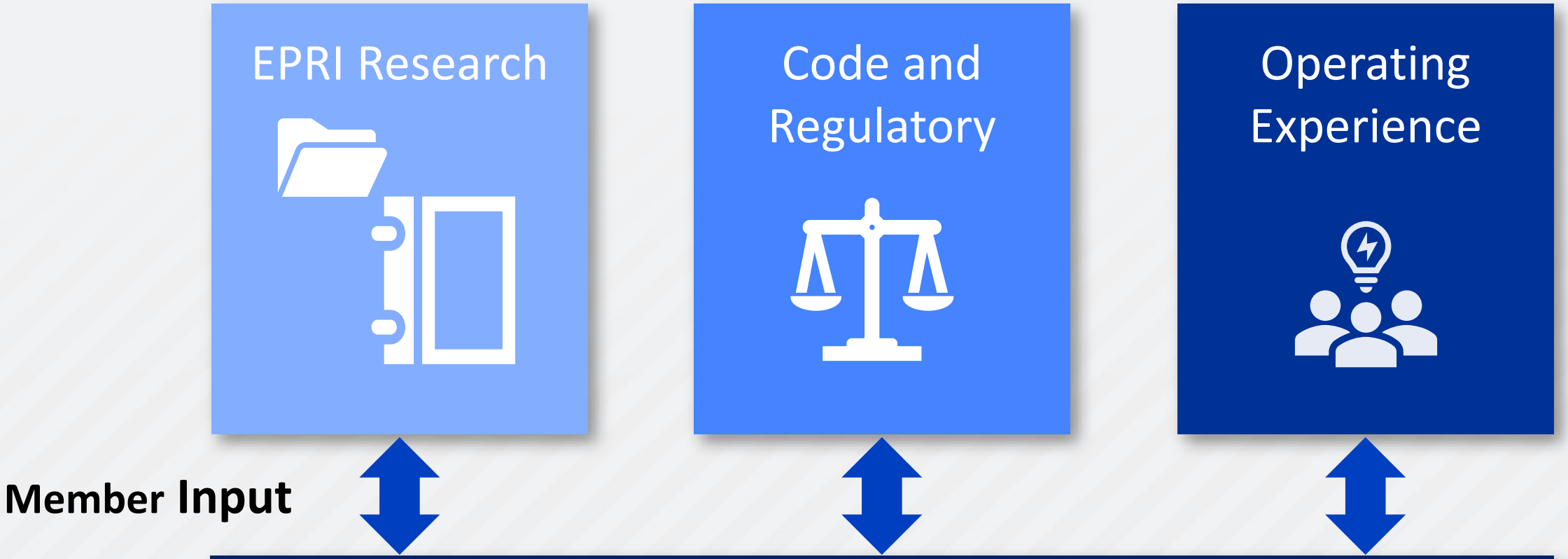
All three pieces of information are necessary for members to make the best decision

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Value/Objective:

Provide EPRI members the needed information to make informed decisions in one location in reduced time

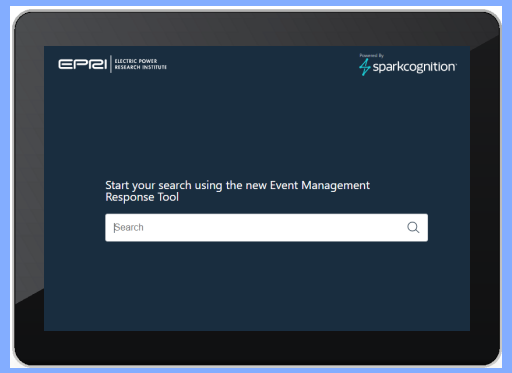
Event Management Response Tool (EMRT)

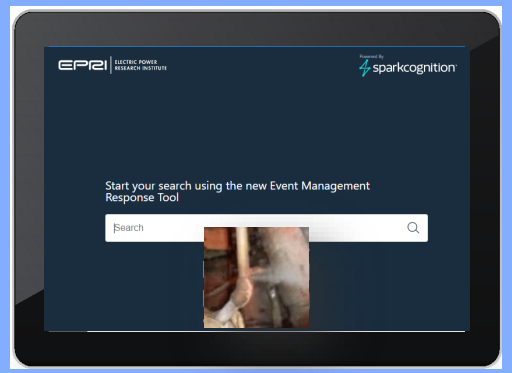


Member inputs a search and relevant information across all three buckets is presented based on relevancy

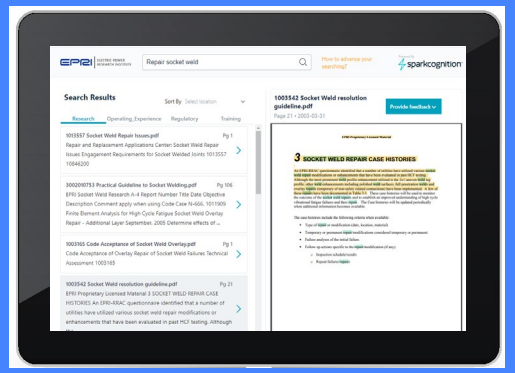
EMRT: Natural Language Processing & Access Full Data Library

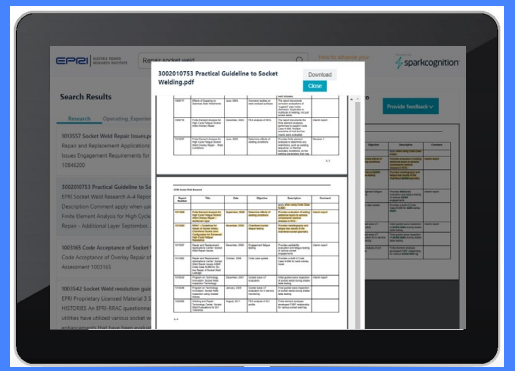
Input



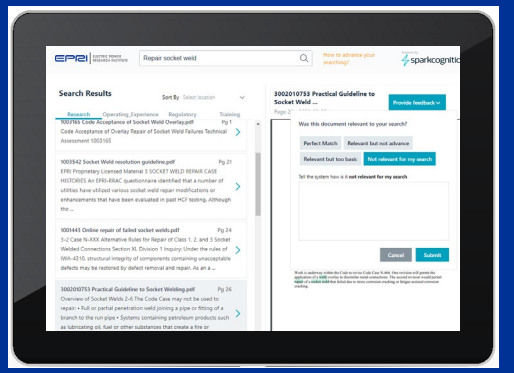


Display of Output





Feedback Loop

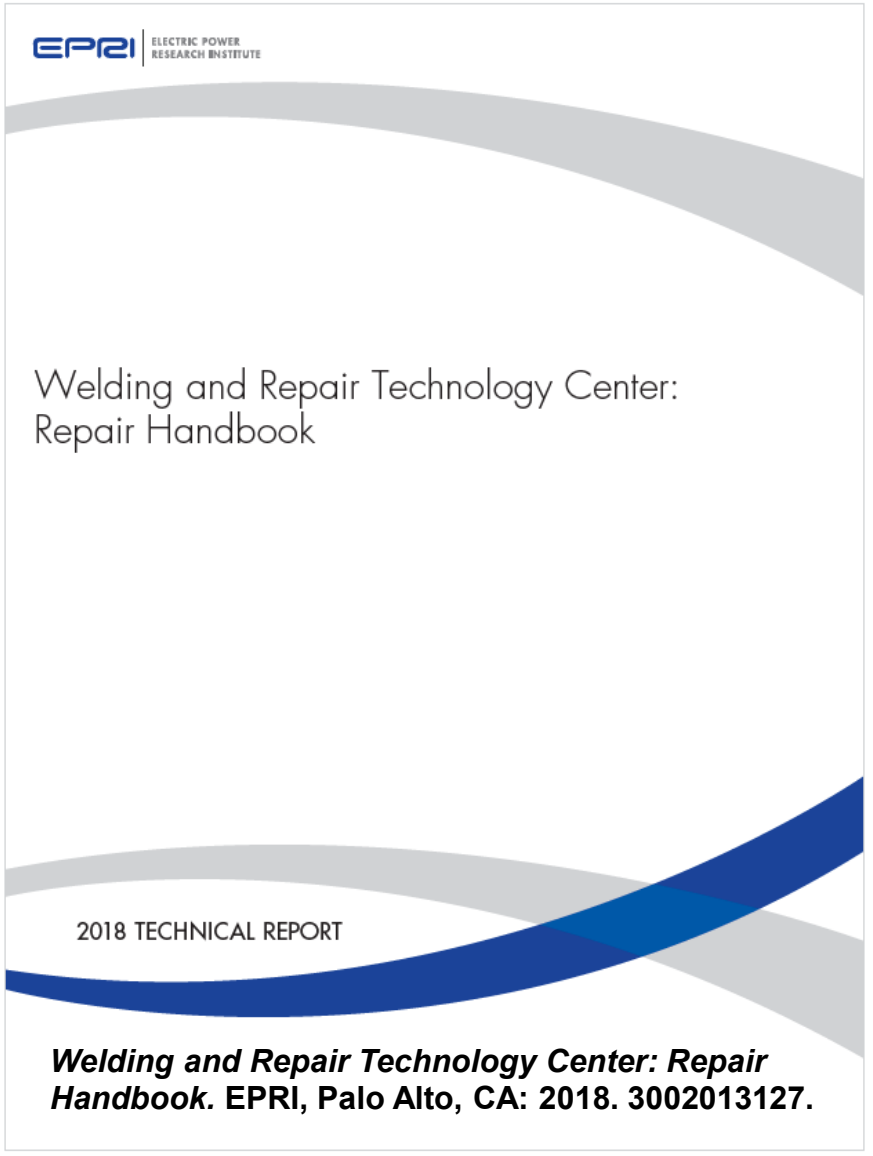


Machine Learning & Refinement of Output

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) New10CFR50.55a 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

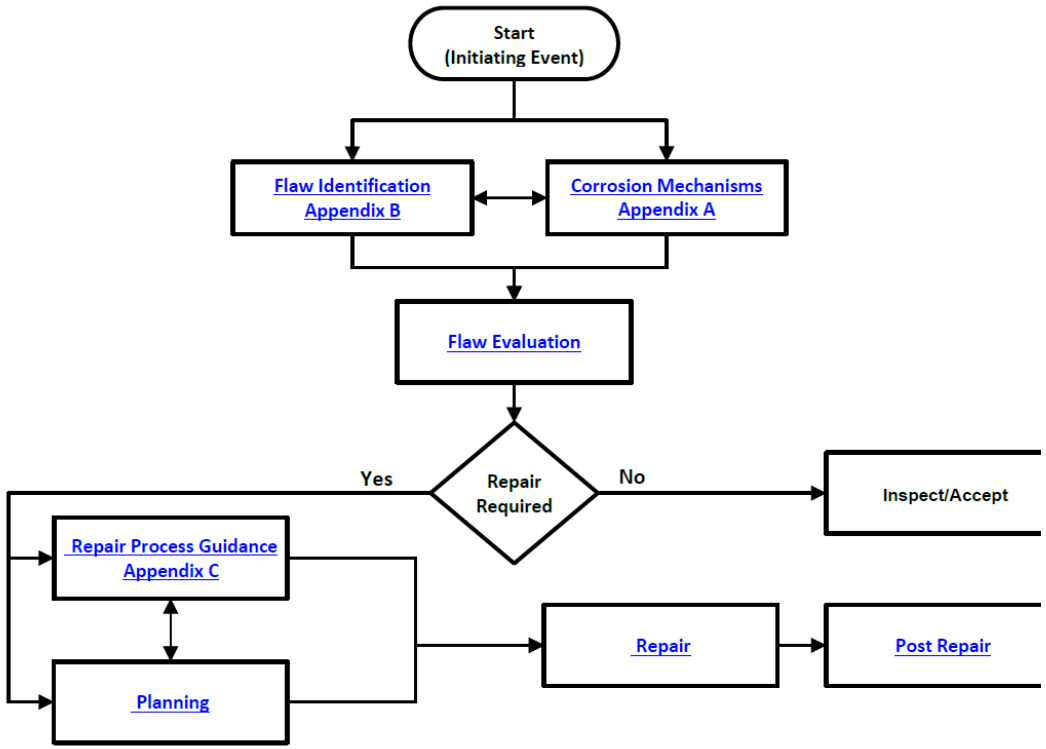
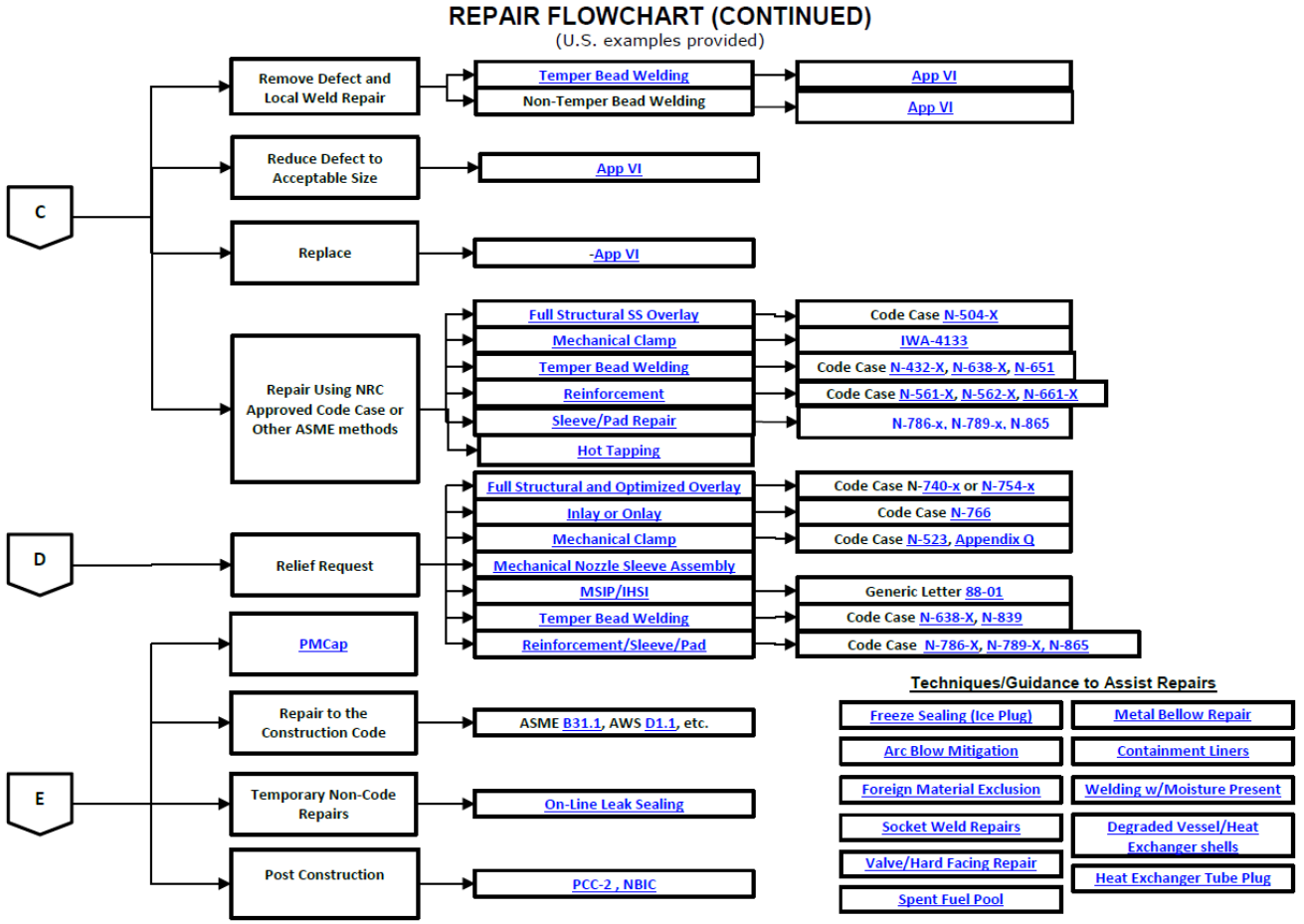


Figure 1-1
Repair handbook flowchart



Together...Shaping the Future of Electricity