# NRC/RES/DE Materials Research

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# Introduction

## Purpose, Outcomes, Process

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- Purpose:
  - Provide update on NRC/RES/DE materials research programs, focus, and prioritization
- Outcomes:
  - Update of NRC materials research programs
  - Identify areas of potential cooperative research
  - Inform NRC materials research prioritization efforts
- Process:
  - Overview of RES/DE Materials Research
  - RES/DE/CIB Programs
  - RES/DE/CMB Programs

# RES/DE Materials Research

## Overview of Branches

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- Materials research conducted by two RES/DE branches:
  - RES/DE/CIB: Component Integrity Branch
    - Fracture Mechanics, NDE, HDPE, and Safety Assessments
  - RES/DE/CMB: Corrosion & Metallurgy Branch
    - Corrosion, Metallurgy, and Advanced Reactors
- Research related to needs of other NRC offices
  - Generally, through a User Need Request (UNR)
  - Staff Requirements Memorandum from Commission
  - RES Research Plans
- Overall DE Budget ~$23M (6 Branches Total)
- Materials Research Budget ~$11.5M

# CIB Materials Research

## Overview of Research

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- Materials research supporting NRR:
  - Evaluating short/long term regulatory issues:
    - UNRs and expedited needs
    - 'Ready to serve' efforts include research
- Topical areas:
  - Component integrity assessments:
    - Probabilistic and deterministic fracture mechanics
    - PWSCC mitigation and residual stress validation
    - High Density Polyethylene (HDPE) piping research
    - SCC, EAF, thermal aging, high-temperature creep
  - Non-Destructive Evaluation (NDE):
    - Dissimilar metal welds and advanced techniques
    - Cast austenitic stainless steel
    - HDPE piping
  - Codes and standards

# CMB Materials Research

## Overview of Research

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- Materials research supporting NRR:
  - Evaluating short/long term regulatory issues:
    - UNRs and expedited needs
    - RES Research Plans
- Topical areas:
  - Irradiation assisted stress corrosion cracking (IASCC)
  - Primary water stress corrosion cracking (PWSCC)
  - Aging of materials used for wet/dry storage of spent fuel
  - License renewal research (long term operation)
  - Steam generator tube integrity
  - New reactor materials
  - Codes and standards

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# Division of Engineering
# Component Integrity Branch

# CIB Materials Research

## General Technical Areas

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| | UNR # | UNR/Work Title | MOU U | pdates | Contracts |
|---|---|---|---|---|---|
| xLPR/Piping/CRDM | NRR-2010-018 (DR) | Development of a Probabilistic Method for Evaluating the Probability of LBB of Ni-Based Alloys Exposed to PWR Environments | xLPR (2009)<br>WRS (2009/11) | • xLPR Program Plan: Summer 2011<br>• xLPR Pilot Study Reports: Summer 2011<br>• ACRS Presentation: Summer 2011<br>• WRS Phases I-IV Reports: Fall 2011<br>• Commission Paper: Fall 2011<br>• PWSCC Mitigation Research<br>• MRP PWSCC Flaw Evaluation Guideline Report<br>• WRS Model Validation<br>• CRDM Work<br>• Emergent Support for LBB & Flaw Evaluations<br>• ASME Code Support | • V6143: SNL-xLPR Development<br>• N6438: ORL-Prob PB Intg SA<br>• V6144: BMI-Pipe Integrity Analysis<br>• N6958: BMI-DMW Fracture<br>• N6899: Emc$^2$-Pipe Intg Anly & Sprt<br>• V6146: CNWRA-V&V of xLPR<br>• V6200: xLPR Anl & Tech Sprt<br>• N6637: Emc$^2$-PB Integrity Analysis<br>• V6141: Hill Eng-Contour/Slittling<br>• V6194: BMI-PARTRIDGE<br>• V6207: Alaron-Decontam PZR<br>• N6864: Veqter/N6774: ORL WRS |
| | NRR-2006-006 (DR) | PWSCC of Ni-Base Alloy Primary Pressure Boundary Components | | | |
| | NRR-2005-011 (DR) | PWSCC in LBB Systems | | | |
| RPV | NRR-2007-001 (MK) | RPV Integrity Issues | None | • Appendix H to NRR/NRO: 2009<br>• RG1.99R3/TBD NUREG to NRR/NRO: 12/2010<br>• Appendix G to NRR/NRO: July 2011<br>• 50.61a Implementation RG: December 2011 | • N6438: ORL-Prob PB Intg SA<br>• N6578: NSWC-PB Materials II<br>• N6450: NSWC-Mat Mod Dev |
| | NRR-2010-006 (CIB Support Only-GC) | Support in Developing Tech Info to Support Evaluating the Feasibility of License Renewal Beyond 60 Years | | | |
| NDE | Commission Direction (MK & WN) | Jaczko: RPV Inspection Quest. for 50.61a | NDE (2006)<br>New (2011) | • 50.61a RPV Inspection review; VT of RPV Internals; & UT in lieu of RT for fabrication,<br>• Assess Industry Actions re: DMW, HPDE, CASS, inspector training/qualifications (PDI),<br>• Knowledge Management of SXI, App VIII (PDI)<br>• RG 1.84R35/36 SIII CC, 1.147R16/17 SXI CC, 1.192R1 OM CC, & 1.193R3 CC Not Approved | • N6398: PNL-Evl Eff & Reli of NDE<br>• N6319: PNL-PWSCC in LBB Sys<br>• V6085: PNL-Degrad in xLPR Sys<br>• V6097: PNL-Eff & Rel of UT & RT<br>• N6593: PNL-Ass Emerging NDE<br>• G6010: ASME-ANDE Grant |
| | NRR-2010-014 (WN) | Volumetric Examination of Vessels & Piping | | | |
| | NRR-2006-012 (WN) | NDE of Vessels and Piping | | | |
| HDPE | NRO-2010-008 & NRR-2010-020 (WN) | Request for NDE of Polyethylene Piping and Fittings (Dual Request) | | | |
| | NRR-2006-007 (EF) | Development of a Tech Database on the Use of HDPE in Safety-Related Piping Systems | New (2011) | • HDPE piping in buried Class 3 safety systems<br>• Assess industry efforts re: service life allowable temps/stresses with an existing flaw (N-755) | • N6637: Emc$^2$-PB Integrity Analysis<br>• N6899: Emc$^2$-Pipe Intg Anly & Sprt |
| EAF | NRO-2010-006 & NRR-2010-019 (GS) | Support for Environmental Fatigue Consultation and High Energy Line Break Criteria (Dual Request) | None | • Develop tech basis for revised RG on HELB postulated break locations in new/operational rx<br>• Update/develop EF & component evaluation methods for license renewal/new rx applications<br>• Review and assess ASME SIII fatigue analyses & subsequent adoption into 50.55a | • V6069: ANL-Environmental Fatigue Consultation (Omesh Chopra)<br>• Rest of Project is Internal CIB Effort with Data Collection from ANL |
| CSGTR | NRR-2010-005 (RI) | Support in Developing Analytical Bases and Guidance for Future Risk Assessments of C-SGTR | None | • Develop C-SGTR risk tool of proposed mods to existing requirements and evaluation of risk significance of SG tube degradation (in ROP) | • In ternal Work Only |
| | RES Plans (SM/IP) | Adv. Rx/NGNP Research Plans (SM) | None | • High-temperature Creep Model Development | • N6654: ORL-Elev. Temp Design |
| | | Long Term Research Plan (IP) | None | • V6060 Extended In-Situ & Real-Time Monitoring | • V6060: ANL |

# NRC Piping Research

## Supporting NRR UNR 2006-006 & 2010-008

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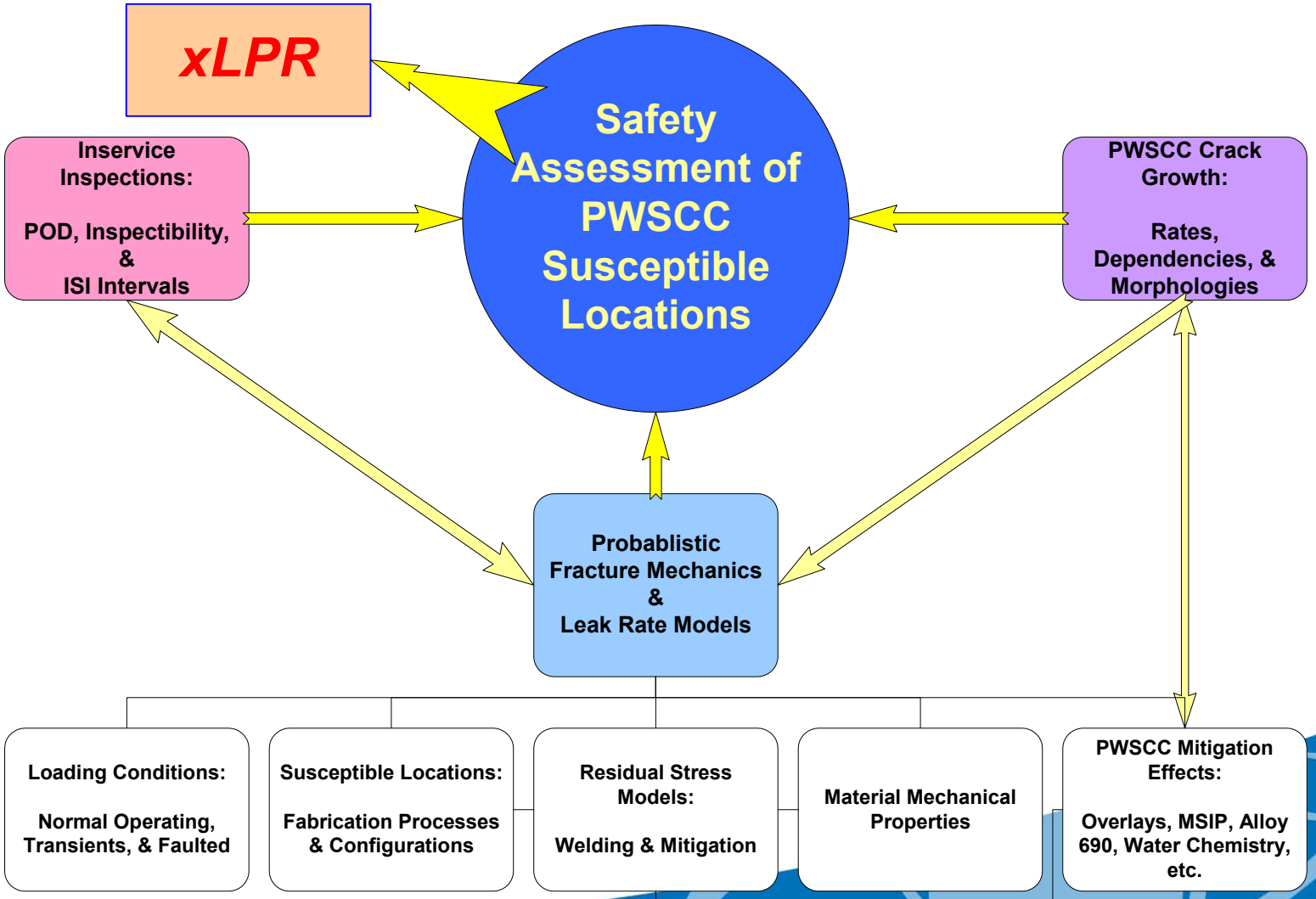

# NRC Piping Research

## Supporting NRR UNR 2006-006 & 2010-008

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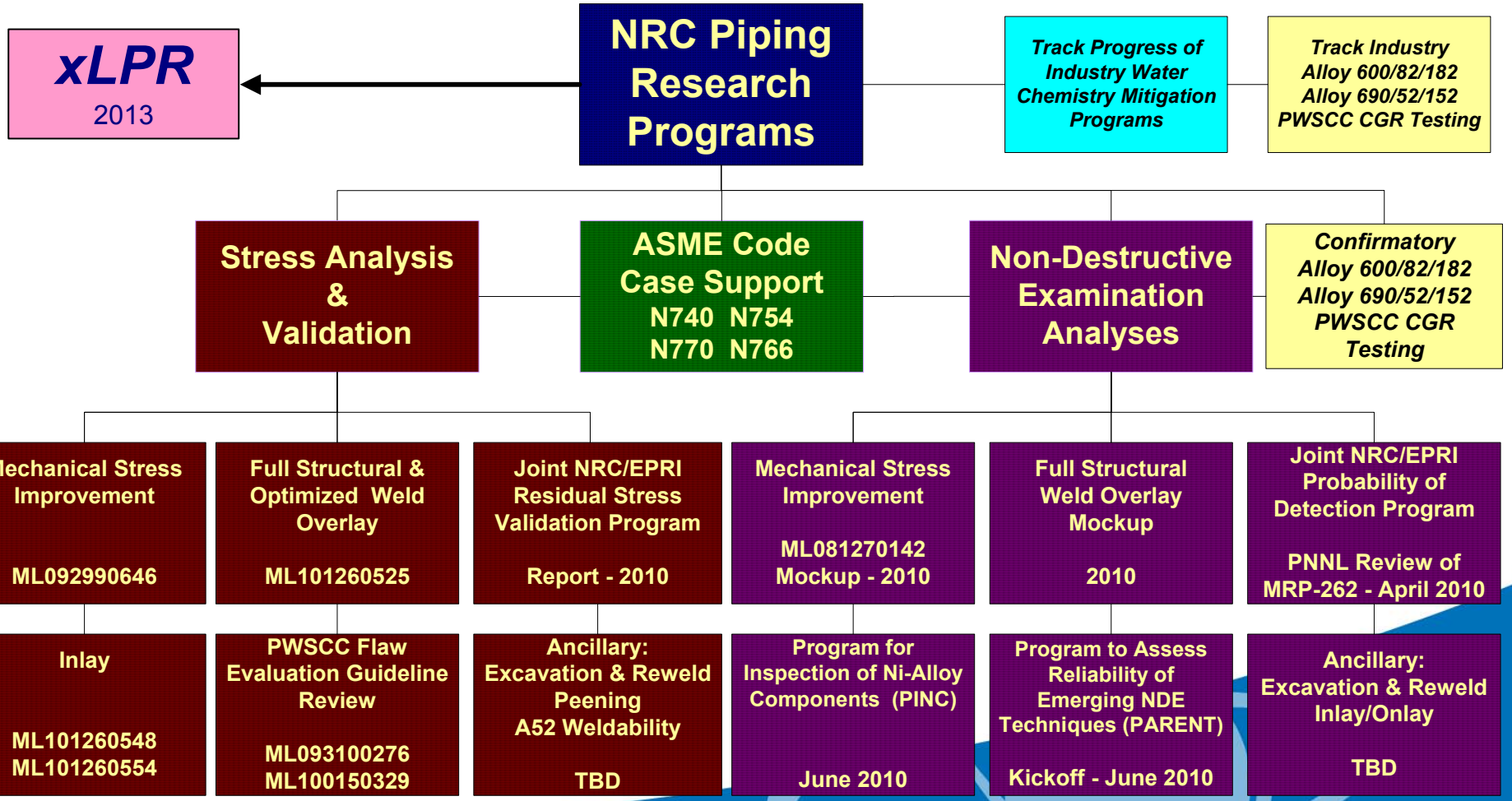

# NRC Piping Research: xLPR

## Supporting NRR UNR 2006-006 & 2010-008

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- Purpose(s)
  - Develop a modular probabilistic computer code for the prediction of the probability of failure of reactor coolant system components
  - Currently, primary piping systems approved for leak-before-break (LBB) that are undergoing primary water stress corrosion cracking
- Point of contact:  David Rudland
- Coordination: Battelle (V6144,N6958,V6194), Emc$^2$(N6899), PNNL(V6085), ORNL (V6428), SNL(V6143), CNWRA(V6146)
- Industry Cooperation: MOU Addendum with EPRI
  - DEI, SIA, Westinghouse, AREVA, PEAI, Exelon
- UNRs: NRR-2006-006 & NRR-1010-018

# NRC Piping Research: xLPR

## Supporting NRR UNR 2006-006 & 2010-008

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- Basis/Prioritization:
  - UNR Title: Development of a probabilistic method for evaluating the probability of leak-before-break of nickel-based alloys exposed to primary water environments
  - Prioritization: High
- Project Background:
  - Code to directly assess compliance with 10CFR50 App A GDC-4
  - Pilot study conducted to evaluate feasibility
  - Code to be expanded for all LBB approved systems
- Project Deliverables:
  - Version 1.0 (pilot study) March 2011
  - Version 2.0 (LBB) Dec 2013
  - Version 3.0 (All RCS Components) 2016
- Project Schedule: 2009-2013 (LBB)
  2009-2016 (All RCS Components)

# NRC Piping Research: HDPE

## Supporting NRR UNR 2006-007 & 2011-001

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- Purpose:
  - Confirm design requirements proposed in ASME CC N-755
  - Provide technical support to NRR/NRO related HDPE piping
- Project Background:
  - Licensees requested use of high density polyethylene (HDPE) piping in ASME Class 3 safety-related NPP applications
    - Essential service water systems at Catawba and Callaway plants
  - ASME CC N-755 under development for generic use of HDPE
    - NRC has not endorsed CC N-755
    - Identified three major areas of concern:
      - Long-term piping integrity
      - Fusion process qualification
      - Volumetric inspection process qualification
  - NRC evaluating adequacy of requirements in N-755
  - Research areas assessing three areas of concern

# NRC Piping Research: HDPE

## Supporting NRR UNR 2006-007 & 2011-001

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- Project Background (continued):
  - Other activities include interacting with ASME regarding N-755, assisting NRR and NRO with reviews of relief requests, RAIs, topical reports and other related technical assistance as needed.
- Project Deliverables:
  - Confirmation HDPE piping structural integrity: December 2012
  - Confirmation of HDPE fusion joint structural integrity: June 2013
  - Confirmation of HDPE fusion process variables: June 2012
  - Confirmation of NDE methods and acceptance criteria: June 2012
- Project Schedule:
  - Piping structural integrity evaluations: 2011-2013
  - Fusion joint structural integrity evaluations: 2011-2013
  - Fusion process variables evaluations: 2011–2015
  - NDE methods & acceptance criteria evaluations: 2011–2015

# NRC RPV Research

## Supporting NRR UNR 2007-001

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- RG1.99R3:
  - Update ($\Delta$T30, $\Delta$USE, margins, surveillance assessment, attenuation)
  - Technical basis report to NRR/NRO December 2010
  - RG publication / public comment: 2011/12
- 10CFR50 Appendix G:
  - Review industry proposals (MRP-250 & WCAP-15315) & update (heatup, cooldown, leak test, nozzles, beltline definition, flange limits, USE limits) &
  - Technical basis report to NRR/NRO July 2011
  - Rulemaking for RG1.99R3 coincident with Appendix G/H (2012-15)
- PTS Implementation Reg Guide:
  - Provide guidance on how to assess compliance with 10CFR50.61a
  - Technical basis report to NRR/NRO December 2011
  - RG publication / public comment: 2012
- Expanded Embrittlement Database for RG1.99R4:
  - Expand database to include non-US surveillance and test reactor data

# Environmentally Assisted Fatigue

## Supporting NRR & NRO Joint UNR 2010-019

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- Purpose:
  - Evaluate the effects of environmental fatigue on the RCS pressure boundary components and pressure vessel internals and in developing fatigue usage factor acceptance criteria for High Energy Line Break piping systems
  - Revise RG 1.207 and NUREG/CR-6909
- Basis/Prioritization:
  - Requesting Offices: NRR and NRO
  - UNR Title: Request for RES Support for Environmental Fatigue Consultation and High Energy Line Break Criteria
  - Prioritization: Low
- HELB task to be re-assigned to xLPR Project
- Schedule: 2012

# NRC NDE Research

## Supporting NRR UNR 2006-012 & 2010-014

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**Confirmatory Research and ISI/NDE Activities**
(including support as-needed to program offices)

**ASME**
- N6398, V6085, V6230
- Assess industry NDE/ISI-related changes to ASME Code and Code Cases

**RPV**
- N6398
- Effectiveness/reliability of RPV exams
- Fabrication flaw density/distribution

**Methods**
- N6398, V6085, V6097, V6230
- Effectiveness and reliability of UT, RT, and VT
- UT in lieu of RT
- Digital RT

**Equipment**
- N6398, V6085, V6097, V6230
- Verification of capabilities of new data processors
- Enhancements in phased-array
- Digital RT sensors

**Piping, Welds**
- N6398, V6085, V6230
- xLPR
- All Class 1, 2, and 3 piping (separate tasks on CASS)
- Effects of stress improvement on weld overlays on NDE

**PDI, ANDE**
- N6398
- Effectiveness/reliability of procedure, equipment, and personnel qualifications

# NRC NDE Research

## Reliability of NDE for NPP ISI

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- Evaluate accuracy and reliability of NDE methods used for ISI
- Assess adequacy of proposed industry changes to ISI programs
- Evaluate effectiveness of NDE ISI techniques for detecting degradation
- Primary Research Areas
  - ISI Effectiveness and Reliability; Code Requirements
    - Assessment of Advance NDE Methods; Assessment of Inspection Requirements/Guidelines
  - Inspection of Piping (e.g., CASS, DMWs, high-density polyethylene piping)
  - Evaluation of Failure Goals, NDE Reliability, and Fracture Mechanics Methods
  - Flaw Density and Distribution in RPVs
  - Assessment of effect of fabrication and repair flaws as related to potential for vessel failure for pressurized thermal shock events
  - Assessment of Current VT Requirements; Investigate Performance-Based VT
  - Assessment of Interchangeability of  UT and RT
- PNNL provides technical assistance on NDE and related issues to
- NRC regulatory offices on as-needed basis

# NRC NDE Research

## Examination of CASS Piping & Associated Welds

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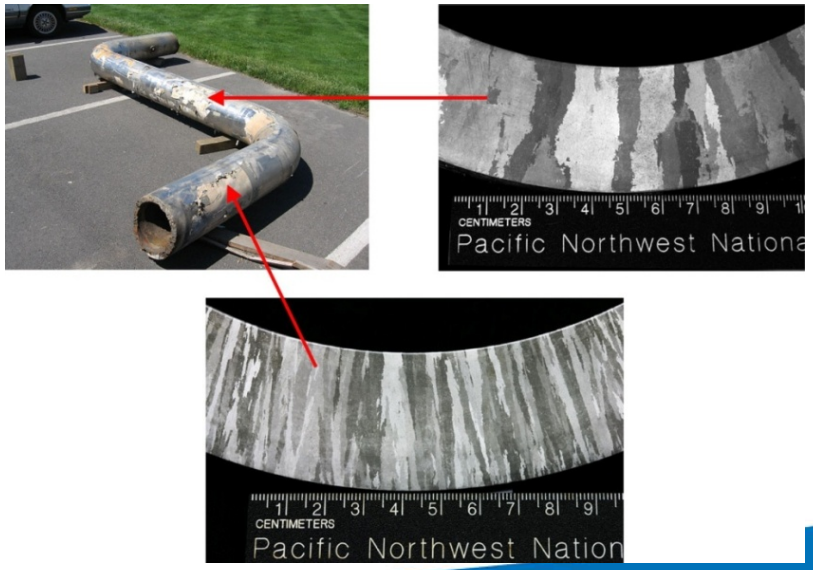
- CASS used in RCS piping susceptible to thermal aging embrittlement
- CASS microstructure makes examination of welds through CASS very difficult
- PA-UT used to examine CASS pressurizer surge line welds (t < 2” thick)
- A set of thermal fatigue cracks implanted into three CASS specimens fabricated from vintage CASS material formed in the 1970’s
- Flaw responses from these cracks used to evaluate detection and sizing performance of the PA-UT methods applied




- Frequencies ranged from 800 kHz to 2.0 MHz – produced strong signal-to-noise ratios enabling accurate length- and depth-sizing results
- Examination results on specimens less than 2” thick look promising
- Results of PNNL study to be used as basis for ASME Code action

# NRC NDE Research

## Examination of CASS Piping & Associated Welds

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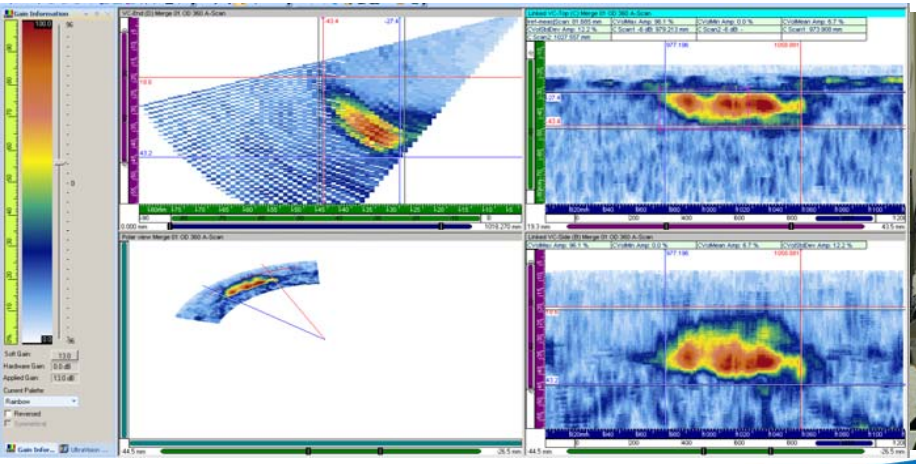
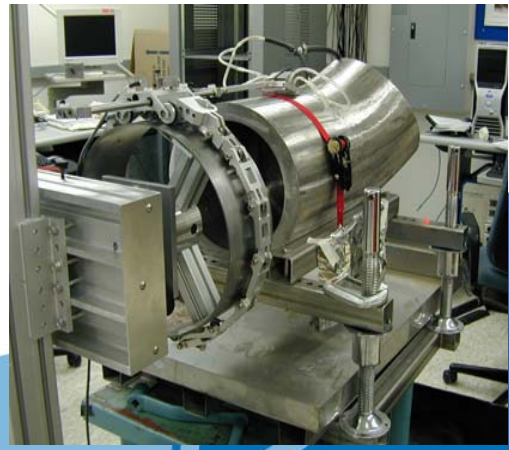
- Recent Results:
  - Mockups scanned by PNNL and ISI supplier (with PDI qualified Supplement 10 procedure)
    - ISI supplier and PNNL results almost identical
    - **All flaws** are easily detected; some tips available for depth sizing
    - Good S/N ratios for implanted and in-situ grown flaws
  - Axial and circumferential UT beam redirection measured
  - End-of-block corner trap scans to ascertain material effects





# NRC NDE Research

## Dissimilar Metal Weld (DMW) Examinations

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- Welds susceptible to PWSCC - active degradation mechanism
- Austenitic weld materials and buttering attenuate and re-direct sound fields and may produce excessive noise
- OD surface features (diametrical shrinkage, weld crowns, tapers) cause transducer “lift-off” and/or limit accessible volumes of weld
- Safe end-to-component (nozzle, valve, etc.) geometries primarily limit examinations to single side (from safe end)
- Other piping welds in close proximity (safe end-to-pipe) may also impact these examination
- Mitigation activities, e.g. overlays, MSIP, inlays, onlays, etc.

- Assurance that reliable and effective examinations are performed
  - Includes full coverage of area of interest, including base metal
- NRC and International Cooperative Programs (PINC/PARENT)

# NRC NDE Research

## UT in lieu of RT

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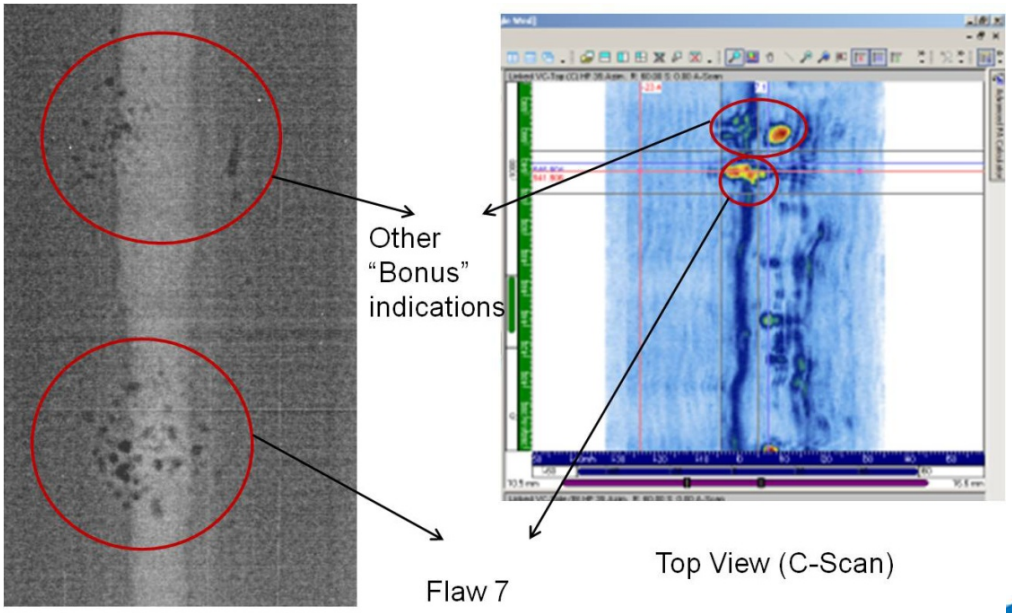
- Purpose is to evaluate the interchangeability of RT and UT, and to address the use of RT for repair, replacement and inservice inspection for materials commonly found in NPPs
- Assessing capabilites of computed RT, DRT, and film RT, and UT imaging methods to detect and size different flaw types and orientations




- Round robin test & assessment of probability of detection, probability of false calls
- Recommendation on performance-based qualification parameters for ASME Code, Sections III and XI UT/RT procedures, equipment and personnel

# NRC NDE Research

## HDPE Piping NDE

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- HDPE application for non-safety system applications
- ASME CC N-755 being developed to support generic HDPE use
- NRC concerned about lack of fusion flaws in butt fusion joints
- RES assessing NDE technologies to perform volumetric inspections of butt fusion joints (laboratory and commercially available technologies)
  - UT with phased arrays and time-of-flight diffraction
  - Microwaves
  - Developing destructive evaluation plan using high speed tensile tests, guided bend tests and mechanical slicing

# NRC NDE Research

## Remote Visual Testing (VT) Activities

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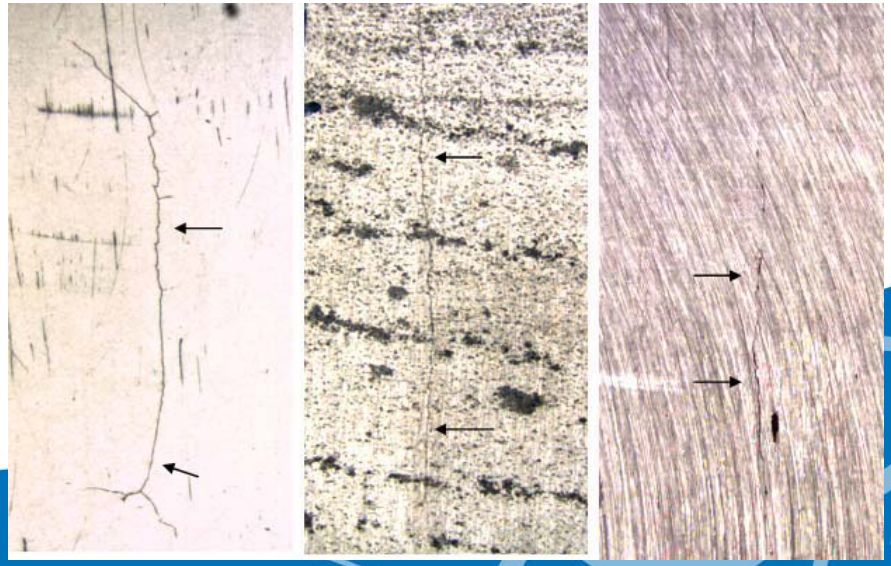
- Utilities expressed interest in greater use of VT
- VT significantly relied upon for vessel examinations
- Research to assess effectiveness and reliability of VT
- Assess capabilities and limitations of remote visual (ASME VT-1) to detect cracking in RPV internal components
  - Define parameters affecting reliable examinations
- Round-robin to evaluate application and assess new technologies
- Phase 1 Round Robin testing at EPRI NDE Center completed 08/10

Images of three 12-µm COD cracks using diffuse axial lighting on three very different surfaces



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# Office of Research
# Division of Engineering
# Corrosion & Metallurgy Branch

# Environmentally-Assisted Degradation Overview

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- Purpose(s)
  - Provide information to support the development of technical bases for the safety evaluation of materials subject to degradation in the reactor environment, including:
    - PWSCC of Ni-base primary system pressure boundary components
    - IASCC of reactor internals
- Project Managers: Appajosula Rao (IASCC), Carol Moyer (IASCC), Darrell Dunn (PWSCC), Greg Oberson (PWSCC)
- Coordination: EPRI (K6000), PNL (N6925, N6783), ANL (N6519)
- Basis/Prioritization:
  - Requesting Office: NRR
  - UNR Titles:
    - Environmentally Assisted Degradation of Light Water Reactor Internal Components
    - User Need Request for Information on PWSCC of Nickel-base Alloy Primary Pressure Boundary Components
    - Development of a Probabilistic Method for Evaluating the Probability of Leak-Before-Break of Nickel-Based Alloys Exposed to Primary Water Environments
  - Prioritization: High

# Aging of Materials for Wet and Dry Storage of Spent Fuel Overview

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- Purpose(s)
  - Provide information to support the development of technical bases for the safety evaluation of wet and dry storage of spent nuclear fuel including:
    - Degradation of neutron absorber materials in spent fuel pools
    - Extended dry storage and transportation of spent fuel

- Project Managers:  April Pulvirenti (neutron absorber materials), Darrell Dunn (extended storage and transportation)

- Coordination: Tom Haley, consultant – neutron absorber materials (V6073)

- Basis/Prioritization:
  - UNR Titles:
    - User Need Request to Develop the Technical Bases for the Evaluation of Neutron Absorbing Materials in Spent Fuel Pools (NRR)
    - Extended Storage and Transportation Regulatory Program Review (NMSS)
  - Prioritization: High

# License Renewal Research Overview

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- Purpose(s)
  - Provide technical information to support the development of a regulatory framework for licensing a potential second extended operating period from 60 to 80 years, including:
    - NRC/industry workshops
    - Expanded materials degradation assessment
    - Assessment of licensees' aging management programs
    - Engagement with domestic and international research partners
- Project Managers: Gene Carpenter, Amy Hull
- Coordination: ORNL (V6075), PNNL (V6231); MOUs with EPRI and DOE
- Basis/Prioritization:
  - Requesting Office: NRR
  - UNR Title: Support in Developing Technical Information to Support Evaluating the Feasibility of License Renewal Beyond 60 Years
  - Prioritization: High

# Steam Generator Research Overview

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- Purpose(s)
  - Provide information to support the oversight and review of steam generator issues including the review of industry assessments of steam generator tube integrity.
  - Provide research products to facilitate the development and review of future risk assessments involving consequential steam generator tube rupture (C-SGTR) events.
- Project Manager:  Charles Harris
- Coordination: Argonne National Laboratory (V6162)
- Basis/Prioritization:
  - Requesting Office: NRR
  - UNR Titles:
    - User Need Request for Steam Generator Tube Inspection and Integrity Issues
    - User Need Request for Office of Nuclear Regulatory Research Support in Developing Analytical Bases and Guidance for Future Risk Assessments of Consequential Steam Generator Tube Rupture Events
  - Prioritization: High

# Advanced Reactor Technologies Overview

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- Purpose(s)
  - Provide information to support the development of technical bases for licensing of advanced reactor designs such as the high-temperature gas reactor (HTGR) including:
    - Graphite research
    - NDE of advanced reactor materials
    - Codes and standards
- Project Managers: Makuteswara Srinivasan, Amy Hull
- Coordination: ORNL (V6210, N6988), ANL (V6218, N6989), PNNL (N6907) ASME (V6132)
- Basis/Prioritization:
  - Requesting Office: NRO
  - UNR Titles:
    - NGNP: Next Generation Nuclear Plant
    - Advanced Reactor Research Program
  - Prioritization: Medium

# Containment Liner Degradation Overview

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- Purpose(s)
  - Provide information to support the assessment of corrosion initiating at the liner-concrete interface and assist staff in the evaluation of containment liner inspection requirements
- Project Manager: Darrell Dunn
- Coordination: Sandia National Laboratory (V6070)
- Basis/Prioritization:
  - Requesting Office: NRR
  - UNR Title:
    - User Need Request Related to Containment Liner Corrosion
  - Prioritization: High

# Summary

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- Awareness of NRC materials research programs
- Identify areas of potential cooperative research
  - Please contact appropriate staff member
- Facilitate materials research prioritization efforts
  - Work through NRR/NRO with industry priorities
- Contact Information:

Aladar Csontos
aladar.csontos@nrc.gov
(301) 251-7640 (O)
(301) 512-3375 (B)

# CIB Materials Research

## PM Point of Contacts

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- xLPR/Piping/CRDM/Flaw Evaluations/ASME:
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