



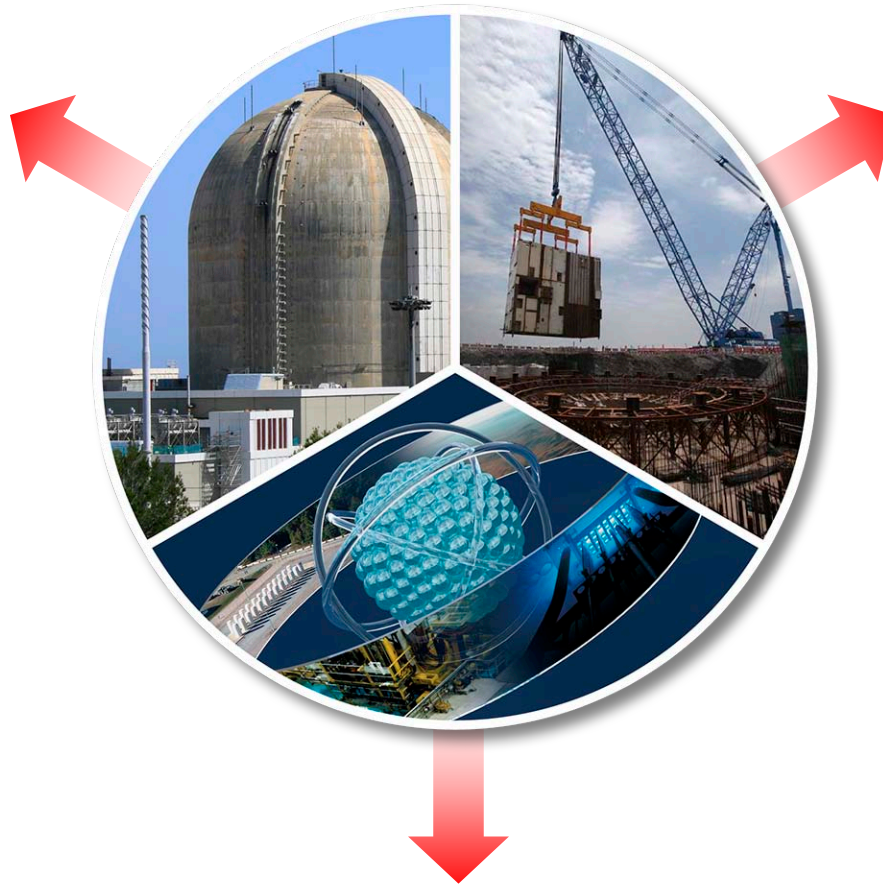
# **EPRI Long Term Operations Program R&D to Support Aging Management**

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**Madrid, Spain**  
September 2014

# Core Drivers

**Maximize the safe utilization of existing nuclear assets**



**Enable the deployment of advanced nuclear technologies**

**Assess long-term sustainability of nuclear energy**

# EPRI LTO Program Goals and Objectives

- Technical basis for **decision** to operate through extended life time
  - Supports business case for life extension and refurbishments
- Technology to **manage** plant assets throughout the lifetime
  - Aging management, asset management and risk management
  - Addresses safety, performance and costs

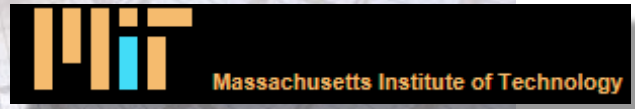


**On track to provide program deliverables in the 2014 through 2019 timeframe.**

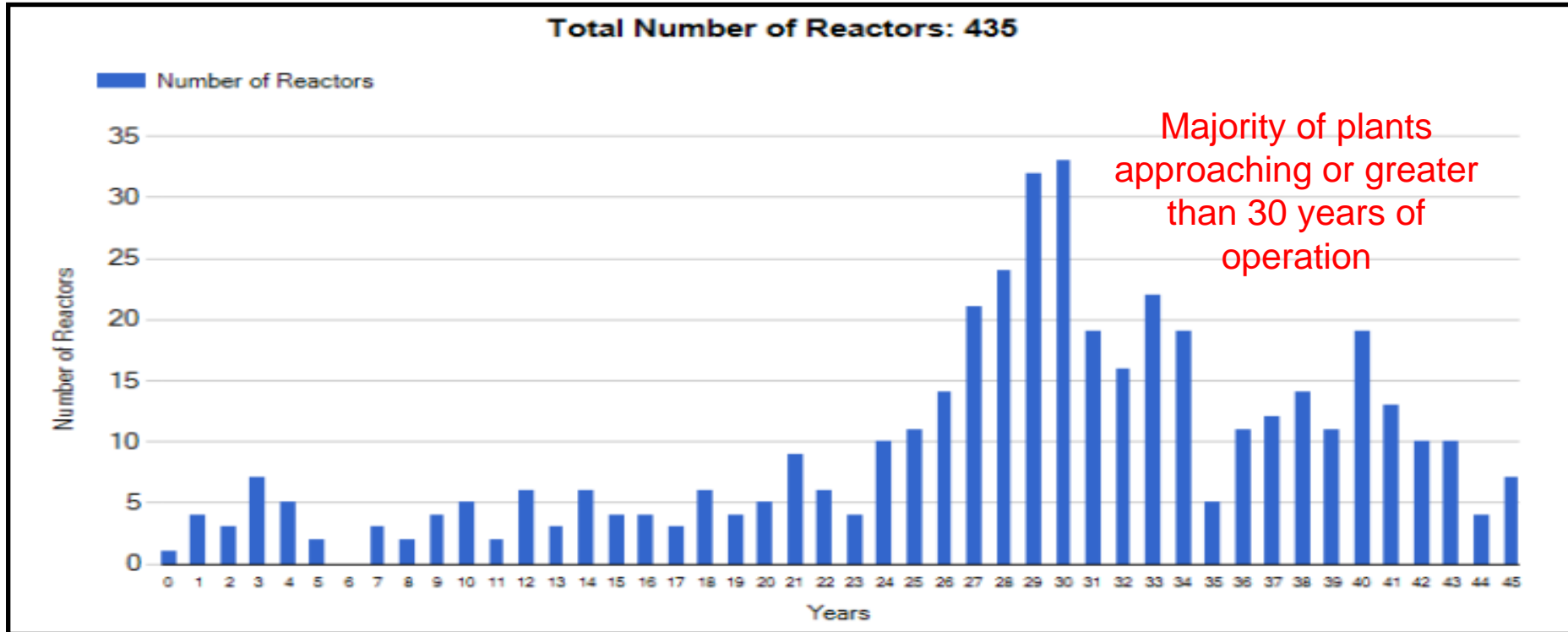
# International R&D Partnerships



**Active  
Collaboration with  
Global Research  
Institutes, National  
Laboratories,  
Universities and  
Vendors**



# Extended Operations is an International Opportunity



\* Source: <http://www.iaea.org/pris> (2014)

# Consideration for Extended Operations

## Economics

- Future electricity prices
- Energy policy for carbon and renewables
- Upgrades and refurbishments
- Equipment obsolescence

## Regulatory Process

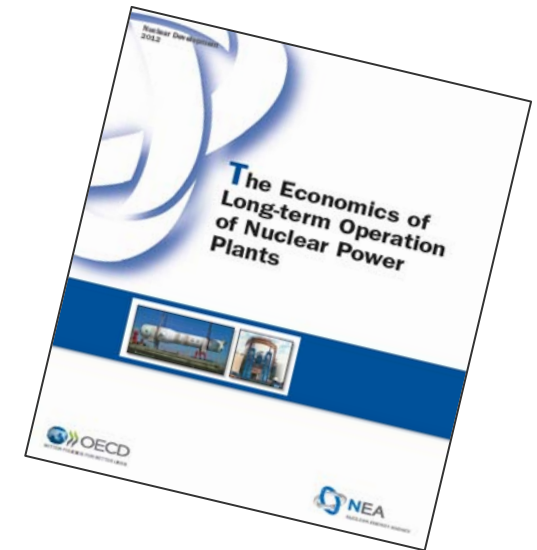
- 'License Renewal'- US
- 'Periodic Safety Review'- EU
- Some countries use elements of both
- Duration of license renewal period varies

## Potential Life Limiting Components

- Reactor coolant system metals
- Reactor pressure vessel
- Electrical Cables
- Containment and concrete structures
- Buried commodities

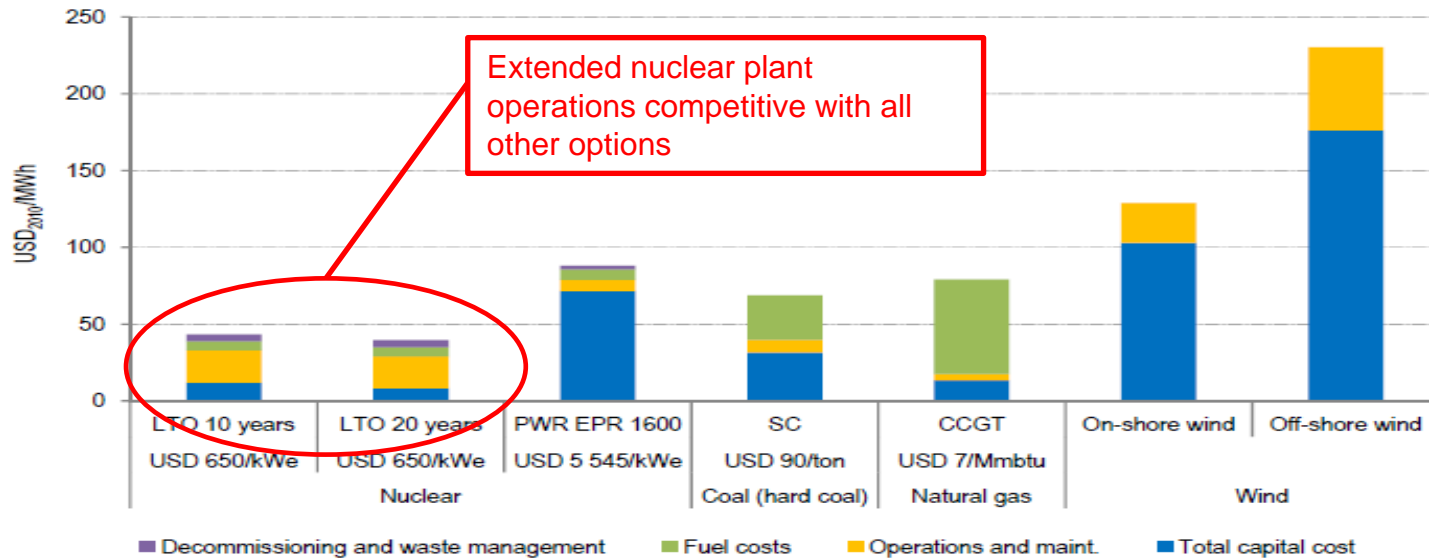
# Economics

- “*The Economics of Long-term Operation of Nuclear Power Plants*”, NEA No. 7054, OECD NEA, Paris, December 2012.
- Organization for Economic Co-operation and Development Nuclear Energy Agency (OECD NEA) has 30 member countries
- Economics of LTO Working Group convened during 2011-2012 with 9 member countries, IAEA, and EU



# Comparative Cost of Alternatives

Figure E2. Projected costs of electricity generation in Belgium, at 8% real discount rate



Note: CCGT = Combined-cycle gas turbine. PWR = Pressurised water reactor; EPR = European pressurised reactor; SC = Supercritical.

**U.S. analysis provides similar results except in low gas price scenario.**

# Regulatory Process

- Generic Aging Lessons Learned (GALL) - NRC
  - GALL, rev 2 for 40 to 60 years
  - GALL, rev 3 in development for 60 to 80 years
- International-GALL - IAEA
  - Developed by international working groups
  - Passive and some active components that are safety or important to safety
  - PWR, VVER, BWR, CANDU and PHWR

**IAEA has a working group formed to revise the IGALL.**

IAEA Safety Report Series No. XX

Draft 27 November 2012

## International Generic Ageing Lessons Learned (IGALL) for Nuclear Power Plants

INTERNATIONAL ATOMIC ENERGY  
YYYY



### SALTO Peer Review Guidelines

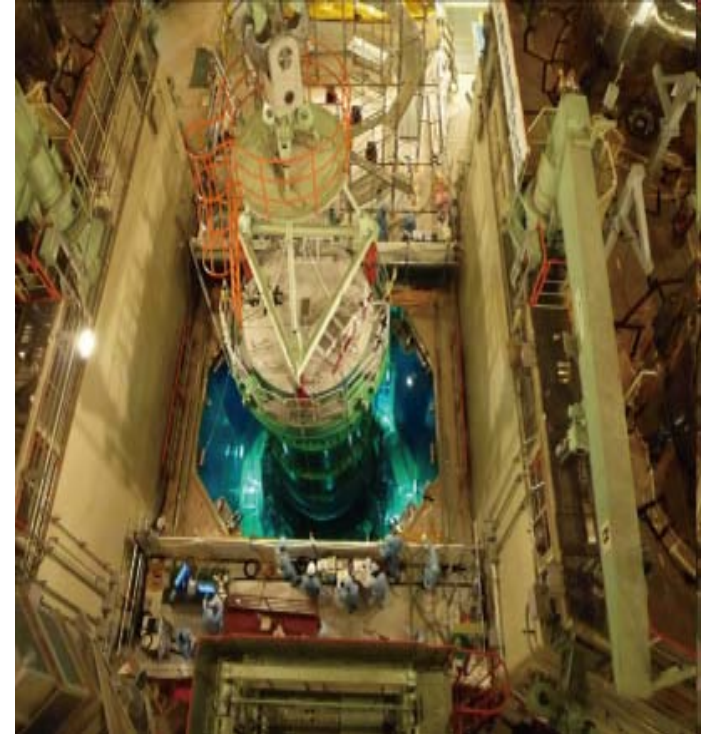
Guidelines for Peer Review of  
Safety Aspects of Long Term Operation  
of Nuclear Power Plants

Vienna, January 2014

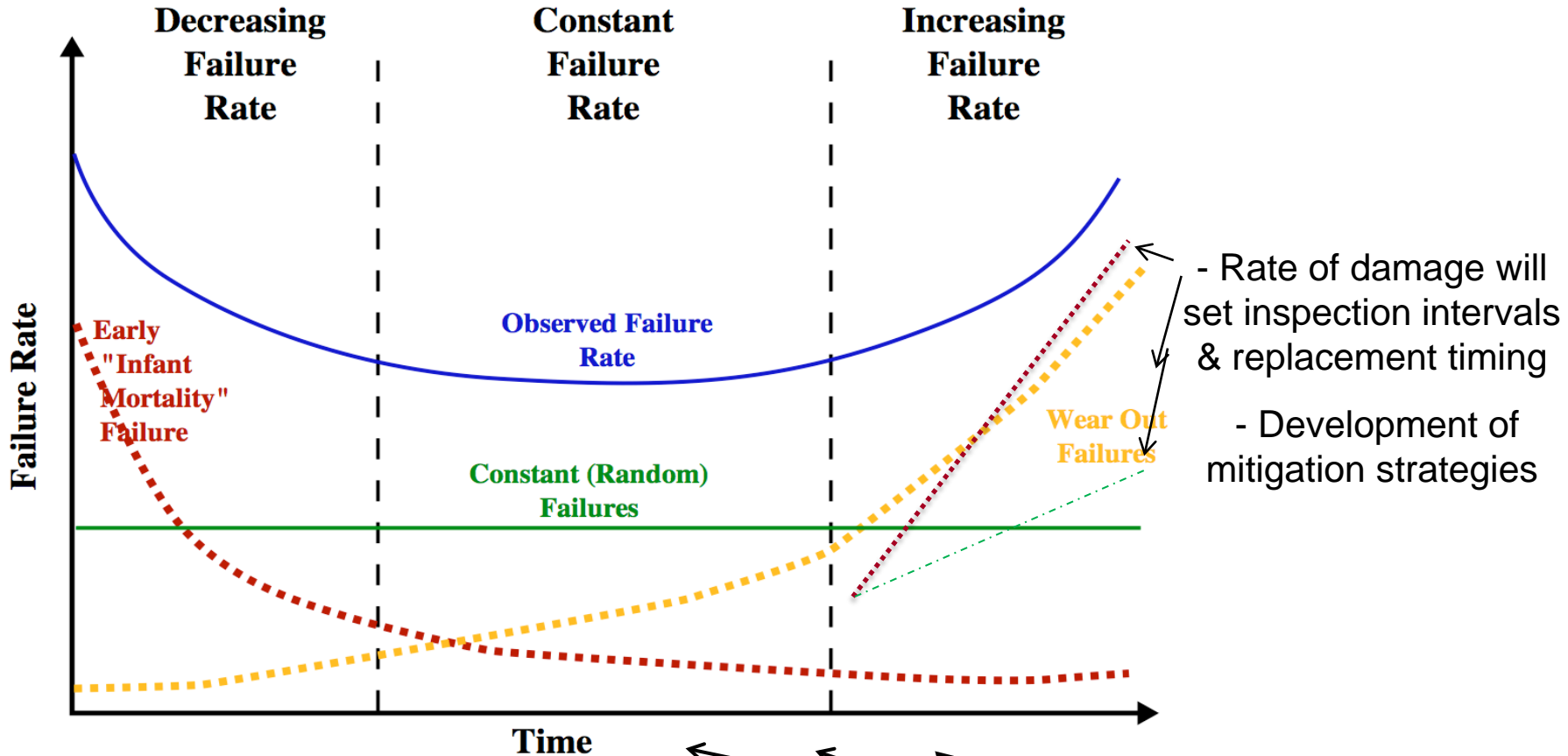
Services Series 26

# Long-Term Operations R&D Focus Areas

- Aging Management:
  - Reactor Coolant System (RCS) metals, welds and piping
  - Reactor pressure vessel
  - Electrical cables
  - Concrete and containment structures
  - Buried piping
  - Service coatings
- Modernization Opportunities:
  - Instrumentation & Controls Systems
  - Centralized on-line monitoring
  - Upgraded T/H and risk assessment codes
- Social & Political Considerations:
  - Clean Energy Standards
  - Long-term storage of used fuel
  - Water Usage



# Aging Management Programs (AMPs)

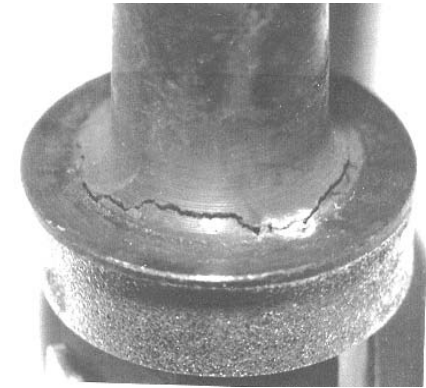


Typical Bathtub Curve (source: Wikipedia)

**What happens with long-term operations?**

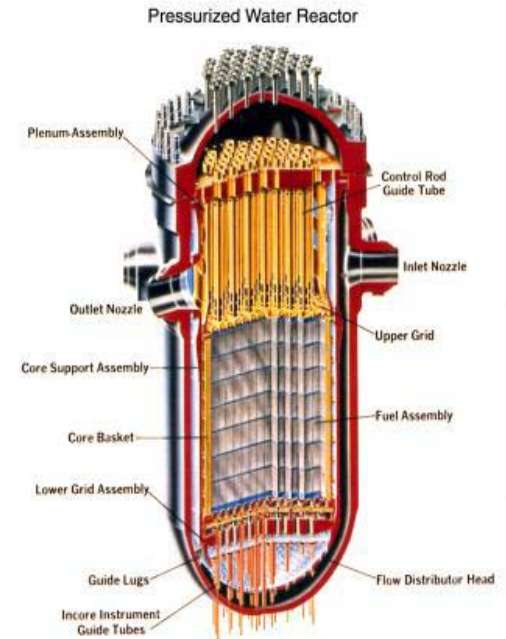
# RCS Metals

- Issues:
  - Core internals
    - Threshold stress
    - Reduction in toughness properties
    - Void swelling
  - Impact on core periphery materials (fluence and temperature)
  - Late life Stress Corrosion Cracking (SCC) initiation
  - Fatigue usage
    - Increased fatigue cycles
    - Environmental effects on fracture properties
- Research Path:
  - EPRI invests over \$50 million per year on metals R&D
  - Studies on initiation, propagation and mitigation
  - EPRI reports are referenced in the Aging Management Programs for the US GALL and IAEA IGALL



# Reactor Coolant System Metals

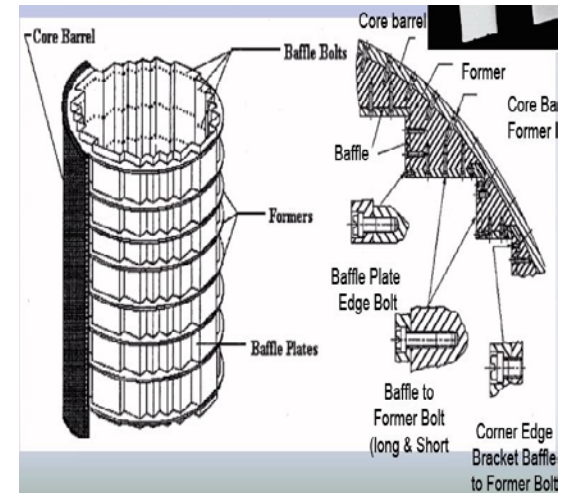
- EPRI Technical Reports:
  - ✓ PWR Internals Inspection and Evaluations
  - ✓ BWR Internals Inspection and Evaluations
  - ✓ Inspections and Evaluations for Ni-based Alloys
  - ✓ Thermal Aging and Neutron Embrittlement for Cast Austenitic Stainless Steel (CASS)
  - ✓ Flaw Tolerance Evaluation for CASS Materials
  - ✓ Environmentally Assisted Fatigue (EAF) Management
  - ✓ Primary Water Chemistry Guidelines
  - ✓ Stress Improvement Technologies



**Initial PWR internals inspections in the US have detected no significant issues**

# RCS Metals Ongoing/Future

- Ongoing and future projects:
  - ❑ International collaboration on SCC modeling
  - ❑ Harvested materials testing
  - ❑ Alloy 690 crack initiation and growth rates
  - ❑ Screening criteria and flaw evaluations parameters for CASS materials
  - ❑ Technical basis for environmentally-assisted fatigue management guidelines reflective of plant operating stresses
  - ❑ Improved inspection technologies
  - ❑ Advanced welding (repair/replacement) methodology for highly irradiated materials



**EPRI Technical Reports will be reviewed and updated as needed to support LTO.**

# Zorita Internals Research Project (ZIRP)

**Objective:** Characterize the effects of neutron irradiation on the mechanical and microscopic properties of stainless steel materials irradiated under service conditions to increase the understanding of fluence effects at end of service life (40, 60 years and beyond)



Jose Cabrera NPP “Zorita”  
Westinghouse design  
1968 – 2006 (~26 EFPY)

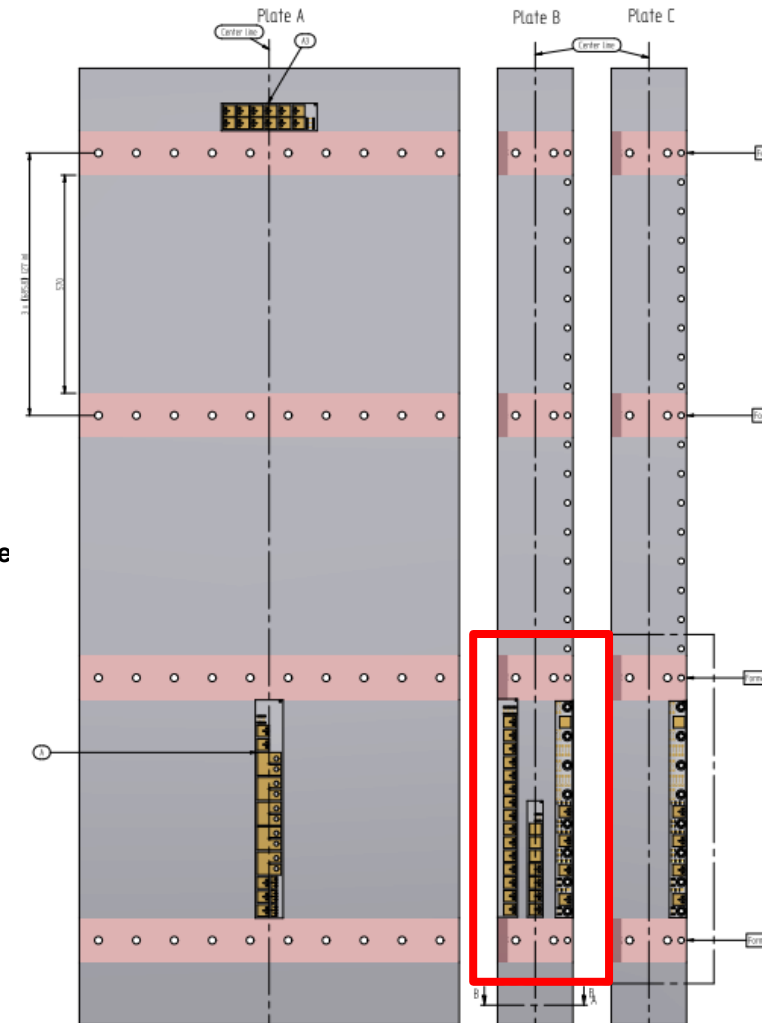
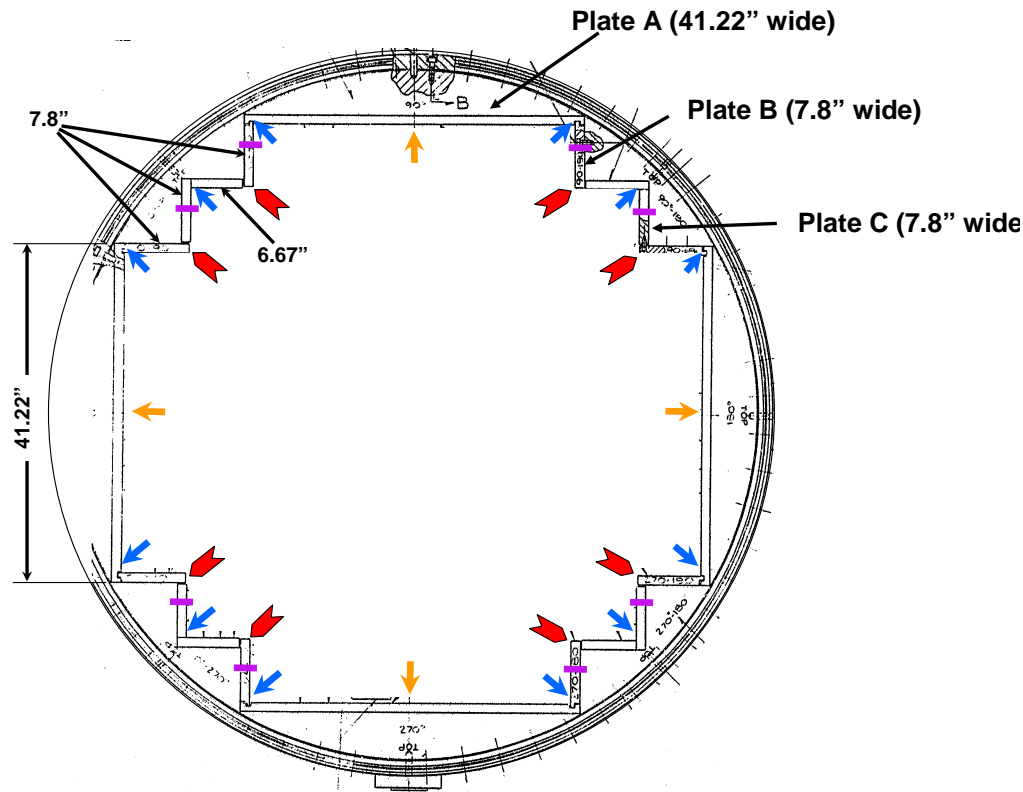
## Current Participants

- EPRI
- U.S. NRC
- CSM (Spanish regulator)
- SSM (Swedish regulator)
- Tractebel
- AXPO
- Additional in-kind contribution from Japanese utilities/MHI

# Zorita Internals Research Project

## Cutting Plan – Baffle Plates

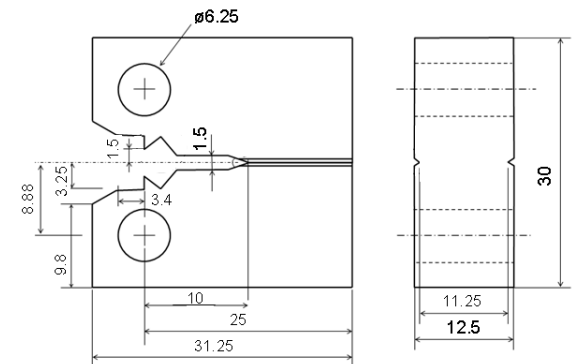
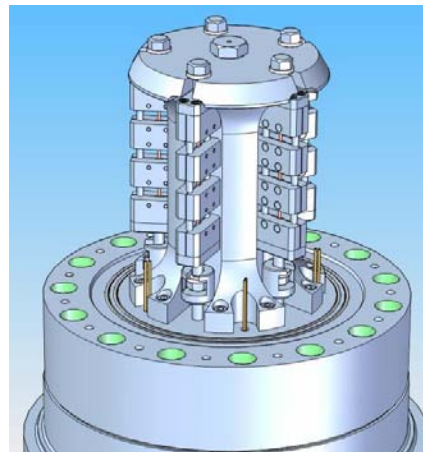
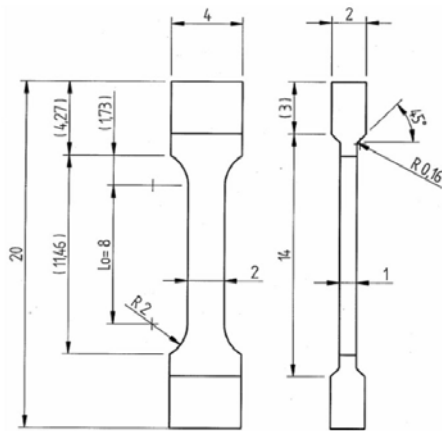
- Baffle plate material between 3<sup>rd</sup> and 4<sup>th</sup> formers
- Type 304 Stainless Steel
- Doses ranging from a few dpa to ~50 dpa
- Thickness 28.6 mm
- **ZIRP uses Pieces B1, B2, and B3**



# Zorita Internals Research Project

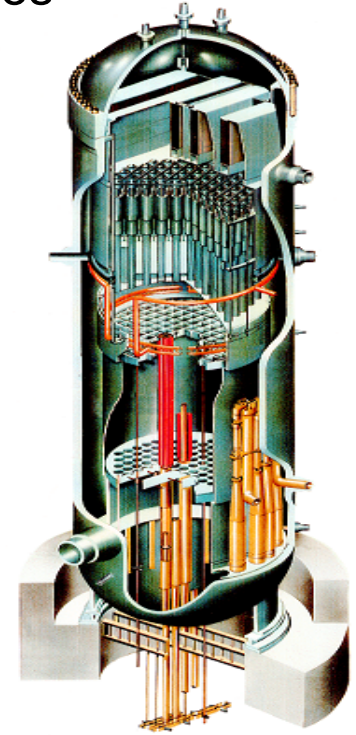
## Mechanical Testing

Property	Dose (dpa)	Schedule	Notes
Tensile Testing	10, 30, 50	2014	
IASCC Crack Initiation		2014-2016	O-ring and UCL specimens
IASCC Crack Growth Rate	10, 30, 50	2014-2015	3 temperatures and 2 $K_I$ levels
Fracture Toughness	10, 30, 50	2014-2015	Air and primary coolant



# Reactor Pressure Vessel

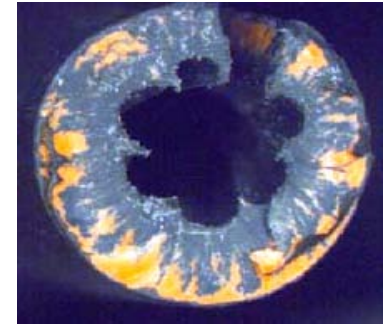
- Monitor changes in fracture toughness of the RPV and nozzles due to irradiation
- EPRI Technical Reports:
  - ✓ BWR Integrated Surveillance Program for 40 to 60 years
  - ✓ PWR Embrittlement Trend Correlations Master Curve
  - ✓ Through-wall Attenuation of Radiation Embrittlement
  - ✓ PWR Coordinated Surveillance Program
- Ongoing and future projects:
  - BWR Integrated Surveillance Program for 60 to 80 years
  - PWR Supplemental Surveillance Program



**Data and trend correlations exist for LTO. Additional data will expand and improve existing correlations.**

# Electrical Cables

- Aging of cable insulation materials due to radiation, temperature and submergence
- EPRI Technical Reports:
  - ✓ License Renewal Electrical Handbook
  - ✓ Cable Aging Reports
  - ✓ Medium and Low Voltage Aging Management Guidelines
  - ✓ Cable Testing Guidelines
  - ✓ In-containment Radiation and Temperature Measurements
  - ✓ Medium Voltage Cable Failure Mechanism Research



**Electrical cable systems are performing well and tools exist for aging management.**

# Electrical Cables Ongoing/Future

- Ongoing and future projects:
  - ❑ Continued collection of in-containment radiation and temperature data
  - ❑ Enhanced condition monitoring technology
  - ❑ Low voltage cable susceptibility to wet (submerged) environments
  - ❑ Cable materials handbook
  - ❑ Forensic analysis of harvested cables
  - ❑ Service aged cables for determination of remaining qualified life
    - Cable harvesting guidelines
    - Testing of field returned (harvested) cables
    - Determine ***Remaining Useful Life***



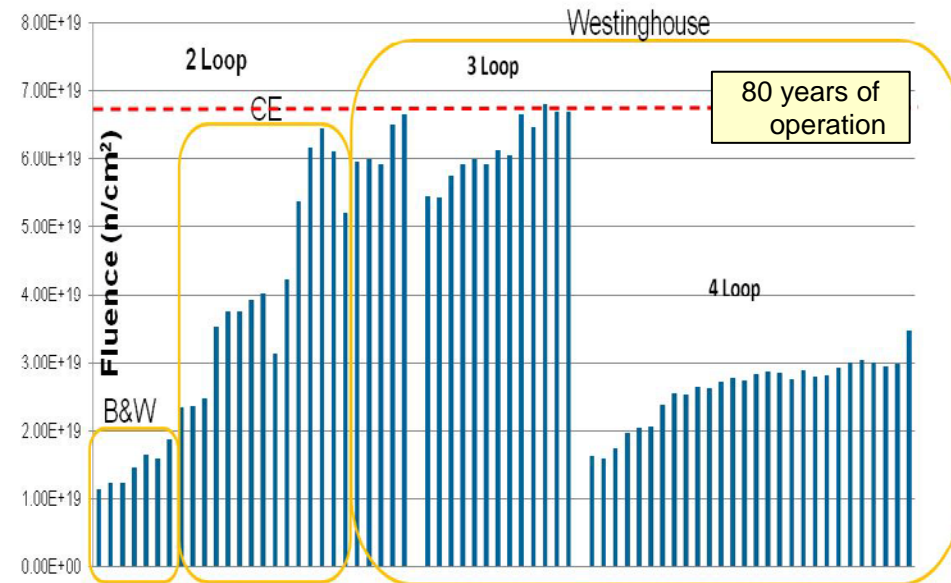
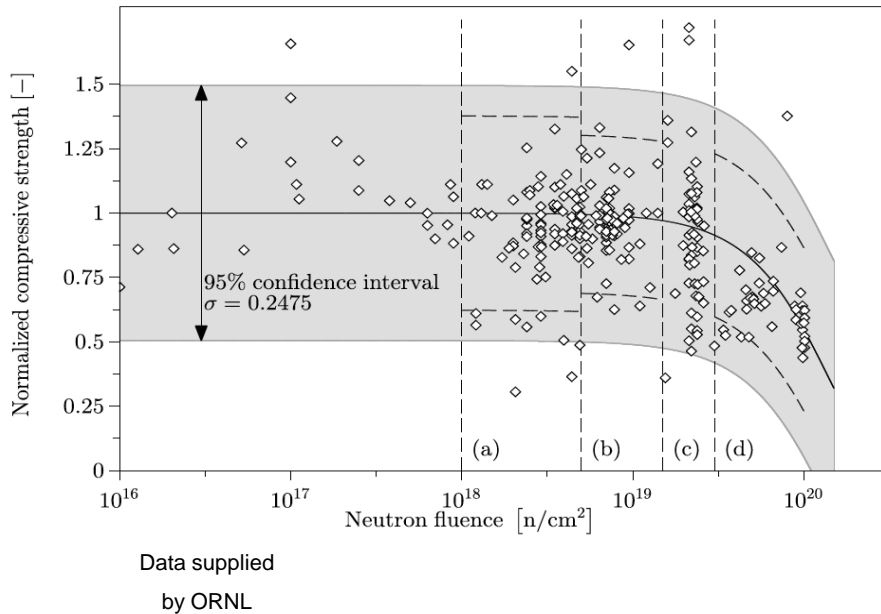
**Remaining useful life will inform need for possible cable replacements.**

# Containment and Concrete Structures

- Monitoring and aging management of concrete structures due to radiation and environmental exposure
- EPRI Technical Reports:
  - ✓ Nuclear Concrete Structures Aging Reference Manual
  - ✓ Nondestructive Evaluation Inspection of Concrete Structures
  - ✓ Literature Survey of Effects of Radiation on Concrete
  - ✓ Expected Conditions of Reactor Cavity Concrete at 80 Years of Radiation Exposure
  - ✓ Boric Acid Attack of Concrete and Rebar in PWR Spent Fuel Pools
  - ✓ Nonlinear Ultrasound to Evaluate Integrity of Aged Concrete
  - ✓ Pilot Plant Augmented Containment Inspection Results



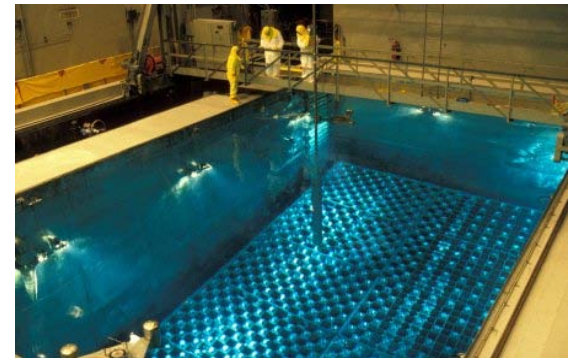
# Recent International Irradiation Data Compiled by ORNL



**No appreciable impacts on biological shield wall concrete for LTO.**

# Concrete Structures Ongoing/Future

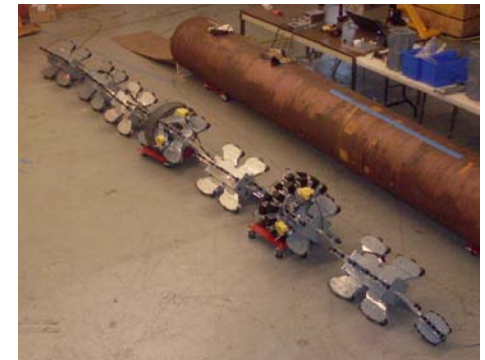
- Ongoing and future projects:
  - ❑ Alkali Silica Reaction (ASR) mapping and structural evaluations
  - ❑ Irradiation and gamma heating effects on mechanical properties
  - ❑ Modeling and structural evaluation of biological shield wall
  - ❑ Creep fatigue evaluations
  - ❑ Mechanistic model of boric acid attack on spent fuel pool structure
  - ❑ Tool box for concrete aging management



**Structural evaluation and inspection methodologies for aging infrastructures.**

# Buried and Underground Piping and Tanks

- Industry Initiative developed in response to operating experience
- Utility Implementation
  - Programs developed
  - Inspections in progress
  - Long range asset management plans being developed
- Continuing EPRI R&D Projects (Buried Pipe, Tanks, Cathodic Protection, and Coatings)
  - Programmatic support and Guidance
  - Corrosion analysis
  - Inspection methodology advancements
  - Mitigation Strategies
  - Repair and replacement options



# Instrumentation & Controls Program

*Improve plant productivity*



Use advanced I&C technology to improve overall plant health & productivity

- Plant monitoring
- Advanced simulation, visualization & controls
- Advanced sensor designs



*Replace*



Enable implementation of replacement I&C systems

- New technology (e.g. FPGA's)
- New issues (e.g. cyber-security)
- New analysis methods for safety & reliability



*Maintain*

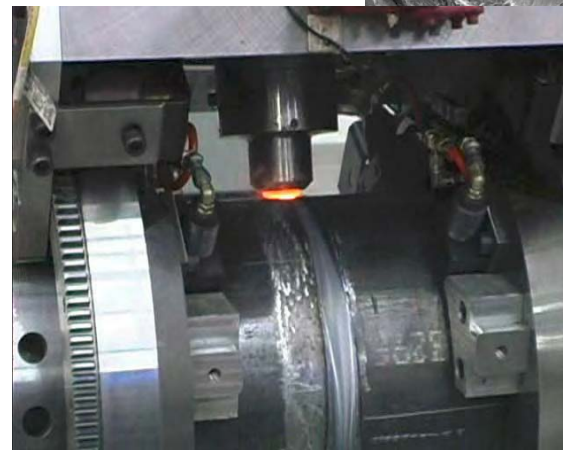
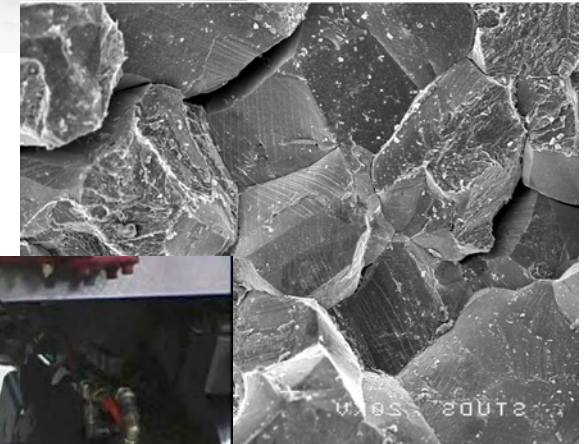
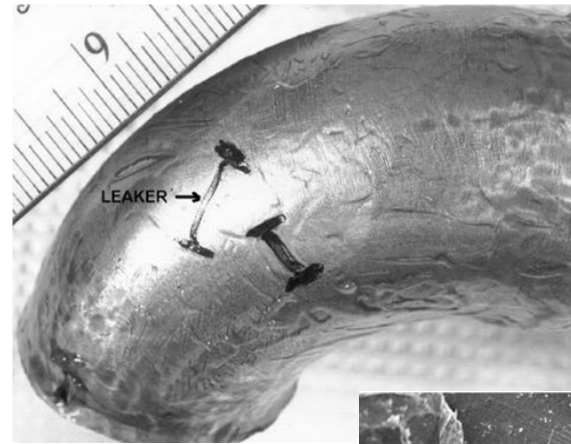


Improve reliability of existing I&C systems and components (e.g., circuit cards)

- Preventive maintenance

# Summary – Technical Basis for Robust Aging Management

- R&D to understand aging degradation
- Inspection methods
- Mitigation strategies
- Condition Monitoring
- Prediction of Remaining Useful Life
- Repair & Replacement Decisions





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