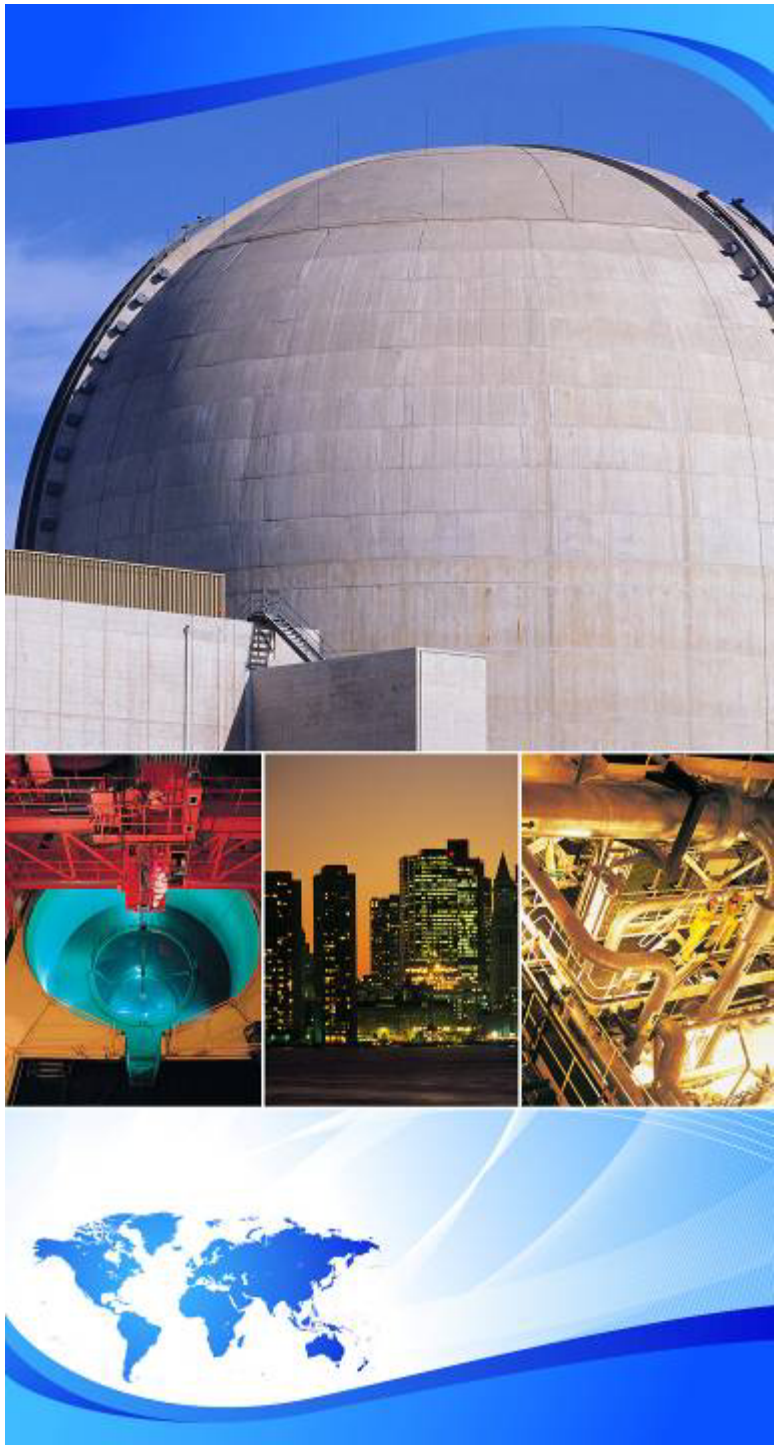

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MRP Reactor Internals Modeling and Testing Projects

Raj Pathania

Rick Reid

EPRI

EPRI-NRC Technical Exchange Meeting May 25-26, 2010

Modeling

- Models Developed to Predict Aging Effects in Austenitic Stainless Steels
  - Includes IASCC, void swelling, embrittlement and stress relaxation/creep
  - Models will be updated to incorporate the results of ongoing test programs
- Suite of Models form a Comprehensive Material Constitutive Model (MRP-135)
  - Model was verified and MRP-135 will be revised this year
  - Software IRRADSS will be published this year
  - Software is used as a subroutine within a finite element code to predict the aging of the structures with temperature and irradiation

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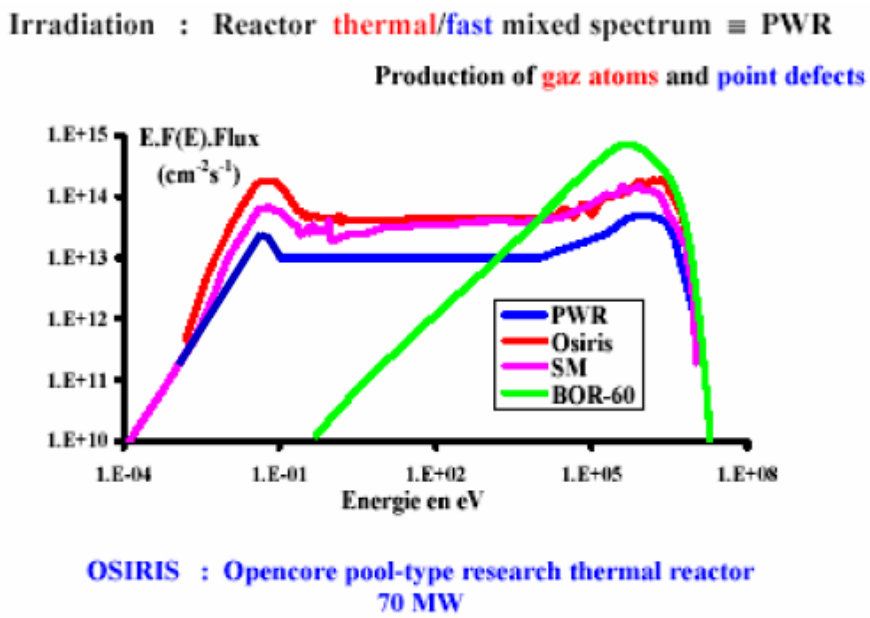
PWR Irradiated Materials Testing Projects

- Zorita Internals Research Project (scheduled to start this year)
- GONDOLE Void Swelling Experiment (in progress)
- Halden Crack Growth Project (in progress)



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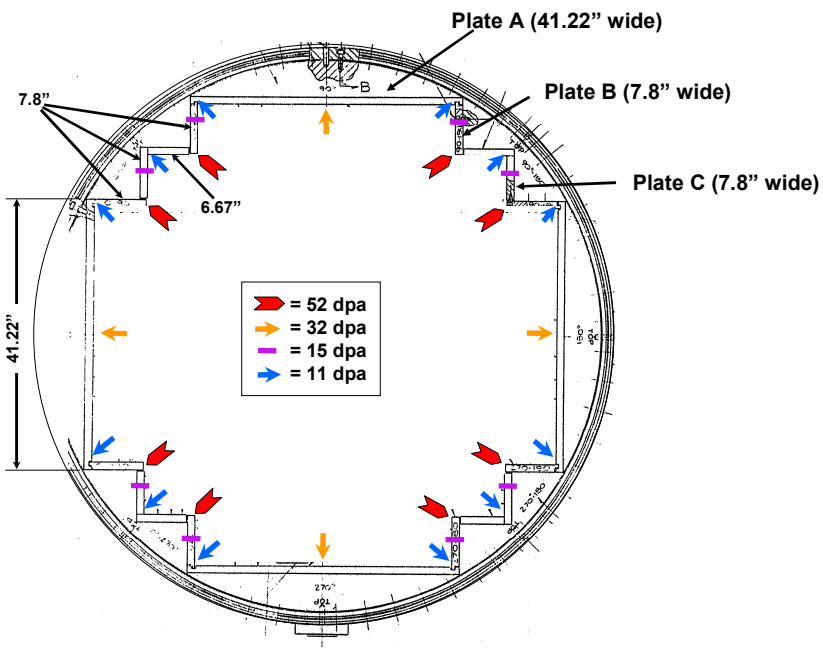
Zorita Internals Research Project: Goals

- Addresses some of the gaps in IASCC initiation and crack growth rate, fracture toughness, and void swelling related to lack of data at high fluence for the LWR spectrum irradiated material
- Provide database and predictive equations for PWR internals long-term operation functionality analysis



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Zorita Internals Research Project: Testing

- Generate IASCC initiation & crack growth rate data, mechanical properties (tensile & fracture toughness) & micro-structural data (including swelling/void formation & gas contents)
- Planned IASCC initiation testing time is 9000 hours, as one of the gaps for IASCC initiation data is the lack of long-term incubation data
- Optical, TEM, EDS observations & gas chromatography analysis to determine H & He content

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Zorita Internals Research Project: Materials

- Test highly irradiated PWR internals harvested from Zorita, a decommissioned Spanish PWR
- Materials Samples Harvesting – Early 2012
- Materials
  - Baffle plates: 1.25 thick, 304 SS
  - 10, 30 and 50 dpa (nominal)
- Fluence and Temperature
  - 26.36 EFPY prior to shut down
  - Baffle plates:
    - ~306 °C estimated maximum operating temperature at inner baffle plate surface
    - ~350 °C estimated maximum temperature due to gamma heating
    - To be confirmed by analysis

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Zorita Internals Research Project: Participants

- Japan
  - 5 Japanese utilities (Kyushu Electric Power Co., Shikoku Electric Power Co., Hokkaido Electric Power Co, JAPC, Kansai)
  - MHI
- Europe
  - TRACTEBEL Engineering
  - RINGHALS AB (includes Swedish Regulator, SSM)
  - NOK
- US
  - EPRI
  - Westinghouse
  - US NRC (includes Spanish Regulator, CSN)

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GONDOLE Void Swelling Irradiation & Testing: Overview

- Goals
  - To quantify void swelling of PWR spectrum irradiated PWR internals materials
  - To provide database and void swelling predictive equations for PWR internals long-term operation functionality analysis
- Approach
  - Irradiate PWR internals materials in mixed spectrum Osiris reactor
- Materials
  - Virgin PWR internals materials
  - Pre-irradiated materials
- Status
  - Phase 1 ongoing (2004-2010)
  - Phase 2 in planning (2010-2018)

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GONDOLE Void Swelling Irradiation & Testing: Phase 1

- Objective: Determine if void swelling of reactor internal materials can be observed under irradiation conditions close to the PWR conditions (temperature, spectrum and flux) in a mixed spectrum reactor
- From 2004-2010:
  - 5 cycles of irradiation (4 cycles completed) up to ~15 dpa
  - Virgin PWR internals materials & pre-irradiated materials (304 & 316)
  - Results to date using density measurements indicate that some materials could already present onset of swelling, a majority however have not significantly evolved.

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GONDOLE Void Swelling Irradiation & Testing: Project Extension (Phase 2)

- Extension main objectives: Increase the dose (~30 dpa for virgin materials at the end of irradiation); Confirm the observed tendencies & obtain swelling on other materials in order to determine swelling kinetics; Establish an incubation dose or an increased upper limit for no significant swelling; Investigate the possibility of a T threshold.

- Measurements
  - Density: Increase the number of density measurements per specimen.
  - Profilometry: Measurements after each irradiation cycle
  - Characterizations: Microstructure by TEM and gas content.
    - Measurements on 5 samples after irradiation cycle 5 and 8.
  - Modeling: Empirical modeling of the results & quantitative modeling of the Gondole results by cluster dynamics

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Crack Growth Tests in Halden under PWR Environment

- Objectives
  - Generate long-term crack growth rate data for irradiated stainless steel under irradiation in simulated PWR environments.
  - To study the effects of fluence, flux & temperature on crack growth rate for materials with different neutron fluence.
- A third PWR crack growth test matrix is planned for the 2009-2011 period.
- Materials include cold worked 316 SS & a Ti stabilized 316 SS irradiated in inert conditions (at 335-340 °C) in Halden to 1.5-2 dpa & CW 316 SS bolt sample ~9 dpa from a French PWR.
- Specimens exposed to PWR primary water chemistry conditions
  - Exposure at two temperatures (288 and 325-335°C) to determine the effect of temperature on cracking response.

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Crack Growth Tests in Halden under PWR Environment (contd.)

CT	Material	Source	Dose (dpa)	PIA treatment
6 (low flux)	304L SS	Barseback 1 control rod handle # 1701	7.7	YES*
5 (low flux)	304L SS	Barseback 1 control rod handle # 1701	7.7	No
4 (hi flux)	Chooz A	EDF, center filler assembly	~30	YES*
3 (hi flux)	CW316SS	EDF, bolt	9 (av)	No
2 (hi flux)	CW316Ti	AREVA	~2	No
1 (hi flux)	304L SS	Barseback 1	5.9	No

* Post Irradiation Annealing (PIA) treatment: 500 C for 6 hours

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