

Overview of Primary Systems Corrosion Research (PSCR)

Robin Dyle, EPRI

Jim Cirilli, Exelon

NRC – Industry Meeting

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Outlines

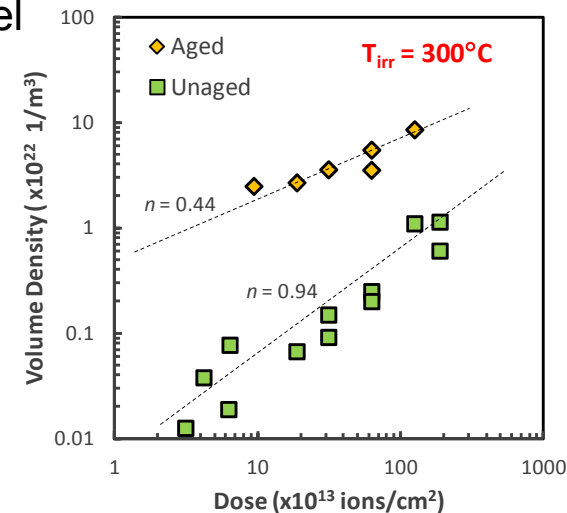
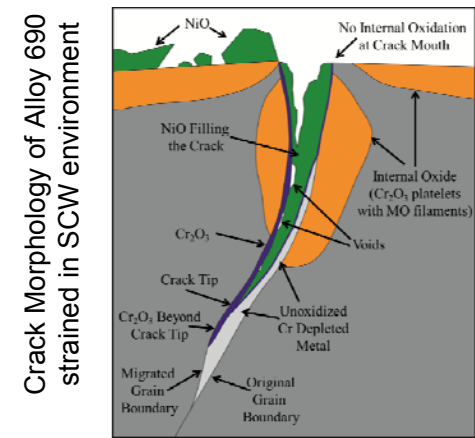
- **2014 R&D Results**
- 2015 R&D

2014 Deliverables – Available through PSCR Cockpit

- ✓ 3002003103 **IASCC Crack Growth prediction Model**
- ✓ 3002003105 **Identifying Mechanisms and Mitigation Strategies for Irradiation Assisted Stress Corrosion Cracking of Austenitic Steels in LWR Core components**
- ✓ 3002003041 **Role of hydrogen in PWSCC crack initiation of Ni-based alloys**
- ✓ 3002003100 **Summary Report on SCC Initiation Experiment of Alloy 690 in Supercritical Water**
- ✓ 3002003047 **Nano-Scale Characterization of PWSCC Initiation in Ni-based Alloys**
- ✓ 3002003051 **Study of Cause-and-Effect between localized deformation and IASCC initiation**
- ✓ 3002003106 **In-situ TEM study of combined effects of thermal and irradiation aging on CASS microstructure**
- ✓ 3002003049 **Annual POLIM Program Report on International Cooperative Research in Mechanistic Understanding of Stress Corrosion Cracking**
- ✓ 3002003042 **Role of Creep and Creep Crack Growth in SCC in Austenitic Materials**
- 3002003104 *Effects of Environments on Fracture Resistance of Alloy 182 -- Delayed to 2015*

Key R&D Projects Completed in 2014

- Development of IASCC Crack Growth Models For BWR and PWR Internals
- (EPRI-DOE /LWRS co-fund) Identifying mechanisms and mitigation strategies for irradiation assisted stress corrosion cracking of austenitic steels in LWR core components
- Investigating the effect of irradiation on the microstructure of thermally aged cast austenitic stainless steel (CASS)
- Investigating the feasibility of using supercritical water testing for SCC initiation evaluation in Alloy 690
- Development of stress severity-based IASCC initiation model
- POLIM – an international cooperative research on SCC of Ni-alloys and stainless steels in LWR environments



Highlight -- Development of IASCC Crack Growth Models For BWR and PWR Internals

- The models account for effects of irradiated yield stress (dose), stress intensity K, ECP, temperature, type of loading (constant load vs. PPU)
 - Model for high ECP environment – BWR NWC
 - Model for low ECP environment – BWR HWC & PWR
- There was no significant difference in the CGRs between BOR 60 fast reactor and LWR irradiated materials after accounting for the above factors
- Analysis showed that a common model can be used for BWR-HWC and PWR environments with a temperature term to account for higher PWR temperatures
- After accounting for above parameters there is still a large heat-to-heat (and specimen-to-specimen) variability. This variability is reflected in heat coefficients in the models

Knowledge Transfer with the New IASCC Models

- EPRI report has been published: 3002003103 -- “Models of Irradiation-Assisted Stress Corrosion Cracking of Austenitic Stainless Steels in Light Water Reactor Environments”; and is available to PSCR, MRP and BWRVIP members
- The report will provide the technical basis for **crack growth disposition** curves for irradiated BWR and PWR stainless steel internals
- A paper based on the report will be presented at the July 2015 **ASME PVP** Conference in Boston
- The paper will provide the basis for the proposed disposition curves and will be used to develop an **ASME code case**

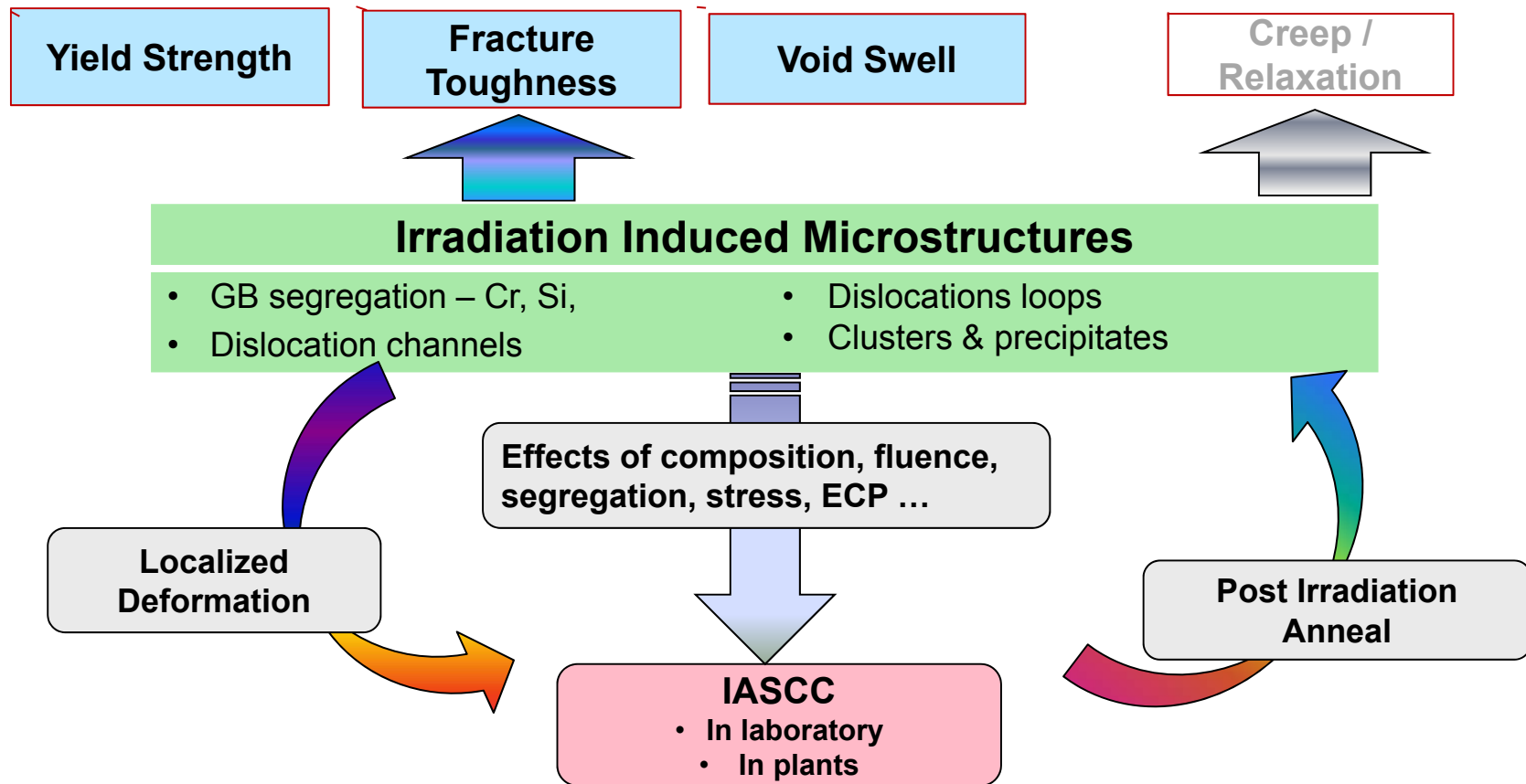
Outlines

- 2014 R&D Results
- **2015 R&D**

List of 2015 Project

Irradiated materials	Development of Radiation Resistant Material (ARRM)	Base
	CT size and orientation effects on IASCC (Zorita)	Base
	IASCC CGR Models Codification	Base
	Modeling of irradiated mechanical properties & Fracture Toughness	Base
	Small-volume mechanical property evaluation for irradiated materials	TI
	Effects of high fluence neutron irradiation on localized deformation and IASCC	TI
	Develop engineering solutions to counter IASCC	TI
	Rapid Simulation of High Fluence -- Ion radiation of LWR irradiated FTT	TI
	Round Robin – APT Data Acquisition and Analysis for Irradiated SS	MAI
SCC	Determine distinct SCC dependence (e.g. effects of microstructures)	Base
	Investigate GB oxidation of Alloy 600/600TT in PWR (<i>in discussion with PNNL</i>)	Base
EAF	Mechanistic understanding of loading effects on EAF CGR	Base
	Investigation the effects of irradiation on EAF CGR	Base
	Mechanistic model for environmental fatigue CGR	Base
MDM	Development of MDM-VVER & CANDU - IMT	Base
	Revision of Materials Handbook	Base
	Materials Information Portal (MIP) update	Base

Continuing Focus on Irradiation Damage Mechanisms



Irradiated Materials Research is Aimed to Improve Mechanistic Understanding Based on Irradiated Microstructures

- ❑ TI-Breakthrough Project -- Rapid simulation of the effects of high fluence on irradiation embrittlement and void swelling
- ❑ TI Project, co-funded with LWRS: Studying the effects of high fluence neutron irradiation on localized deformation, and developing engineering solutions to counter IASCC
- Co-funded with LWRS: Development of Radiation Resistant Material (ARRM)
- MALL project, with CRIEPI: Modeling of irradiated mechanical properties & Fracture Toughness
- Preparation for code development of IASCC crack growth model
 - Study the effects of heat variability on effectiveness of HWC for IASCC mitigation in BWR

New Project: Rapid Simulation of Irradiation Damage in LWR Internals at High Fluence

- Objective: Develop and validate an approach based on heavy ion irradiation (Fe^{2+} or Ni^{2+}) with He/H implantation and fast neutron irradiation for cost effective and rapid simulation of irradiation damage in PWR internals at high fluence

Background: PWR Internals are expected to experience high fluence exceeding 100 dpa at certain locations during first and second license renewal (60-80 years). There is a need for data and validated models to predict the degree of irradiation damage expected in austenitic stainless steel internals at high fluence.

- Benefit:
 - A validated approach could be used to evaluate the effect of high fluence more rapidly and more cost effectively than using extracted irradiated materials to be re-irradiation in LWRs
 - The project will provide a technical basis for fitness assessment of PWR reactor internal component materials with increased fluence, to ensure the safe and reliable operation of nuclear power plants for extended operation life.

Overall Project Plan

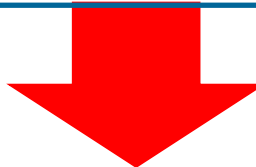
Receive LWR plant materials → Select locations with LWR fluence at 0, 50, 75, 100 dpa



Benchmark ion irradiation → At equivalent fluence, LWR (neutron) vs. simulated (ion+neutron)

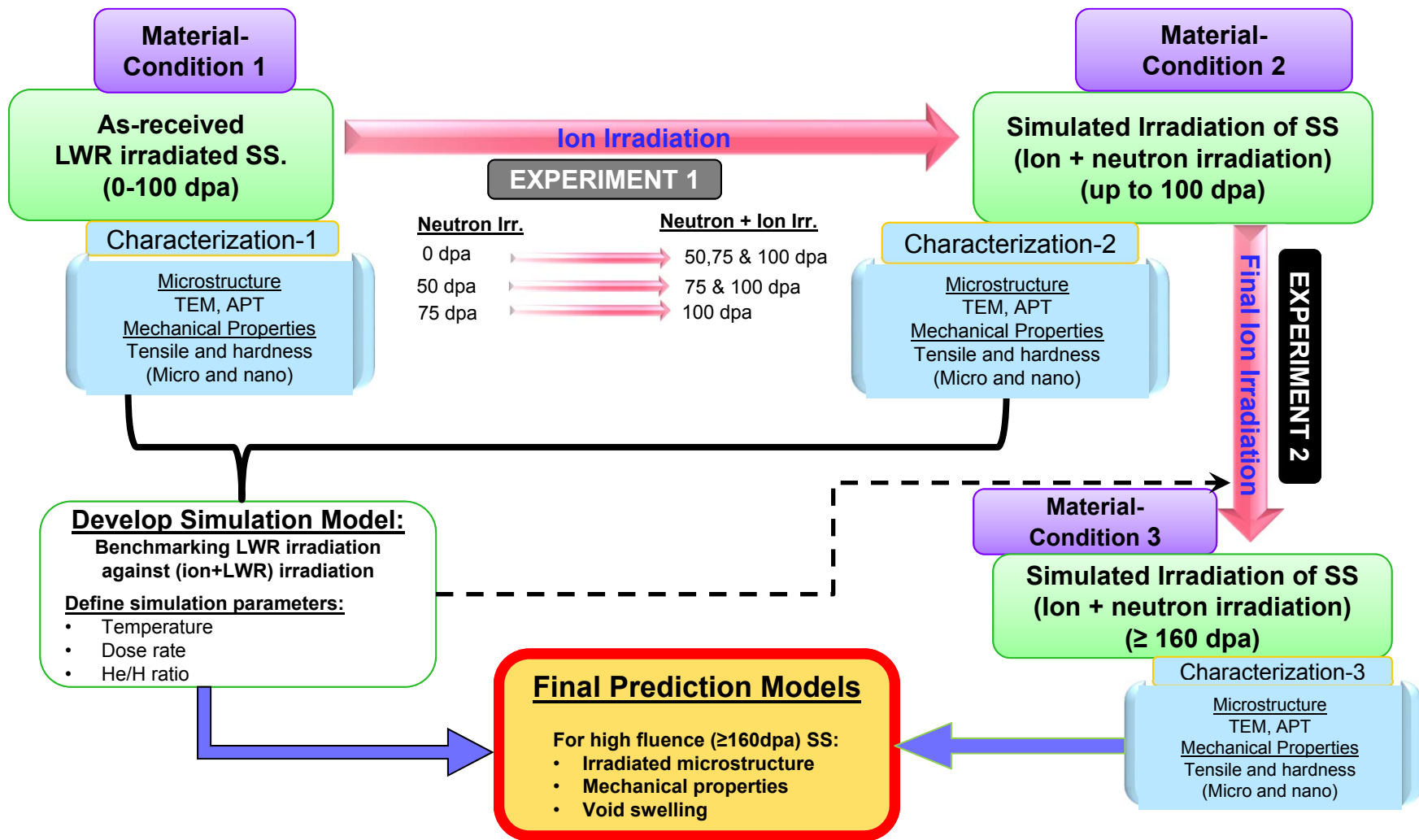


Rapid Simulation → Ion irradiation to achieve high fluence (≥ 160 dpa, ion+neutron)



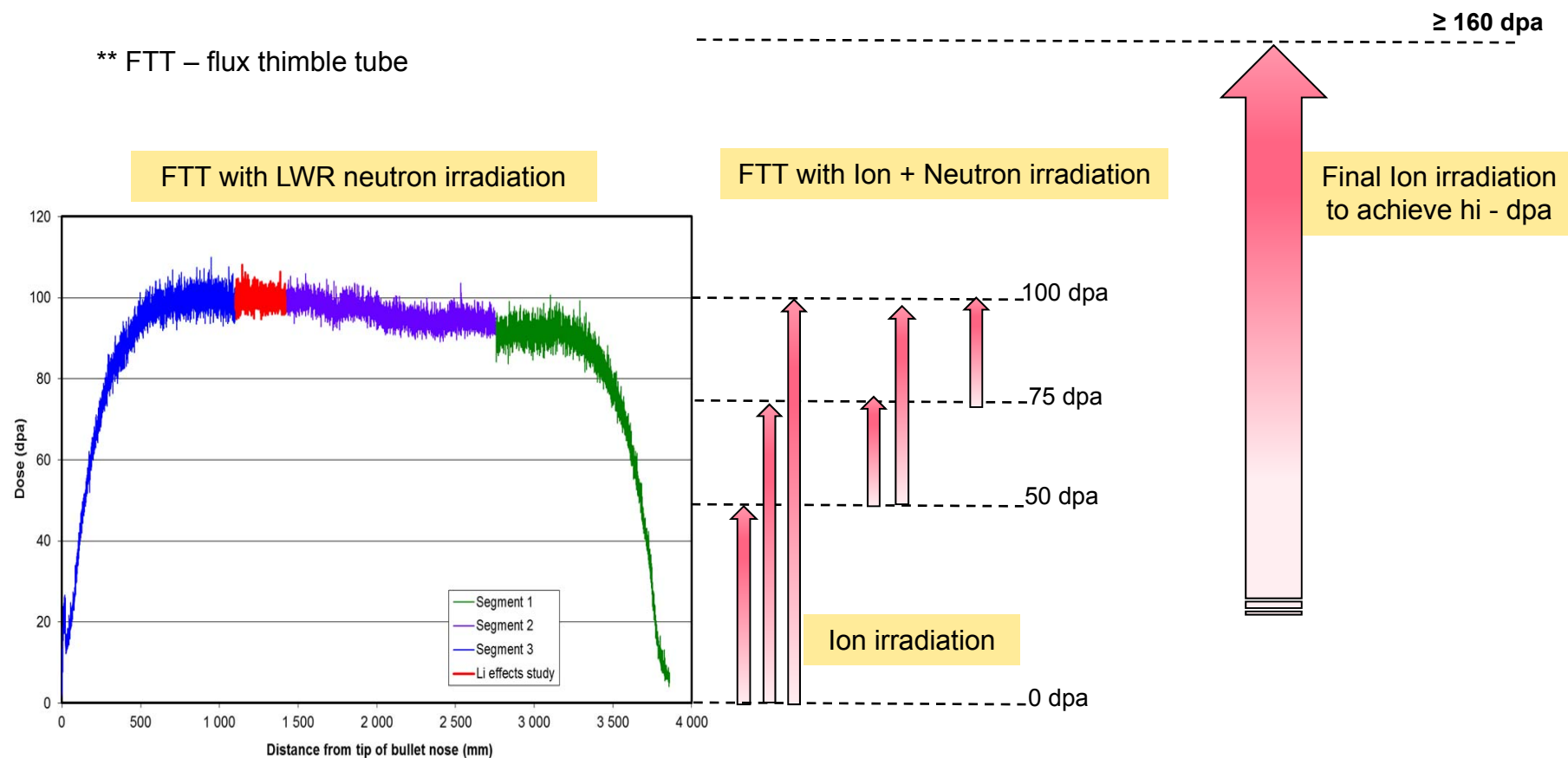
Prediction models for high fluence (≥ 160 dpa) stainless steel:

- Irradiated microstructure and microchemistry
- Mechanical properties
- Void swelling behavior

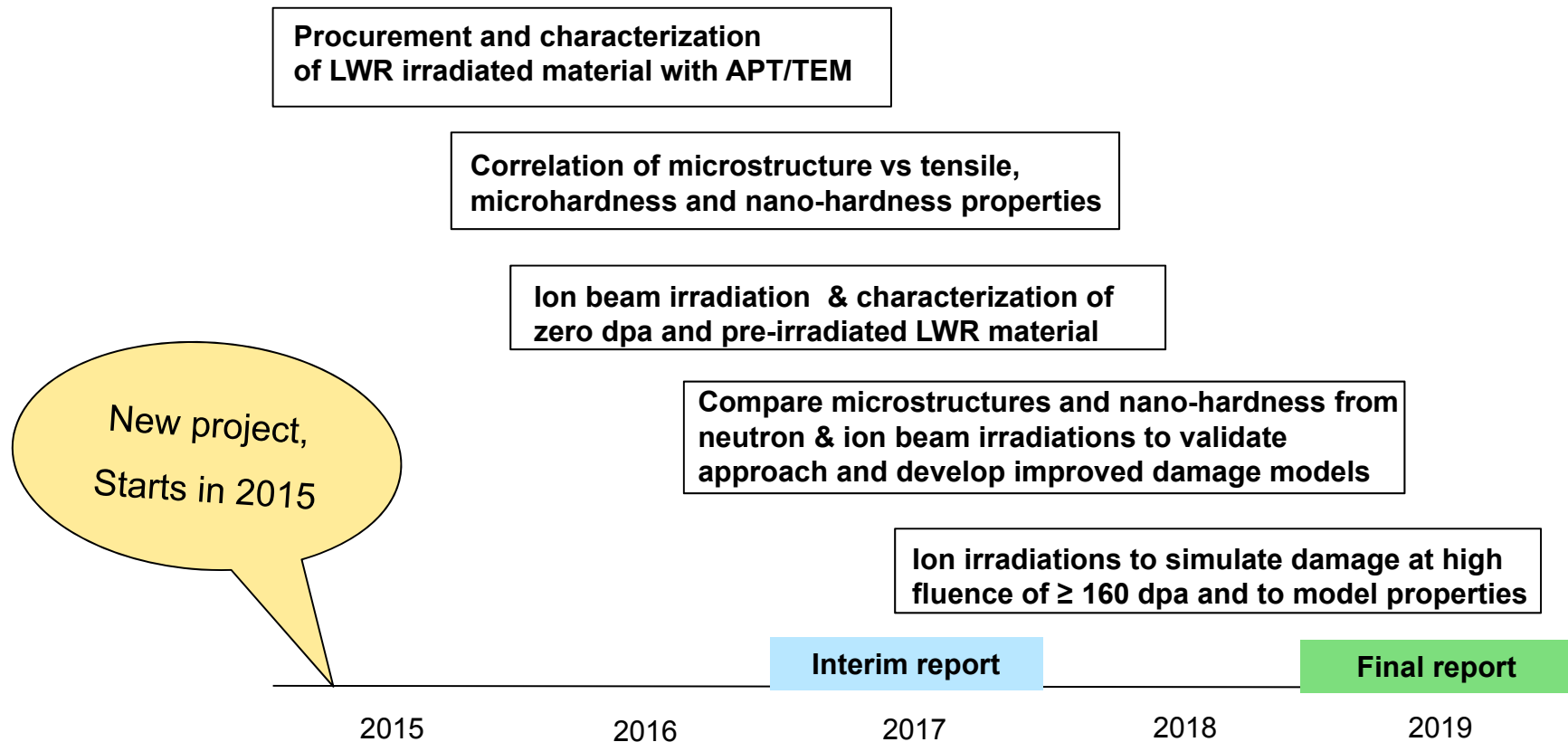


Rapid Simulation of High Fluence by Ion Radiation to FTT**

** FTT – flux thimble tube

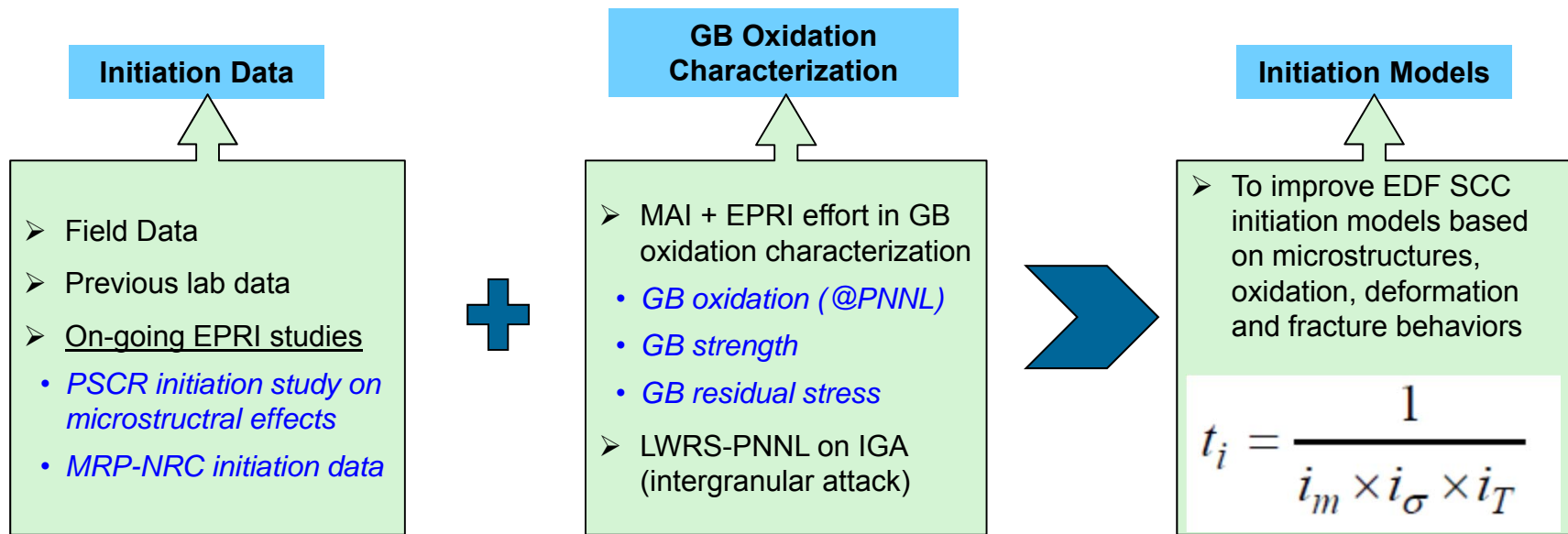


Schedule and Milestones



SCC Mechanistic Studies: Grain Boundary Oxidation and Cohesive Strength of Grainboundary in LWR Environments

Work closely with EDF-MAI in developing mechanistically based SCC initiation models. Initial efforts focused on nickel alloys.



2015 PSCR Deliverables -- Committed

3002005475	Mechanistic Understanding of Effects of Post Irradiation Annealing on IASCC
3002005476	Crack-tip Strain Rate Model for Environmental Assisted Fatigue
3002005474	Irradiation Assisted Stress Corrosion Cracking (IASCC) Initiation Model for Stainless Steels
3002005478	Summary Report on Recent Oxidation Studies – Literature Review
3002005623	Guidelines for Material Procurement for Use in LWR Environments
3002005470	Materials Handbook for Nuclear Plant Pressure Boundary Applications
3002005473	Integrated Materials Information DVD

PSCR R&D Through Broader Collaboration

- Increase collaborations with DOE-LWRS
 - Current co-funding: IASCC mechanisms, ARRM
 - In discussion: high fluence effects/void swelling, SCC mechanisms
- Better coordination with MAI
 - In discussion: Microstructural investigations on GB for SCC & IASCC
 - Approved: APT round robin (2015-16)
- Collaboration with CRIEPI in MALL program
 - Modeling of mechanical properties for irradiated stainless steels
- Increase participation in DOE NSUF program
 - To utilize ATR and partner user facilities
 - To engage with US universities through NSUF projects

Collaboration, Coordination, & Integration

New Approach in Strategic Planning for PSCR R&D

Objective: Effectively integrate PSCR R&D activities into resolution of key materials degradation issues identified in MDM and IMTs

- Expected result will be more focused prioritization, coordination and support across materials programs to optimally utilize the resources and target research at the most appropriate gaps
 - Use IMTs as initial starting point
 - Consider key needs and existing tools
 - Mechanistic understanding -- degradation mechanisms and correlations/models to support model development and mitigation solutions
 - Engineering solutions – develop data, test methods and fundamental models to support IP efforts to close gaps and create engineering solutions in areas such as assessment methodologies, guidelines, codes/regulations, etc.

New Approach

- 1. Down Selection -- Review entire set of IMTs gaps, identify and down-select the gaps to which fundamental research can help to resolve**
 - *DM and MT gaps usually fall in this category*
 - *RG and I&E gaps usually do not fall in this category*
 - *AS and RR gaps are mixed*
- 2. Gap Analysis -- For each selected IMTs gap, understand the issue and identify the near-term and long-term strategies to resolve the issue.**
 - *Describe the key elements of the IMT gap selected*
 - *Understand the projects associated to the IMT gap*
 - *Evaluate the adequacy for issue resolution*
 - *Identify remaining or additional fundamental R&D items needed for issue resolution*
- 3. Compile all fundamental R&D items, and prioritize**
 - *Cross-check list with the MDM (including LWR, PHWR/CANDU, VVER ...)*
 - *Consider needs to support subsequent license renewal (SLR) or long-term operation*
- 4. Develop PSCR portfolio**
 - *Consider projects with substantial impact*
 - *Coordinate with issue programs*
 - *Collaborate with DOE & international R&D groups*

PSCR 2015 Annual Technical Meeting

- **Will be held on October 7 - 8, 2015, at EPRI office in Charlotte, NC**
- Provides an opportunity for in-depth technical presentations & discussions, and for interaction between members and technical experts
- First annual technical meeting was held on November 3 - 4, 2014, Charlotte, NC
 - New meeting format to add a meeting with more technical focuses
 - Well attended with more than 40 attendees:
 - *Good representation of US and international members*
 - *Strong participation of US and international researchers*
 - *Participation by NSSS vendors*
 - *DOE-LWRS and ATR NSUF staffs*
 - *EPRI technical staffs*



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