IN USE: SILICON CARBIDE COMPOSITE BWR CHANNEL DEVELOPMENT

ISSUE STATEMENT

The shift to higher fuel duty and longer cycles in recent years has increased the number and severity of zirconium alloy-based fuel channel distortion/bow events in boiling water reactors (BWR). The phenomenon occurs due to the combination of fast neutron flux gradient and shadow corrosion. Channel bow reduces the inter-channel spacing, and can lead to control blade insertion issues that reduce the shutdown margin.

Moreover, in light of the recent Fukushima accident, there is interest in reducing hydrogen generation in severe accident conditions. BWR channels, which are made of zirconium-based alloys and make up 40% of the material in the core, readily reacts with water at elevated temperatures and releases large quantities of heat and hydrogen. In the absence of sufficient heat removal, the exothermic reaction becomes autocatalytic and accelerates the melting of the core.

Silicon carbide composite has demonstrated irradiation and high temperature stability that could significantly improve the condition of both issues.

DRIVERS

Public Safety

Control blades are part of a safety system and the distortion of the channel can retard or prevent the proper function of the component. Reduced functionality can affect safety margins and can lead to regulatory and operational penalties.

Nuclear Safety in Beyond Design Basis Accident

The Fukushima accident highlighted the need for new fuel materials that can extend plants operators' reaction time in a severe accident. Analysis has shown the time to core melting can be extended if the zirconium based fuel components are replaced with a high temperature tolerant material. Introduction of advanced materials adds defense-in-depth to severe accident responses.

Plant Performance and Cost

Channel distortion can lead to premature re-channeling or redesign of the core in a less efficient configuration. Such modifications can result in increased operating costs.

RESULTS IMPLEMENTATION

Research results from this work will provide non-irradiated and irradiated material property data to support the design and demonstration of SiC-based BWR channels in a commercial reactor. The results will be available to vendors interested in the design/fabrication of SiC-based BWR fuel channels.

As a first-of-a-kind effort, the R&D results are expected to address several key issues associated with the use of the SiC ceramic material:

- Resistance to severe fragmentation during a handling accident
- Accommodation of an initial irradiation-induced volumetric swelling
- Thermal shock resistance during a loss-of-coolant accident
- Other thermal/mechanical properties important to normal operations
- Identification and resolution of key design, fabrication and performance issues prior to commercial implementation

PROJECT PLAN

The project is divided into four phases.

Feasibility Evaluation

An initial high-level evaluation of the concept taking into consideration known SiC properties and fuel channel design requirements.

- Acceptability of temporary channel bow due to known initial irradiation-induced volumetric swelling
- Benefits and potential issues from the lower neutron capture cross-section of SiC
- Fabrication of test articles and execution of impact tests to evaluate SiC composite fragmentation resistance

Data Generation

The bulk of the project is focused on generating non- and irradiated material thermal/mechanical property test data to support the design of a commercial SiC-based BWR fuel channel. While SiC materials have been extensively studied, the focus had been on higher temperature fusion or gas-cooled reactor applications. To support the BWR channel application, detailed lower temperature properties for the specific SiC composite architecture are needed. Testing in the following areas are planned:

- Initial irradiated-induced volumetric swelling at multiple damage levels
- Irradiation-induced creep at multiple stress levels
- Corrosion/material loss from interaction/reaction with coolant (concerned with silica release)
- Evaluate surface treatments to mitigate high corrosion rate in BWR environment
- Quench survivability under loss-of-coolant/severe accident conditions
- Other thermal/mechanical/hydraulic properties for normal operation
- Stress analysis under normal and seismic conditions

It should be noted high-temperature steam oxidation testing is being performed by the national laboratories.

Irradiation Verification

A small-scale demonstration in the form of a 1.25"x1.25" channel has been tentatively planned to verify parametric measurements and to confirm recovery of the initial channel bow due to volumetric swelling upon swelling saturation. Post irradiation mechanical tests are also planned to evaluate any fragmentation degradation from irradiation damage.

Implementation

The last phase of the project is a demonstration of the SiC channel concept in a commercial reactor. The design aspects of a full scale fuel channel demonstration will necessitate greater fuel vendor involvement. Project management specifics have not been decided, but it is assumed that a fuel vendor takes over from this point onward. Fuel vendors have shown interest and have been involved in project planning.

RISK

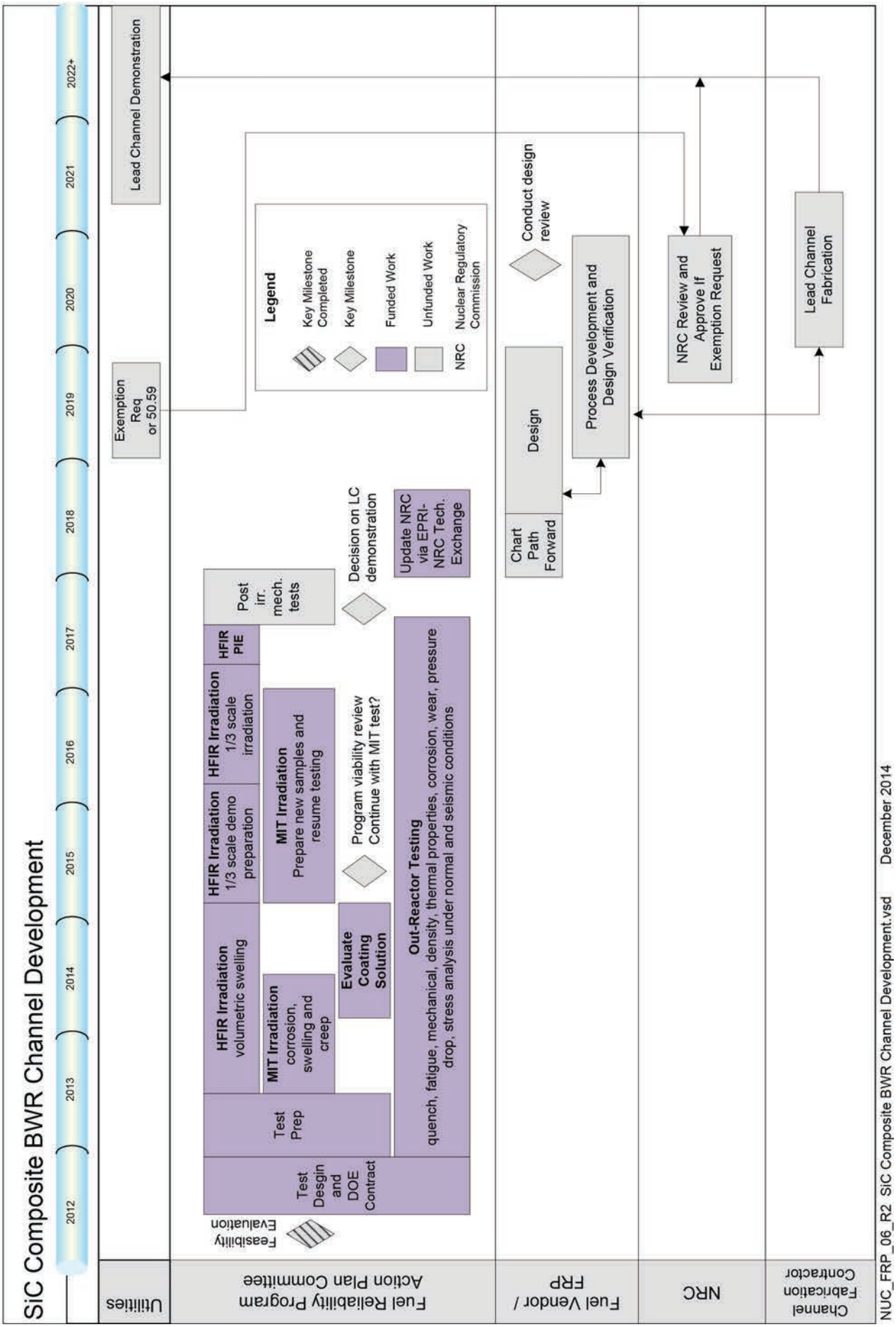
Risks associated with the research include:

- The material is known to be brittle and testing could produce results inconsistent with design requirements; such issues could lead to the need to develop more complicated and expensive 3D fiber architecture.
- Initial MIT test results indicate corrosion rate is high in BWR oxidizing environment, a solution to mitigate the high corrosion rate is needed
- Competing programs for test reactor resource.

RECORD OF REVISION

This record of revision will provide a high level summary of the major changes in the document and identify the Roadmap Owner.

Revision	Description of Change
0	Original Issue: December 2012 Roadmap Owner: Ken Yueh
1	Revision Issued: December 2013 Roadmap Owner: Ken Yueh Changes: Revised ORNL test schedule, added wear and pressure drop tests, and stress analysi
2	Revision Date: December 2014 Roadmap Owner: Ken Yueh Changes: Added coating evaluation step and revised HFIR and MIT test schedule


SiC Composite BWR Channel Development
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022+
Utilities
Fuel Reliability Program Action Plan Committee
Fuel Vendor / FRP
NRC
Channel Fabrication Contractor
Lead Channel Demonstration
Exemption Req or 50.59
Legend
Key Milestone Completed
Key Milestone
Funded Work
Unfunded Work
NRC Nuclear Regulatory Commission
Feasibility Evaluation
Test Desgin and DOE Contract
Test Prep
HFIR Irradiation volumetric swelling
MIT Irradiation corrosion, swelling and creep
HFIR Irradiation 1/3 scale demo preparation
MIT Irradiation Prepare new samples and resume testing
HFIR Irradiation 1/3 scale irradiation
HFIR PIE
Evaluate Coating Solution
Program viability review Continue with MIT test?
Out-Reactor Testing quench, fatigue, mechanical, density, thermal properties, corrosion, wear, pressure drop, stress analysis under normal and seismic conditions
Post irr. mech. tests
Decision on LC demonstration
Update NRC via EPRI-NRC Tech. Exchange
Chart Path Forward
Design
Conduct design review
Process Development and Design Verification
NRC Review and Approve If Exemption Request
Lead Channel Fabrication
NUC_FRP_06_R2 SiC Composite BWR Channel Development.vsd December 2014