Post Irradiation Examination of Stainless Steel Cladding from In-Reactor Permeation Experiment

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Presentation Outline

- **Motivation**
  - Understand in-reactor tritium permeation performance
    - Support predictive modeling and design efforts
    - Mitigate environmental release

- **TMIST-2: In-Reactor Permeation Test**
  - Experimental description
  - In-situ permeation measurements

- **Pre- and Post Irradiation Examination**
  - Metallography
  - Auger Electron Spectroscopy (AES)
  - Helium-3 Analyses

- **Summary and Conclusions**
Motivation

- Understand in-reactor tritium permeation in stainless steel
  - Fission Reactor
    - Secondary Source Rods
  - Fusion Reactor
    - Containment Materials
  - TPBARs
    - Cladding

- Mitigate tritium release to environment
  - Compliance with Regulatory Authority
  - Environmental Stewardship
TMIST-2: In-Reactor Permeation Test

- Evaluate permeation performance for 316 Stainless Steel
  - Temperature dependence (292° and 330° C)
  - Pressure dependence (0.1, 5, 50 Pa)
Experimental Description (1/2)

- Experimental lead-out test assembly
  - Irradiated in Advance Test Reactor (ATR) at Idaho National Laboratory (INL)
Experimental Description (2/2)

- Test Irradiation
  March 2009 - April 2010
- Flux wire analysis
  - 258 EFPD at $18\text{MW}_{\text{th}}$
  - 1.63 dpa
Permeation Discussion

- Ex-reactor permeation measurements
  - > 100 Pa → Diffusion-limited → $P^{0.5}$
  - < 100 Pa → Surface-limited → $P^1$

- In-reactor permeation mechanism uncertain for test conditions
  - Direct dissociative chemisorption
    - Associated with diffusion-limited permeation
    - Disrupted ex-reactor at low pressure by:
      - Surface impurities
      - Oxide films
  - Radiation-enhanced dissociation
    - Radiolysis of $T_2$ in gas phase
    - Physical or chemical changes in surface in-reactor
Results of Permeation Measurements

- Observed $P^{0.5}$ pressure dependence in-reactor
  - Suggests diffusion-limited permeation at low pressure
  - PIE performed to evaluate radiation effects on physical or chemical condition of surface
Pre-Test Characterization

- Evaluate pre- and post-irradiation microstructure and surface chemistry
  - Identify radiation effects on physical structure or surface chemistry of the sample

- Microstructure
  - Optical micrograph indicates prototypic microstructure for 316 SS

- AES
  - Preliminary results typical of 316 SS
  - Suggest presence of a thin oxide-layer
Post-Irradiation Examination

Microstructure
- Grain structure not as well defined post-irradiation
- Further inspection needed

AES
- Preliminary results suggest enhanced carbon content and low oxygen content at surface
- Further inspection needed
Performed at end of sample outside active region

Decay product of $^3$H

- Suggests slower permeation through sputter-coated region
Summary and Conclusions

- In-reactor measurements indicate diffusion limited permeation under test conditions
- Preliminary post irradiation results suggest:
  - Possible change in microstructure
  - Potential differences in surface chemistry
  - Enhanced $^3$He concentration suggests slower permeation
- In-reactor permeation mechanism is still unclear
  - Additional inspections needed to determine irradiation effect on microstructure and surface chemistry
  - Radiolysis in the gas phase may also contribute to in-reactor permeation
Back-up Slides
Back-up Slides

Permeation Supply Gas System

Temperature Control & Sweep Gas System

He

$+1000\text{ ppm } H_2$
(for startup only)

T_2

He

To Stack

Getter Bed

Cracking Bed

IC

B

B

Ne

M

M

IC

IC

ATR Pressure Vessel

Proudly Operated by Battelle Since 1965
Permeation results at 290° C
- Observed $P^{0.5}$ pressure dependence