Corrosion Assessment of Candidate Materials for the SHINE Subcritical Assembly Vessel and Components

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Scope of ORNL Laboratory Corrosion Task

- Examine corrosion properties of candidate materials to be used in the target solution vessel (zirconium alloys) and support piping (various stainless steels)

- Minimize risk and bound corrosion expectations via

  - extensive laboratory corrosion testing using *depleted* uranyl sulfate environments

  - more limited testing of materials under gamma irradiation conditions (radiolysis) at the HFIR/GIF

- Ultimately, provide information to support various approvals (e.g., NRC) to operate the SHINE system

  - information developed is further supported by irradiation test campaign at ORNL (K. Leonard, W. Geringer)

Corrosion Assessment Activities to Date

- Comprehensive literature review (Homogenous Reactor experience)
- Extensive matrix for coupon exposures in a wide range of environments
  - simple immersion
  - galvanic couples
  - vibratory horn
  - SCC – U-bends
  - SCC – slow strain rate
  - electrochemical polarization
- Preliminary HFIR/GIF exposures
  - establish handling protocols
  - initial experiments

Wide range of environments:

- 70-280 g dU/L
- ambient to 94˚C fluid temp
- to 1.0 M excess H_2SO_4
- immersion and vapor
- to 0.25M HNO_3
- stagnant to rapid fluid velocity
- to 50 wppm iodine (typically 50% as KIO_3 and 50% as KI)

Test Materials

- **Zr-4** and a **Zr-2.5Nb** alloy are primary candidates for the Target Solution Vessel (TSV) based on expected radiation damage characteristics

- Several **stainless steels** under consideration for support piping

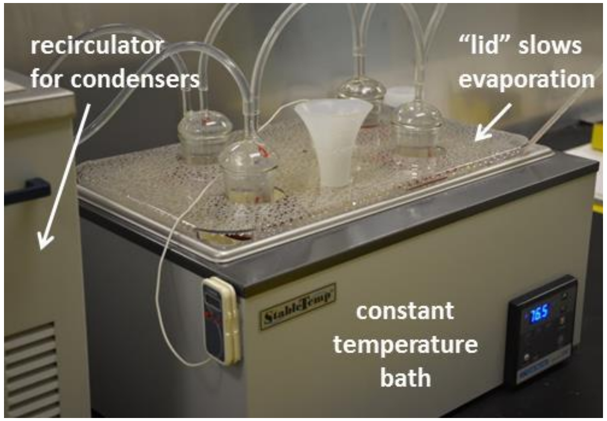
  - 316L austenitic stainless steel ↔ Workhorse stainless with known pedigree and good resistance to expected environments

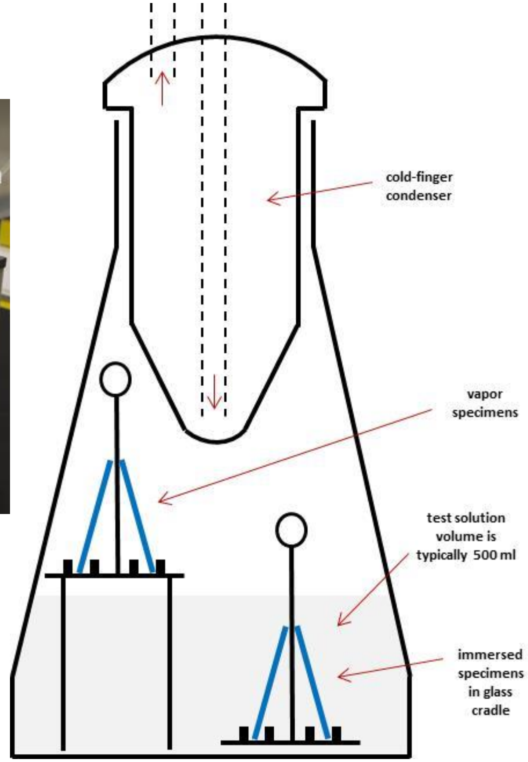
  - 2304 duplex stainless steel ↔ Expensive, high alloy stainless steel with ~ 2x strength of 316L

  - 304L stainless steel ↔ Less expensive and perhaps more readily available than 316L, but has reduced corrosion resistance

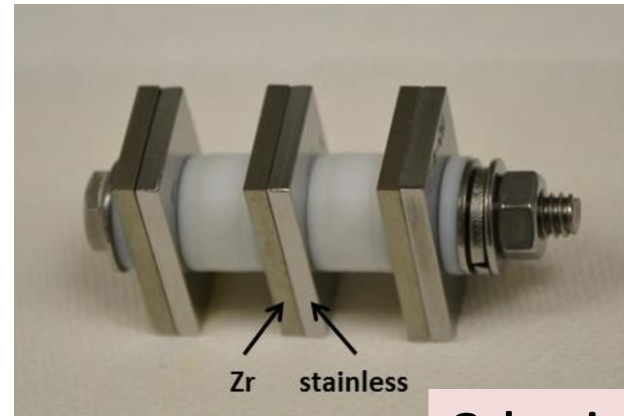
  - 17-4 PH stainless steel ↔ Considered as a candidate alloy for compression fittings to join pipes

Current Testing

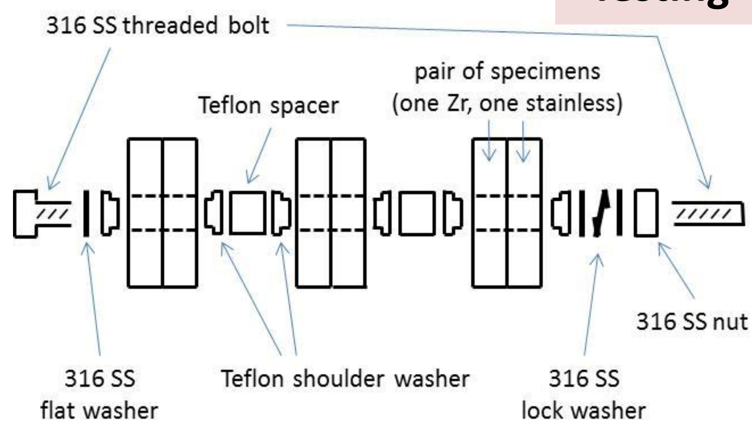


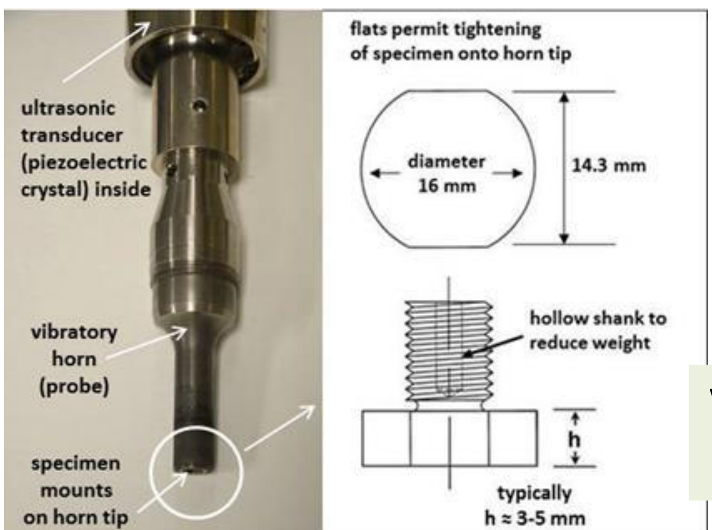


Immersion Testing



Galvanic Testing

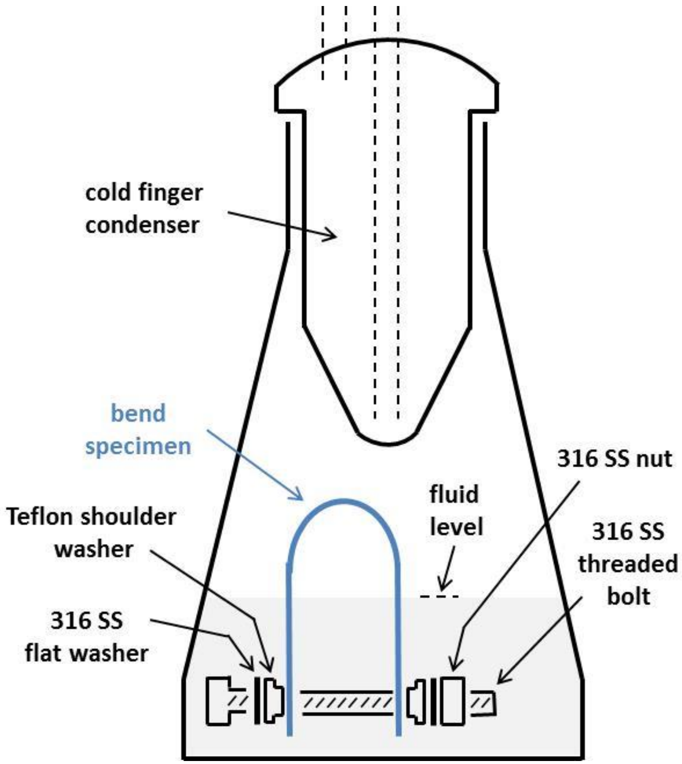




Vibratory Horn

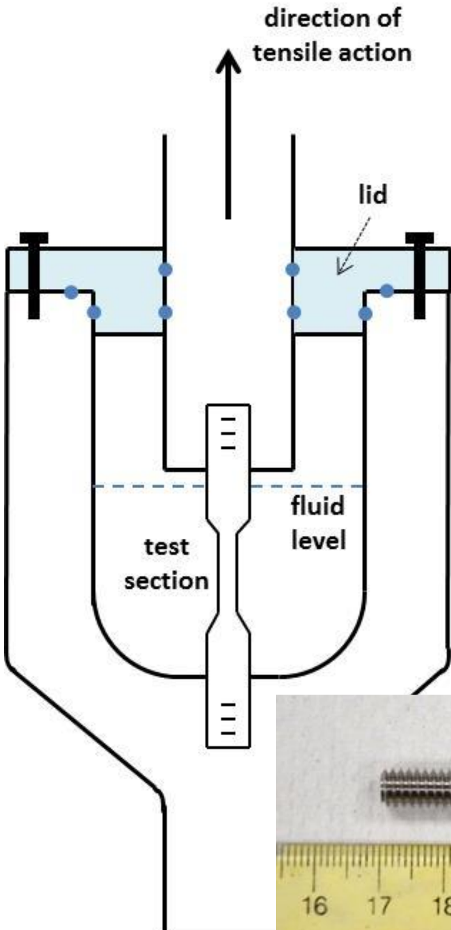
Stress Corrosion Cracking – U-bend testing

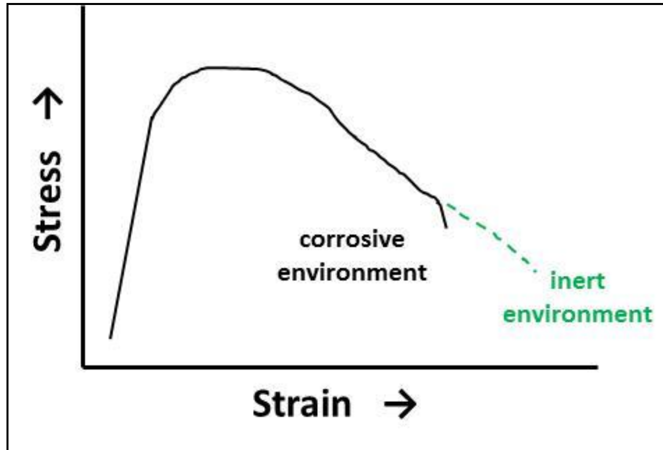
- expose pairs of U-bends in each solution:
  - fully immersed
  - bend in vapor space
  - 10 days 80˚C, 10 days 94˚C

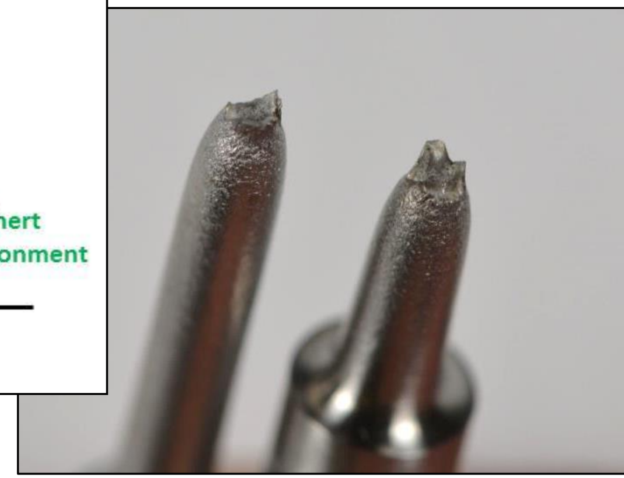


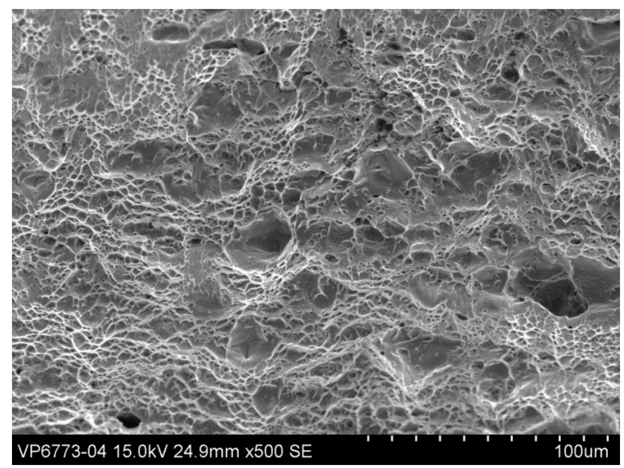
17-4 PH
140 g dU/L + 0.1 M excess H_2SO_4
after 10 days at 80-81˚C

Stress Corrosion Cracking – slow strain rate testing

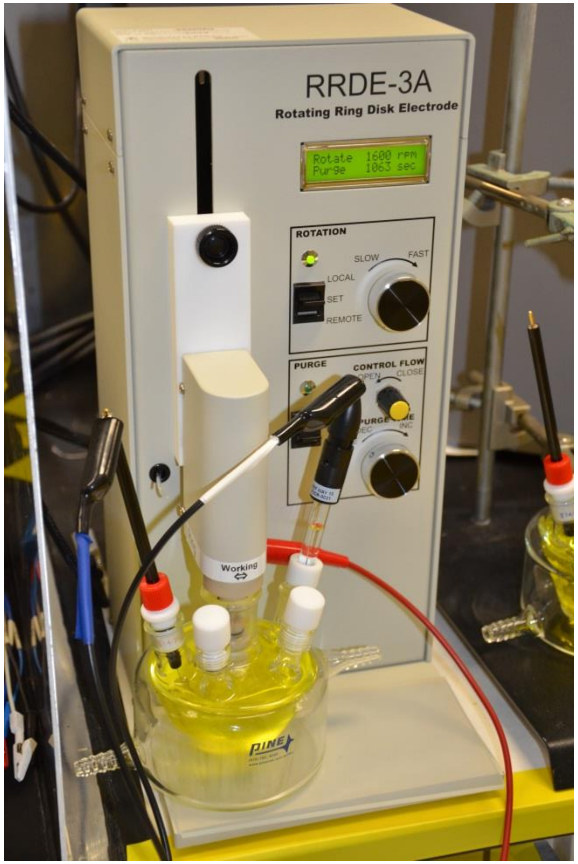


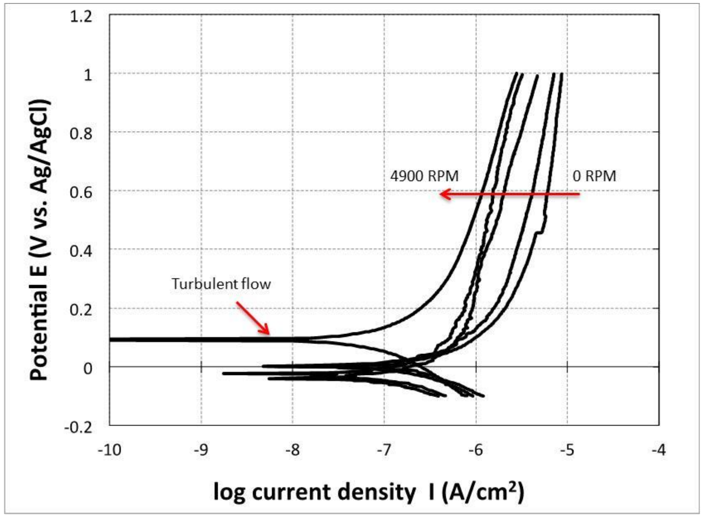




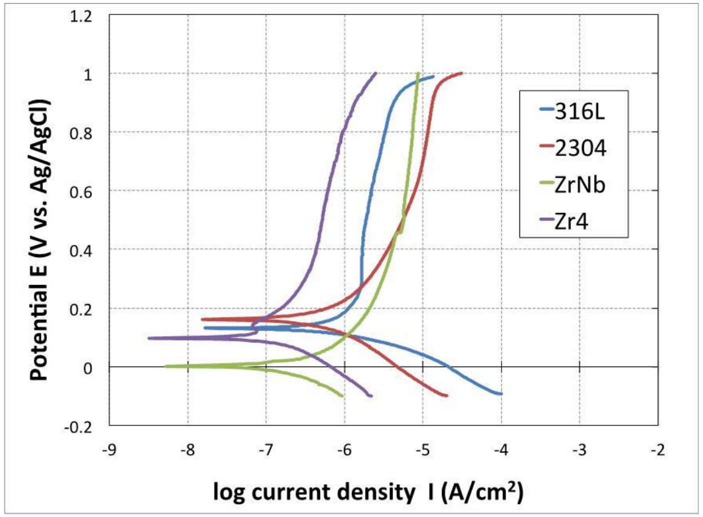


Electrochemical Polarization – rotating disk electrodes





Zr-4



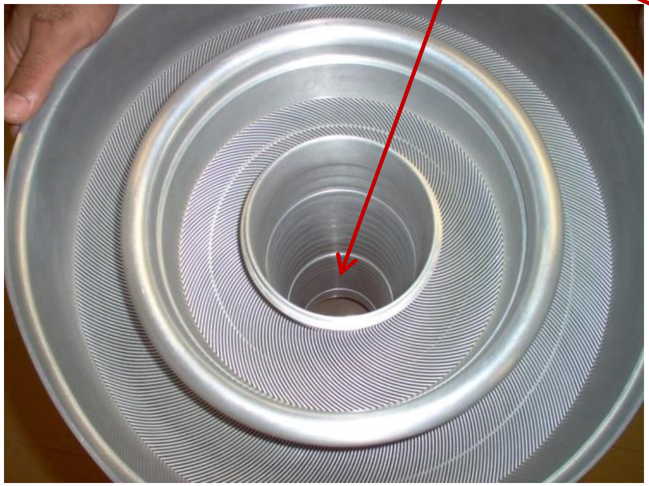
baseline solutions

Corrosion Testing Under Irradiation Conditions – HFIR/GIF exposures

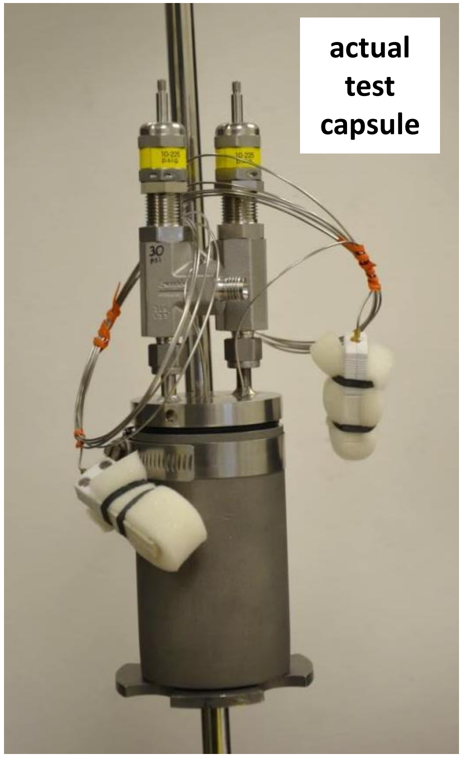
- Radiolysis-induced changes in chemistry and electrochemistry
  - formation of predominantly H_2, O_2, and H_2O_2 and related radicals

- Little influence of irradiation on corrosion performance in HRE-1 and -2, but the SHINE environment may be somewhat different

- Gamma Irradiation Facility at the High Flux Isotope Reactor can be used to exposure test materials and solutions of interest

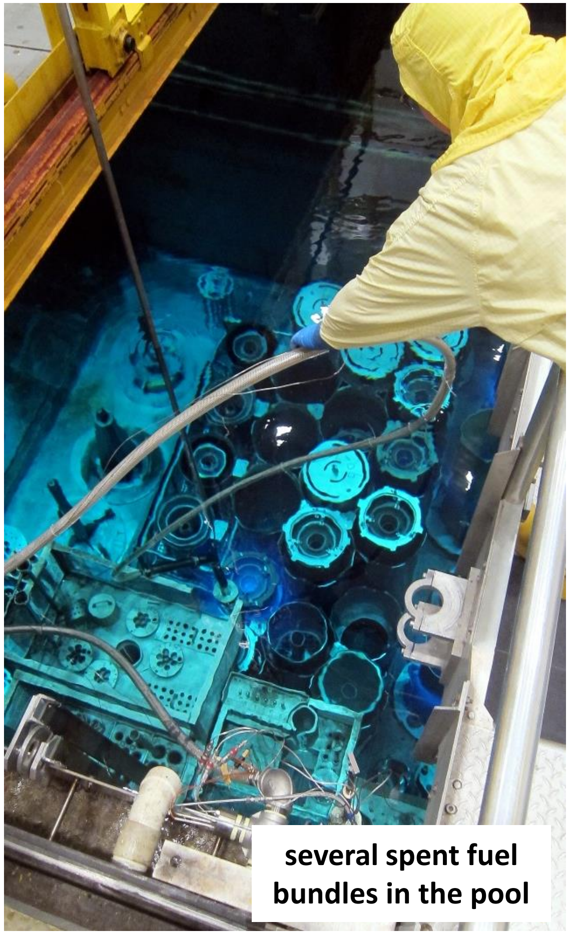


Flux trap of spent fuel assembly

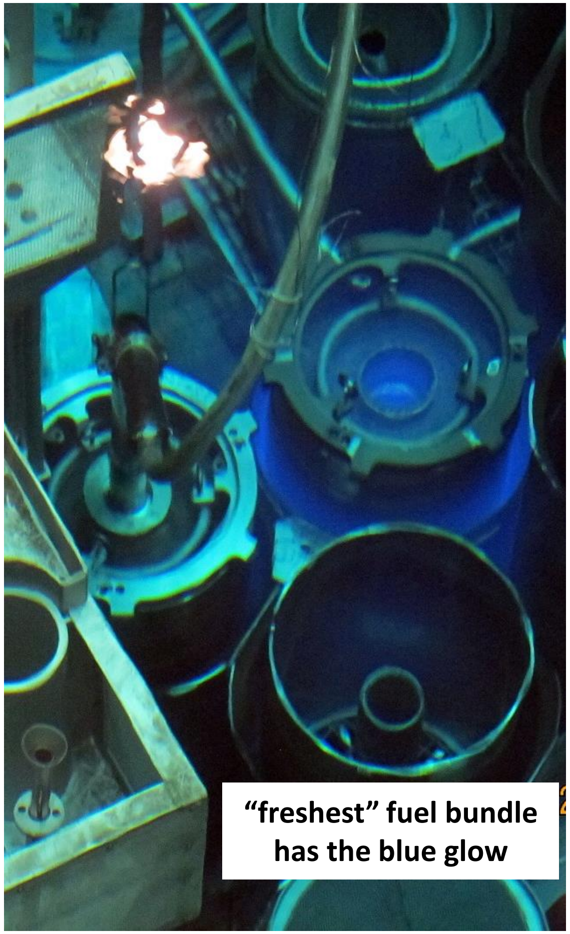


Loading Assembly into Pool within Spent Fuel Bundle

lowering package into place



several spent fuel bundles in the pool



"freshest" fuel bundle has the blue glow

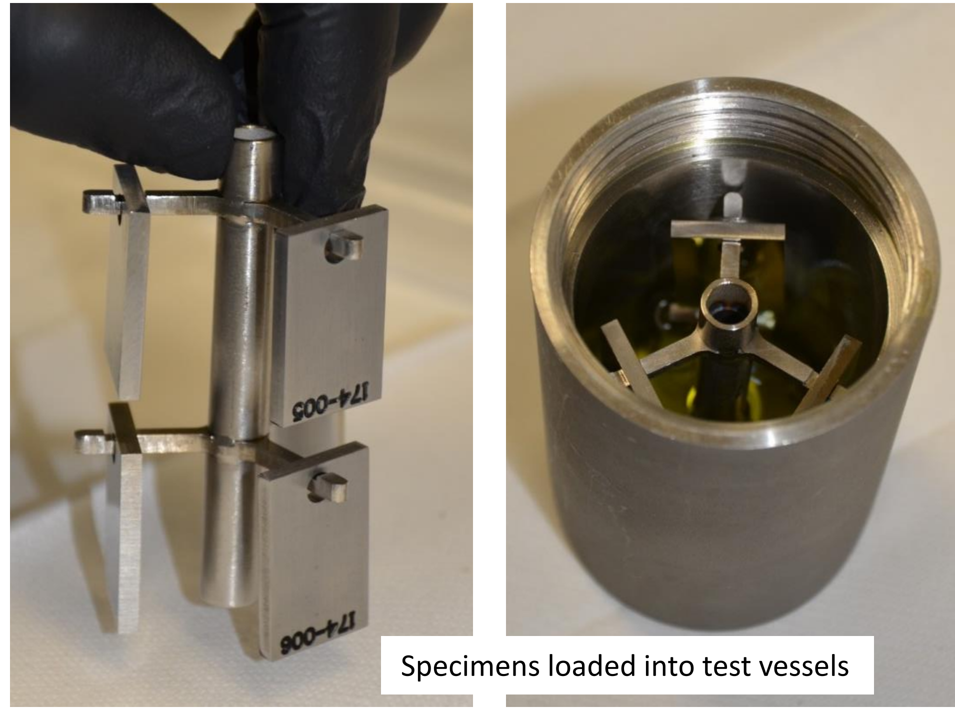
Initial Test Details

- Top tier of specimens exposed in vapor, bottom tier immersed

- Solution was 140 g dU/L + 0.1 M H_2SO_4 (pH ≈ 0.5)

- Two vessels exposed, straddling the expected peak position for gamma irradiation intensity

- One vessel contained 316L, 2304, and 17-4 PH; the other contained 316L, Zr-4, and Zr-2.5Nb



Specimens loaded into test vessels

- One week exposure, average solution temperature ~ 70˚C at a high dose (consistent with several months of SHINE process exposure)

Initial Test Results

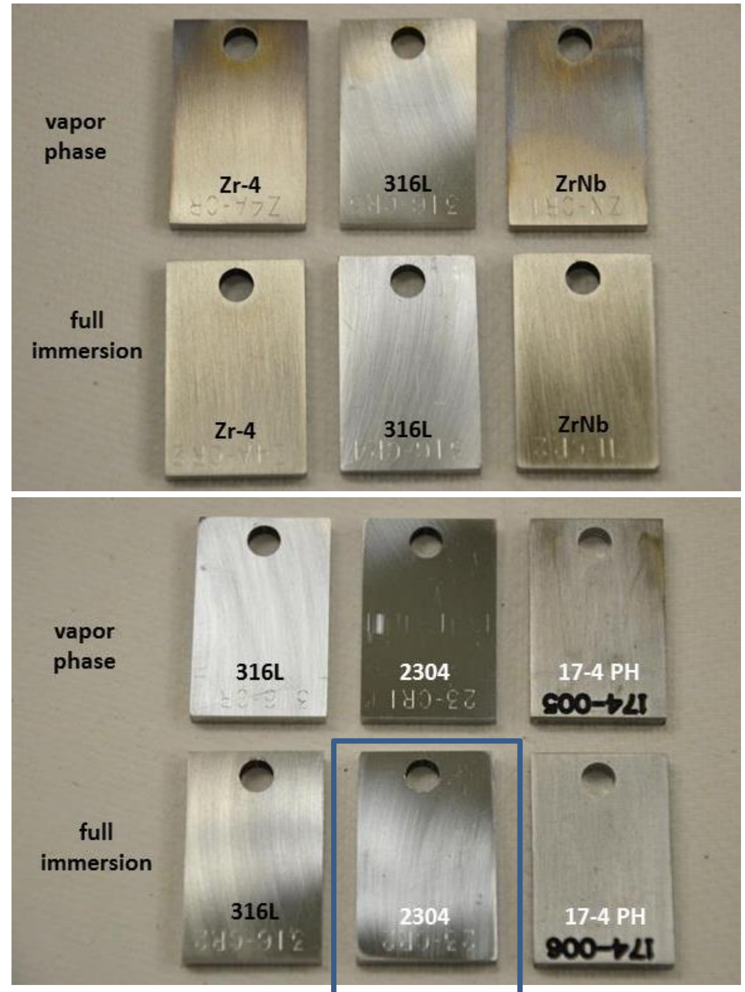
- All specimen surfaces free of changes in surface roughness

- Identical to other exposures, Zr alloys exhibit light golden brown film; 316L and 2304 unchanged; 17-4 PH has dull luster

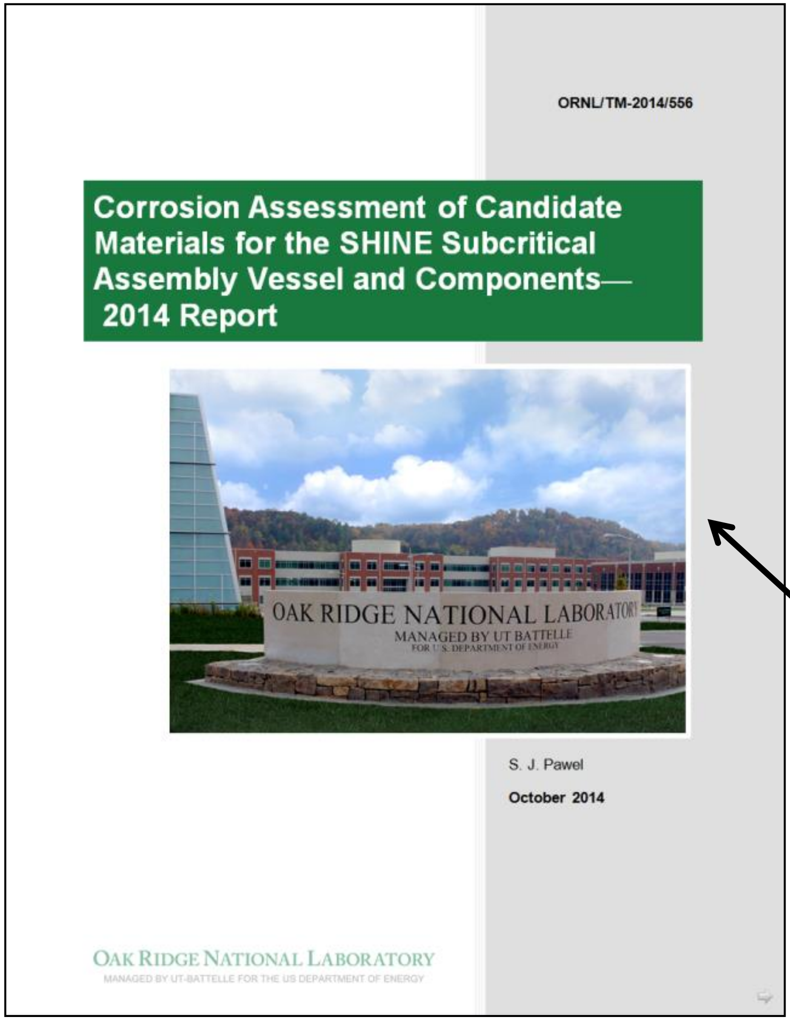
- Corrosion rates based on weight change suggest slight increase for most alloys

corrosion rates in mil/y

	no radiolysis	potential radiolysis
--- immersion position ---		
316L	< 0.05	0.21-0.27
2304	< 0.05	0.37
17-4 PH	--------	0.07
Zr-4	< 0.05	0.14
Zr-Nb	< 0.05	0.22
--- vapor position ---		
316L	< 0.05	0.11-0.20
2304	---------	0.17
17-4 PH	---------	0.09
Zr-4	< 0.05	0.17
Zr-Nb	< 0.05	0.09



Simplified Results


ORNL/TM-2014/556

Corrosion Assessment of Candidate Materials for the SHINE Subcritical Assembly Vessel and Components—2014 Report

S. J. Pawel

October 2014

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

In prototypic conditions as well as some "off-normal" environments, all candidate alloys exhibit remarkable passivity

- **corrosion rates < 0.1 mil/y** (with only modest exception)
- **no cracking**
- **not sensitive to velocity**
- **not sensitive to localized corrosion**
- **radiolysis may very slightly increase corrosion**

More story here

Similar report will be generated for FY15