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Continued investigation into the behavior of breached TPBARs during reactor operation

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PNNL

38th Tritium Focus Group Meeting

U.S. DEPARTMENT OF ENERGY

Past Work

- Primary Concerns
  - Transfer of tritium from the TPBAR to the RCS could present problems for release schedule and worker dose control throughout the reactor facility.
  - Loss of lithium could cause local neutronics and subsequently thermal abnormalities of concern.
- Experimental Results
  - Argonne Carius tube experiments (Graczyk 1998)
  - PNNL pressure vessel tests (Baldwin 2002)
- Modeling
  - Various calculations involving a range of different tritium and lithium release scenarios
  - Parametric Studies

Current Expanded Focus

- What mechanisms exist upon the formation of a micro-scale breach that might lead to physical damage that could compromise the handling of a TPBAR? How do we determine these mechanisms?
  - Could the reaction of RCS fluid with TPBAR components lead to dimensional changes that cause bulk changes in TPBAR shape?
  - Could changes in pH and chemical composition of liquid within the breached TPBAR lead to corrosive attack on TPBAR components?
  - These mechanisms are determined with leaching tests
- What are the actual conditions within a breached TPBAR after a breach formation? How do we determine these conditions?
  - Will the TPBAR be filled with liquid or will some pellets be in contact with vapor?
  - These conditions will be determined with modeling efforts.

Past Work Conclusions and Current Usage

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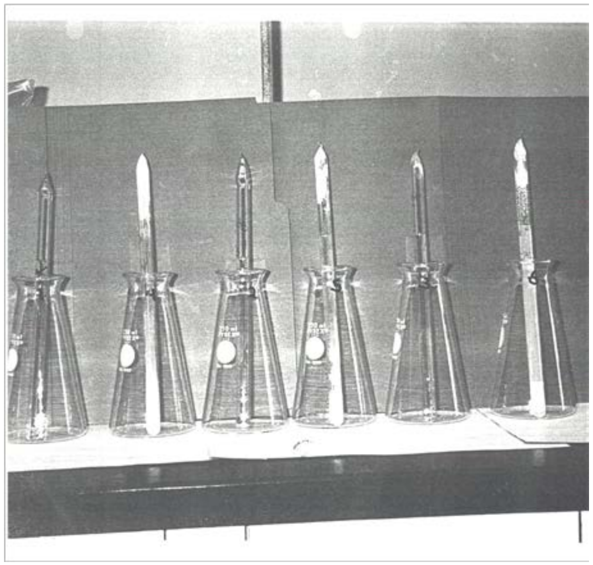
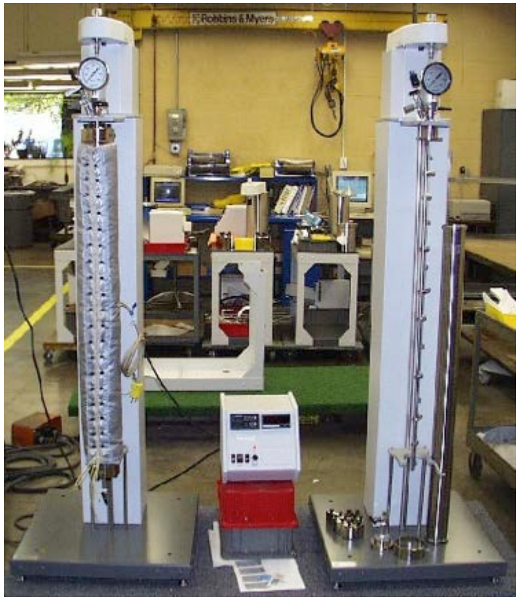
Grazcyk



- 1% of Li leached in pure water
- Up to 4.5 % in borated water
- No change if pH adjusted

Baldwin



Time, days	Apparent Li Leaching, %	Apparent Al Leaching, %	pH Values
0	0	0	6.18
0.17	113	51	7.18
0.33	216	89	7.14
1	346	136	7.49
2	389	153	7.96
5	111	38	6.29
8	14	6	5.88
14	2	1	5.36

PNNL FY17 Scoping Tests

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2 scoping tests were performed with DI water with unirradiated pellets at 320° C in a stainless steel vessel. The test durations were 24 hours (first) and 4 hours (second)

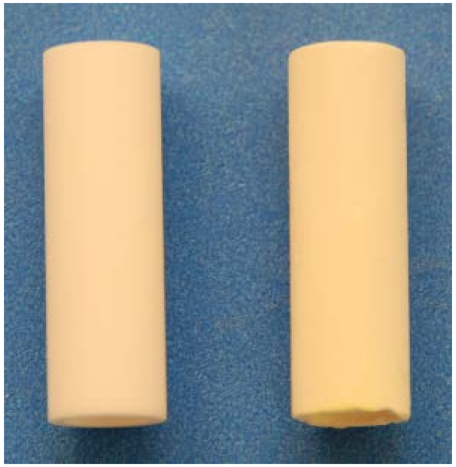
Parameter	4 hours	24 hours
Pellet weight	-33%	-49%
Pellet OD	-2%	-2%
Pellet ID	+1%	+3%
Pellet Length	-0.2%	-2%
Solution Mass	-0.6%	-0.4%
Solution pH	7 -> 12.4	7 -> 12.5

Post test observations

Caustic attack leads to leaching of chrome from stainless steel

Pellet holder used during leaching scoping studies with pellet leached for 24 hours

Particulate deposition visible on vessel dip tubes



Fresh pellet (left) and pellet leached for 24 hours (right)

Post test examinations

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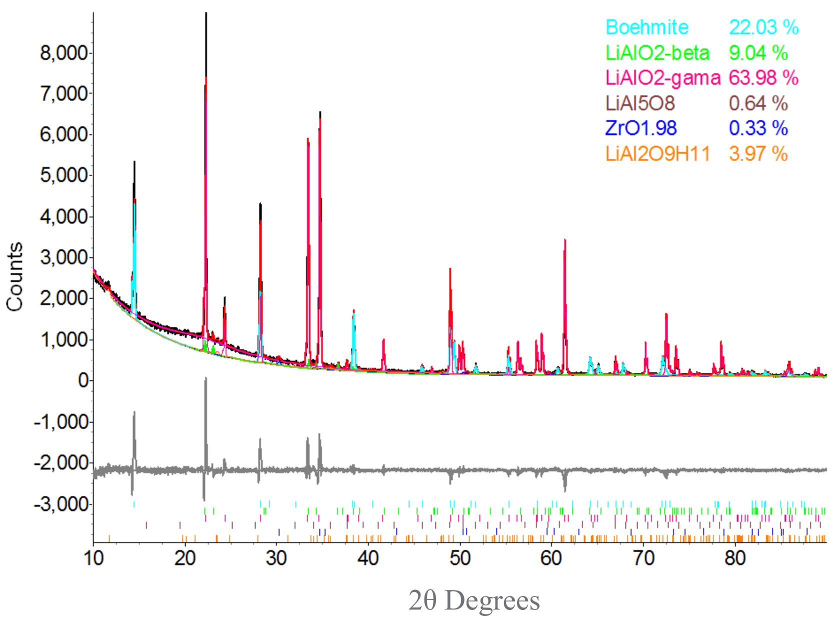
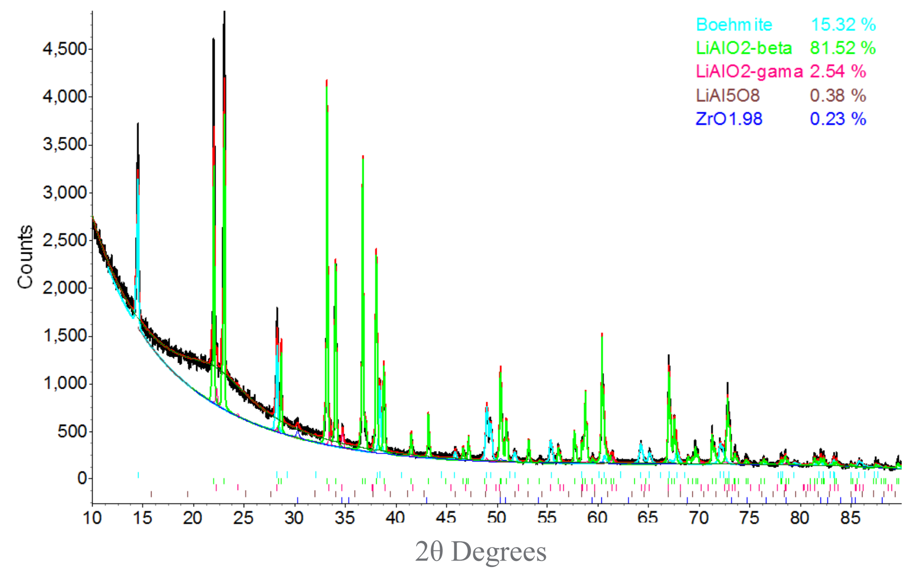
4 hr



Spec	Original	Liquid	Solids	Calc. Pellet
Al	524864	11101	66272	89539
Li	130504	34348	9056	18639
Cr	---------	620	96	---------

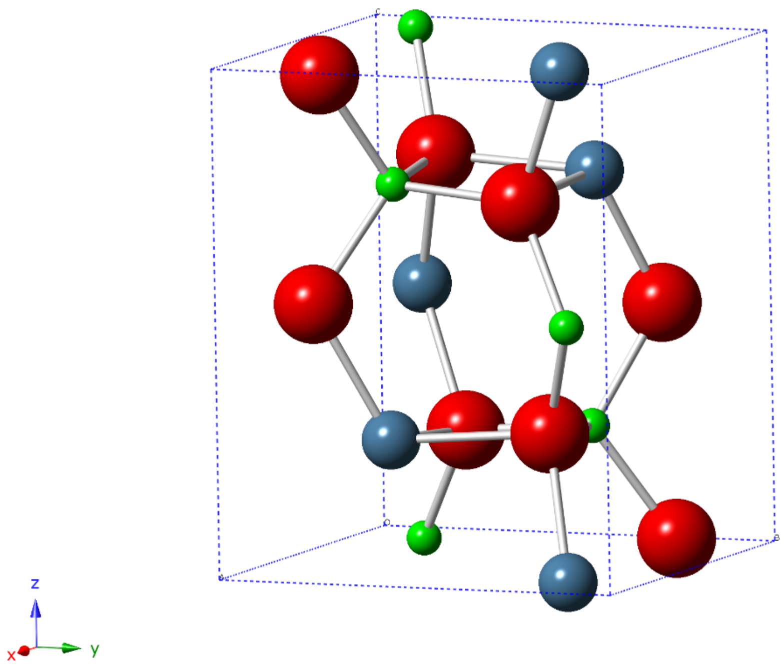
24 hr



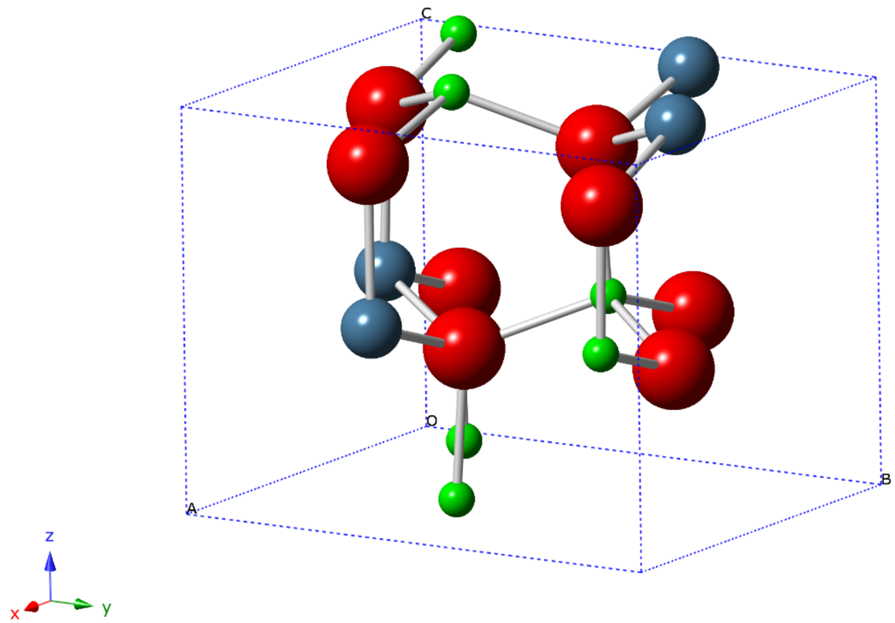
Spec	Original	Liquid	Solids	Pellet
Al	528421	11648	18984	171953
Li	131388	45166	2635	37444
Cr	---------	2578	113	---------

$LiAlO_2$ Crystal Structures (γ & β Phases)

Red = Oxygen, Blue = Lithium, Green = Aluminum



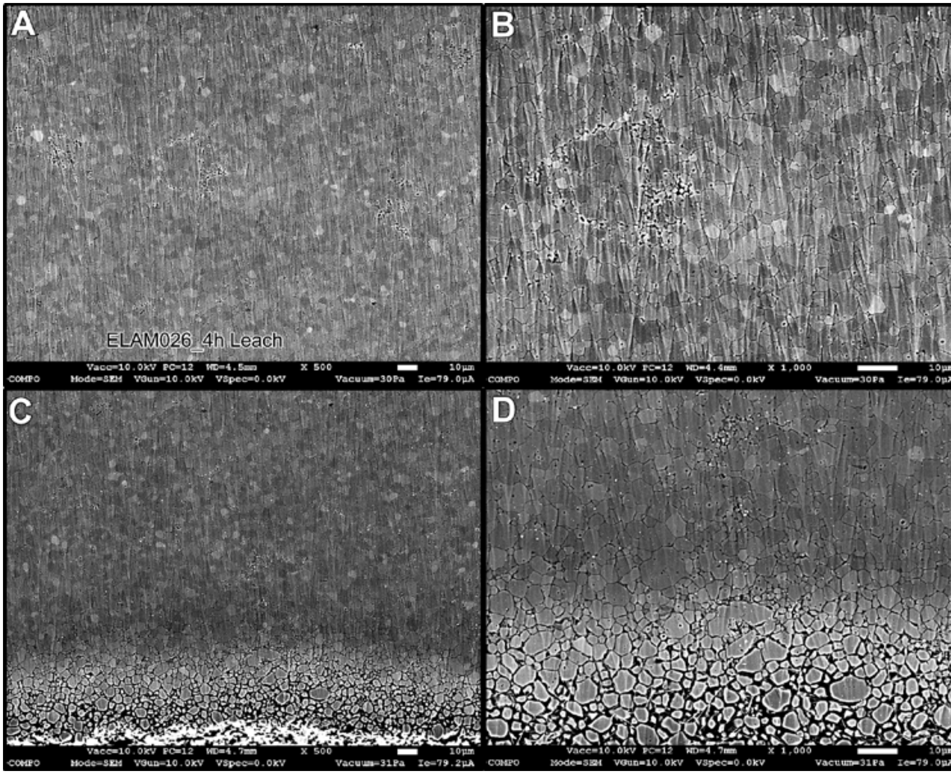
γ $LiAlO_2$

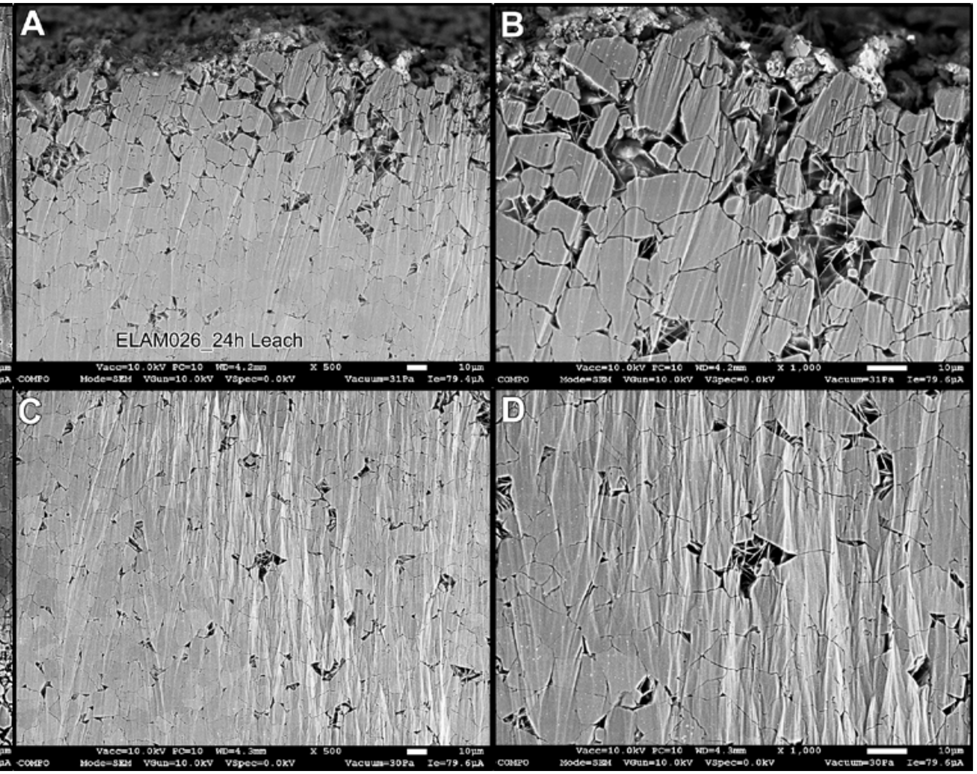


β $LiAlO_2$

Major re-orientation required to change phases.

SEM Images of Leached Pellets

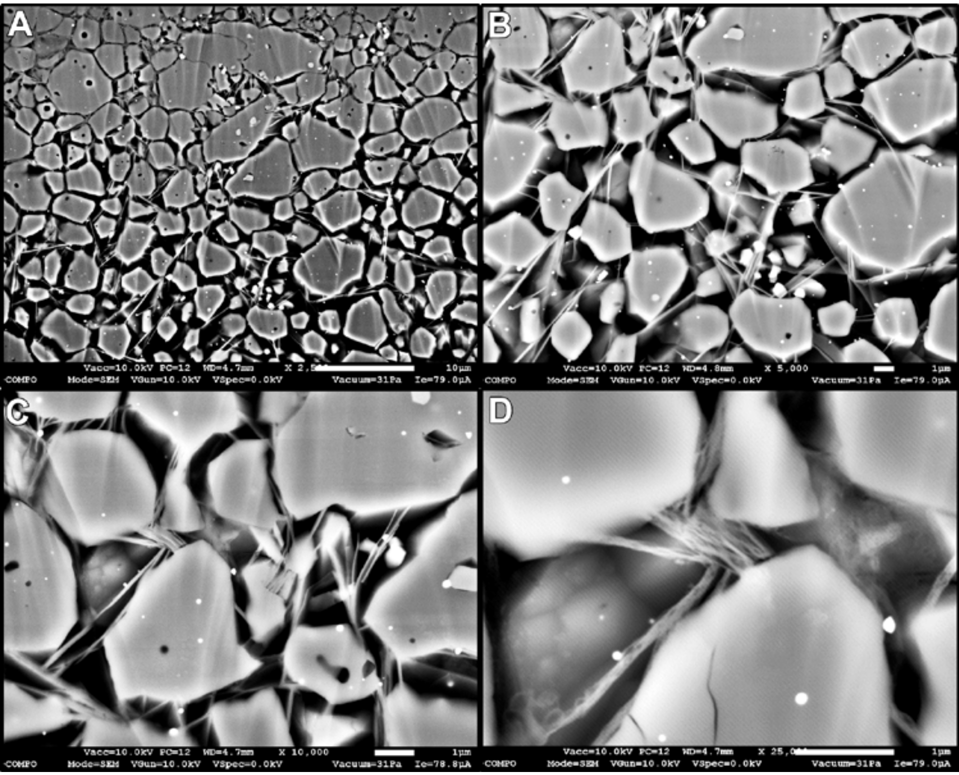


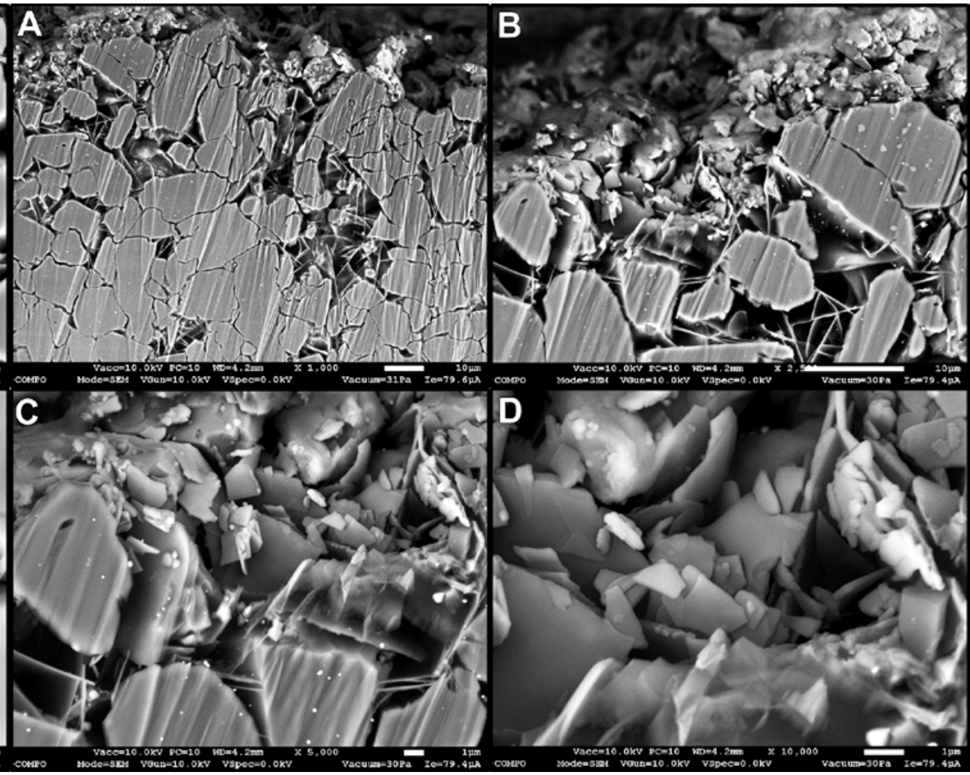


- Pellet leached for 4 hours
- A & B are from "Center" of pellet residue
- C & D are from the pellet inside diameter
- Structural degradation is observed at the pellet edge

- Pellet leached for 24 hours
- C & D are from "Center" of pellet residue
- A & B are from the pellet outside diameter
- Pellet degradation has progressed further at the edges and some degradation is seen in the pellet interior

Higher Magnification SEM Images of Leached Pellets





- Pellet leached for 4 hours
- Successively higher magnification images on the inner diameter
- Potentially grains of LiAl5O8 visible along with different structural phases.
- High porosity observed

- Pellet leached for 24 hours
- Successively higher magnification images on the outer diameter
- Further physical evidence of degradation but different physical phases still visible.
- Lines are curtaining artifacts

Pellet Leached for 4 Hours

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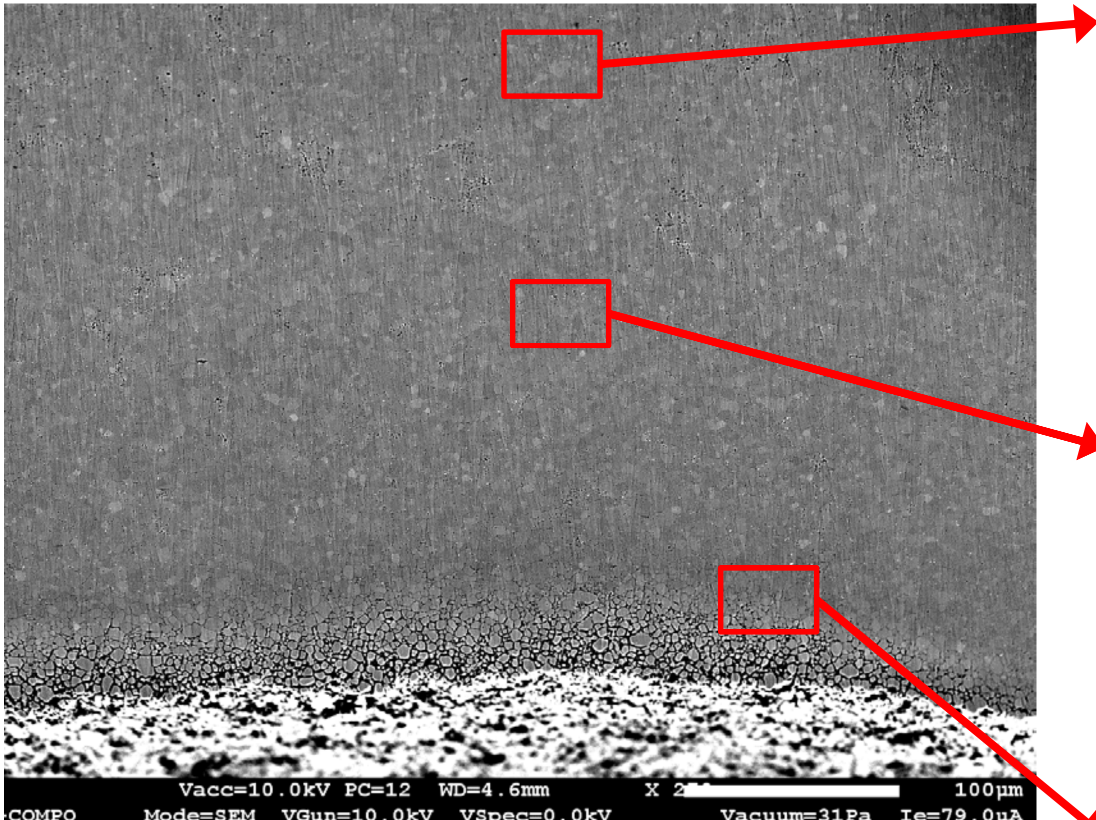
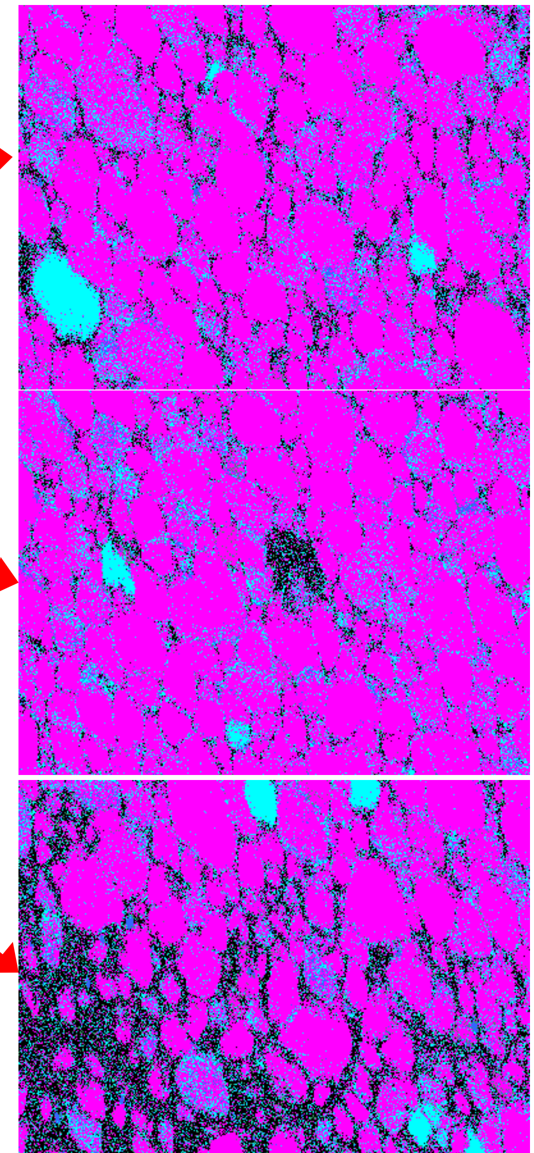
BSE (250x)

(magenta)	γ $LiAlO_2$
(cyan)	β $LiAlO_2$

EBSD





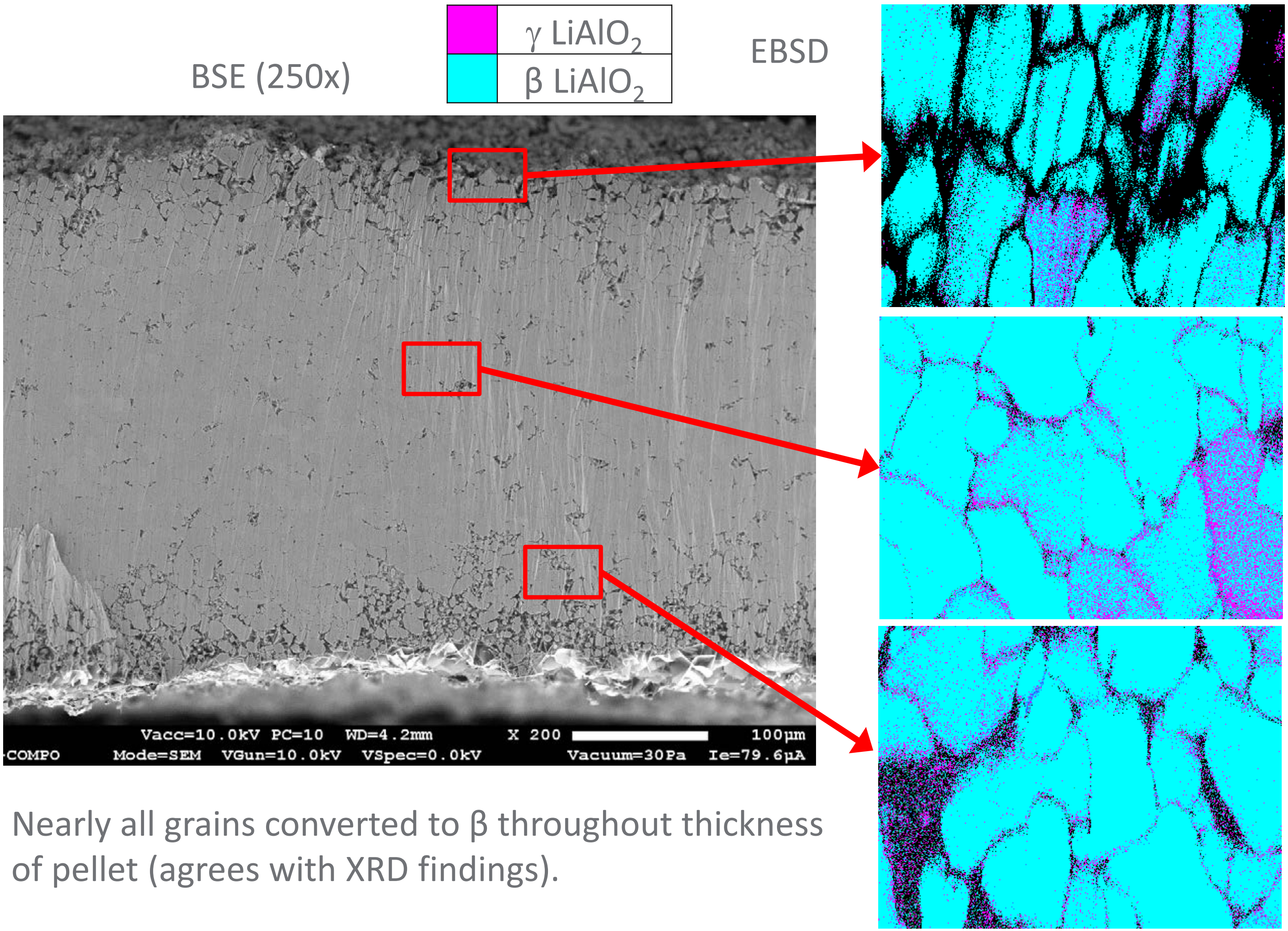
OD
(2500x)

Middle
(2500x)

ID
(2500x)

Individual random grains converted to β throughout thickness of pellet.

Pellet Leached for 24 Hours



OD (2500x)

Middle (2500x)

ID (2500x)

Nearly all grains converted to β throughout thickness of pellet (agrees with XRD findings).

Modeling Approach – Address Phenomenology with Greater Scrutiny

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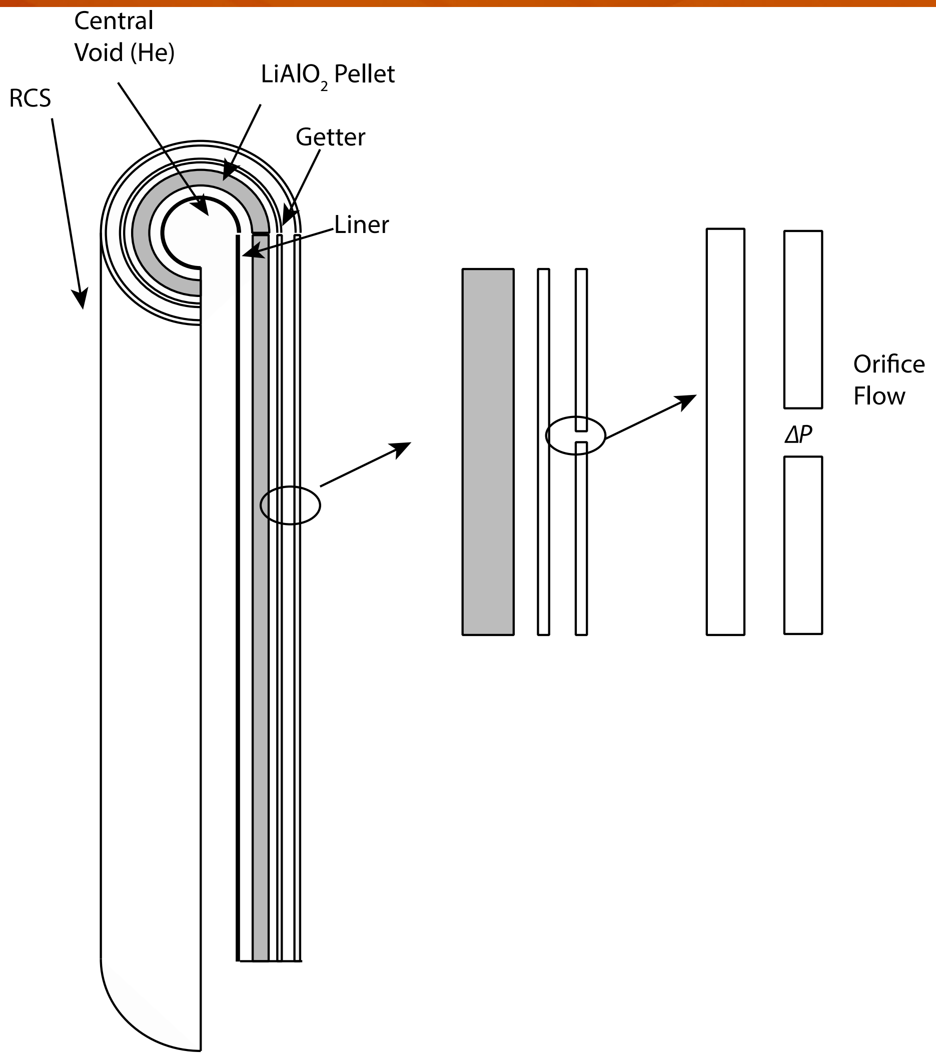

- Based on the thin wall of the cladding, the flow through the breach will be jet or orifice flow.
- Will a jet drill into the getter?
- Depending on the internal pressure at time of breach formation, does the RCS fluid enter as steam or water?
- If steam, the dissolved Li and B will crash out.
- What reactions will the steam or water have with the getter and cladding?
- Will the transient system result ultimately in a water, steam, or water/steam system?
- What will contact the pellets? Pure water, Borated/LiOH water, or steam?
- What is the result of reactions with the pellet?
- What stresses, strains, corrosion are all TPBAR components ultimately exposed to?
- What are ultimately the major concerns within a TPBAR following a pinhole breach?
- What are the breach parameters of greatest concern?

Guidance from previous work

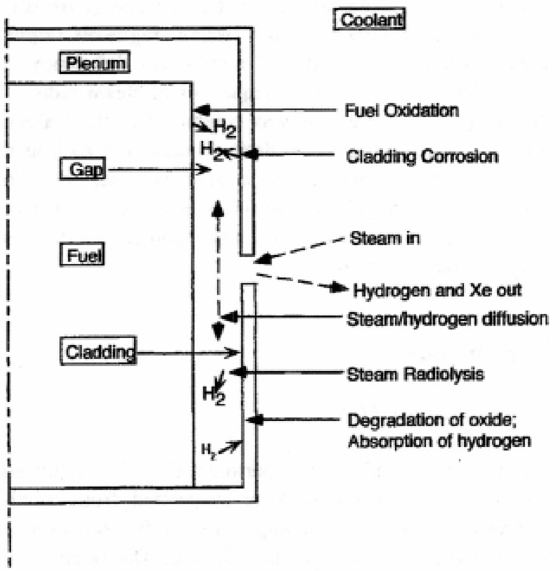

Fig. 1. Sources of hydrogen in a defective fuel rod.

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Chemical processes in defective LWR fuel rods

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- Due to gamma heating, internal TPBAR components are hotter than RCS…though not as hot as internal fuel rod components.
- The materials within the TPBAR are not the same as materials within the fuel rod and different reactions will result.
- For the majority of the irradiation time, the internal TPBAR pressure will be less than RCS pressure.
- ΔP will be a function of irradiation time.

Conclusions and future work

- Model Development
  - Determine the transient and steady-state conditions within the TPBAR for various breach geometries and times of formation.
  - Determine the form of the water when it comes into contact with pellets after post-breach formation ingress.
- Experimental Studies
  - Further determine the true kinetics and final product from the reaction of DI water with unirradiated lithium aluminate at reactor operating temperatures.
  - Determine potential for impacts of post-leach caustic attack on the TPBAR cladding
  - Determine effects of other RCS components on deviations from results from experiments with DI water.
  - Determine the effects of replacing liquid water with steam.
  - Determine effects of geometry and liquid limitations within the TPBAR.