Current Status of Tritium Release Data from the TMIST-3A Irradiation Experiment

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Overview

- TMIST-3 Experiment
  - Motivation and Objectives
- TMIST-3 Design Overview
  - Sample Pellets
  - Capsule
  - Test Train
  - Irradiation Environment
- Current Status
  - Tritium Release Data through Cycle 163A
  - Initial observations of temperature dependence from PALM cycles
- Summary of Preliminary Observations
- Future Work
  - Post Irradiation Examination (PIE)
TMIST-3 Experiment

- **TMIST**
  - TPBAR Materials Irradiation Separate Effects Test (TMIST)
  - Enhance predictive modeling capability for Tritium Producing Burnable Absorber Rods (TPBARs)

- **TMIST-3 Pellet Irradiation Experiment:**
  - Reveal tritium release kinetics as a function of burnup and burnup rate
  - Evaluate tritium speciation as a function of burnup, burnup rate, and time (T₂O versus T₂)
  - Improve fundamental understanding of pellet microstructure and its effects on performance

- **TMIST-3 consists of two test trains**
  - -3A is the short term test train (currently under irradiation)
  - -3B is the long term train (to begin irradiation in 2019)
Pellet Design

Test specimens
- Annular, LiAlO$_2$ pellets
  - 1.27 cm long, 0.77 cm outer diameter, 0.10 cm wall thickness

Standard
- 2 µm grain size
- 98% TD

Large Grain
- 10 µm grain size
- 98% TD

Large Pore
- ~0.7 µm grain size
- ~85% TD

Small Pore
- ~0.5 µm grain size
- ~90% TD
Pellet Design

- Cermet pellets
  - LiAlO$_2$ particles in Zr matrix
  - Four ceramic particle loadings from 10-40 v/o

Cermet pellet with 40 v/o LiAlO$_2$
Capsule Design

- **Flow-through capsules**
  - Tritium released from pellets is carried to ex-reactor measurement system for analysis
  - Total tritium measurement only

- **Closed capsules**
  - Used for speciation measurements and pellet integrity/retention tests
  - Tritium released from pellets as $T_2$ and $T_2O$ is spatially segregated and gettered in-situ
  - Speciation data inferred from post-irradiation examination tritium assays
Test Train Design

- Adapter
- Horizontal Section
- Flex Hose
- Upper Vertical Tube
- Handling Ring (6X)
- Coil Tube
- Core Tube
- Bottom End Cap
Test Train Design

Numbers in Parentheses are the Pellet Sample Part Numbers on the Design Drawings and Correspond to the Test Plan Sample Numbers

Lead Out He Gas

TMIST-3A SHORT TERM I-13

FLANGE (56 Tot Lines)

LEAD OUT

TOP of CORE (57 Tot Lines)

13 CLOSED CAPSULES

9 FLOW CAPSULES

22 Temp Control Gas Lines (11 Mass Flow Controls)

18 Sweep Gas Lines (9 Mass Flow Controls)

16 Thermocouples

Top & Bottom Banking
Center Banking
Temp Control Return Header

Note: Crossed Lines are Not Junctions

Lead Out He Gas
## Irradiation Position and Conditions

<table>
<thead>
<tr>
<th>ATR Position</th>
<th>Diameter (cm)</th>
<th>Thermal Flux (n/cm²-s)</th>
<th>Fast Flux (E&gt;1MeV) (n/cm²-s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium I-Hole</td>
<td>8.89</td>
<td>$3.4 \times 10^{13}$</td>
<td>$1.3 \times 10^{12}$</td>
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<tr>
<td>WBN-1</td>
<td>NA</td>
<td>$5.4 \times 10^{13}$</td>
<td>$2.1 \times 10^{14}$</td>
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</tbody>
</table>
Awaiting completion of Cycle 164B (final cycle)
- Anticipate late-November 2018

Completed 5 normal operating cycles and 2 high-powered PALM cycles

Data collected from flow-through capsules from most recent cycle (164A) is currently being evaluated
- Previously presented data thru Cycle 162A
- New data presented here includes Cycles 162B and 163A (PALM)
Ion chamber results scaled to liquid scintillation data from bubbler collections

Observed tritium in sweep gas during first startup
Ion chamber results scaled to liquid scintillation data from bubbler collections

Observed tritium in sweep gas during first startup

Scaled Ion Chamber Response

161A

160B
66 EFPD

160A
46 EFPD

SCRAM

162A
65 EFPD

162B
65 EFPD

163A
5 EFPD

Solid Lines = 140 GVR
Dashed Lines = 70 GVR
- Enhanced release observed in high burnup and porous pellets
- Production calculations based on as-run power histories needed to account for variation in $^6\text{Li}$ burnup
- Significant variation in temperatures observed during PALM
Enhanced release observed in high burnup and porous pellets

Production calculations based on as-run power histories needed to account for variation in $^6\text{Li}$ burnup

Significant variation in temperatures observed during PALM
PALM Cycle temperatures ranged from 589 and 793°F (310-423°C)
- 636°F (336°C) is the nominal setpoint during regular cycles
- Nominal rate data suggest stronger temperature dependence than assumed
  - 95 kJ/mol consistent with $^3$H diffusion in LiAlO$_2$ (80-130 kJ/mol)
Palm Cycle temperatures ranged from 647 and 899°F (310-423°C)
- 636°F (336°C) is the nominal setpoint during regular cycles

Nominal rate data suggest stronger temperature dependence than assumed
- 104 kJ/mol consistent with $^3$H diffusion in LiAlO$_2$ (80-130 kJ/mol)
TMIST-3A: PALM Cycle Rate Data – Both PALM Cycles 161A and 163A

- PALM Cycle temperatures ranged from 589 and 899°F (310-423°C)
  - 636°F (336°C) is the nominal setpoint during regular cycles
- Nominal rate data suggest stronger temperature dependence than assumed
  - 103 kJ/mol consistent with $^3$H diffusion in LiAlO$_2$ (80-130 kJ/mol)
Summary and Preliminary Conclusions

- Overall test train performance is successful
  - Reactor physics were satisfactorily captured and used to inform a robust mechanical design with desired thermal performance
  - Capsule temperature control compensated for varying lobe powers
  - Survived both high-power PALM cycles

- Flow-through capsule data provides insight on tritium release from pellets
  - Tritium entered gas phase upon reactor startup during Cycle 160A
    - No significant delay or incubation period observed
  - Enhanced tritium release observed at higher burnup rates (140 GVR > 70 GVR) and in porous pellets
    - As-run production calculations needed to assess release as a function of $^6$Li burnup
    - Data suggest that larger grain (> 10micron) pellets may offer enhanced tritium retention relative to the nominal grain size (~2 micron)
  - Rate data from PALM cycles indicate temperature dependence is similar to literature values for $^3$H diffusion in LiAlO$_2$
Future Work

➤ TMIST-3A PIE

- Test train shipment currently scheduled for July 2019
- Primary goals include:
  - Speciation data from closed capsules
  - Microstructural evolution of pellets in open capsules