Highlights and Recent Changes to Fuel PIE Activities at CNL

Visual Examination and Fuel Chemical Burnup

October 5, 2016
Outline

• Visual Examination System (Stereomicroscope)
  • Old camera system
  • Stereomicroscope development
  • CMOS camera testing

• Chemical Burnup Measurements Study
  • La as a standard
  • Other techniques investigated
  • Comparison between La and TIMS
Visual Examinations at Chalk River

Background

• Set-up for PHWR fuel (~0.5 m Fuel Pins or Bundles)

• Non-destructive
  • Through cell window
  • Digital periscope
  • In-cell Video Cameras
  • Stereomicroscope

• Destructive
  • Low Mag “macroscope”
  • High Mag microscope: metallography/ceramography
Visual Examinations at Chalk River

Old Stereomicroscope Camera System (before 2011)

- Ported optical system
- Attached digital camera to eyepiece
- Quartz glass was ageing (browning)
- Rulers in-cell for dimensioning
- Separate fuel pin rotating movement stage
Stereomicroscope Upgrades

Stereomicroscope Replacement 2011-2014

- New digital XY stage (√)
- Rad tolerant tube cameras (√)
  - Greyscale (x)
  - Low resolution (x)
- Digitally operated microscope system (√)
- Unit mounted in cell but removable for maintenance (√)
Stereomicroscope Upgrades

Stereomicroscope Replacement 2011-2014

- Halogen to LED lighting
  - Significant reduction in heat generation
  - Using 4 LED banks to control intensity

- Multiple magnification levels (8.4x to 37.7x)

- Digitally operated microscope system (√)

- Unit mounted in cell but removable for maintenance (√)
Stereomicroscope Upgrades
Stereomicroscope Upgrades 2014-2016

• Upgraded electronics

• Upgraded interface

• Switch to 10 megapixel CMOS cameras (√)
  • From greyscale to full color (√)
  • High resolution (√)

• Removal of stereo-capability
Stereomicroscope Upgrades

Stereomicroscope Upgrades 2014-2016

• Why CMOS
  • Higher resolution and color
  • Estimate life of a non-rad tolerant camera under actual conditions

• CCD
  • ~3X longer life than CMOS when tested
  • Inferior image quality

• Hybrid CID cameras
  • Picture quality not comparable with CMOS or CCD
Stereomicroscope Upgrades

Stereomicroscope Upgrades 2014-2016

• Camera Testing
  • CMOS cameras
  • No shielding
  • Fuel inspections from 2014 August to 2016 February
  • CANDU fuel pins (5+ months cooling time)
  • Left in the hot cell

• 2016 February
  • Both cameras failed
  • Recently discharged research reactor driver fuel
Stereomicroscope Upgrades

Camera Upgrades

Pre 2011 Camera Outside of Hot Cell

2011 to 2016 Tube Camera
Stereomicroscope Upgrades

Camera Upgrades

2014 to 2016 CMOS

2/3 Full Resolution
Stereomicroscope Upgrades

Stereomicroscope Upgrades 2016

- Disposable camera approach
  - Quick release sockets
  - Multiple camera type compatibility

- USB 3 camera compatibility

- Refining optimal camera specifications
  - CCD/CMOS/CID
  - 7-20 megapixels
Burnup Evaluation

Why?

- Focus on advanced fuel cycles
  - (MOX and Thorium based fuels)

- Criteria
  - Precision
  - Cost
  - Timeliness
  - Associated dose

- Review recent burnup campaigns
Burnup Evaluation

Methods

• La-139 (HPLC)
  • Standard for Chemical Burnup at Chalk River to 2015

• Uranium and Plutonium Isotopic (TIMS)
  • Used less frequently than La
  • Multiple isotopic ratios to improve precision

• Gamma Spectroscopy
  • Qualitative only
Burnup Evaluation

Nd-148

- Not used at CNL
- More complex than HPLC La (Nd must separate isotopes)
- Requirement for dedicated facilities and special fume hoods
- More expensive
- Higher associated doses
Burnup Evaluation
Comparison between HPLC La and TIMS Isotopics

- Recent experimental burnup measurements
- Compared with code calculated results
- Assess precision
- Reviewed sample preparation methods
Burnup Evaluation - SEU and MOX
Experiments Used for the Study

• Simulated CANDU conditions using experimental loops

• SEU
  • \(\sim 1.4 \text{ wt}\%\); Varied pellet geometry
  • \(\sim 2.3 \text{ wt}\%\); 42-element bundle testing

• MOX
  • \(\sim 3 \text{ wt}\%\) Pu in DU; Pu destruction proof of concept
  • \(\sim 5 \text{ wt}\%\) Pu in DU; Pu destruction/fabrication processes
  • \(\sim 1 \text{ wt}\%\) Pu in DU; Pu homogeneity in the microstructure
  • \(\sim 0.9 \text{ wt}\%\) Pu in NU; Direct Use of PWR fuel in CANDU (DUPIC)
Burnup Evaluation - SEU

Comparison between HPLC La and TIMS Isotopics

- SEU up to 30 MWd/kgHE
- Less scatter in Isotopics
Burnup Evaluation - MOX

Comparison between HPLC La and TIMS Isotopics

- MOX up to 23 MWd/kgHE
- Less Scatter in Isotopics
Burnup Evaluation - Thoria

Experiments Used for the Study

- Thoria up to 50 MWd/kgHE

- Smaller sample size (difficult to make definitive conclusions)

- Thoria
  - $\sim 1.8$ wt% Pu in $(\text{Th}, \text{Pu})\text{O}_2$; Extended burnup testing of Thoria
  - $\text{ThO}_2$ and 1 to 1.5 wt% $^{235}\text{U}$ in $(\text{Th}, \text{U})\text{O}_2$; Thoria fuel cycles
Burnup Evaluation - Thoria
Comparison between HPLC La and TIMS Isotopics

- Less scatter observed in isotopic measurements
- No clear trend observed compared to code predictions
# Burnup Evaluation

## Other Considerations

<table>
<thead>
<tr>
<th>Consideration</th>
<th>HPLC La</th>
<th>TIMS Isotopic U and Pu</th>
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<tbody>
<tr>
<td>Hot Cell Measurement</td>
<td>Requires precise weight of sample (Absolute)</td>
<td>Does not require precise weight of sample (Relative)</td>
</tr>
<tr>
<td>Initial Content</td>
<td>N/A</td>
<td>U and Pu initial content must be known</td>
</tr>
<tr>
<td>Cost</td>
<td>Cost effective</td>
<td>More expensive 2-4 times as much as HPLC La</td>
</tr>
<tr>
<td>Time</td>
<td>Quickest method</td>
<td>Slightly longer for few samples; significantly longer with many samples*</td>
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<tr>
<td>Dose Consequence</td>
<td>Generally less dose; highly automated process</td>
<td>More dilute samples, but much more labour intensive</td>
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*Processing time for large number of samples can be reduced by adding more equipment*
Burnup Evaluation

Overall Results

• Precision of isotopics preferred for experimental programs
• La based measurements for more economical analysis

• NU and SEU fuels
  • U Isotopics preferred

• MOX fuels
  • U and Pu isotopics preferred

• Thoria fuels
  • HPLC La, U and Pu isotopics (more data required)
Conclusions

• Stereomicroscope Upgrades
  • Digitally operated microscope system
  • Successful testing with CMOS cameras
  • A quick mount for on-the-job camera replacement

• Burnups Evaluation
  • TIMS Isotopic measurements (U and Pu) preferred
  • La used for quicker and more cost effective measurements