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

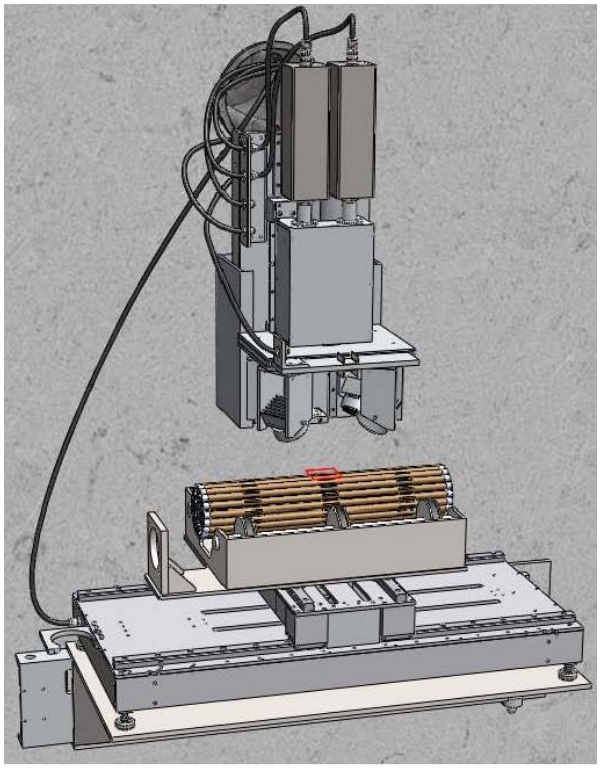
Visual Examinations at Chalk River

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

Stereomicrosocope Upgrades

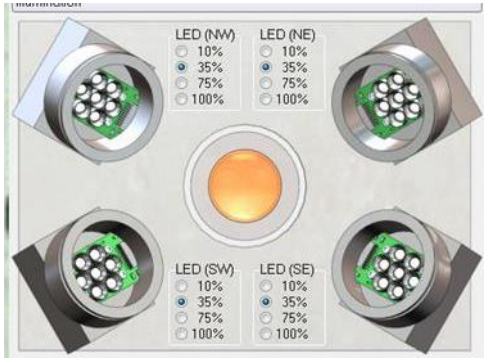
Stereomicroscope Replacement 2011-2014



- 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 **(√)**

Stereomicrosocope 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 **(√)**

Stereomicrosocope 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

Stereomicrosocope 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

Stereomicrosocope Upgrades

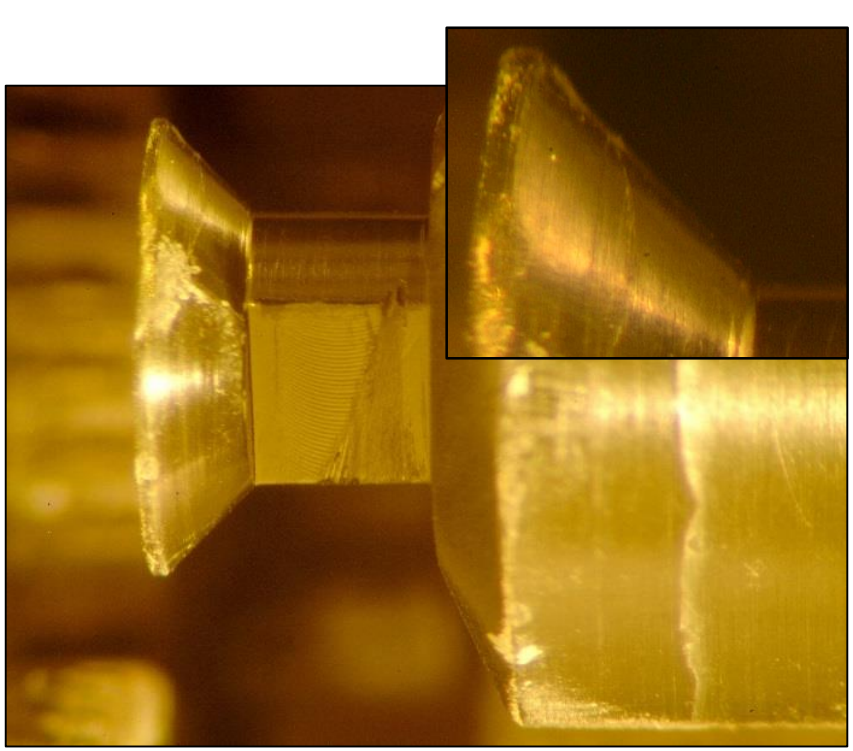
Stereomicroscope Upgrades 2014-2016

- 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

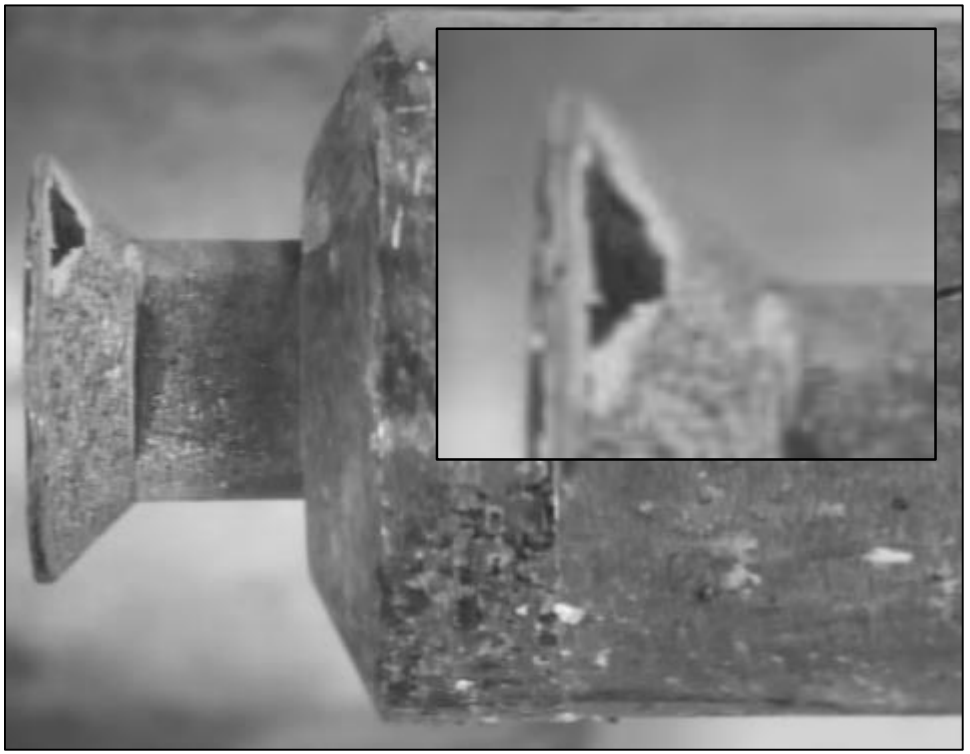
- 2016 February
  - Both cameras failed
  - Recently discharged research reactor driver fuel

Stereomicrosocope Upgrades

Camera Upgrades



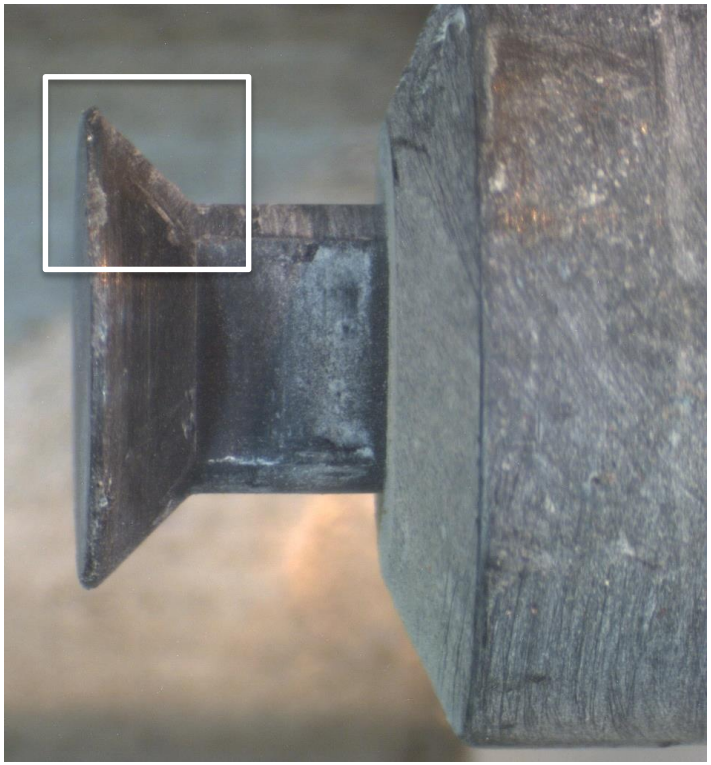
Pre 2011 Camera Outside of Hot Cell



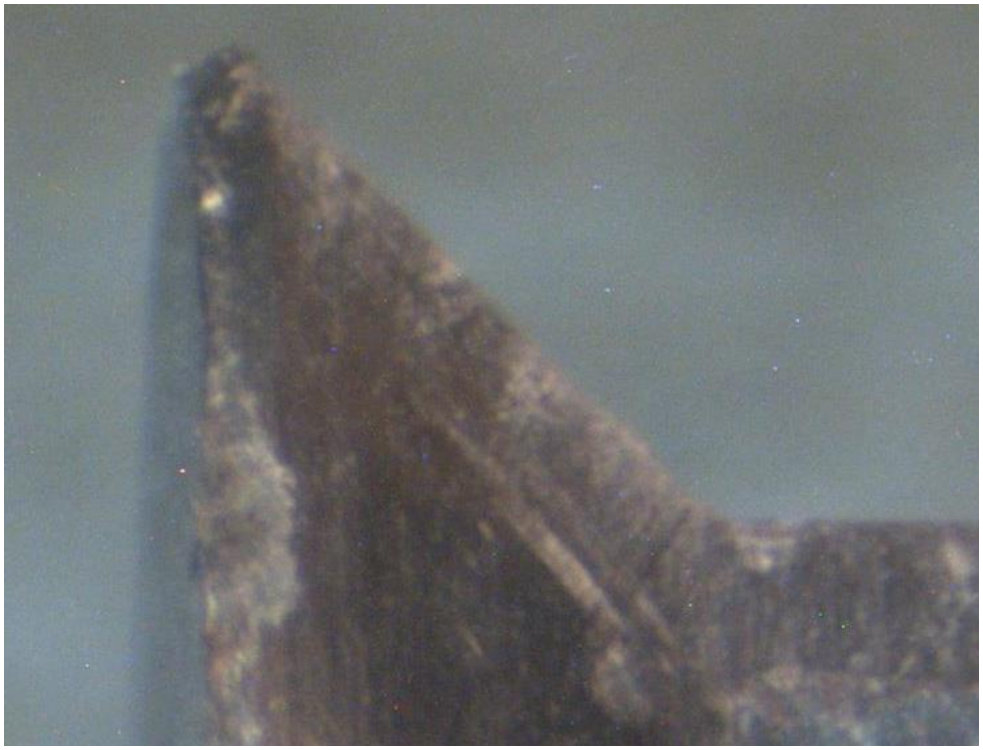
2011 to 2016 Tube Camera

Stereomicrosocope Upgrades

Camera Upgrades



2014 to 2016 CMOS

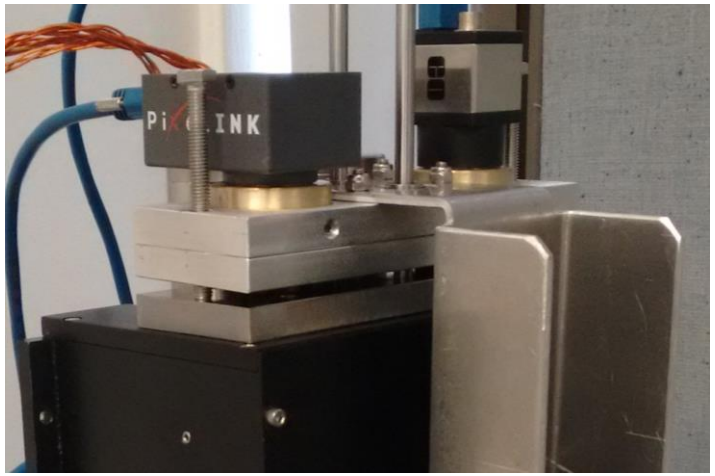


2/3 Full Resolution

Stereomicrosocope Upgrades

Stereomicroscope Upgrades 2016

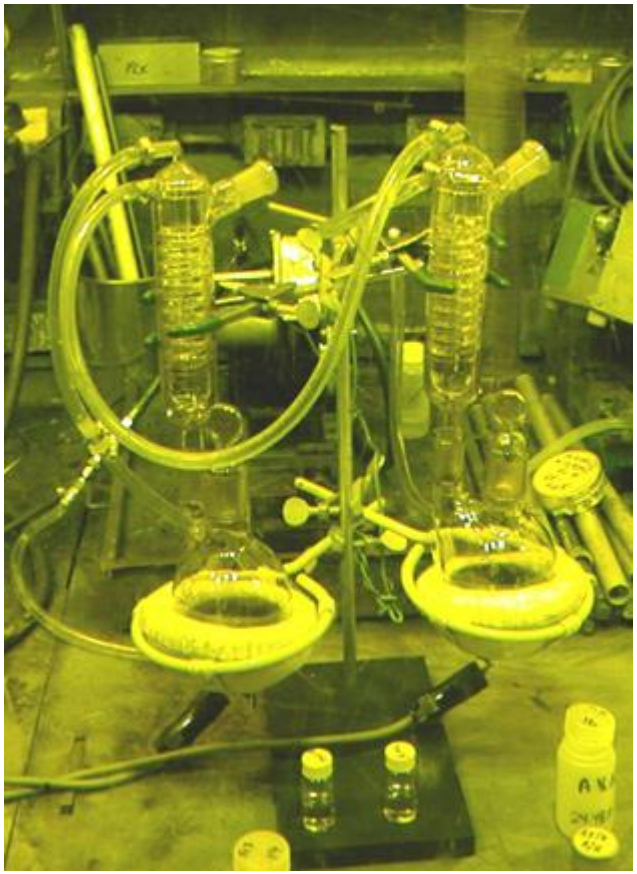
- Disposable camera approach
  - Quick release sockets
  - Multiple camera type compatibility
- USB 3 camera compatibility
- Refining optimal camera specifications
  - CCD/CMOS/CID
  - 7-20 megapixels



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

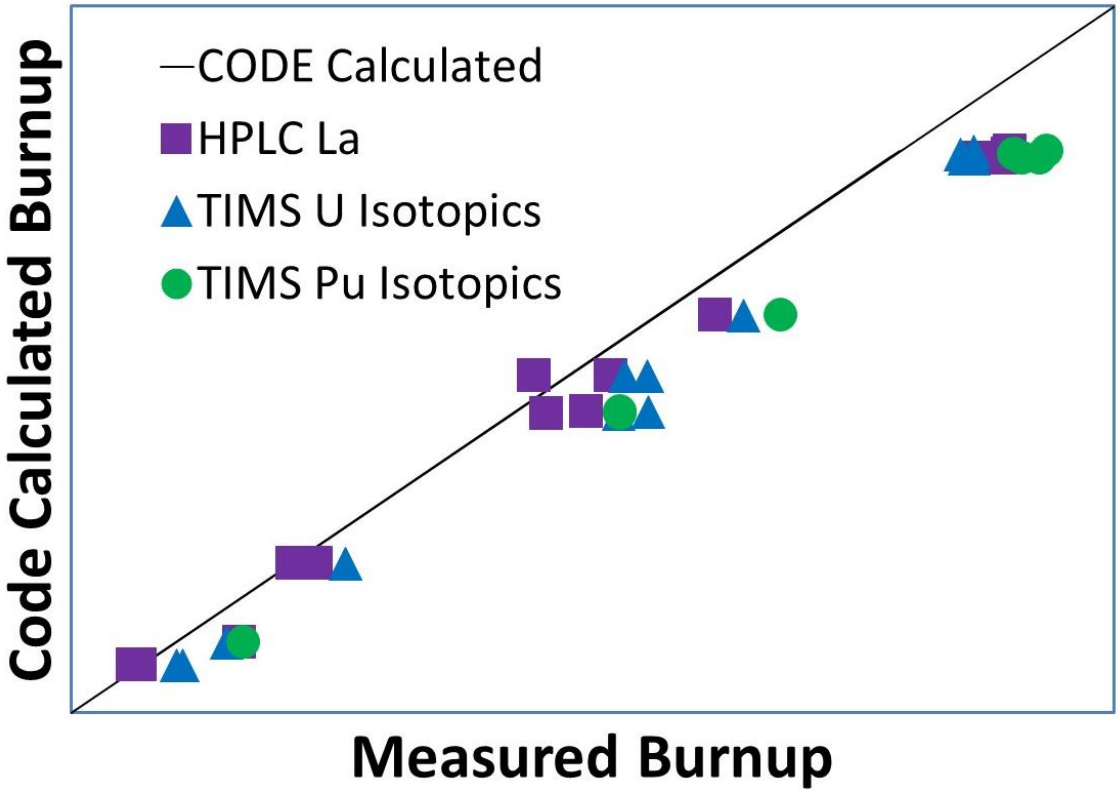
- SEU
  - ~1.4 wt%; Varied pellet geometry
  - ~2.3 wt%; 42-element bundle testing

- MOX
  - ~3 wt% Pu in DU; Pu destruction proof of concept
  - ~5 wt% Pu in DU; Pu destruction/fabrication processes
  - ~1 wt% Pu in DU; Pu homogeneity in the microstructure
  - ~0.9 wt% Pu in NU; Direct Use of PWR fuel in CANDU (DUPIC)

Burnup Evaluation - SEU

Comparison between HPLC La and TIMS Isotopics

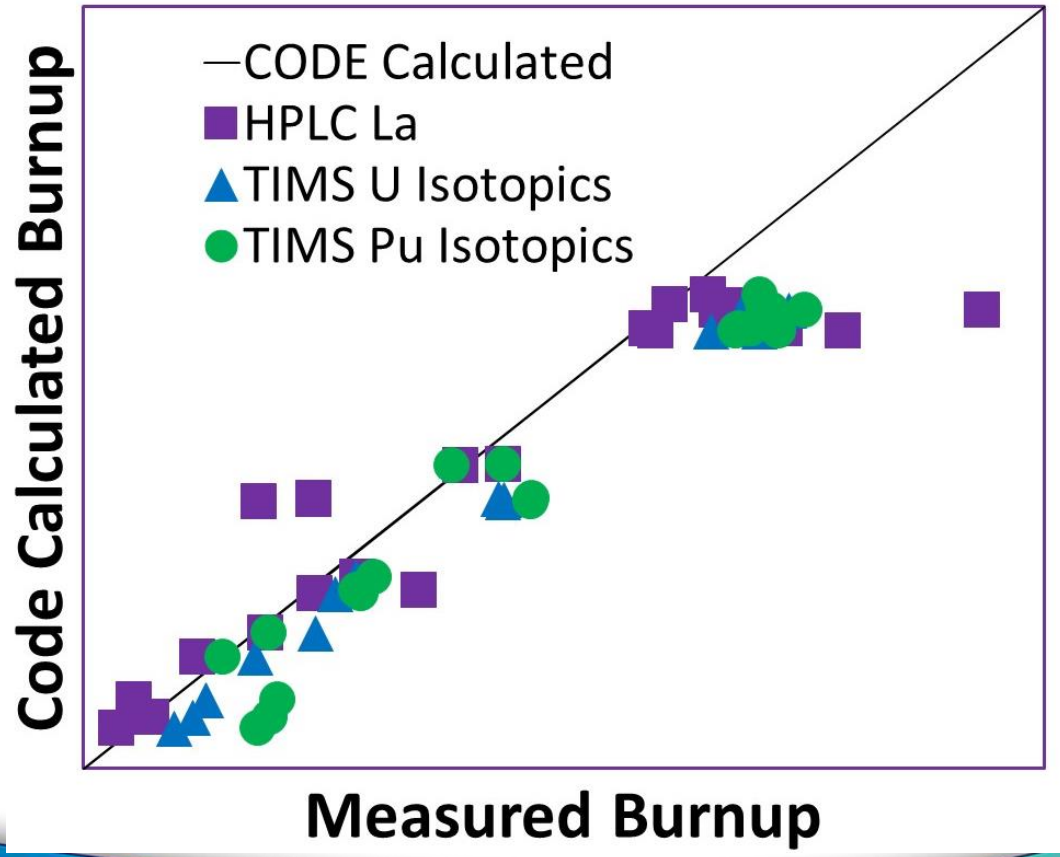
- SEU up to 30 MWd/kgHE
- Less scatter in Isotopics



Burnup Evaluation - MOX

Comparison between HPLC La and TIMS Isotopics

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



Burnup Evaluation - Thoria

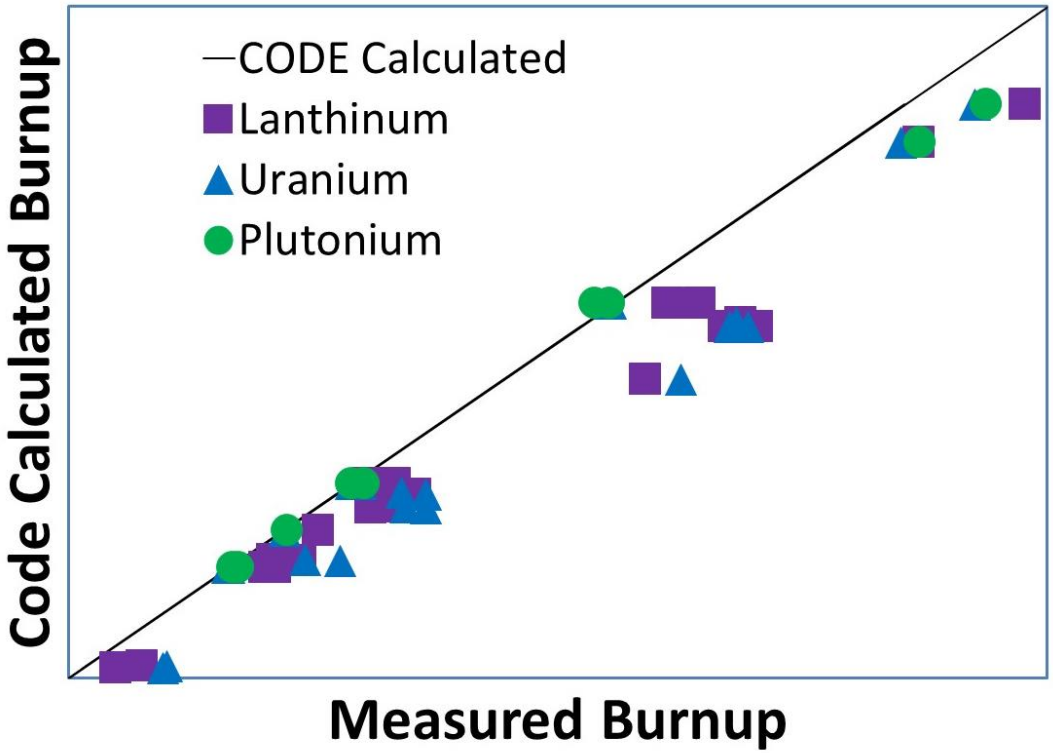
Experiments Used for the Study

- Thoria up to 50 MWd/kgHE
- Smaller sample size (difficult to make definitive conclusions)
- Thoria
  - ~1.8 wt% Pu in (Th, Pu)O_2; Extended burnup testing of Thoria
  - ThO_2 and 1 to 1.5 wt% ^{235}U in (Th, U)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

Consideration	HPLC La	TIMS Isotopic U and Pu
Hot Cell Measurement	Requires precise weight of sample (Absolute)	Does not require precise weight of sample (Relative)
Initial Content	N/A	U and Pu initial content must be known
Cost	Cost effective	More expensive 2-4 times as much as HPLC La
Time	Quickest method	Slightly longer for few samples; significantly longer with many samples*
Dose Consequence	Generally less dose; highly automated process	More dilute samples, but much more labour intensive

*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