Nuclear Fuel Diagnostics (MåBIL-project)

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Prof. Ane Håkansson, UU
Doc. Staffan Jacobsson Svärd, UU
Dr. Peter Andersson, UU
Outline

Background of MÅBiL Nuclear Fuel Diagnostics
Gamma emission tomography of irradiated fuel
Inspection of LOCA transient test rod
Looking ahead
Background of MÅBiL Fuel Diagnostics

• Started February 2015 as a part of SKC – MÅBiL project
• Performing fuel diagnostics in collaboration with the Halden Reactor Project (HRP)

• Research objectives
  • Fission gas release mechanisms
  • Performance of high-burnup fuels
  • Fuel behavior under LOCA conditions
  • Behavior of Accident Tolerant Fuels under normal and accident conditions
Gamma Emission Tomography

Gamma Emission Tomography is an essential tool in the collaboration

Developed in PhD project of Scott Holcombe in collaboration between UU, HRP and WE

Fig 2. CAD and photo of tomography station.

S. Holcombe, P. Andersson, “Gamma Emission Tomography Measurements of Fuel Assemblies at the Halden Reactor"
Principles of operation
Principles of operation

1) Collection of data

2) Selection of gamma ray energy

3) Tomographic reconstruction of selected energies

S. Holcombe, P. Andersson: "Gamma Emission Tomography of Fuel Assemblies at the Halden Reactor"
Fields of use

- Measurement of fission-gas-release fraction \[1\]
- Investigation of fuel fragments relocated into balloon of LOCA test rods \[2\]
- Pin power and burnup validation
- Identification of rod bow
- Other…

Fig 1. Rod-wise activity of Zr-95

Fig 2. Position of test rod in rig at various elevation


LOCA transient tests at HRP
LOCA transient tests at HRP

- HRP test series IFA-650 studies the behavior of high burnup fuel in LOCA transients.
- High-burnup rod segments are instrumented with in-pile sensors and exposed to simulation of blowdown and subsequent heat-up of the fuel.
- Special concerns in high-burnup fuel is the increased fragmentation of the fuel:
  - Higher burnup → Increased fuel fragmentation → Increased relocation to balloon → Further increase of heat load
LOCA transient tests at HRP

- Features of interest in LOCA transient test:
  - Relocation of fuel
  - Fragmentation of fuel
  - Packing fraction

- Gamma Emission Tomography can assess these features

- Allows for inspection at HRP after a minimum of fuel handling and transport

- Fuel distribution still as conserved as possible when inspected

- The tomographic technique was exploratory tested in recent LOCA transient test
Analysis

Plan devised for LOCA rod inspection using gamma emission tomography

1) Measurements
   - Peak selection
   - Net count rate extraction

2) Qualitative tomographic reconstruction
   - Filtered Backprojection
   - Algebraic Reconstruction

3) Fuel and Structure localization
   - Activation products
   - Shadows

Visually interpretable image of the fuel

4) Quantitative tomographic reconstruction

Quantitative results
Results

- Seven axial positions were inspected with a large collimator (2x22 mm)
- The large size was oriented in the axial direction, effectively providing an average in the height of the collimator slit.
- $^{137}$Cs (662 keV) was used to image the fuel
- Large size balloon was revealed (twice the nominal diameter, reaching heater cylinder)

Andersson, Peter; Holcombe, Scott; Tverberg, Terje, Inspection of a LOCA Test Rod at the Halden Reactor Project using Gamma Emission Tomography. Top Fuel, 2016
Results

- Ten axial positions were inspected with a large collimator (2x1 mm)
- Relatively high-resolution image of fuel fragment distribution in balloon region.
- Fragments in the order of a few mm revealed
- In the top of the rod the pellet shape appear to remain

Andersson, Peter; Holcombe, Scott; Tverberg, Terje, Inspection of a LOCA Test Rod at the Halden Reactor Project using Gamma Emission Tomography. Top Fuel, 2016
Results

- Fuel location in relation to rig can be inspected using activation gamma
- $^{51}$Cr and $^{59}$Fe could be used to identify activation in stainless steels
- Inconel heater cables were localized using $^{58}$Co
- Shadow effect from attenuation can also be used
Conclusions from inspection of LOCA

Qualitative reconstructions of fuel revealed:

- Sever ballooning of cladding.
- Fuel fragments in the order of a few mm
- Fuel fragments located primarily on the periphery of the balloon.
- A view of the state of the fuel could be obtained when fuel as conserved as possible
- Rig structures could be localized using template matching algorithms
What will the future bring?
Toward quantitative and detailed Tomographic reconstruction

1) Naïve reconstruction of activation gamma (neglecting attenuation)

2) Identification of rig structures and fuel rods using template matching

3) Reconstruction of fission product to reveal dispersed fuel

4) Creating attenuation map for dispersed fuel

5) Quantitative reconstruction of fuel, where attenuation is correctly accounted for
Toward quantitative and detailed Tomographic reconstruction

Quantitative reconstructions may be used to:

- Better map the distribution of fragments in a LOCA test rod.
- Asymmetric burnup
- Migrating fission products
Toward quantitative and detailed Tomographic reconstruction
Studies published with contribution from MÅBiL Fuel Diagnostics

1. Davour, Anna (et al.), Applying image analysis techniques to tomographic images of irradiated nuclear fuel assemblies. // Annals of Nuclear Energy. - 2016 96 , s. 223-229


Peter Andersson
Peter.andersson@physics.uu.se
Toward quantitative and detailed Tomographic reconstruction

- Available reconstruction methods can obtain
  - qualitative detailed reconstructions
  - quantitative rod-wise reconstructions

- Current focus is to assemble methods to combine the two and to achieve quantitative and detailed reconstruction
  - Spatial resolution in the mm-scale
  - Pixel values correspond accurately to activity

- Requires that the radiation attenuation in fuel material and other rig structures are accounted for