Measurement of Spent Fuel Assemblies
Overview of the Status of the Technology
For Initiating Discussion at
NATIONAL RESEARCH CENTRE KURCHATOV
INSTITUTE

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Brookhaven National Laboratory

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Measurement of Spent Fuel Assemblies

Overview of the Status of the Technology
For Initiating Discussion
at NATIONAL RESEARCH CENTRE
"KURCHATOV INSTITUTE"
June 2013
What I will cover in this presentation:

• Why is the measurement of spent nuclear fuel composition important?
• Safeguards and MC&A applications of spent fuel nondestructive assay [NDA]
• U.S. Nuclear regulatory Commission viewpoint.
• IAEA viewpoint.
  – Spent fuel measurement systems described by IAEA
• The status of spent fuel NDA. Where you can find further information.
Why is the measurement of spent nuclear fuel composition important?

- The quantity of fissile material – primarily Pu-239 and U-235 [and U-233 for thorium fuel cycles] – is necessary input to address criticality concerns.
- Knowledge of the constituents of spent nuclear fuel are necessary for waste management assessments.
- Plutonium and other constituents could have commercial value in the event of a closed nuclear fuel cycle.
- The quantity of fissile material is necessary for MC&A in both international and domestic safeguards.
- However, the focus of measurement efforts has been on partial and gross defects of LWR and research reactor spent fuel.
Safeguards and MC&A Applications of Spent Fuel NDA

- Loss of continuity of knowledge in the event containment and surveillance (C/S) is interrupted or lost.
- Termination of safeguards at geologic repositories.
- Input accountability at reprocessing facilities other than comparing unverified burnup code calculations with [perhaps nonexistent] input accountability tank measurements.
- Enhanced C/S during spent fuel shipment to provide signature identity for specific fuel assemblies.
- Deterrence of diversion by state or by non-state insider
- More accurate recalibration of spent fuel burnup calculation.

U.S. Nuclear Regulatory Commission

- U.S. Nuclear Regulatory Commission has an interest in spent nuclear fuel measurements.
- The NRC has investigated correlations between operating records at nuclear electric utility reactors and out-of-core measurement data.
- One concern is “burnup credit” or the decrease in fissile material reactivity of spent nuclear fuel when considering criticality safety analyses.

The nuclear power reactor records are based on measured core thermal output and computer simulations and in some cases information from in-core detectors.

Out-of-core measurement systems can be used to measure gamma-ray and/or neutron emissions from the fuel assemblies.

The measurements are then compared to a calibration curve obtained by measuring a “primary standard” assembly of known burnup to develop an estimated fissile content and corresponding assembly burnup. Out-of-core measurement systems cannot measure fuel burnup [and fissile content of the fuel] directly.
Some of the problems contributing in measuring spent fuel burnup

- The primary standard fuel assembly should be **geometrically identical** to the measured assembly.

- Dominant $\gamma$-ray emissions may result from neutron capture as well as form fission products.

- Absolute detector efficiency is difficult to calculate
What are the difficulties in obtaining NDA measurements of the fissile material in spent nuclear fuel?

- The special nuclear material content of fresh nuclear fuel assemblies can be measured by standard gamma and neutron techniques in conjunction with knowledge of the fuel geometry and mass.

- The intense background radiation from fission products in the irradiated fuel interferes with detection of neutron and gamma irradiation of interest.

IAEA Concerns - continued

- Dominant $\gamma$-ray emissions that are useful signatures for verifying the *presence* of spent fuel

  - 662 keV $\gamma$-ray from Cs-137 $> 2$ years
  
  - 757/766 keV $\gamma$-ray from Nb-95/Zr-95 $< 2$ years

- Not very quantifiable – it is there or it is not there:
  
  - Gross Defect - fuel assembly replaced by dummy;
  - Partial Defect - fuel assembly pins replaced
### SPENT FUEL MEASUREMENT SYSTEMS DESCRIBED BY IAEA

<table>
<thead>
<tr>
<th>Gross Neutron and $\gamma$-Ray Detection</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fork detector irradiated fuel measuring system (FDET)</strong></td>
</tr>
<tr>
<td><strong>Safeguards MOX python (SMOPY)</strong></td>
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</tbody>
</table>
Fork detector irradiated fuel measuring system (FDET).

Safeguards MOX python (SMOPY) device.
<table>
<thead>
<tr>
<th><strong>γ-Ray Energy Spectral Analysis</strong></th>
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</thead>
<tbody>
<tr>
<td><strong>Spent fuel attribute tester (SFAT)</strong></td>
</tr>
<tr>
<td><strong>Irradiated fuel attribute tester (IRAT)</strong></td>
</tr>
<tr>
<td><strong>Neutron and gamma attribute tester (NGAT)</strong></td>
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</tbody>
</table>
### γ-Ray Intensity Scanning

<table>
<thead>
<tr>
<th>System</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CANDU bundle verifier (CBVB)</td>
<td>Verification of the <em>presence</em> of CANDU fuel bundles stored in either stacks or baskets in a spent fuel pond</td>
</tr>
<tr>
<td>Cask radiation profiling system for dry storage casks (CRPS)</td>
<td><em>Gross defect</em> device takes radiation profiles from dry-cask spent fuel storage containers for <em>re-verification</em>. The scan – a radiation profile or fingerprint – is used for re-verification of the dry cask contents.</td>
</tr>
<tr>
<td>Optical Fiber Radiation Probe System (OFPS)</td>
<td>Performs <em>gross</em> γ measurements supporting the <em>re-verification</em> of CANDU spent fuel bundles stored in the spent fuel bay without requiring movement of the horizontal storage trays.</td>
</tr>
</tbody>
</table>
# SPENT FUEL MEASUREMENT SYSTEMS [Continued]

## Neutron Coincidence Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced experimental fuel counter (AEFC)</td>
<td>Characterization of spent fuel from research reactors stored under water. The signal is approximately proportional to the fission rate in the fuel item.</td>
</tr>
<tr>
<td>Spent fuel coincident counter (SFCC)</td>
<td>Underwater verification of Pu in canned fast breeder reactor spent fuel. Specially developed software converts the measured single and double neutron count rates to Pu mass.</td>
</tr>
<tr>
<td>Čerenkov Radiation Detection</td>
<td></td>
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<tr>
<td>-----------------------------</td>
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</tr>
<tr>
<td>Digital Čerenkov viewing device (DCVD)</td>
<td>Highly sensitive digital device for viewing Čerenkov light from long cooled, low-burnup fuel</td>
</tr>
<tr>
<td>Improved Čerenkov viewing device (ICVD)</td>
<td>Hand-held light intensifying device optimized to view Čerenkov light (near ultraviolet) in a spent fuel storage pond. System can be used in a lighted area. Primarily used to identify irradiated light water reactor fuel assemblies</td>
</tr>
</tbody>
</table>
So where are we with regard to measurement of spent nuclear fuel?

• The quantity of fissile material is necessary for MC&A in both international and domestic safeguards.

• However, the focus of measurement efforts has been on partial and gross defects of LWR and research reactor spent fuel.

• It would be desirable to directly quantify the Pu mass in spent fuel with an uncertainty of less than 5% independently of nuclear reactor operating parameters, spent fuel cooling time, and continuity of knowledge.

• No existing NDA technique can by itself determine Pu content to that accuracy independently of spent fuel historical parameters.

• The nondestructive assay of spent nuclear fuel is the subject of ongoing development. See, for example, J. Nucl. Mat. Mgmt, Spring 2012, Volume 40, which was a topical issue on NDA of spent nuclear fuel.
References


• Safeguards Techniques and Equipment 2011 Edition, IAEA/NVS/1/2011 (Rev. 2) - §2.3.1