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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*

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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<sup>[1]</sup>

- 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.

<sup>[1]</sup>M. A. Humphrey, K. D. Veal, and S.J. Tobin, *J. Nucl. Mat. Mgmt.*, Vol 40, No. 3, Spring 2012, pp 6 -10

# U.S. Nuclear Regulatory Commission<sup>[2]</sup>

- 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.

<sup>[2]</sup> NUREG/CR-6998 – Review of Information for Spent Nuclear Fuel Burnup Confirmation

# U.S. Nuclear Regulatory Commission - continued

- 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.**

# U.S. Nuclear Regulatory Commission - continued

- **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 from fission products.
  - Absolute detector efficiency is difficult to calculate

# IAEA Concerns<sup>[3]</sup>

- 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.

<sup>[3]</sup> Safeguards Techniques and Equipment 2011 Edition, IAEA/NVS/1/2011 (Rev. 2) - §2.3.1

# 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

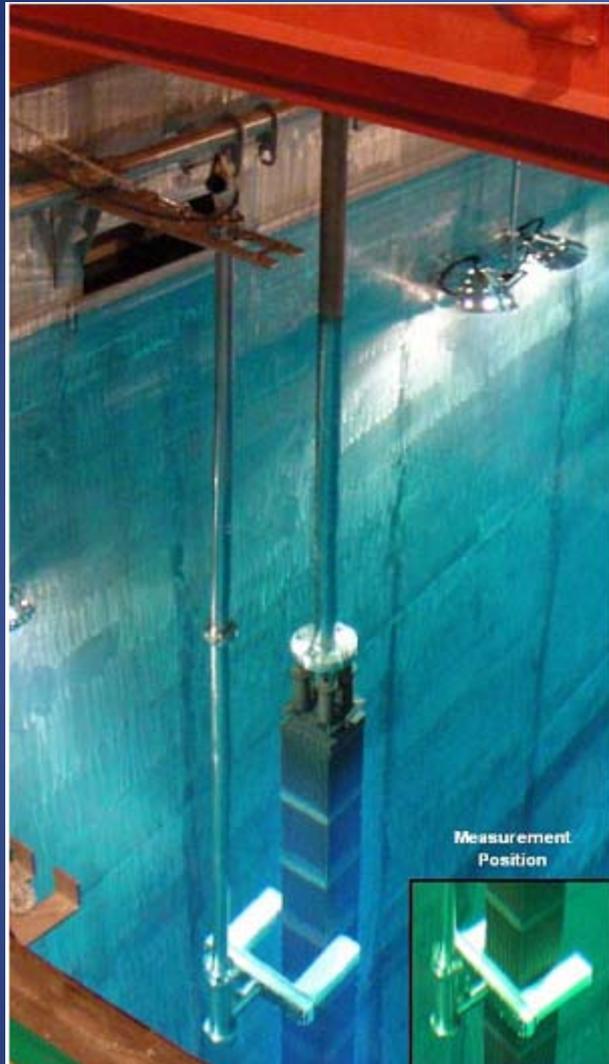
## Gross Neutron and $\gamma$ -Ray Detection

Fork detector  
irradiated fuel  
measuring  
system (FDET)

Detector system that straddles light water reactor fuel assemblies with pairs of neutron and  $\gamma$ -ray detectors and provides *gross defect* verification of irradiation history, initial fuel content.

Safeguards  
MOX python  
(SMOPY)

*Gross defect* device combines gross neutron counting with low level  $\gamma$  spectroscopy to characterize spent fuel. It can verify and distinguish irradiated MOX fuel from LEU fuel and can confirm the burnup of a spent fuel assembly.



*Safeguards MOX python (SMOPY) device.*

*Fork detector irradiated fuel measuring system (FDET).*

# SPENT FUEL MEASUREMENT SYSTEMS [Continued]

<b><math>\gamma</math>-Ray Energy Spectral Analysis</b>	
Spent fuel attribute tester (SFAT)	<i>Gross defect</i> device used for verifying the <i>presence</i> of fission product or activation product at the top of the irradiated fuel assembly in a spent fuel pool. Helpful when Čerenkov radiation is weak.
Irradiated fuel attribute tester (IRAT)	<i>Gross defect</i> device used for verifying fission product presence in an irradiated fuel assembly in a spent fuel pool. Helpful when Čerenkov radiation is weak.
Neutron and gamma attribute tester (NGAT)	<i>Gross defect</i> device used for verifying spent fuel assemblies, fresh MOX fuel assemblies and open or closed containers holding various radiated and non-irradiated materials including non-fuel items.

# SPENT FUEL MEASUREMENT SYSTEMS [Continued]

## $\gamma$ -Ray Intensity Scanning

CANDU bundle verifier (CBVB)	Verification of the <i>presence</i> of CANDU fuel bundles stored in either stacks or baskets in a spent fuel pond
Cask radiation profiling system for dry storage casks (CRPS)	<i>Gross defect</i> device takes radiation profiles from dry-cask spent fuel storage containers for <i>re-verification</i> . The scan – a radiation profile or fingerprint – is used for re-verification of the dry cask contents.
Optical Fiber Radiation Probe System (OFPS)	Performs <i>gross</i> $\gamma$ measurements supporting the <i>re-verification</i> of CANDU spent fuel bundles stored in the spent fuel bay without requiring movement of the horizontal storage trays.

# SPENT FUEL MEASUREMENT SYSTEMS [Continued]

## Neutron Coincidence Methods

<p>Advanced experimental fuel counter (AEFC)</p>	<p>Characterization of spent fuel from research reactors stored under water. The signal is approximately proportional to the fission rate in the fuel item.</p>
<p>Spent fuel coincident counter (SFCC)</p>	<p>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.</p>

# SPENT FUEL MEASUREMENT SYSTEMS

[Continued]

## Čerenkov Radiation Detection

Digital Čerenkov viewing device (DCVD)	Highly sensitive digital device for viewing Čerenkov light from long cooled, low-burnup fuel
Improved Čerenkov viewing device (ICVD)	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

# 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

- B.B. Brevard, J.C. Wagner, C.V. Parks, and M. Aissa, “Review of Information for Spent Nuclear Fuel Burnup Confirmation,” NUREG/CR-6998, U.S. Nuclear Regulatory Commission, December 2009.
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