BROOKHAVEN
NATIONAL LABORATORY

BNL-101126-2013-IR

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

Barry Siskind

June 2013

Nonproliferation and National Security Department/GARS Directorate

Brookhaven National Laboratory

U.S. Department of Energy
NA25 – International Materials Protection and Emergency Cooperation Program

DISCLAIMER

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[1]

- 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.

[1]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[2]

- 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.

[2] 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 γ-ray emissions may result from neutron capture as well as form fission products.
  - Absolute detector efficiency is difficult to calculate

IAEA Concerns[3]

- 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.

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

IAEA Concerns - continued

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

  - 662 keV γ-ray from Cs-137 > 2 years

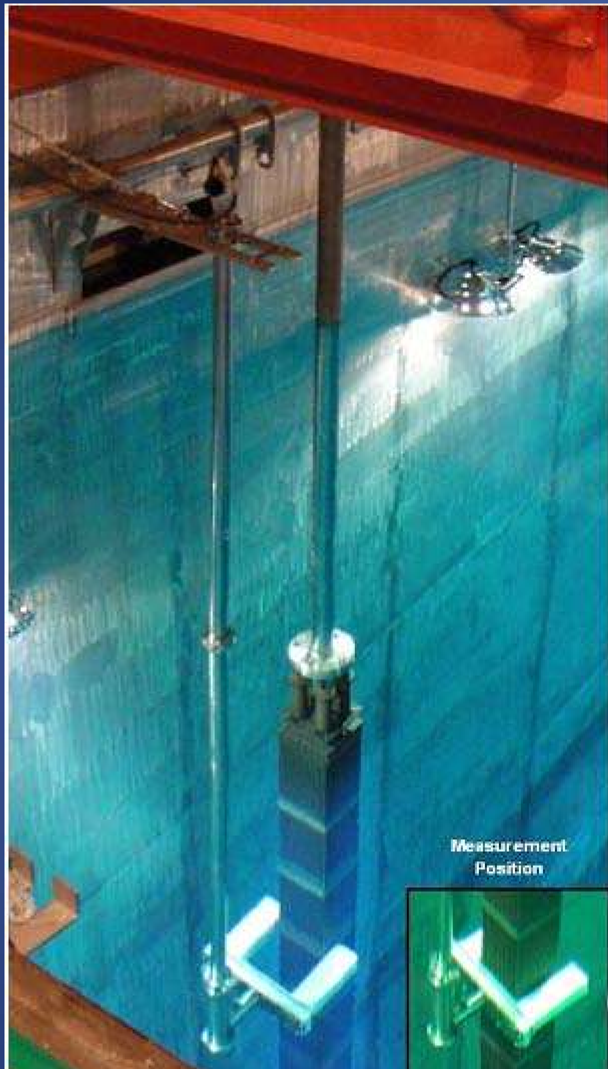
  - 757/766 keV γ-ray from Nb-95/Zr-95 < 2 years

  - Not very quantifiable – it is there or it is not there:

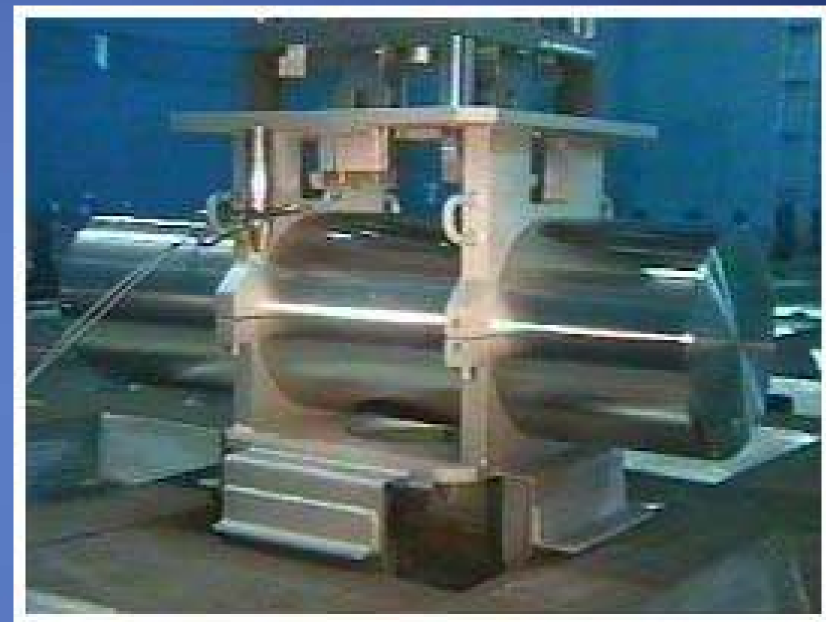
    - Gross Defect - fuel assembly replaced by dummy;
    - Partial Defect - fuel assembly pins replaced

SPENT FUEL MEASUREMENT SYSTEMS DESCRIBED BY IAEA

Gross Neutron and γ-Ray Detection	
Fork detector irradiated fuel measuring system (FDET)	Detector system that straddles light water reactor fuel assemblies with pairs of neutron and γ-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 γ 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.



Fork detector irradiated fuel measuring system (FDET).



Safeguards MOX python (SMOPY) device.

SPENT FUEL MEASUREMENT SYSTEMS [Continued]

γ-Ray Energy Spectral Analysis	
Spent fuel attribute tester (SFAT)	*Gross defect* device used for verifying the *presence* 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)	*Gross defect* 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)	*Gross defect* 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]

γ-Ray Intensity Scanning	
CANDU bundle verifier (CBVB)	Verification of the *presence* of CANDU fuel bundles stored in either stacks or baskets in a spent fuel pond
Cask radiation profiling system for dry storage casks (CRPS)	*Gross defect* device takes radiation profiles from dry-cask spent fuel storage containers for *re-verification*. The scan – a radiation profile or fingerprint – is used for re-verification of the dry cask contents.
Optical Fiber Radiation Probe System (OFPS)	Performs *gross* γ measurements supporting the *re-verification* 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	
Advanced experimental fuel counter (AEFC)	Characterization of spent fuel from research reactors stored under water. The signal is approximately proportional to the fission rate in the fuel item.
Spent fuel coincident counter (SFCC)	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.

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.
- Safeguards Techniques and Equipment 2011 Edition, IAEA/NVS/1/2011 (Rev. 2) - §2.3.1
- Topical Issue – Nondestructive Assay of Spent Fuel, *Journal of Nuclear Materials Management*, Spring 2012, Volume XL, No. 3