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SPENT-FUEL VERIFICATION MEASUREMENTS USING PASSIVE AND ACTIVE RADIATION TECHNIQUES

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ABSTRACT

This paper describes an evolutionary development process that will lead to spent fuel measurements that directly measure fissile reactivity. First, the Fork measurement system has been used to verify the burnup of pressurized water reactor (PWR) spent-fuel assemblies at U.S. nuclear utilities. Fork measurements have demonstrated the utility of the passive Fork system to verify reactor records with a single 100-second measurement on each assembly. Second, an Advanced Fork system incorporating collimated gamma-ray spectroscopy has been designed to permit advanced calibration techniques that are independent of reactor burnup records and to allow rapid axial scanning of spent fuel assemblies. Third, an Active Fork system incorporating a neutron source to interrogate spent fuel is proposed to provide the capability to measure fissile reactivity, when compared to measurements on fresh fuel assemblies of the same design. The Advanced and Active Fork systems have wide applicability to spent fuel verification for PWR, boiling water reactor (BWR), and U.S. Department of Energy (DOE) spent fuel.

FORK SYSTEM

The Fork measurement system has been used to verify the internal consistency of reactor records for assembly burnup at U.S. nuclear utilities[1,2], and it has been proposed by the DOE as a verification system for the implementation of actinide-only burnup credit for spent fuel from a PWR.[3] The Fork detector is submerged in the spent fuel storage pool and moved to the location of the assembly to be measured. The assembly is partially raised from its rack position, and the passive neutron and gamma-ray emissions are measured at the center point of the assembly. The Fork operational procedures have proven to be compatible with utility operations. The neutron measurements are correlated with the reactor records for burnup, cooling time, and initial enrichment to determine with a high sensitivity the random variation in burnup and the internal consistency of the reactor records. Because of the strong dependence of the neutron yield on burnup (about the fourth power) the neutron measurements can detect significant discrepancies in burnup with higher sensitivity than can be obtained from gamma-rays alone. Results with the Fork system indicate a high degree of consistency in the PWR records examined to date (2% to 4% average deviation).[1,2] The gamma-ray yield is used as a backup measurement to analyze anomalous neutron signals.

ADVANCED FORK SYSTEM

The Advanced Fork system uses the same basic detector shape and procedures described above, while providing additional capability for axial burnup scans, calibration, and indication of minimum cooling time. The rapid axial scan capability may be important for burnup verification at a BWR, since BWR burnup profiles are not as easily categorized as those at a PWR. The Advanced Fork detector contains two neutron detectors imbedded in polyethylene cylinders to measure the epithermal neutron yield, an ion chamber to measure gross gamma-ray yield, and a gamma-ray spectroscopy crystal to measure the energy distribution of gamma-rays. Tungsten collimators are used to define the spatial resolution of the gamma-ray detectors along the axis of the assembly. The ion chamber has a rapid response time (about 1 second) so that readings can be taken while the assembly is continuously moving past the detector. The Advanced Fork design utilizes well-proven and utility-accepted procedures developed with the current Fork system with an improved capability to discriminate specific isotopes using enhanced gamma-ray measurements.

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GAMMA-RAY SPECTROSCOPY

Gamma-ray spectroscopy techniques are needed to permit the identification of cesium-137 by its characteristic 662 keV gamma-ray. Cesium-137 is produced in about 6% of all fissions and can be useful in determining the total number of fissions that have occurred in an assembly. Cesium-134, with gamma-rays of energy 605 and 796 keV, is also produced in spent fuel. The two cesium isotopes are produced by different processes in the reactor and decay with different half-lives. Cesium-137 is produced as a fission product and has a half-life of 30.2 years. Cesium-134 is produced by a more complex activation of fission products and has a half-life of 2.06 years. The spectrometer resolution required to separate and clearly define the 662 and 605 keV gamma-rays is about 3% full-width half-maximum (FWHM). Calculational techniques can be used to estimate the relative intensities of the two cesium isotopes as a function of cooling time if the spectrometer has poorer resolution than 3% (FWHM). For example, after six years of cooling time, it may be possible to neglect the cesium-134 contribution to the spectrum. In that case, the resolution of room temperature spectroscopy crystals such as NaI, CsI, and CdTe may be sufficient to identify the cesium-137 concentration. This would avoid the use of high-purity germanium crystals which provide high resolution but require liquid nitrogen cooling.

NEUTRON YIELD

The primary source of neutrons from spent fuel assemblies that have cooled for several years is curium-244, which is produced by successive neutron capture beginning with uranium-238 and decays with a half-life of 18.1 years. In the Advanced Fork system, the neutron yield is measured with polyethylene moderated fission chambers in the same method used in the Fork system. The deviations in burnup among a group of spent fuel assemblies can be determined from the neutron signal extrapolated to the date of discharge using the 18.1 year half-life, and corrected for variations in initial enrichment and burnup. This method makes use of the reactor records for burnup, initial enrichment, and cooling time, and it produces a relative burnup determination in which all the assemblies are used as an internal calibration. Due to the strong dependence of the neutron signal on burnup, the neutron measurements provide a sensitive determination of variations in burnup that can identify discrepancies between burnup records and the neutron yield for an individual assembly.

CALIBRATION

The gamma-ray spectrometer of the Advanced Fork system, after appropriate calibration, permits a determination of assembly burnup that is independent of reactor records. There are several methods to calibrate the cesium-137 signal, which is directly proportional to the burnup. One technique would consist of Advanced Fork measurements conducted on spent fuel assemblies for which chemical analyses of rod composition (including the concentration of cesium-137) are available. Another method under consideration would employ a mock-up of a section of an assembly that incorporates a National Institutes of Standards and Technology (NIST) traceable calibrated source of cesium-137. A third method would employ a single NIST-traceable calibrated source for efficiency calibration, and a calculation of scattering, absorption, and geometric effects. The absolute uncertainty in these calibration techniques is estimated to be about 20%, primarily due to the variability in the extrapolation of the calibration data to a particular assembly.

ACTIVE FORK CONCEPT

The addition of a neutron source and suitable electronics to the Fork system can provide the capability to perform reactivity measurements on spent fuel by use of active neutron interrogation. The need for such measurements has arisen from the requirements to characterize DOE-owned spent fuel for which records may be incomplete. DOE-owned fuel includes fuel from research reactors, foreign reactors, weapons production, and experimental reactors. Candidate neutron sources include accelerators (deuterium-deuterium and deuterium-tritium), and isotope decay sources (californium-252 and alpha particle-beryllium, for example). Detection of neutrons produced in fission reactions in the fuel can be accomplished by measurement of the neutron multiplication, die-away, delayed fraction, and from time distribution analyses of the neutron signal. Reactivity measurements can be obtained by comparing signals from spent and fresh fuel assemblies of identical design. The detailed definition of an Active Fork system will be considered after the requirements for characterization of DOE-owned spent fuel have been finalized.

REFERENCES

1. R. I. Ewing, G. E. Bosler, R. Siebelist and G. Walden, "Burnup Verification Measurements on Spent-Fuel Assemblies at Oconee Nuclear Station,"

Electric Power Research Institute Report TR-103591, Project 3290-07, January 1994.

2. R. I. Ewing, D. R. Bronowski, G. E. Bosler, R. L. Siebelist, J. Priore and S. Sullivan, "Burnup Verification at Arkansas Nuclear One Using the Fork Measurement System, *Proceedings of the Sixth Annual International Conference on High Level Radioactive Waste Management*, Las Vegas, Nevada, April 30 - May 5, 1995, pg. 556.

3. *Topical Report on Actinide-Only Burnup Credit for PWR Spent Nuclear Fuel Packages*, DOE/RW-0472, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, May 1995.