CONF-960421--24

SAND96-0644C

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MAR 1 1 1996
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DESIGN OF AN ADVANCED FORK SYSTEM FOR ASSEMBLY BURNUP MEASUREMENT

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ABSTRACT

An Advanced Fork System has been designed to add gamma-ray collimation and spectroscopy capability to the Fork measurement system, which has been used for burnup verification at pressurized water reactors (PWR). The Advanced Fork System measures the neutron and gamma-ray yields and the energy spectrum of gamma-rays from spent fuel assemblies. A cadmium-zinc-telluride (CZT) crystal permits the identification of the radioactive isotopes of cesium (134 and 137). The cesium isotope concentrations, with proper calibration, can be used to determine the assembly burnup independent of reactor records, and to provide a measure of minimum cooling time. Tungsten gamma-ray collimators are used to define the spatial resolution of the gamma-ray detectors along the axis of the assembly. The capability to rapidly perform a burnup distribution scan using the collimated ion chamber may be important to the verification of burnup for boiling water reactors (BWR).

I. INTRODUCTION

The Fork system has been used to verify the internal consistency of reactor records for assembly burnup at U.S. nuclear utilities[1,2] and has been proposed by the U.S. Department of Energy 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 measures the passive neutron and gamma-ray emission from a spent fuel assembly raised part-way out of its rack. These procedures have proved to be compatible with utility operations. The neutron measurements are correlated with the reactor records for burnup, cooling time, and initial enrichment to sensitively determine 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.

The Advanced Fork system uses the same basic detector shape and procedures, while providing additional capabilities for axial burnup scans, calibration, and indication of minimum cooling time. The rapid axial scan capability may be important for burnup verification of each assembly at BWRs, since BWR burnup profiles are not as easily categorized as those at PWRs.

II. DESIGN

The Advanced Fork detector contains two fission chambers imbedded in polyethylene cylinders to measure the neutron yield, an ion chamber to measure the gross gamma-ray yield, and a CZT 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 CZT crystal is used as a gamma-ray spectrometer. The gamma-ray spectrum is collected simultaneously with the neutron yield measurement, which requires about 100

[a]A U.S. Department of Energy facility operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, under contract DE-AC04-94AL85000.

seconds of counting time per assembly. The design makes use of the well-proven and utility-accepted procedures developed with the Fork system.

III. GAMMA-RAY SPECTROSCOPY

Gamma-ray spectroscopy permits the identification of cesium-137 by its characteristic 662 keV gamma-ray, and cesium-134 by its gamma-rays of energy 605 and 796 keV. The resolution required to separate and clearly define the 662 and 605 keV gamma-rays is about 3% (FWHM), which is readily attainable with commercial CZT crystals. It is necessary to resolve the gamma-rays of the two isotopes because they are produced by different processes in the reactor, and they decay with different half-lives. Cesium-137 is produced as a fission product, and it is therefore a direct measure of the fission heat produced (and the burnup). Cesium-137 decays with a half-life of 30.2 years. Cesium-134 is produced by activation of fission products, and has a half-life of 2.06 years. Assembly cooling times of less than about six years can be gauged by the ratio of the measured concentrations of the cesium isotopes. The ratio is a function of cooling time due to the different decay rates of the isotopes. After about six years of cooling time, the decay of cesium-134 limits the ratio technique to an indication of minimum cooling time.

IV. 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. The neutron yield is measured with polyethylene moderated fission chambers in the same method used in the Fork system. The deviations in burnup amongst 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 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 (about the fourth power), the neutron measurements provide a sensitive determination of variations in burnup and discrepancies between burnup records and the neutron yield for an individual assembly.

V. CALIBRATION

The design of the Advanced Fork System, after appropriate calibration, permits a determination of assembly burnup that is independent of reactor burnup records, and includes a measure of minimum cooling time. The calibration of the cesium-137 signal, which is directly proportional to the burnup, will 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. This calibration will permit the determination of burnup for an assembly with an uncertainty estimated to be about 15%, primarily due to the variability in the extrapolation of the calibration data to a particular assembly. The final calibration of the Advanced Fork system will be performed after suitable spent fuel assemblies have been selected for chemical analysis.

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