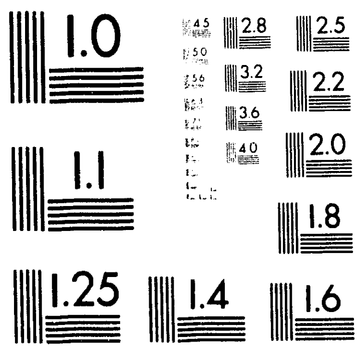
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BURNUP VERIFICATION MEASUREMENTS AT A U.S. NUCLEAR UTILITY USING THE FORK MEASUREMENT SYSTEM

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INTRODUCTION

The FORK measurement system, designed at Los Alamos National Laboratory (LANL) for the International Atomic Energy Agency (IAEA) safeguards program, has been used to examine spent reactor fuel assemblies at Duke Power Company's Oconee Nuclear Station. The FORK system measures the passive neutron and gamma-ray emission from spent fuel assemblies while in the storage pool. These measurements can be correlated with burnup and cooling time, and can be used to verify the reactor site records. Verification measurements may be used to help ensure nuclear criticality safety when burnup credit is applied to spent fuel transport and storage systems. By taking into account the reduced reactivity of spent fuel due to its burnup in the reactor, burnup credit results in more efficient and economic transport and storage. The objectives of these tests are to demonstrate the applicability of the FORK system to verify reactor records and to develop optimal procedures compatible with utility operations. The test program is a cooperative effort supported by Sandia National Laboratories, the Electric Power Research Institute (EPRI), Los Alamos National Laboratory, and the Duke Power Company.

BURNUP

Burnup is a crucial parameter in fuel management and in calculations of nuclear criticality and residual fissile content. Burnup of the fuel is determined by monitoring the thermal output of the reactor, and is usually specified as the integrated thermal output per tonne of uranium (gigawatt days/metric ton of uranium). The average burnup for each assembly is determined with an accuracy of about 2% from in-core neutron measurements taken during reactor operations. The reactor site records of interest for each spent fuel assembly are the initial enrichment, the burnup, and the date of discharge from the core.

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Studies have concluded that the reactor records are of higher precision and reliability than could be provided by post-discharge radiation measurements [Ref. 1]. The role of a burnup measurement after discharge is to demonstrate the consistency of the reactor records, to detect possible mis-identification of assemblies, and to detect anomalous assemblies that might affect safety or safeguards concerns.

FORK

The FORK measurement system, designed at Los Alamos National Laboratory, has been used for more than a decade by the International Atomic Energy Agency to verify reactor records by measuring neutron and gamma-ray emissions from spent fuel assemblies [Ref. 2]. This technique has proved to be adequate, and eliminates the need for more complex active or high-resolution measurement techniques [Ref. 3]. The system appears to be particularly well suited for application to spent fuel verification measurements at U.S. storage sites.

The system is diagrammed in its operational arrangement in Figure 1. The detector head is moved in the storage pool to the spent fuel assembly to be examined. The assembly is raised in the storage rack so that its midpoint is several feet above the top of the rack. The detector head is positioned at the midpoint of the assembly for the verification measurement. A burnup profile can be obtained by performing measurements at various locations along the length of the assembly.

Each arm of the FORK contains two fission chambers to measure the yield of neutrons and one ion chamber to measure gross gamma-ray emission. A battery-powered electronics unit is used to supply all power to the detectors, collect and analyze the detector outputs, and perform necessary calculations and documentation.

Analysis of the measurements is simplified by the fact that the fuel assemblies of immediate interest have been cooled for over five years, leaving only a few gamma and neutron sources.

The predominant neutron emitter is curium-244, which is formed by successive neutron capture beginning with uranium-238, and decays following discharge with a half-life of 18y. The neutron signal follows a power law relationship with burnup, in which the neutron signal increases with burnup to about the fourth power. The neutron signal is therefore very sensitive to burnup The major gamma emitter is cesium-137, a fission product that decays with a half-life of 30y. The production of cesium-137 is essentially a linear function of burnup. The combination of the gamma and neutron measurements allows both the burnup and the cooling time of each assembly to be checked.

OCONEE SPENT FUEL

Oconee Nuclear Station is a three unit generating site utilizing Babcock and Wilcox 2568 MWt Pressurized Water Reactors. Duke Power Company began commercial operation on the site in 1973. The FORK measurements were performed in the spent fuel storage pool that is shared by Units 1 and 2. The demineralized water in the pool contained approximately 2000 ppm boron. There is about 25 feet of water above the top of the storage racks. During testing the fuel assemblies were lifted in the storage racks by means of an auxiliary hoist mounted on the Stearns-Roger fuel handling bridge. No assembly was completely removed from the rack. The spent fuel assemblies are a Babcock and Wilcox 15 X 15 design that accepts separate control components such as control rods, burnable poison rods, and neutron source rods. Each assembly contains 208 fuel rods and 16 guide tubes. The maximum cross section is 8.54 inches, and overall length is 165.6 inches. The nominal uranium weight is 464 kilograms.

PROCEDURES

The FORK detector was suspended from a moveable carriage on the fuel handling bridge over the spent fuel pool. The detector head was fixed at a location about six feet above the top of the storage rack in the spent fuel pool. Each selected assembly was raised in its rack until the detector was at the center point of the asssembly. The detector was placed in contact with the assembly, and data were accumulated for 100 seconds to ensure that more than 10,000 neutron counts were obtained. The ion chamber (gamma) current reaches its maximum value in about one second.

RESULTS

Ninety-three assemblies were measured in about 3.5 working days of operation. The initial enrichment of the assemblies ranged from 2.91 to 3.92 weight per cent uranium-235. The range in burnup was from 20.3 to 58.3 GWd/tU. The cooling times varied from 4.2 to 14.8y. Background data (no raised assembly) were taken each time the location of the detector was changed appreciably, and were found to be less than one percent of the signal with the assembly in place.

The observed data were extrapolated back to the date of discharge for each assembly. The gamma data fit an inverse time curve, and could also fit a 30y exponential decay (cesium-137). The gamma-ray data correlated with the reactor records for burnup ± 25%, with no significant anomalies.

The neutron data were extrapolated using an exponential decay of half-life 18y, the half-life of the principal neutron emitter, curium-244. The extrapolated neutron data are shown in Figure 2., a log-log plot of neutron signal vs. burnup (reactor record) for each assembly. The data are shown with and without a correction for the initial enrichment of the assemblies. The neutron signal depends on the initial enrichment since curium-244 is produced by activation rather than fission. The "uncorrected data" can be fit by a power law curve such that the average absolute deviation in burnup is about 10%. This would be the best fit to the data if the initial enrichments were unknown. An enrichment correction factor was derived for the IAEA application using the CINDER isotope production code benchmarked against destructive analysis of spent fuel from several reactors. The correction factor (applied to the neutron signal) varied from -7% to +40% for these data. The "Enrichment Corrected Data" are fit by the calibration curve shown, in which the neutron signal is proportional to the 3.81 power of the burnup. This value matches closely the values observed in earlier operations with the FORK system. With the enrichment correction applied, the data have an average absolute deviation in burnup from the calibration curve of about 2.5%.

The two data points marked "Outliers-not explained" indicate two assemblies that exhibited much higher neutron signals than expected from the burnup records. Both sets of neutron detectors indicated this anomalous result, but the gamma signals fell within the expected range. The anomalies were noted at the time of measurement and re-measured, but since the objective of this operation was to examine as many assemblies as possible, the two assemblies were not investigated further. For the purposes of this test it is adequate to determine that anomalous assemblies can be detected. The exact source of the anomalous signals has not yet been identified.

UTILITY COMMENTS

In genera', he FORK detector performed quite well and proved relatively easy to set up and operate. It would provide an acceptable means for verifying burnup of fuel assemblies prior to loading into a burnup credit cask or canister. The preferred mode of operation would be to verify burnup of all the assemblies to be loaded in a specified time period in a single sustained campaign, and segregate the acceptable assemblies in a seperate section of the spent fuel pool until they are actually loaded. It would be preferable to have this campaign performed by a certified vendor, rather than to commit utility resources and personnel to a training, certification, and maintenance program. A number of specific recommendations concerning operations, interfaces, shielding, radiation protection, decontamination, etc., have been noted, and will be integrated with further tests of the FORK at utilities.

CONCLUSIONS

The FORK measurements correlated with the Oconee reactor records to a high degree of accuracy (2.5%). Two anomalous assemblies were detected that would require further study in a verification campaign. The system proved to be compatible with utility operations, and appears to be adequate to verify reactor records for assemblies to be loaded into burnup credit casks.

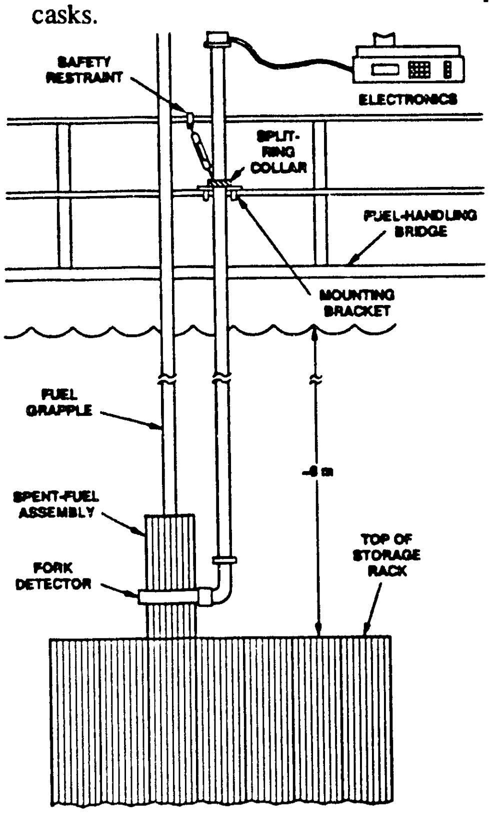

FIG. 1 FORK ARRANGEMENT

ACKNOWLEDGEMENTS

Richard Siebelist of LANL prepared the FORK equipment and participated in all the measurements. The authors appreciate the help of the staff at Oconee Nuclear Station and Duke Power Company in the training, planning, and execution of this operation. The essential support of EPRI is very much appreciated.

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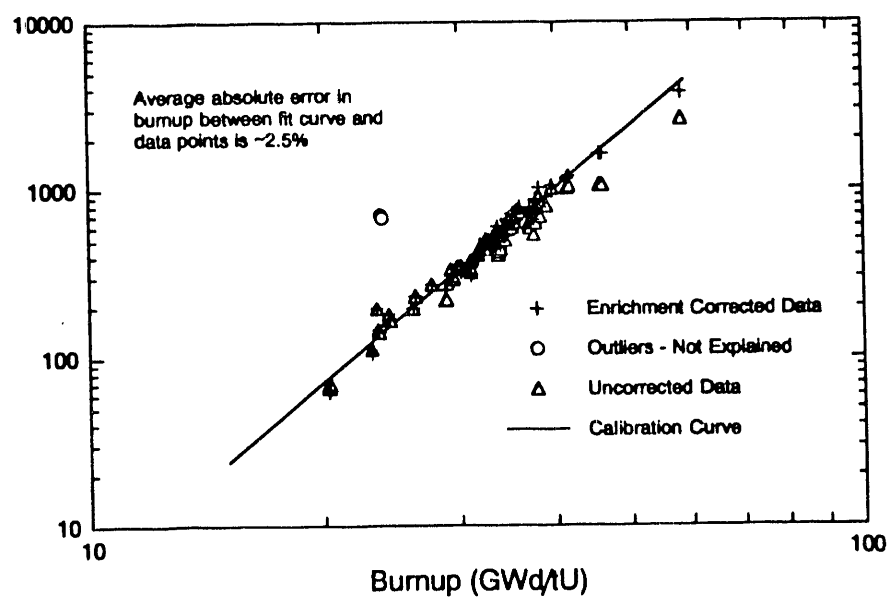

FIG. 2 NEUTRON SIGNAL VS. BURNUP

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