Burnup Verification Measurements for Spent Nuclear Fuel*

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INTRODUCTION

The U.S. Department of Energy is presently scheduled to begin transport of spent fuel from utility reactor sites to a federal storage facility in 1998, using casks certified by the U.S. Nuclear Regulatory Commission. Maximizing the capacity of transport casks now being designed is essential to reduce costs and to maintain public and occupational risks "as low as reasonably achievable." The spent fuel to be transported in the immediate future has been cooled for a decade or more, and its radiation output is greatly reduced due to natural radioactive decay. The reduced requirements for heat dissipation and radiation shielding allow more spent fuel to be loaded into a cask of a fixed gross weight. Conceptually, cask capacity can be increased to the point where, under certain conditions, nuclear criticality safety must be considered in the design of transport casks (Sanders and Westfall, 1990). The reduced reactivity of the "burned up" fuel permits about twice as many spent assemblies to be safely transported in each cask as could be accommodated if the assemblies were fresh, unburned fuel. The loaded casks are to be transported in a dry condition. Nuclear criticality becomes possible during the transport of spent fuel only if: (1) the cask is involved in an accident, (2) the accident is severe enough to breach the cask, (3) the cask is flooded with water that contains a low level of neutron absorbers, and (4) the fuel has unacceptably high reactivity.

The criticality of the loaded, flooded cask can be calculated from three parameters which are cataloged at the reactor for each assembly. The three factors are: initial enrichment, usually expressed as weight percent U235; burnup (gigawatt days per metric tonne of U metal); and the cooling time (years) (Brady and Sanders, 1991). Casks designed taking advantage of the reduced reactivity of the burned fuel to calculate criticality are called "burnup credit" casks. The characteristics of fuel acceptable for loading into a burnup credit cask can be specified by a loading curve as shown in the example of Figure 1. Acceptable assemblies are configured in the cask so that, under flooded conditions, the system is less than 95% of critical. The curve delineates the minimum burnup credit required for a particular initial enrichment. The use of burnup credit in cask design raises the possibility that a cask could be misloaded with unacceptable fuel, if such assemblies are present. Radiation measurements can be used to help prevent misloading of a cask by verifying that each assembly has the appropriate characteristics.

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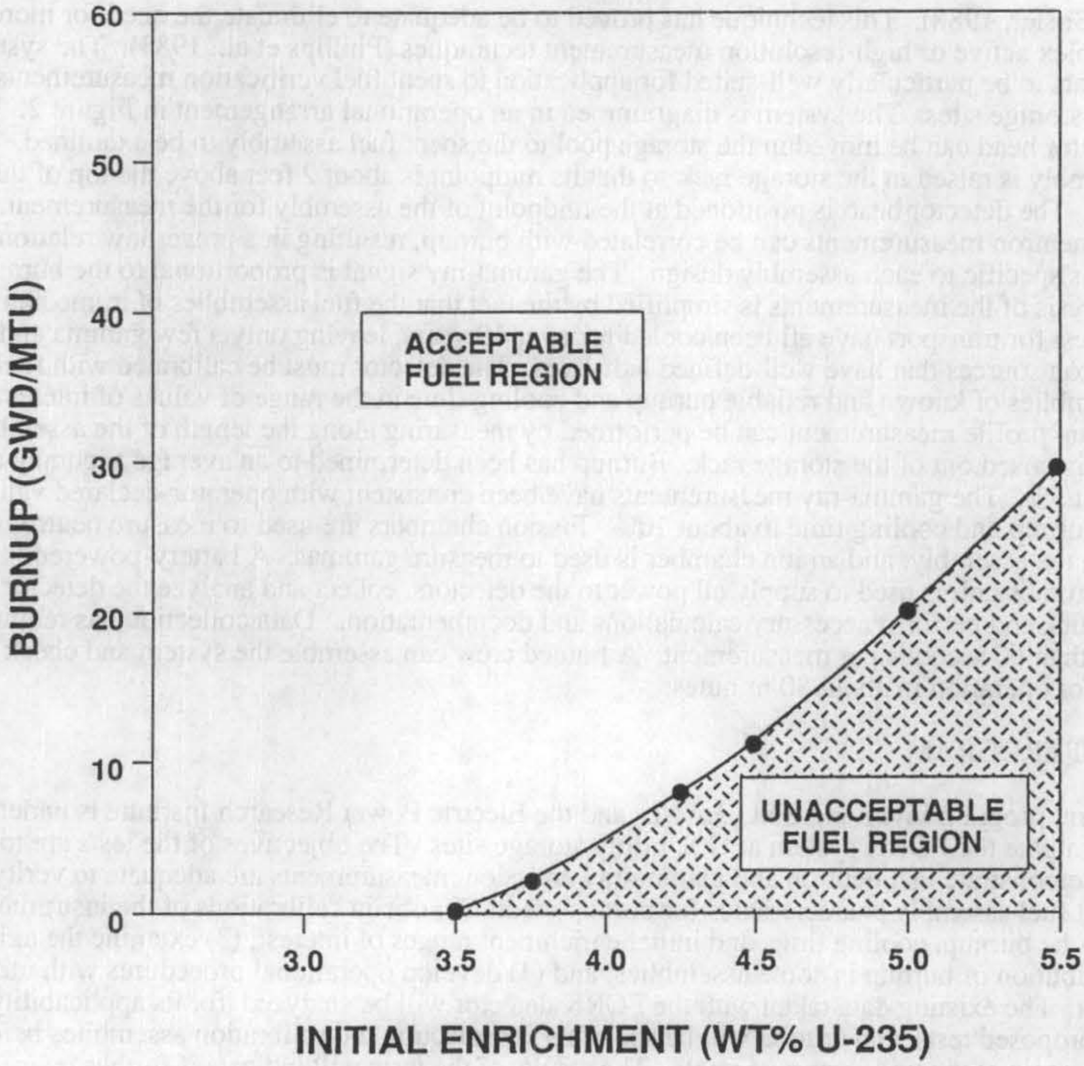

Figure 1. Loading Curve for a Burnup Credit Cask

RADIATION MEASUREMENTS

Studies have concluded that the utility-supplied data on burnup, cooling time, and initial enrichment is of greater accuracy and reliability than could be provided by additional radiation measurements on spent fuel assemblies (ORNL, 1988). However, radiation measurements can be used to help prevent misloading of casks with unacceptable fuel by screening assemblies to confirm reactor records and to detect accidental selection of overreactive assemblies. To confirm reactor records, it is sufficient to determine burnup and cooling time, since the initial enrichment is common to a large number of assemblies and generally is not in question. For purposes of screening fuel for burnup credit, it is necessary only to establish that burnup is greater than the burnup credit required for the cask at the initial enrichment of the assembly, and that the cooling time is greater than 5 years.

The FORK measurement system, designed by Los Alamos National Laboratory (LANL), has been used for many years by the International Atomic Energy Agency to verify reactor records worldwide by measuring neutron and gamma-ray emissions from spent fuel assemblies (Rinard and Bosler, 1988). This technique has proved to be adequate to eliminate the need for more complex active or high-resolution measurement techniques (Phillips et al., 1983). 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 an operational arrangement in Figure 2. The detector head can be 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 about 2 feet above the top of the rack. The detector head is positioned at the midpoint of the assembly for the measurement. The neutron measurements can be correlated with burnup, resulting in a power law relationship that is specific to each assembly design. The gamma-ray signal is proportional to the burnup. Analysis of the measurements is simplified by the fact that the fuel assemblies of immediate interest for transport have all been cooled for over 10 years, leaving only a few gamma and neutron sources that have well-defined half-lives. The detector must be calibrated with fuel assemblies of known and reliable burnup and cooling time in the range of values of interest. A burnup profile measurement can be performed by measuring along the length of the assembly as it is raised out of the storage rack. Burnup has been determined to an average accuracy of about 5%. The gamma-ray measurements have been consistent with operator-declared values for burnup and cooling time to about 10%. Fission chambers are used to measure neutrons from the assembly, and an ion chamber is used to measure gammas. 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. Data collection has required less than 60 seconds per measurement. A trained crew can assemble the system and check it out for operation in about 30 minutes.

TEST PROGRAM

A joint program involving SNL, LANL, and the Electric Power Research Institute is under way to evaluate the FORK system at U.S. utility storage sites. The objectives of the tests are to: (1) demonstrate that neutron and gamma-ray emission measurements are adequate to verify spent fuel assembly characteristics for burnup credit; (2) obtain calibrations of the instrument over the burnup, cooling time, and initial enrichment ranges of interest; (3) examine the axial distribution of burnup in some assemblies; and (4) develop operational procedures with utility input. The existing data taken with the FORK detector will be analyzed for its applicability to the proposed tests, and criteria will be specified for selecting the calibration assemblies before tests begin at the utility storage pools. The results of the tests will indicate if further development of the FORK detector is required for the burnup credit application. An important part of these tests is the development of operational procedures that meet the requirements of the utilities and the management of the spent fuel storage pools. It is imperative that any measurement system selected be as simple, inexpensive, quick, and nonintrusive as possible.

SUMMARY

The number of shipments of spent fuel could potentially be reduced by about one-half by the use of burnup credit casks, considerably enhancing public and occupational safety, and reducing costs. Radiation measurements can be used in burnup credit operations to help prevent misloading of fuel that does not meet the minimum specifications for a particular cask design. Neutron and gamma-ray yield measurements are proposed as a means of qualifying spent fuel assemblies. Plans are under way to evaluate the FORK measurement system at utility spent fuel storage pools.

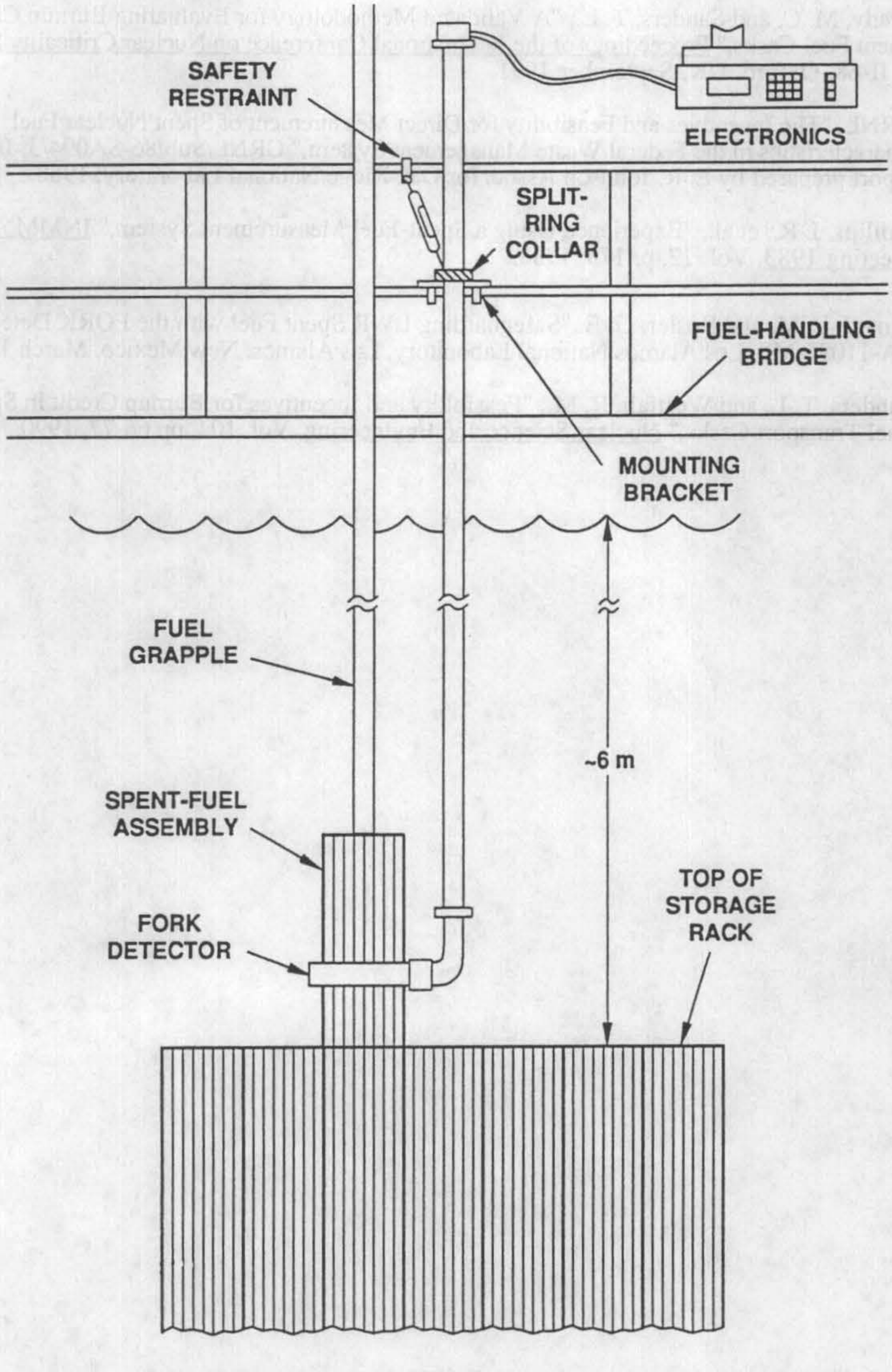

Figure 2. Sketch of a FORK Detector in Operation

REFERENCES

Brady, M. C. and Sanders, T. L., "A Validated Methodology for Evaluating Burnup Credit in Spent Fuel Casks," Proceedings of the International Conference on Nuclear Criticality Safety, p. II-68, Oxford, UK, September 1991.

ORNL, "The Incentives and Feasibility for Direct Measurement of Spent Nuclear Fuel Characteristics in the Federal Waste Management System," ORNL/Sub/86-SA094/3, JAI-296, report prepared by E. R. Johnson Assoc. for Oak Ridge National Laboratory, 1988.

Phillips, J. R., et al., "Experience Using a Spent-Fuel Measurement System," INMM Annual Meeting 1983, Vol. 12, p. 175, 1983.

Rinard, P. M. and Bosler, G. E.,"Safeguarding LWR Spent Fuel with the FORK Detector," LA-11096-MS, Los Alamos National Laboratory, Los Alamos, New Mexico, March 1988.

Sanders, T. L. and Westfall, R. M., "Feasibility and Incentives for Burnup Credit in Spent-Fuel Transport Casks," Nuclear Science and Engineering, Vol. 104, pp 66-77, 1990.