DOE/RW/00134--M97-001

CONF-970607--10

# Appropriate Burnup Measurements for Transportation Burnup Credit

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## I. Introduction

On May 31, 1995, DOE submitted the "Topical Report on Actinide-Only Burnup Credit for PWR Spent Nuclear Fuel Packages[1]" to the NRC for approval of a generic methodology to analyze spent fuel packages to gain burnup credit. The methodology will be used by cask vendors who will use various neutronic codes but will follow the same steps. As part of the methodology it is required that a burnup verification measurement be performed. This is consistent with the requirements in the ANSI/ANS-8.17 standard on "Criticality Safety Criteria for the Handling, Storage and Transportation of LWR Fuel Outside Reactors[2]" which states a verification must be performed to take credit for burnup. In the original version of the Topical Report submitted to the NRC the burnup measurement was discussed by using an example detector, the fork detector.[3,4] Since the measurement of burnup is becoming commercialized by the introduction of a measuring device by BNFL,[5] the Rev. 1 version of the Topical Report (issued around 3/31/97) contains a set of measurement specifications. This paper addresses two of those specifications.

## II. Verification Philosophy

It is important to state that the measurement for burnup is aimed at verification of the utility reactor record burnup. The criticality analysis will use the reactor record burnup and the reactor record uncertainty. The measured burnup and uncertainty will not be used in the criticality analysis. It will only be used for verification purposes. The reactor record burnup is considered more accurate than the measured burnup. Two reasons for this follow. First, the average error in the reactor record burnup is the error in the reactor power (combined with the error in MTU). The utilities have strong incentives to know the reactor power and the error is quite low. Second, the reactor record burnup comes from integration of piecewise data where each entry is small compared to the total burnup. Transcription errors can be checked by summing up the burnups of all assemblies and comparing this sum to the energy produced by the reactor. Hence, the measurement is designed to detect gross errors and then to reject loading these assemblies.

The level of confirmation of the burnup should be consistent with the reactivity margin of the cask system. This statement is needed to set the accuracy requirements for the detectors. The verification measurement limits the maximum error in the reactor records. The maximum acceptable error in the reactor records is set by a determination of an acceptable reduction in the margin.

## DISCLAIMER

## III. Measurement System Design Requirements

There are seven areas of requirements for the measurement system described in Rev. 1 of the Topical Report. They are: 1) Rejection Criteria, 2) Measurement Accuracy, 3) Correct Horizontal Averaging, 4) Operational Considerations, 5) Characteristics of Assemblies to be Measured, 6) Analytical Tools, and 7) Spent Fuel Pool Compatibility. This paper will concentrate on the first two.

### III.A Rejection Criteria

An assembly should be rejected if the reactor record and verification measurement are in disagreement. Disagreement is defined as no overlapping of the 95% prediction bands of the reactor records and the measurement system. Crudely this is estimated as a disagreement greater than $2*\sigma_{reactor\ record} + 2*\sigma_{measurement}$. This definition results in rejection of assemblies when there is greater than 95% confidence that there is some problem with either the measurement or the reactor record. To limit the maxium uncertainties, this concept is turned into a fixed number. Since the current estimate of easily achievable accuracy of the reactor record and measurement systems is about 5% ($2\sigma$) each, a reasonable fixed number of 10% is selected. Simply stated, any assembly where the declared measured value and reactor record value deviate by more than 10% will be rejected.

In the philosophy section it was pointed out that the consequences of this selection must be acceptable. Since the uncertainty in the reactor record is accounted for in the methodology, the only "uncovered" possible error is: 10% minus reactor record uncertainty. The maximum burnup allowed for credit is 50 GWD/MTU. Therefore, the maximum deviation would be 5 GWD/MTU minus the reactor record uncertainty. The reactivity associated with this deviation is much less than the worth of the fission products which are conservatively not considered for actinide-only burnup credit. Hence the consequences of the selection of this 10% criterion are clearly acceptable.

### III.B Measurement Accuracy

The rejection criteria can still be met with a random detector. It would have a large number of rejections yet an occasional "hit." It is desirable to control this with a requirement on the measurement system. Measurement systems exist that depend on the reactor records for the calibration, e.g.,: the fork detector.[3,4] Those will be called dependent systems. The other type of measurement systems, independent systems, establish their own measurement uncertainty.

In a dependent measurement system the calibration curve contains the uncertainties of both the reactor records and the measurement system. The accuracy of the calibration curve depends on the number of assemblies measured. In order to establish the proper number of measurements a criterion must be set. This criterion is that the 95% prediction band of the measurement must be less than or equal to 10%. The standard statistical equation for the prediction band[6] yields the following requirement:

$$0.1*BU \geq t_{\alpha/2,n-2}\sqrt{\left(\frac{n+1}{n}+\frac{(x-\bar{x})^2}{S_{xx}}\right)\frac{SS_R}{n-2}}$$

where:

$$S_{xx} \equiv \sum_{i=1}^{n}(x_i-\bar{x})^2$$

and

$$SS_R \equiv \sum_{i=1}^{n}(y_i-y_{fit})^2$$

For independent measurement systems, a similar 10% based requirement is set. Since the dependent system contained a statistical combination of uncertainties in the reactor record and measurement, it is appropriate to do the same for independent measurement systems. When the standard deviations are known the correct way to statistically combine the standard deviations is to take the square root of the sum of the squares. This statistically combined uncertainty should be 10%. To set the measurement accuracy requirement, it is nominally assumed that the reactor record uncertainty is 5%. This yields a requirement on the independent measurement system of 9% ($2\sigma$).

## IV. Summary

The measurement system requirements have been tested against data from the fork detector and the BNFL detector and are achievable. The only assemblies rejected are those for which a clear error in the records or measurement is observed. The requirements assure safe operation without extra cost.

## References


1. "Topical Report on Actinide-Only Burnup Credit for PWR Spent Nuclear Fuel Packages," DOE/RW-0472 Rev. 0 (May,1995), Rev. 1 (March, 1997), U. S. Department of Energy, Office of Civilian Radioactive Waste Management.

2. "Criticality safety criteria for the handling, storage, and transportation of LWR fuel outside reactors," ANSI/ANS-8.17-1984, American Nuclear Society.

3. R. I. Ewing, G. E. Bosler, R. Siebelist, and G. Walden, "Burnup Verification Measurements on Spent Fuel Assemblies at Oconee Nuclear Station," EPRI TR-103591, Electric Power Research Institute (January, 1994).

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5. A. S. Chesterman, et. al., "Preliminary Report on Arkansas Nuclear One PWR Spent Fuel Measurements - 1996," BNFL TR-0267-00-50-001, BNFL Instruments Limited, Pelham House, Calderbridge, Cumbria CA20 1DB England (September 26, 1996).

6. S. M. Ross, *Introduction to Probability and Statistics for Engineers and Scientists*. Wiley and Sons (1987).