APPLICATION OF REACTIVITY METHOD TO MTR FUEL BURN-UP MEASUREMENT

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ABSTRACT

Fuel element burn-up has been measured for the first time by reactivity method in a MTR reactor. The measurement was performed in RP-10 reactor of Peruvian Institute for Nuclear Energy (IPEN) in Lima. It is a pool type 10MW material testing reactor using standard 20% enriched uranium plate type fuel elements. A fresh element and an element with well defined burn-up were selected as reference elements. Several elements in the core were selected for burn-up measurement. Each of them was replaced in its original position by both reference elements. Change in reactivity was measured using control rod calibration curve. The burn-up reactivity worth of fuel elements was plotted as a function of their calculated burn-up. Corrected burn-up values of the measured fuel elements were calculated using the fitting function at experimental reactivity for all elements. Good agreement between measured and calculated burn-up values was observed indicating that the reactivity method can be successfully applied also to MTR fuel element burn-up determination.

1. CONTENT

The most usual non destructive methods for burn up determination are reactor calculations and gamma spectrometry. As an alternative, a semi-experimental method for determining TRIGA reactor fuel burn-up was proposed [1]. It is based on theoretical background that the reactivity has a linear (or at least simple polynomial) dependence on the burn-up. Burn-up of selected fuel elements can be determined by measuring their reactivity worth at a selected position in the core and comparing them to reactivity worth of reference elements with known burn-up. The method was originally developed in TRIGA reactors. By the original method the measured fuel elements are not part of the experimental core configuration. For application in RP-10 reactor, this method was modified. The reactivity worth of measured fuel elements was measured in their original positions while the elements remained part of the experimental core. Each of them was replaced in its original position by two reference elements and the reactivity change was measured. Change in reactivity was measured using the control rod calibration curve.

The experiment was performed at zero power and xenon free conditions. Normal operating core configuration (N° 20) was used, except that one element was extracted from the core in order to reduce the excess reactivity. The calibration curve of the control rod BC1 was measured before the experiment by standard rod exchange method and using in-hour equation. The experimental conditions of the reactor are presented in the reference [2].

Two reference elements were selected: one fresh (NN-025, denoted RF) and one with well defined and high burn-up (NN-008, denoted RB). The burn-up of all fuel elements was determined before the experiment by reactor calculations. Fuel management computer code package based on WIMS and CITATION [3], which is normally used for fuel management calculations in RP-10, was applied. It was calculated in two group approximation by considering entire reactor burn-up history (20 operating cores, actual burn-up cores 14-20). It was considered that the control rods are withdrawn during reactor operation. Total reactor burn-up was obtained from reactor operation log-book in terms of total energy produced (2032.41 MWd).

2. EXPERIMENTAL RESULTS

Thirteen fuel elements (denoted ME) were selected for measurement. Their positions in the core, identification numbers and WIMS/CITATION calculated burn-up are presented in first columns of Table 1 Control rod BC1 critical position and corresponding reactivity for reference elements RF and RB inserted in the location of each measured fuel element ME are presented in next four columns for all measured elements. Reactivity difference between fresh (RF) and burned (RB) reference element is calculated in next column for all

measured positions. Note that it varies for different positions in proportion to their neutron importance in the reactor. Normalized reactivity difference presented in the last column is proportional to neutron importance distribution.

Note that excess reactivity with measured fuel element in its original position is the same for all measured elements. Consequently, the BC1 control rod reactivity was the same in all steps for measured elements (1.578$). Using the reactivity values corresponding to the fresh RF and burned RB reference elements at the location of the measured fuel element ME one can determine the burn-up of the measured element by linear interpolation for each location. However, the accuracy of the measurement can be improved if the reactivity differences are normalized to eliminate the effect of neutron importance of measuring position such that the differences in reactivity worth between measured and reference fuel elements are only due to burn-up. The reactivity difference between measured and reference elements is divided by relative importance for given location (i.e., by normalized reactivity difference in last column of Table 1. Results are presented in Figure 1.

Table 1. Results of the measurements.

Step	Position	Measured fuel element	Calculated burn-up, (%)	Critical position (BC1), reference elements inserted (steps)		Control rod reactivity, reference elements inserted ($)		Reactivity change with respect to measured fuel element ($)		Reactivity difference RF-RB ($)	Norm. reactivity difference (RF–RB) / 1.21 ($)
		ME		RF	RB	RF	RB	RF	RB		
1	F-5	NN-004	50.0	10.0	43.1	0.082	1.287	1.496	0.291	1.21	1.00
2	F-6	NN-009	43.1	21.3	46.1	0.367	1.436	1.211	0.142	1.07	0.89
3	D-4	NN-013	35.9	36.5	49.0	0.970	1.583	0.608	-0.005	0.61	0.51
4	E-2	NN-017	22.6	41.8	51.6	1.223	1.715	0.355	-0.137	0.49	0.41
5	H-2	NN-021	14.7	46.0	52.3	1.431	1.750	0.147	-0.172	0.32	0.26
6	E-4	NN-002	47.1	24.0	46.5	0.452	1.456	1.126	0.122	1.00	0.83
7	H-4	NN-015	35.3	36.5	49.7	0.970	1.618	0.608	-0.040	0.65	0.54
8	D-3	NN-006	29.5	39.5	50.6	1.111	1.664	0.467	-0.086	0.55	0.46
9	H-5	NN-016	35.6	32.9	49.1	0.808	1.588	0.770	-0.010	0.78	0.65
10	H-6	NN-012	32.8	35.0	50.5	0.901	1.659	0.677	-0.081	0.76	0.63
11	G-4	NN-003	46.7	24.0	45.2	0.452	1.391	1.126	0.187	0.94	0.78
12	G-2	NN-018	22.6	43.4	51.6	1.302	1.715	0.276	-0.137	0.41	0.34
13	H-7	NN-022	6.3	46.4	54.8	1.451	1.877	0.127	-0.299	0.43	0.35

Discrete dots in Figure 1 correspond to normalized reactivity plotted against calculated (WIMS/CITATION) burn-up for all measured fuel elements. Theoretically, the reactivity ρ(BU) depends on burn-up, BU, approximately as a linear function (or low order polynomial) with short exponential contribution at low burn-up due to samarium build-up as shown in Eq.(1) below.

$$\rho(BU) \approx \alpha + \beta.BU + \gamma.\exp(-\delta.BU) \qquad (1)$$

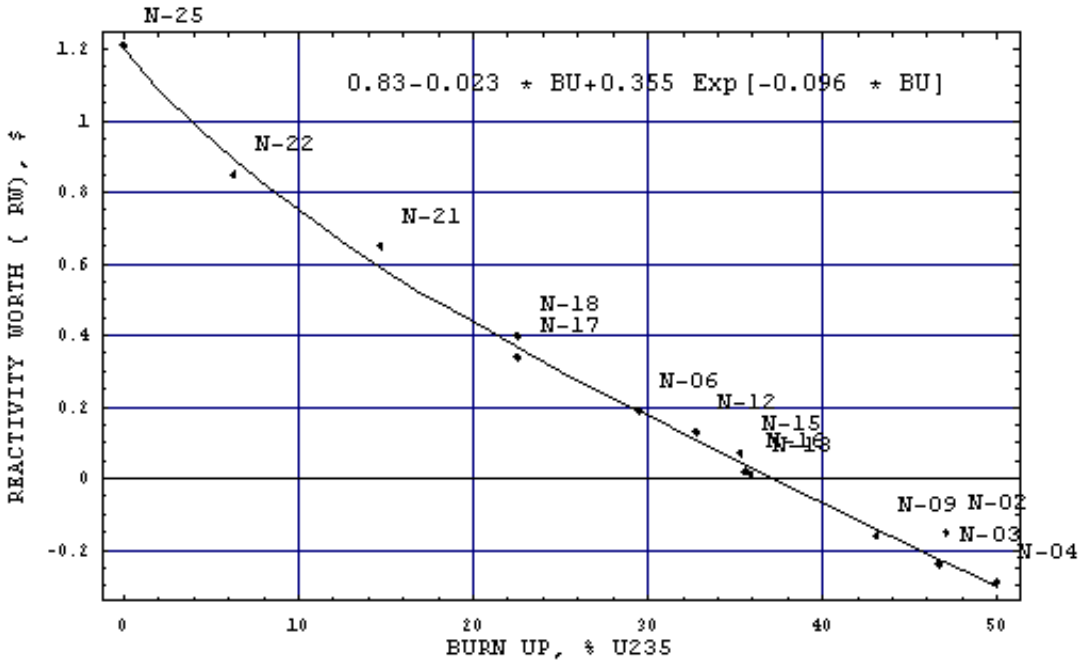

Figure 1. Measured fuel element reactivity as a function of their WIMS/CITATION calculated burn-up.

Solid line in Figure 1 corresponds to this function in which the coefficients were determined by least square fitting to experimental points. Note that the curve is determined in semi-experimental way as the burn-up is its independent variable. Deviations of the discrete measured points from the least square fitting curve are due to:

- Experimental error in reactivity measurement and error in burn-up distribution calculation.

The experimental error in reactivity was estimated by repeating certain measurements (reproducibility), measuring reactivity of the same element in original position and rotated for 180^0 around its vertical axis (influence of flux and burn-up gradient) and by evaluating the control rod calibration curve. The estimated error in measured relative reactivity is in the order of +/- 0.05$ (less than 0.05 relative errors).

The burn-up error depends on the accuracy of WIMS/CITATION calculations. As the calculation model is relatively simple (two-group diffusion approximation in X-Y geometry, control rods not considered) it is estimated that the burn-up relative error significantly exceeds the reactivity measurement relative error. According to the experience with similar computer code packages it is estimated to be 0.10.

Assuming that the deviation of the measured points from the fitting curve are due to burn-up errors, one can make corrections to the burn-up of particular elements by adjusting their measured reactivity to the fitting curve. Relative discrepancy between calculated and measured burn-up values is less than 0.05 [2] for almost all elements. Larger deviations are observed for fuel elements that spent their burn-up life near control rods or other core irregularities not considered in the burn-up calculations. In their case the measurements significantly improve the information on their actual burn-up.

3. CONCLUSIONS

Good agreement between measured and calculated burn-up values was observed indicating that the reactivity method can be successfully applied also to MTR fuel element burn-up determination. In future, we expect to compare the results of this method with gamma scanning for general validation.

4. REFERENCES

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