126

INFLUENCE OF DELAYED NEUTRON PARAMETER CALCULATION ACCURACY ON RESULTS OF MODELED VVER SCRAM EXPERIMENTS

V.G. Artemov, V.I. Gusev, R.E. Zinatullin, and A.S. Karpov
Alexandrov Research Institute of Technology, Sosnovy Bor, Russia

ABSTRACT

Using modeled VVER scram rod drop experiments, performed at the Rostov NPP, as an example, the influence of delayed neutron parameters on the modeling results was investigated. The delayed neutron parameter values were taken from both domestic and foreign nuclear databases.

Numerical modeling was carried out on the basis of SAPFIR_95&RC_VVER program package. Parameters of delayed neutrons were acquired from ENDF/B-VI and BNAB-78 validated data files.

It was demonstrated that using delay fraction data from different databases in reactivity meters led to significantly different reactivity results.

Based on the results of numerically modeled experiments, delayed neutron parameters providing the best agreement between calculated and measured data were selected and recommended for use in reactor calculations.

INTRODUCTION

Delayed neutron parameters affect the rate of neutronic processes occurring shortly after the core perturbation. The most widely spread scheme for neutronic process calculation is the scheme where all precursors (emitters) of delayed neutrons are divided into 6 groups. Effective group parameters of delayed neutrons are used in computer codes. Each group has effective delayed-neutron fraction β_m and effective decay constant λ_m.

Traditionally, neutron kinetics was analyzed using delayed neutron parameters obtained from macroscopic experiments. The most widely used was validated nuclear data based on G. R. Keepin's fundamental studies [1]. These delayed neutron data estimates have been used in creation of the BNAB-78 data file [2].

Since the issue of this paper [1] much information has been accumulated concerning nuclear debris emitting delayed neutrons. This made it possible to define group parameters of delayed neutrons as a sum of fission contributions from individual nuclides.

This large experimental base was used to obtain data on the yield of delayed neutrons, and it was recommended to add these validated data to ENDF/B-VI data file [3, 4]. The same data is taken as a base in BNAB-93 data file [5]. Based on different studies, the total fractions of

delayed neutrons can differ by 6 to 7%. Relative fractions α_m in some groups can differ by 15 to 20%.

Since Keepin's data (BNAB-78 data file) and modern data from ENDF/B-VI and BNAB-93 data files is used nowadays in practical calculations, differences between validated delayed neutron parameters of these data files can be defined as nuclear data uncertainty.

The following section of the report analyzes the modeled scram rod drop experiments using kinetic parameters taken from different nuclear databases. It was assessed how the selected system of nuclear data influences the modeling results and the correctness of measurements interpretation.

1. MODELING OF REACTIVITY METER READINGS USING DIFFERENT SETS OF KINETIC PARAMETERS

Two factors influencing the accuracy of rod drop experiments modeling results are as follows:
- nuclear data uncertainty;
- consideration of spatial effects.

Below are the results of modeling the reactivity meter readings in scram rod drop experiment carried out at the power unit #1 of the Rostov NPP.

Reactivity was measured using three out-of-core ionization chambers located in measuring channels #4, #14, #25 (see Figure 1).
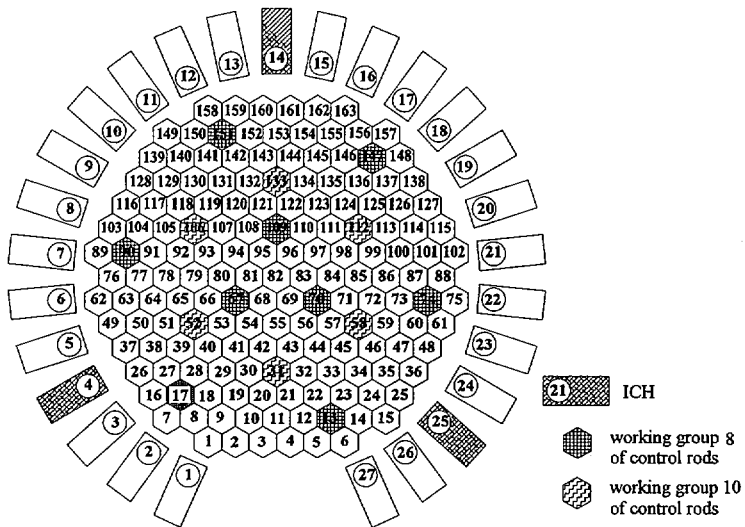

Fig. 1. Rostov NPP, power unit #1. Lay-out of ionization chambers (ICH)

When in primary positions, all groups of control rods are in the upwardmost position. Working control rod group 10 is immersed into the core to one-fifth of the core height. Scram rod drop was simulated with one rod of group 8 located in fuel assembly 17 being dropped into the core 30 sec later.

To check the sensitivity of reactivity measurement results to delayed neutron parameters, experimental neutron flux measurement data was used in conjunction with the models of reactivity meters having different delayed neutron parameters.

Figure 2 shows the results of modeling the reactivity meter readings based on ionization chamber currents registered after scram rod drop. Three sets of delayed neutron parameters were used in reactivity meter equations.
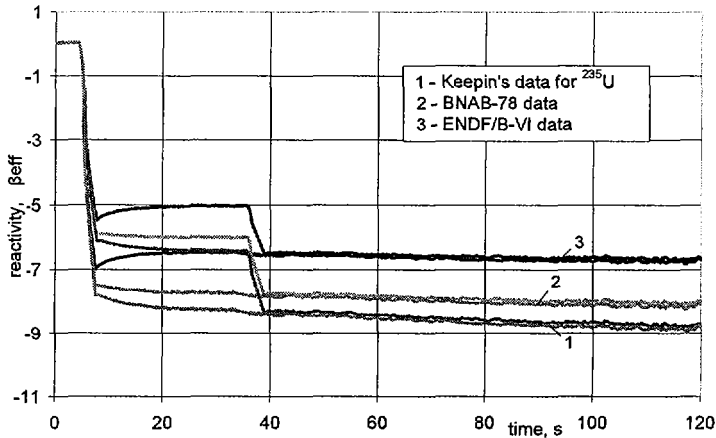

Fig. 2. Modeling of reactivity meters readings using different delayed neutron data sets

It can be seen that discrepancies between validated nuclear data lead to the uncertainty of reactivity calculations that can reach approx. 20%: 6.5 β_{eff} (ENDF/B-VI) and 8 β_{eff} (BNAB-78).

For on-site reactivity measurements using the standard reactivity meter, Keepin's delayed neutron parameters for one isotope ^{235}U (the lower curve in Fig. 2) were used. Comparison of "Keepin's data for ^{235}U" and "BNAB-78 data" curves shows that reactivity decay estimate increases by approx. 8 to 10%. The fact is that BNAB-78 data file also contains Keepin's parameters, but for isotope mixture (^{235}U, ^{238}U) simulating the core composition, which is surely more correctly.

The given value of 8 to 10% corresponds to the lowest limit of error. Using of delayed neutron data from the data files other than the BNAB-78 data file results in a larger error and, consequently, lower reactivity decay. (see Figure 2).

It is difficult to decide on the optimal delayed neutron parameters because measurement results are affected by systematic error arising from the influence of the so-called spatial effects. This error can be assessed with numerical modeling.

2. MODELING OF EXPERIMENTS USING SAPFIR 95&RC_VVER PROGRAM PACKAGE

Scram rod drop experiments carried out during startup of power unit #1 at the Rostov NPP were simulated with SAPFIR_95&RC_VVER program package by solving nonstationary diffusion equation.

In reality, the set of parameters that would be optimal for the given core composition is not known and can be determined only from detailed calculations.

Figure 3 shows the results of modeling the real experiment on scram efficiency assessment by scram rod drop method.
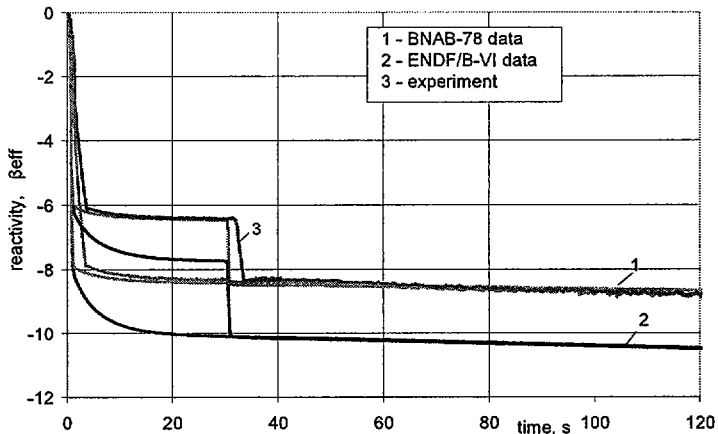

Fig. 3 Results of modeling the scram rod drop experiment using different sets of delayed neutron data in kinetic equations

The readings of reactivity meters connected to out-of-core ionization chambers have been simulated. Density of neutron flux from the fuel assemblies that are the closest to measuring channels is averaged with weight function. Scram rod drop and neutron flux change are numerically modeled using kinetic parameters taken from BNAB-78 and ENDF/B-VI data files.

Results of reactivity change modeling are compared with the dependences obtained by processing the ionization chamber readings with inverse kinetic equation method (hereinafter referred to as "IKE method") using delayed neutron parameter for ^{235}U (as in real experiment). The results of modeling with BNAB-78 data are in the best agreement with the experiment. Discrepancy between experimental and calculated data is no more than 5%.

912

Using the ENDF/B-VI delayed neutron parameters has resulted in a larger discrepancy between calculation and measurements results.

Adequate simulation of the experiment with the SAPFIR95&RC VVER program package using BNAB-78 kinetic data makes it possible to assess the systematic errors for scram efficiency measurements (see Figure 4).

The chart legend reads:
1 - Keeping's data for 235U
2 - BNAB-78 data
3 - direct calculation with RC program

$$\Delta\rho = \left(\frac{1}{k_{ef}^1} - \frac{1}{k_{ef}^2}\right)\bigg/\beta_{ef}$$
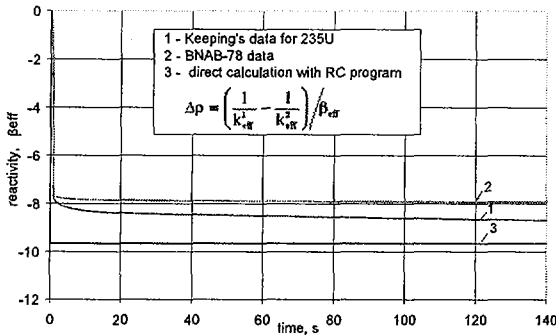
Fig. 4. Assessment of systematic error for scram efficiency measurements depending on kinetic data sets used in reactivity meter. BNAB-78 kinetic data is used in kinetic equations.

A discrepancy between reactivity curves 1 and 2 characterizes the error arising from using kinetic parameters not corresponding to the parameters of core isotope mixture. A discrepancy between reactivity curves 2 and 3 characterizes the error arising from the influence of spatial effects. This error can be eliminated by using computed corrections.

Analogous investigations of experiments on measuring the efficiency of single control rods have demonstrated that if with rod drop the core is perturbed by less than 0.1 β_{eff}, asymptotic distribution of neutron flux is reached within measurement period, and the readings of reactivity meters connected to different ionization chambers equalize. Figure 5 shows the results of modeling the drop of single control rod of group 10.
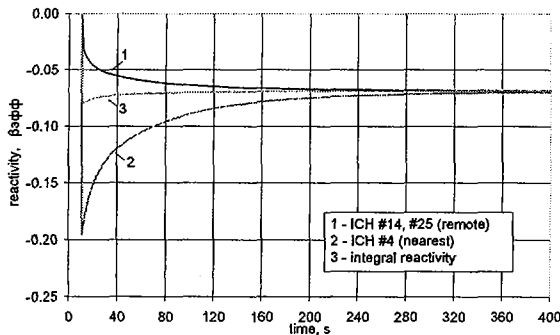

The chart legend reads:
1 - ICH #14, #25 (remote)
2 - ICH #4 (nearest)
3 - integral reactivity

Fig. 5. Modeling of rod drop

913

In this case, the relative reactivity measurement error arising from the influence of spatial effects is too small to make a difference, but the error resulting from parameters uncertainty used in reactivity meter equations remains and does not depend on perturbation value.

Table below shows the results of calculating single control rods efficiency. The results were obtained by modeling reactivity meter readings and using the difference of neutron multiplication factor values.

Table   Assessment of efficiency of single control rods

Number of control rod group	Number of fuel assembly with control rod being dropped	$\Delta\rho = \left(\dfrac{1}{k_{eff}^1} - \dfrac{1}{k_{eff}^2} \right)$	Numerical experiments		Experimental results. Reactivity meter parameters for ^{235}U
			Reactivity meter parameters (BNAB-78)	Reactivity meter parameters for ^{235}U	
1	2	3	4	5	6
10	52	0.0716	0.0718[*)	0.0766[*) (0.0904)[**)	0.080
9	155	0.0971	0.0982[*)	0.105[*) (0.125)[**)	0.110
8	151	0.0982	0.0997[*)	0.107[*) (0.127)[**)	0.107

[*) BNAB-78 delayed neutron data is used in kinetic equations for core modeling.
[**) ENDF/B-VI delayed neutron data is used in kinetic equations for core modeling.

Column 6 presents the experimental results of control rods efficiency measurements using standard reactivity meters with Keepin's delayed neutron parameters for ^{235}U. The results of numerical modeling (column 5) differ from experimental results (column 6) by approx. 5% provided core modeling is done with BNAB-78 delayed neutron data and standard reactivity meter parameters are used for IKE method. Using of ENDF/B-VI delayed neutron parameters in kinetic equations (see bracketed data in column 5) results in a sufficiently larger error.

Control rod efficiency calculated as the difference of neutron multiplication factors (column 3) and using IKE method (columns 4) are practically similar, which points to the fact that spatial effects have no impact on measurement results. As with scram efficiency modeling, using of ^{235}U delayed neutron data in reactivity meter overrates efficiency by approx. 7%.

3. DISCUSSION OF RESULTS

The obtained results show a general consistent pattern of reactivity effects measurements with IKE method: the reactivity measurement error arising from non-conformity of delayed neutron parameters used in reactivity meter to the core composition is systematic and not much dependent on the value and character of perturbation. This shall be taken into account particularly for measuring differential efficiency of control rods and reactivity coefficients.

The above calculated results were obtained for fresh core loading pattern. Isotopic composition and, as a consequence, delayed neutron parameters vary with burnup. These variations can be accounted only in numerical modeling. It is also important to make the right choice of nuclear data file.

914

Based on the performed numerical analyses, the conclusions are as follows:

- Using of delayed neutron data from different nuclear data files (BNAB-78, ENDF/B-VI etc.) for reactivity measurements can result in the reactivity effects uncertainty up to 20%.

- Correct assessment of reactivity effects is possible, if delayed neutron data in reactivity meter is in agreement with fissile isotope mixture composition at the time of measurements. Using of fixed delayed neutron parameters ("hardwired" in reactivity meter) requires drawing on the computed corrections obtained by modeling of experimental conditions.

- Modeled VVER experiments have shown that using of BNAB-78 delayed neutron data results in the best agreement between calculated and measured results.

CONCLUSIONS

The numerical results presented in this paper demonstrate the necessity to perform full-scale modeling of experiments for correct interpretation of reactivity measurements with IKE method.

ABBREVIATIONS:

NPP	—	nuclear power plant
ICH	—	ionization chamber
IKE	—	inverse kinetic equation
β_{eff}	—	effective fraction of delayed neutrons
$\Delta\rho$	—	reactivity change
k_{eff}^1, k_{eff}^2	—	initial and finite values of neutron multiplication factor

REFERENCES

1. G. R. Keepin *Principal physics of nuclear reactor kinetics.*-- M.: Atomizdat, 1967

2. L.P. Abagyan *Group constants for reactor and scram calculations.*-- M.: Energoizdat, 1981

3. England T. R., Wilson W. B., Schenter R. E. *Aggregate delayed neutron intensities and spectra using augmented ENDF/B-V precursor data.*-Nucl. Sci. Eng., 1983,vol.85, p.139

4. Brady M. C. and England T. R., *Delayed Neutron Data and Group Parameteres for 43 Fissioning Systems.*- Nucl. Sci. Eng., 1989, vol.103, p.129-149

5. S. V. Zabrodskaya, M. N. Nikolaev, A. M. Tsibulya *Delayed neutron data in BNAB-93.* -- VANT, Nuclear constants. Edition 1, m., 1998