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GENERATION OF CONSISTENT CONSERVATIVE CROSS SECTION DATA FOR THE COUPLED SYSTEM CODE ATHLET-QUABOX/CUBBOX

Kiril Velkov and **Siegfried Langenbuch**
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH
85748 Garching, Germany
Kiril.Velkov@grs.de; Siegfried.Langenbuch@grs.de

ABSTRACT

The paper gives an overview on first experiences in generation and application of conservative two group assembly homogenized cross section data for the couple system code ATHLET-QUABOX/CUBBOX. A methodology is worked out based on adapting the macroscopic scattering cross sections, which allows to convert the integral reactor void reactivity curve in a predefined manner e.g. from a steep to more flat dependence. The studies will be applied to ATWS analyses.

Key Words: Conservative cross section data, Void reactivity, ATHLET, QUABOX/CUBBOX, ATWS

1. INTRODUCTION

The coupled codes like ATHLET-QUABOX/CUBBOX [1, 2, 3] with 3D neutron kinetics are applied for specified core loadings. The core loading is defined by the fuel and fuel assembly design, the arrangement of fuel assemblies in the core, the burn-up condition and operational parameters like boron concentration, coolant temperature and Xenon concentration. The corresponding reactivity characteristics of the core are defined by the nuclear data.

For safety studies it may be desirable to adjust the reactivity characteristics in a predefined manner. This is easily achieved in point kinetics calculations by adjusting the reactivity coefficients or reactivity functions. In space-dependent core calculations the reactivity characteristics are determined by the nuclear cross-section data. Up to now, no systematic approach exists to determine consistent cross section data for specified reactivity characteristics. This paper describes a first approach to treat this problem.

The intended application of the method will be the analysis of ATWS cases. Practically, for these ATWS cases the void reactivity curves of cycle specific conditions are compared with limiting void reactivity curves. The plant transient calculations have been mainly performed applying point kinetics models in the thermal-hydraulic system code, because the reactivity feedback coefficients can be easily varied in the predefined manner. The degree of conservatism depends on the slope of the void reactivity curve. Supplementary, coupled calculations are performed for specified core loadings for confirmation of results for limiting values like the maximum pressure in the primary loop and the DNB margin.

2. PROBLEM DESCRIPTION AND APPROACH OF SOLUTION

2.1. Description of problem

The objective of the performed study is a physically consistent reduction of the moderator density effect or void reactivity effect of a PWR. At the same time other reactivity characteristics of the core like the Doppler effect and the fission rates should be kept unchanged. An adaptation of the nuclear cross-sections is required by the coupled code ATHLET-QUABOX/CUBBOX to enable ATWS analysis under conservative conditions corresponding to a reduced slope of the void reactivity curve (Fig. 1). The yellow arrow points the desired change of the original (red) void curve which should be adapted to the blue one. In that way it will be transformed to a more flat (conservative) one.

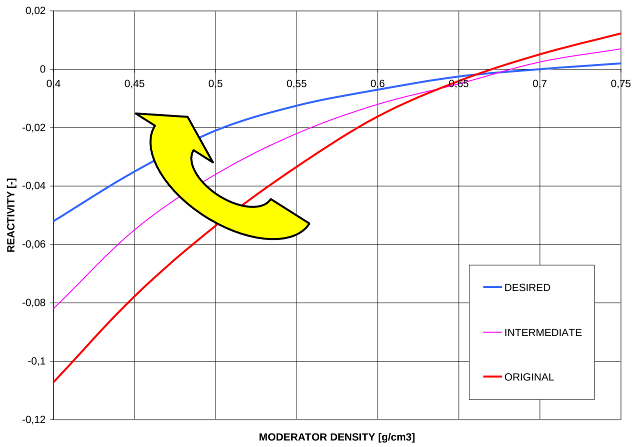

Fig.1 Reduction of the void reactivity curve slope

2.2. Outline of the approach

In order to reach the above formulated goal the following steps have been taken into account in the study:

- Selection of the 2-group assembly homogenized cross sections type to be influenced in order to reach the desired conservative slope of the void reactivity dependence
- Studying the effects of different cross section changes on the void reactivity and Doppler effect for infinite lattice
- Choosing the form and the parameters of the correction factor

- Studying the effect of the correction factor on different types of fuel assemblies (Uranium, Uranium with Gd absorbers, MOX) considering the influence of different feedback parameters
- Generation of an integral full core correction factor which fulfils the conservative criteria for the ATWS analysis and transforms the void reactivity curve to a more flat one

The reactivity (in infinite lattice) is defined as:

$$\rho_\infty = 1 - \frac{1}{K_\infty} \tag{1}$$

Where the multiplication factor K_∞ can be estimated in a two neutron group approximation directly as a function of nuclear cross sections,

$$K_\infty = \frac{\upsilon_1 \Sigma_{f1} \frac{\Sigma_{a2}}{\Sigma_s} + \upsilon_2 \Sigma_{f2}}{\Sigma_{a1} \frac{\Sigma_{a2}}{\Sigma_s} + \Sigma_{a2}} \tag{2}$$

It can be seen that there are three reasonable possibilities to influence (change) the K_∞ and in that way the reactivity response:

- absorption cross section - Σ_a
- scattering cross section - Σ_s
- ratio absorption /scattering - Σ_a / Σ_s

3. DETERMINATION OF CORRECTION FACTORS

All three above listed possibilities to influence the void reactivity curve have been considered in the study. The original cross section Σ_{jo} is being manipulated with the correction factor C_{cor} i.e.:

$$\Sigma_i = C_{cor} \Sigma_{i\circ} \tag{3}$$

By all cases C_{cor} had to be chosen less than unity in order to have the reactivity effect in the desired direction. At first the void reactivity curves were calculated with this constant correction factor for different types of assemblies for controlled and uncontrolled status and for different values of the reactor parameters (burnup, boron concentration, fuel temperature and historical moderator density). Figures 2-5 show an example of these studies performed for different values of C_{cor} (applied to the scattering cross section). In most of the cases the constant value of C_{cor} leads to unsatisfactory results concerning the gradient, the monotony and also the absolute values of the reactivity curves.

To resolve this problem the correction factor was not chosen as a constant value but as an inverse linear function of the moderator density:

$$C_{cor} = \frac{1}{a + b \cdot R_{H_2O}} \tag{4}$$

A series of tests were performed on single assemblies with different fuel compositions with the correction factor in the form of (4) changing separately Σ_a , $\Sigma_{s,}$ and Σ_a / Σ_s.

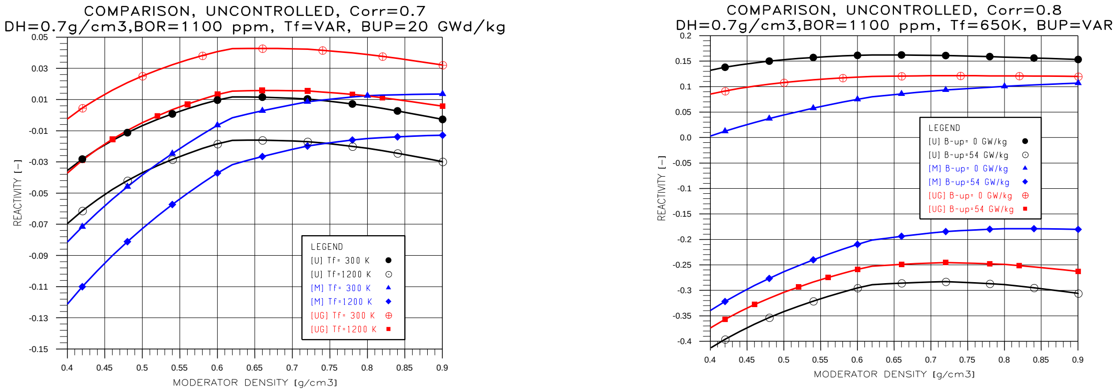

Fig. 2-3 Void reactivity curves for different types of fuel (U, U+Gd, MOX) at different fuel temperatures and at different burnup and for C_{cor}= 0.7 and C_{cor}= 0.8

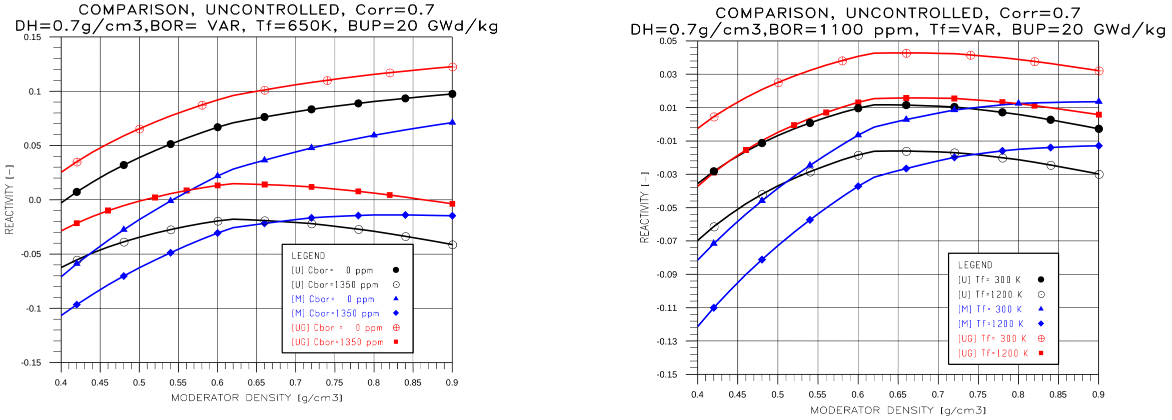

Fig. 4-5 Void reactivity curves for different types of fuel (U, U+Gd, MOX) at different boron concentrations and at different fuel temperatures (C_{cor}= 0.7)

Optimal results were obtained applying the correction to the scattering cross section as most effective and reasonable way to change the void reactivity curve in the required direction.

$$\Sigma_s = \frac{\Sigma_{so}}{a + b \cdot R_{H_2O}} \tag{5}$$

The analysis proved that for each type of assembly ‘i’ can be found a specific correction factor C^{i}_{cor} which can fulfil the desired reactivity slope but a lot of additional factors must be taken into account to have the form of the curves preserved (the curves for one type of assembly for the same value of the C^{i}_{cor} are not parallel for different burnup values and boron concentrations, see Fig. 2-5). That means that if the core loading has a lot of different types of fuel assemblies (which is the case in reality) for each assembly a correction factor should be tuned depending on the burnup and the other feedback parameters, which is practically impossible.

Therefore, another way was chosen – only one and the same C_{cor} was used for the full core (global C_{cor}). The experience gained with the assembly-wise analyses helped to find a way to determine such an integral single correction factor (4) for the core.

For different fuel assembly types a moderator density dependence, i. e. coefficients ‘**a**’ and ‘**b**’, have been determined by predefining the correction value at two support points of the moderator density values. As an example: The conditions to have a correction value C_1 at moderator density 0.7 g/cm^3 and a correction value C_2 at moderator density 0.4 g/cm^3 define two equations to determine both parameters. Such a pair of values ‘**a**’ and ‘**b**’ has been calculated for each fuel assembly type (UO_2, UO_2-Gd, MOX) and for various fuel conditions (burnup, boron concentration, fuel temperature). The values were spread over a certain range, nevertheless, it seemed reasonable to calculate firstly average values for each fuel assembly type and secondly to use the relative portion of fuel assembly types in the core loading to calculate the final averaged value. Finally, this global (single) correction function C_{cor} was applied in the core calculations for each fuel assembly.

For checking the introduced global C_{cor} applied for all types of scattering cross sections of fuel assemblies, core calculations were performed with the coarse-mesh neutron-kinetics code QUABOX/CUBBOX at a critical boron concentration. The results were reasonable but the reactivity curve at higher moderator density tended to change its gradient. In order to tune that, different support points in the procedure of determining of ‘**a**’ and ‘**b**’ were looked for. The influence of the boron concentration was also studied in detail, after which the final coefficients were calculated and accepted for further application.

The curve labelled with ‘conservative’ on the Fig. 6 is the finally accepted conservative void reactivity curve which is fully equivalent to the conservative point kinetic void curve applied for the analysis of the ATWS cases.

Additional series of calculations were performed with QUABOX/CUBBOX in order to test the conservative void reactivity curve and to analyse the corresponding Doppler reactivity curve (Fig.7). Changing the scattering cross section in the described way transformed the void reactivity curve with the desired slope and the Doppler curve remained parallel to the original one. That means that applying the correction factor to the scattering cross section have affected only the void reactivity behaviour as desired. In previous stages a non parallel behaviour of the

Doppler curve was observed while applying the proposed correction procedure to the absorption cross section.

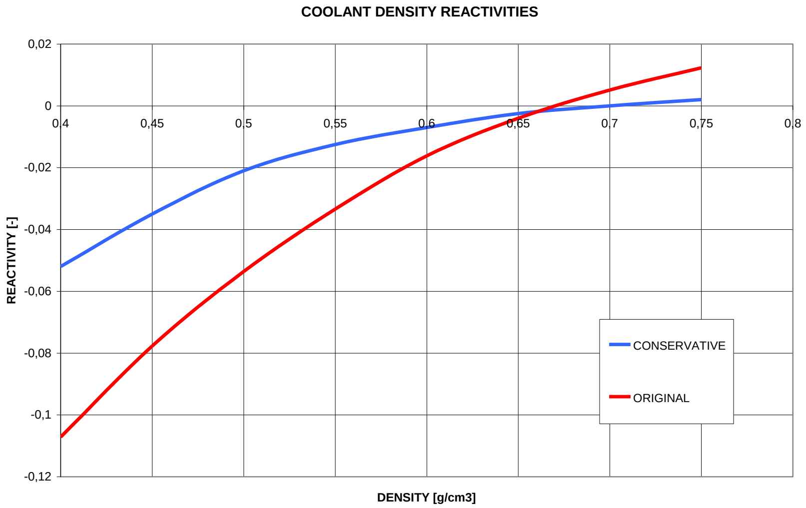

Fig. 6 Final conservative void reactivity curve compared with the original one

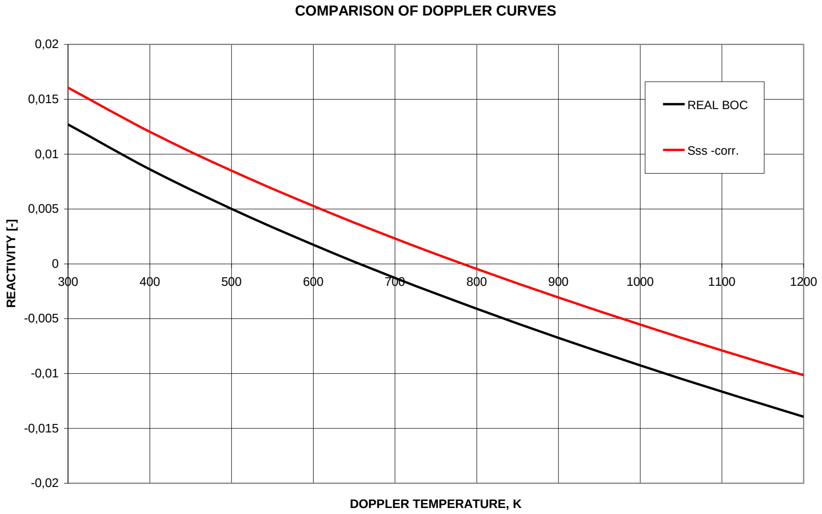

Fig. 7 Doppler reactivity curve compared with the original one for the BOC

4. SUMMARY

The paper describes a first attempt to generate conservative cross section data for applications of 3D neutron-kinetics codes. The validation of the methodology will be performed by transient calculations with the coupled thermal-hydraulics neutron-kinetics system code ATHLET-QUABOX/CUBBOX and the results will be compared with corresponding point kinetics calculations. The code system with the conservative cross section data will be used for the ongoing studies of the influence of the reactivity void curve slope on the ATWS cases (for example: a total loss of feed water). The proposed method is expected to improve the application of coupled codes for safety analysis including uncertainty and sensitivity analysis.

REFERENCES

1. G. Lerchl, H. Austregesilo, ATHLET Mod2 Cycle A, *User's Manual*, GRS, 2003
2. S. Langenbuch, K. Velkov, Capability of the Coupled Code System ATHLET-QUABOX/CUBBOX for Safety Analysis, *Progress in Development and Use of Coupled Codes for Accident Analysis*, 26-28 Nov., IAEA, Vienna, 2003
3. Langenbuch S**.,** Velkov K., Overview on the Development and Application of the Coupled Code System ATHLET-QUABOX/CUBBOX, *M & C and SNA05, Mathematics and Computation, Supercomputing, Reactor Physics and Nuclear and Biological Applications*, Avignon, France, Sept. 12-15, 2005