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Sensitivity Analysis on Various Parameters for Lattice Analysis of DUPIC Fuel with WIMS-AECL Code

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Abstract

The code WIMS-AECL has been used for the lattice analysis of DUPIC fuel. The lattice parameters calculated by the code is sensitive to the choice of number of parameters, such as the number of tracking lines, number of condensed groups, mesh spacing in the moderator region, other parameters vital to the calculation of probabilities and burnup analysis. We have studied this sensitivity with respect to these parameters and recommend their proper values which are necessary for carrying out the lattice analysis of DUPIC fuel.

1. Introduction

The computer code WIMS-AECL[1] is currently being used for the lattice analysis of DUPIC fuel. It performs multigroup transport calculations for a reactor cell producing flux distributions, eigenvalues and reaction rates. It uses an 89-group cross section library generated from ENDF/B-V data. It offers a choice for the basic method of calculation like collision probability (CP) and the DSn method. For PHWR cluster geometry, two variants are normally used. In the first variant, the CP method is applied for detailed two-dimensional geometry, whereas in the second variant, clusters of fuel pins are smeared into the appropriate annular geometry and then the CP method is used in the one-dimensional annular geometry. The second method is computationally more efficient but less accurate. For DUPIC fuel, the collision probability method is being applied for the actual geometry.

2. Sensitivity of Lattice Modelling Parameters

2.1 Number of Tracking Lines

The calculation of probabilities P_{ij} in two-dimensional geometry requires the evaluation of a double integral of the type :

$$P_{ij} = \frac{1}{2\Pi V_i \Sigma_{ti}} \int d\phi \int dR[\,Ki_3(\tau_{ij}) - Ki_3(\tau_{ij}+\tau_i) - Ki_3(\tau_{ij}+\tau_j) + Ki_3(\tau_{ij}+\tau_i+\tau_j)]$$

where τ_i and τ_j denote the optical path length of regions i and j, respectively, τ_{ij} is the total optical path length between the two regions, V_i denotes the cross sectional area of the region i and Ki_3 is the third order Bickley Neyler function. The integration is over angle ϕ measured from any arbitrary direction and R is the radial distance along the line perpendicular to the direction of ϕ. These integrals are evaluated by numerical methods. The accuracy of their evaluation will depend upon the number of angles and number of lines into which the domain of these integrals are divided.

A sensitivity analysis was carried out with respect to the number of lines taken and it was found that at least 100 lines should be taken in order to have an error in k_∞ less than 0.42 *mk* compared with the k_∞ of 400 tracking lines. In order to check it further, the option of AUTOTRACK, which is available in the code was used. In this option, the code automatically finds the suitable number of lines and angles by successively increasing them by a factor of 1.5 until the change in the mean chord length in any mesh path is less than the tolerance. Applying of this option with a tolerance of 0.05 gave the total number of angles and lines to be 7 and 136, respectively. The value of k_∞ obtained with these values was 1.15248, which is very close to the case of 400 lines (k_∞= 1.15234). This gives the standard values of the two parameters required for calculating probabilities. In the following analysis, the number of angles and lines are taken to be 7 and 136, respectively.

2.2 Number of Condensed Groups

Condensing the energy groups reduces both the computing time and memory requirements. Therefore, in the WIMS-AECL code, calculations are performed in two stages. In the first stage, the 89-group neutron spectra in the main regions (fuel, clad, coolant and moderator) are obtained by a fast but less accurate method of SPECTROX. Using this spectrum, the 89-group cross sections of all the materials are condensed to a small number of groups and then detailed transport theory calculations are performed. In order to see the adequacy of this, calculations were performed in different number of groups and the results compared with the reference value not involving any condensation. For example, the k_∞ calculated with the 33-group, which is typically used for production calculations, has an error of -0.84 *mk*, which is considered to be tolerable.

2.3 Sensitivity of Mesh Spacing in Moderator

Another parameter determining the k_∞ is the mesh spacing in the moderator. One of the assumptions of the CP method is the flat flux approximation; that is, the flux in a region is assumed to remain constant. The flat flux approximation can be satisfied by taking meshes of smaller sizes. The mesh spacing considered for the DUPIC fuel analysis was approximately 1.06 cm. The results of varying mesh spacing in the moderator have shown that the k_∞ is not very sensitive to the choice of mesh spacing in the moderator. For example, the present model of 1.06 cm gives only 0.52 *mk* more reactivity as compared to the model of 0.1 cm mesh spacing in the moderator. However, it is recommended to choose an appropriate mesh spacing that can compensate for the reactivity loss due to group condensation.

2.4 Effect of Fuel Gap

In the fuel pins, there is a small air gap between the pellet and cladding. In the lattice calculations, the air gap is usually homogenized with the cladding. This is done to reduce the computer time and is believed to have no appreciable effect on reactivity. In order to quantify this effect, calculations were performed with and without the air gap for DUPIC fuel. The results have shown that the effect of homogenization of a void with cladding is very small and is of the order of 0.03 mk or less.

2.5 Lattice Boundary Modelling

When the CP method is applied in the WIMS-AECL code, it occasionally gives negative fluxes in some regions and energy groups. The input used for the DUPIC analysis was scrutinized. It was found that in one region, the sum of all the probabilities from one region to all other regions was very different from the unity and the error was of the order of 14%. It was further found that the outer radius of this zone was more than half the pitch of 14.2875 cm, though less than the equivalent radius of the cell (16.1217 cm). That is, the zone was extending beyond the physical (square) boundary of the cell. When the radius of this zone was reduced to 14.2 cm, the problem of getting a larger error in probabilities and negative fluxes disappeared. Thus the problem of negative fluxes can be avoided by choosing the radius of all the zones such that they lie within the square boundary of the cell.

3. Sensitivity of Burnup Parameters

3.1 Burnup Step

In the WIMS-AECL code, a burnup calculation follows the main transport and edit calculations. At the end of the main transport calculation, cell-averaged macroscopic cross sections are calculated in the condensed group structure from the flux-weighted regional cross sections. The k_{eff} is calculated from the neutron balance in the equivalent homogeneous cell using cell-averaged homogeneous cross sections and a fundamental buckling mode. This calculation also gives cell-averaged condensed group fluxes. For the burnup calculation, the fine group flux structure resulting from the main transport calculation is assumed to remain constant. At the start of each burnup time step T, the cell-averaged fluxes are normalized to the quantity Q, which can be expressed in various units such as W/g etc. The regional fluxes are determined from the normalized cell-averaged fluxes and the main transport calculation in a fine structure. The burnup equations are then integrated over the time step (δt) in each fuel region using these constant regional fluxes. At the end of the time step, new isotope number densities and cell-averaged cross sections are determined.

The time step should be small enough so that the approximation of the constant power to the flux is good. However, it should be noted that the smaller the time step, the larger the computer time requirement will be. This process is repeated N times with the flux spectrum being renormalized at the beginning of each time step but with the fine flux structure remaining constant.

We shall now give the sensitivity of k_∞ with respect to the time step δt. Table 1 gives the variation of k_∞ with the time step δt. In this table, the time step for the first 5 days will be slightly different from the others, such that the first step is of 0.1 days, followed by 4.9 days, and the rest of the steps

is given in the table. In the first three cases, the main transport calculation is performed after each time step. In the last case, the burnup step of 5 days is repeated 5 times. In this case, the main transport calculations are performed after 25 days and this case is similar to the fourth case as far as computer time is concerned. It can be seen from Table 1 that the results of δt=10 days can be considered appropriate. However, in the case of δt=25 days (third case), the k_∞ differs from the first case by as much as 4.27 mk. The results of the fourth case, in which the flux is renormalized after every 5 days and the main transport calculations are performed after 25 days, are surprisingly close to the first case. Thus it is recommended that this approach as it be followed, gives quite accurate results and provides a large saving in computer time as well.

3.2 Burnup Power Q

As stated above, the cell-averaged fluxes are normalized to the quantity Q which can be expressed in various units, such as the W/g of the initial heavy elements, at the start of each burnup step. The regional fluxes are determined from the normalized cell-averaged fluxes and the main transport calculation in a fine structure. As a reactor is started, the xenon builds up and the saturating fission products present in the DUPIC fuel tend to decrease. Their rates will be determined by the absolute value of the flux, which is determined by the parameter Q. Table 2 gives the variation of k_∞ with the burnup for different values of Q. The average value of Q for DUPIC fuel is 32.72 W/g when weighted by a squared flux. Two other values which have been taken for Q are 16.36 W/g and 65.44 W/g. It is seen that the largest difference of k_∞ is about 5.4 mk during fuel burnup. The number density of Xe-135 for the different Q values is shown in Fig.1. The xenon reactivity load as a function of time after shutdown for the different Q values is shown in Fig.2, which indicates that it is necessary to find the correct weighting factor for the depletion power of a DUPIC lattice to perform the consistent Xe load calculation.

4. Conclusions

This study has shown that the number of tracking lines should be increased to at least 100. The other parameters, namely, the number of condensed groups and mesh spacing being considered presently for DUPIC fuel analysis appear to be adequate. The effect of homogenization of the void between the pellet and cladding is negligible. The present study has also shown that the problem of large errors in the calculation of probabilities in some regions, which is intimately linked to problem of getting negative fluxes, can be avoided by taking the boundary of all regions less than half the lattice pitch. For burnup analysis, the better strategy is to take smaller burnup steps with their repetition so as to save computer time without affecting accuracy.

Reference

1. J.V. Donnelly, "WIMS-CRNL : A User's Manual for the Chalk River Version of WIMS", AECL-8955, Chalk River, Canada(1986).

Table 1. Sensitivity of Burnup Step to k_∞

Burnup (days)	k_∞			
	δt=5 days	δt=10 days	δt=25 days	δt=5 days (N=5)
0	1.15248	1.15248 (0.00)	1.15248 (0.00)	1.15248 (0.00)
50	1.14619	1.14632 (0.13)	1.14674 (0.55)	1.14628 (0.09)
100	1.11750	1.11779 (0.29)	1.11865 (1.15)	1.11763 (0.13)
150	1.08796	1.08840 (0.44)	1.08967 (1.71)	1.08811 (0.15)
200	1.05862	1.05922 (0.60)	1.06089 (2.27)	1.05878 (0.16)
250	1.02984	1.03060 (0.76)	1.03258 (2.74)	1.02999 (0.15)
300	1.00182	1.00270 (0.88)	1.00500 (3.18)	1.00196 (0.14)
350	0.97476	0.97577 (1.01)	0.97833 (3.57)	0.97489 (0.13)
400	0.94884	0.94995 (1.11)	0.95272 (3.88)	0.94896 (0.12)
450	0.92424	0.92542 (1.18)	0.92836 (4.12)	0.92436 (0.12)
500	0.90115	0.90237 (1.22)	0.90539 (4.24)	0.90126 (0.11)
550	0.87969	0.88093 (1.24)	0.88396 (4.27)	0.87979 (0.10)
600	0.86001	0.86122 (1.21)	0.86422 (4.21)	0.86011 (0.10)
CPU Time	7739.6 sec	3993.9 sec	1691.9 sec	1702.0 sec

( ) Difference of k_∞ in mk

Table 2. Effect of Parameter Q on k_∞

Burnup (MWD/T)	k_∞		
	Q=16.36 W/g	Q=32.72 W/g	Q=65.44 W/g
.00	1.15248 (0.00)	1.15248	1.15248 (0.00)
3.27	1.14667 (1.95)	1.14862	1.14985 (1.23)
162.75	1.15138 (4.58)	1.14680	1.14394 (2.86)
1629.72	1.15171 (5.43)	1.14628	1.14117 (5.11)
3258.77	1.12226 (4.63)	1.11763	1.11313 (4.50)
4887.74	1.09210 (3.99)	1.08811	1.08413 (3.98)
6516.55	1.06225 (3.47)	1.05878	1.05521 (3.57)
8145.65	1.03302 (3.03)	1.02999	1.02675 (3.24)
9774.80	1.00463 (2.67)	1.00196	0.99896 (3.00)
11403.97	0.97725 (2.36)	0.97489	0.97208 (2.81)
13033.40	0.95107 (2.11)	0.94896	0.94629 (2.67)
14663.28	0.92627 (1.91)	0.92436	0.92179 (2.57)
16293.34	0.90303 (1.77)	0.90126	0.89876 (2.50)
17923.80	0.88146 (1.67)	0.87979	0.87734 (2.45)
19554.65	0.86172 (1.62)	0.86010	0.85769 (2.41)

( ) Difference of k_∞ in mk

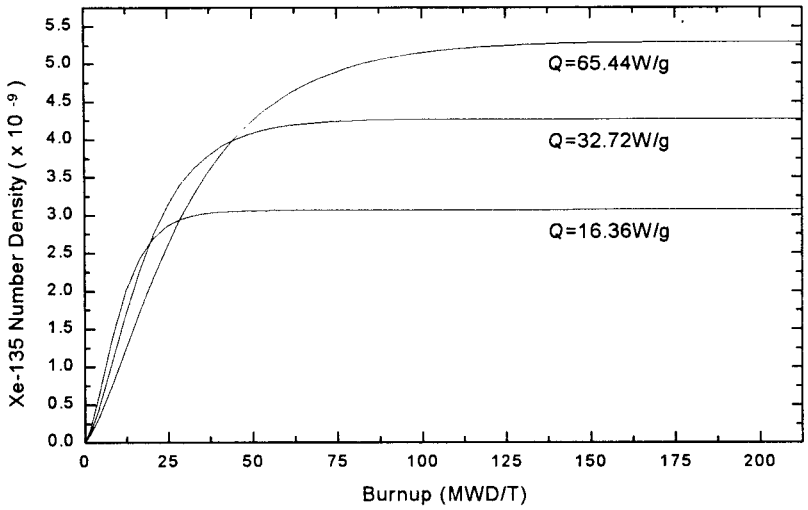

Figure 1. Xe-135 Number Density for Different Q Value

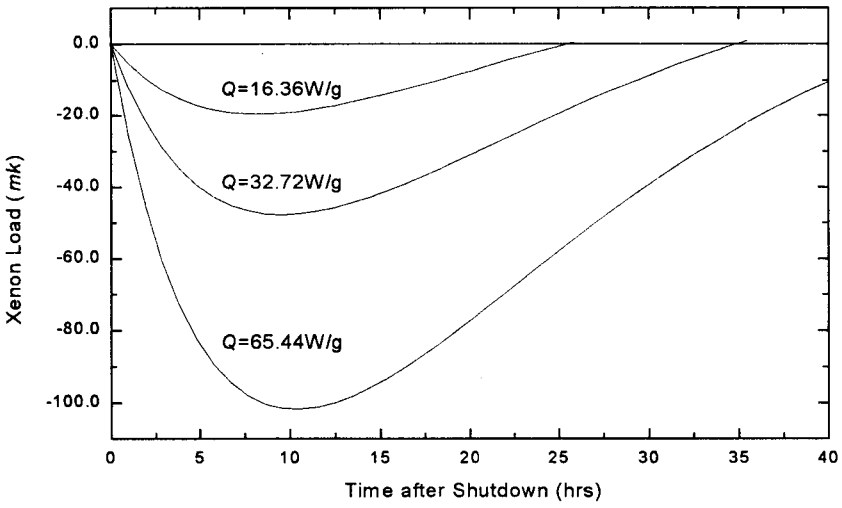

Figure 2. Variation of Xenon Reactivity Load as a Fuction of Time