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Need for High Temperature Nuclear Data Library for LWR Design Computations

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WIMS Library Update Project (WLUP) was taken up by the IAEA for updating the nuclear cross section data libraries. The 172 group WIMS libraries (45 fast, 47 resonance groups and 80 thermal) obtained under WLUP are used for reactor physics computations. These libraries have cross section data for 173 nuclides up to ^{244}Cm. Resonance Integral Tabulation (RIT) data for 28 resonant nuclides are provided for a set of background cross sections and temperature values up to 1100 °K. In the reactor design computations, one requires simulation of reactor states with fuel temperatures reaching nearly up to melting point of 2800 °C for UO_2 fuel. While using deterministic codes for high temperature calculation beyond 1100 °K, a linear extrapolation w.r.t. $\sqrt{T_{\rm fuel}}$ is normally done. This is not quite satisfactory since even a small error in the slope near the highest temperature of 1100 °K data point could lead to significant error if the extrapolation is done up to very high temperatures. Recently an updated WIMS library has become available through WLUP follow up activities. This library contains RIT data for 48 resonant nuclides including several minor actinides and temperature extended up to 2500 °K and burnup chain has been extended up to ^{252}Cf. Use of the new library has alleviated the problem of possible error in extrapolation.

The new library called 'HTEMPLIB' has been tested for the design computations of VVER-1000 MWe reactor being constructed at Kudankulam, Tamilnadu, India. Two fuel types containing 4% and 3.6% enriched fuel were analyzed using the hexagonal lattice burnup code EXCEL. The results of the lattice analyses with the new WIMS library as well as the original WIMS library 'JEFF31GX', containing data up to a temperature of 1100 °K are presented in this paper.

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I. INTRODUCTION

The multigroup libraries obtained under WIMS library Update Project (WLUP) [1] initiated by IAEA are used for reactor calculations. The libraries have nuclear cross section data in 172 groups (45 fast, 47 resonance groups and 80 thermal) and 173 nuclides with a burnup chain up to ^{244}Cm. The RIT data in these libraries is up to a maximum temperature of 1100 °K. In practical reactor calculations the fuel may attain a temperature almost up to the melting point. Hence there is a need to extend these data for higher temperature. In the absence of data beyond 1100 K, the deterministic codes use a linear extrapolation w.r.t. $\sqrt{T_{\rm fuel}}$. This is not quite satisfactory since even a small error in the slope near the highest temperature of 1100 °K data point could lead to significant error if the extrapolation is done up to very high temperatures.

II. HIGH TEMPERATURE LIBRARY

Recently a high temperature library became available. The new library called "HTEMPLIB.LIB" has cross section data for 185 nuclides. The burn up chain in the new library has been extended up to ^{252}Cf. The HTEMPLIB library uses point data based on Joint Evaluated Fission and Fusion format (JEFF-3.1) [2]. The RIT data in the new library is up to 2500 K. The resonant nuclides having RIT data in the new library is increased. The new library has the RIT data for 48 nuclides compared to 28 nuclides provided in IAEA WIMS libraries. The new nuclides having RIT data are ^{237}Np, ^{241}Am, ^{242}Am, ^{242m}Am, ^{243}Am, ^{242}Cm, ^{243}Cm , ^{244}Cm, ^{245}Cm, ^{246}Cm, ^{247}Cm, ^{248}Cm, ^{249}Cm, ^{250}Cm, ^{249}Bk, ^{250}Bk, ^{249}Cf, ^{250}Cf, ^{251}Cf, and ^{252}Cf. The RIT data for last 12 nuclides is, however, up to 1100 K.

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III. LIBRARY COMMISSIONING

The generated library was commissioned to work with lattice burn up code EXCEL. The lattice burn-up code EXCEL uses the multigroup WIMS library file 'HTEMPLIB.LIB' by splitting it into four files. In WIMS library file there are four distinct nuclear data file structure *viz.* a) General data & burn-up chain data, b) Basic cross section data, c) Resonance integral data and d) P_1-scattering matrices. The WIMS library file is processed first and split into four separate files using codes FORBIN, RESTAB47 and FISY172. The following files are created which are by structure compatible with the lattice burn-up code, EXCEL.

1. HTEMPLIB.BIN – General data + Basic cross section library
2. HTEMP185.RES - Resonance integrals
3. HTEMP185.BUR - Burnup chain data
4. HTEMPLIB.P1 - P_1 scattering matrix

The first file is in binary format. Its structure is same as that of original WIMS library. The second and third files are in ASCII format and can be readily viewed as well. The resonance data is restructured by giving the resonance integrals for a single nuclide absorption for all (47) resonance groups before proceeding to next nuclide. ν-fission integrals follow the absorption integrals for fissile nuclides. The burn-up chain data is also recast such that the capture and decay chains, decay constants, fission products yield data are explicitly tabulated with suitable titles. The delayed neutron fission yield data, which is not available in the original WIMS library, is added in the burn-up related data file for each actinide. The fourth file 'HTEMPLIB.P1' consisting of P_1 scattering matrix is not used by EXCEL.

IV. CALCULATION METHODOLOGY

The calculations have been performed using the hexagonal lattice assembly cell burn-up code 'EXCEL' [3]. The calculation methods adopt a combination of 1-D multigroup transport and 2-D few group diffusion theory.

In EXCEL code, the fuel pins are classified into pin cell types based on enrichment and Dancoff factors. The resonance group cross-sections are obtained by considering the equivalence relations and appropriate Dancoff factors for fuel cells. The pin cell calculations consider three main regions for fuel, clad and coolant. The hexagonal cell boundary is cylindricalised to allow 1-D treatment of the Wigner-Seitz cell. Special 1-D supercell simulations are done for each of the heterogeneity present in the fuel assembly. The supercell simulations are done in 1-D cylindrical geometry in multigroups. For 1-D multigroup transport calculations, the first flight collision probability method (P_{ij}) is used. Transport cross section is used in place of total cross section to indirectly account for the anisotropic scattering in light nuclei like hydrogen.

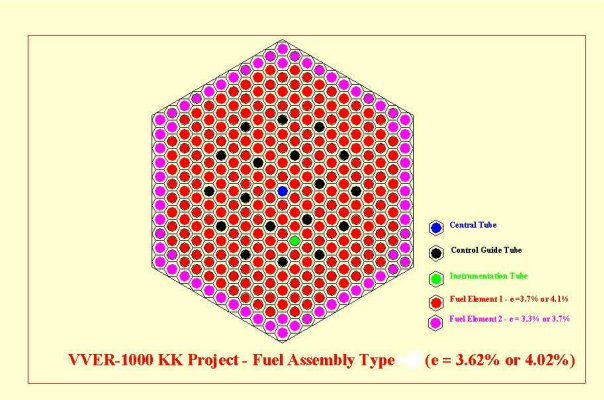

Fig. 1. (Color online) A two region Fuel Assembly of VVER – 1000 KK Core.

The 2-D fuel assembly cell is treated by five group diffusion theory using homogenized cell cross sections obtained as above. Centre-mesh finite difference method with hexagonal meshes is considered. Infinite multiplication factor 'k_∞', group flux and power distribution, homogenized and collapsed (five or two) group cross sections of the entire assembly cell are obtained. Energy yield per fission is calculated as the weighted mean value from the fissions in various actinides.

The fuel types of VVER 1000 MWe type KudanKulam (KK) reactor are used to test the new library. The KK reactor is under construction at Tamilnadu in India. The fuel pins within FA are arranged in regular hexagonal lattice pitch. The fuel enrichment varies from 1.6% to 4.02%. The fuel types containing 4% and 3.6% enriched fuel are analyzed using the EXCEL code. A typical fuel assembly of KK is shown in Fig. 1. There are 331 lattice locations. There are 18 locations occupied by Zr alloy guide tubes filled with water, one central tube for spacer capture and one location for instrumentation.

Control rods or burnable absorber rods (BAR) can be inserted into these 18 guide tubes. The fuel enrichment is uniform within a fuel assembly for low enriched fuel types. In higher enriched fuel, (3.62% & 4.02%) which is considered for equilibrium feed, lower fuel enrichment is considered in the 66 fuel pins and a higher enrichment in the 245 fuel pins.

V. RESULTS AND DISCUSSION

The variation of the k_∞ of fuel type with 4.02% enrichment and 3.62% enrichment with fuel temperature is shown in Figs. 2 and 3 respectively, at two burnup levels. It is seen from the graphs that at fuel temperatures beyond 1100 °K the JEF31GX library is showing a curious behaviour. This is due to the fact that there was no extrapolation used beyond 1100 °K due to lack of data and an apprehension to use a linear extrapolation at very high temperatures. The code used the last value of RIT data for all temperatures beyond 1100 °K. However when linear extrapolation is carried out w.r.t $\sqrt{T_{\rm fuel}}$,

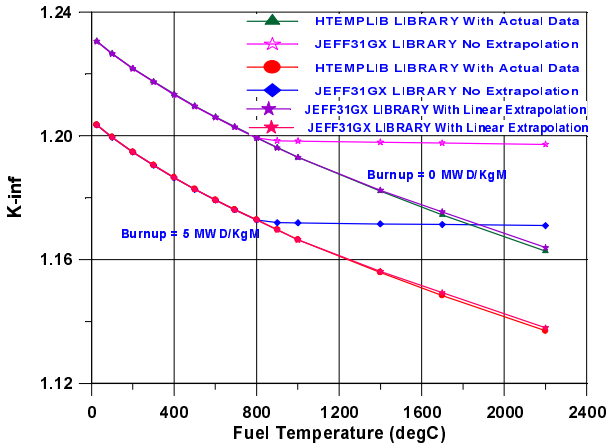

Fig. 2. (Color online) k_∞ variation with Fuel Temperature for two libraries for fuel type with e% = 4.02%.

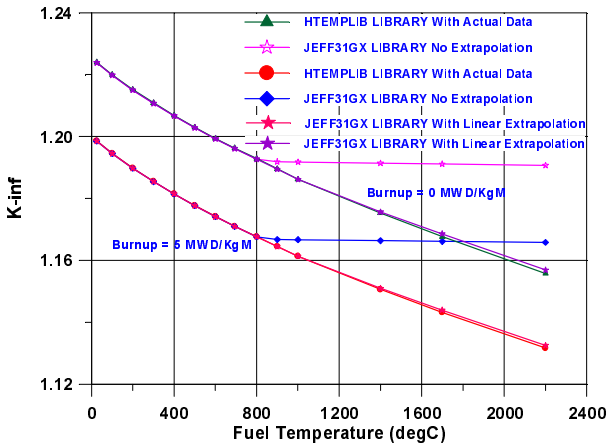

Fig. 3. (Color online) k_∞ variation with Fuel Temperature for two libraries for fuel type with e% = 3.62%.

by taking the slope of last two temperature points below 1100 °K, the k_∞ behaviour is only marginally different from the k_∞ when the temperature dependent data is used. The analysis using HTEMPLIB can be compared with experimental data available in open literature or with the operational data when the power operation of Kudankulam reactors would commence. It is however seen that the variation with temperature shows a smooth expected trend up to 2500 °K indicating a higher degree of reliability of new WIMS library for higher temperatures. With the new library, the fuel temperature coefficient at temperatures beyond 1100 K can be found more accurately.

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