AN ECONOMICAL METHOD FOR THE DETERMINATION OF GROUP CONSTANTS FOR REACTOR LATTICES

by

Ricardo Rogow

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APPROVED:

M. C. Edlund, Chairman

T. F. Parkinson

J. R. Thomas

R. L. Whitelaw

L. W. Johnson

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Blacksburg, Virginia

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CHAPTER I

INTRODUCTION AND OBJECTIVE

1.1 Objective

The objective of the present research is to develop an economical method for determining group constants for heterogeneous lattice configurations consisting of either hexagonal or square cells. The mathematical model constructed for this purpose should be sufficiently comprehensive to characterize the group constants for the entire range of the neutron spectrum. In addition, the proposed model should be rigorous enough to predict the group constants with the required accuracy for a specific range of interest in the energy spectrum, such as the resonance range for high conversion lattices and the thermal range for current LWR lattices. Moreover, such a model should also reproduce the group constants of hexagonal or square lattice configurations. The determination of the group constants and the core parameters of either hexagonal or square lattice arrays may be pursued by implementing the appropriate escape probability function in the scattering integrals of the transport equations, as will be detailed in Chapter II of this work.

The primary motivation for this endeavor resides in the fact that most codes utilized for spectrum calculations (TABLE I-1), though accurate for a specific range of energies, are either not feasible or

uneconomical when implemented outside the range for which they were originally designed. The lack of flexibility of the existing codes to predict group constants in the wide range of the energy spectrum and fuel-to-moderator ratio, limits their applicability to sensitivity studies in reactor design and calculations. The model flexibility is particularly useful in design calculation for compact lattice configurations, whereby the responses of the cross sections and multiplication factor must be characterized as a function of shift in the energy spectrum. Therefore, the coupling between the resonance and thermal energy regions must be rigorously defined for compact lattice calculations. These high conversion lattices proposed by Edlund[1] require an accurate mapping of the cross sections in the high range of fuel-to-water ratio. Therefore, the proposed code should accurately reproduce the flux spectrum and the multiplication factor characteristic for these lattices. Moreover, such a model should also simulate any softening of the spectrum due to relaxations in the fuel-to-water ratio required to induce an increase of the multiplication factor during burnup. Furthermore, the predicted group constant coupled with the multigroup diffusion equation may be utilized to yield the spatial characterization for the reactor lattice. Correspondingly, one of the specifications in formulating the structure of the code has been to enable the predicted cross-sections to be coupled via iterations with the Rapid Fuel Depletion code RFD-2 [2].

Therefore, the principal aims in developing the formulations for the code are three-fold, namely:

(1) To construct a model that is sufficiently comprehensive as a stand-alone code, capable of mapping the group constants over a wide range of the energy spectrum and fuel-to-moderator ratio, as well as to possess the coupling capability with spatial and burnup codes.

(2) To possess sufficient rigor in order to reproduce the group constants in a specific range of the energy spectrum, e.g., resonance or thermal.

(3) To have embedded an economical algorithm capable of determining the group constants without greatly compromising the accuracy of the results.

Items (1) through (3) above are not mutually exclusive; consequently any optimization of the code should incorporate the conflicting goals of accuracy, comprehensiveness, and economy. An additional important feature for encoding a mathematical model with a substantial number of recursive algorithms and integro-differential system of equations is the choice of the high level language. The Continuous System Modelling Program (CSMP) language has been selected as the driving software for the model due to its high versatility and economy of programming, thus allowing the Transport Equations model to be encoded with a minimum number of external modules. Furthermore, the CSMP program may be readily coupled with other FORTRAN modules, such as

the RFD2 burnup code[2]. The latter may be linked to CSMP as a subroutine. An overview of the CSMP language is given in APPENDIX 3.

Prior to detailing the working model of the code, a review of existing codes will be presented in the remaining section of this chapter.

1.2 Overview of Design Calculations Codes

The codes most widely used in design calculations are presented in TABLE I-1. Codes such as STRIP[3], RABLE[4], and MC2[5] use direct numerical methods for solving the Boltzman equation utilizing ultra-fine lethargy widths (i.e., 10^{-4}). The above codes are accurate but not cost-effective. Typical running times are above the five minute range. On the other hand, the Broad Group Integral Method (BGIM)[6] utilizes very effective Kernels within the Integral Transport Equation as well as analytical flux shapes in the low lying resolved resonance region. The CPU running time for BGIM is typically about three minutes for a lethargy width of 3.E-3 units and an integration step size of 1.E-4. It is a very useful code to be implemented specifically for evaluating cross sections of high conversion reactor lattices, whereby the neutrons produced in the resolved resonance energy region account for about 50 percent of the total, compared to 11 percent in current LWR's.

Other codes of the MUFT family such as CEPAK[7,8] and NULIF[4]

TABLE I-1

Codes Most Widely Utilized in Reactor Design Calculations

CODE (#)	ENERGY REGION	DESCRIPTION	REFERENCE (#)
STRIP	Resolved Resonance	Direct numerical Integration of Boltzmann equation with ultrafine lethargy group	3
RABBLE	Resolved Resonance	Same as above except that it cylindrizes the cell and then performs multi-region calculation.	4
MC**2	Fast	Direct numerical integration with ultrafine groups.	5
BEGIM	Resolved Resonance	Broad Integral Group Method. Uses escape probability to obtain spatial coupling between regions. Invokes analytical flux shape within multigroup to obtain cross sections.	6
NULIF	Fast	Utilizes NR approx.	9
CEPAK	Fast	Utilizes intermediate resonance approximation for Pu isotopes and w-search for U-238.	7,8
THERMOS	Thermal	Computes scalar thermal neutron flux with arbitrary scattering model.	10
DTF-4	Thermal	Solves Boltzmann equation with spatial angular and energy dependence. Angular dependence treated by the discrete ordinate approach.	11
GASKET	Thermal	Calculates scattering law $S(\alpha,\beta)$ for different materials. The scattering law is obtained by implementing momentum transfer, $\underline{\alpha}$, and energy transfer, $\underline{\beta}$, in Fourier transform form which is then processed by numerical methods.	16
FLANGE	Thermal	Similar to Gasket, except that it treats larger energy transfers.	17

utilize the narrow resonance escape probability methods. These codes are computationally very fast, but nevertheless lack the required accuracy.

The thermal region codes most widely recognized such as THERMOS and DTF-4 may be categorized in accordance with their scattering kernels. The former models isotropic scattering and the latter utilizes Pn and Sn approximations in a one-dimensional multigroup setting.

THERMOS computes the scalar thermal neutron flux as a function of position in one dimensional slab or cylindrical lattice. The scattering model is arbitrary, but the free gas model is built into the code. This code was written mainly to investigate the thermal neutron flux with emphasis on reaction rate calculations. A typical CPU time for a run in an IBM-704 environment is given approximately by:[10]

$$CPUt = NK(N+K+5)XE-3 \text{ min.},$$

whereby N is the number of space points and K is the number of groups. Faster execution times may be expected in more advanced mainframes.

The DTF-4 code solves the Boltzmann equation with spatial, angular and energy dependent kernels[11]. It invokes a complete matrix of group constants for each of the Legendre polynomial terms. The angular dependence is treated via the discrete ordinate approach, and the anisotropic scattering is approximated by spherical harmonic

expansions. The code requires as input the source term in conjunction with the boundary conditions. The expected CPU running time for DTF-4 is about 16 minutes in an IBM-704 processor for a model consisting of homogeneous media in 30 energy groups and the PO approximation.

1.3 The VIM Monte Carlo Reference Code

VIM has been selected as the benchmark code due to its accepted validity in reproducing the cross sections, reaction rates, fluxes and multiplication factors in the fast as well as thermal energy regions[12]. This code has been inter-calibrated with other known codes and has been verified with several experiments[13,14].

The VIM code operates via continuous Monte Carlo algorithms. In addition, it incorporates a detailed model of the neutron physics and its accuracy is a function of the number of neutron histories tracked. The resonance and smooth cross sections are specified as continuous linear interpolations, while the unresolved resonance is described as the the probability table method. Anisotropic and discrete level inelastic scattering is modeled by probability tables in conjunction with the ENDF/B data base. Thermal scattering laws are also reproduced via the ENDF/B file, and subsequently copied into a library containing the scattering probability tables and thermal cross sections. All the reaction types i.e., fission, elastic scattering, inelastic scattering (n,2n) reactions are concisely defined, while capture is modeled as the

remaining possible outcome of a neutron collision. The eigenvalues are calculated via analog, collision, and track length estimation. Subsequently these are statistically averaged after a specified number of neutron histories for variance reduction purposes.

Reaction rate estimates by region, group and isotope are evaluated by collision and track length estimation methods, while microscopic cross sections are computed from track length evaluated reaction rates and fluxes. Furthermore, VIM possesses the added versatility of collapsing the output variables in space and energy domains via the RETALLY module.

CHAPTER II

METHOD OF SOLUTION

2.1 Formulation and Method of Solution

This chapter describes the derivation of the transport equation kernels implemented in the code. The heterogeneous lattice is represented as an infinite array of identical two-region cells, typically fuel and moderator, in either rectangular or hexagonal configurations. The coupling between the regions is modelled by the escape probability function as will be described later in this development.

The derivation for the fast region begins with the steady state continuity equation specialized in the two-region cells. This in turn yields a coupled set of integro-differential equations, which can either be solved by invocations of direct numerical algorithms or by analytical approaches which involve algebraic equations in the LaPlace variable domain. The former method results in rather costly utilization of computer resources, while the latter approach attempts to make minimal utilization of numerical iterations loops, which generally bear the heaviest cost burden in most numerical solutions. Since the goal of this work has been oriented towards computational economy, stronger emphasis has been designated to the latter approach.

Similarly, for the thermal energy region, the cost-effectiveness of the solution depends mainly upon the definition as well as the choice of integrand kernels.

2.2 Fast Energy Region

The first step in the derivation involves the steady state, energy dependent continuity equation for the two region cell, i.e.,

$$\vec{\nabla}\cdot\vec{J} + \Sigma_{t(k)}(E)\phi(\vec{r},E) = \int_{E'} dE' \; \Sigma_{s(k)}(E'\rightarrow E)\phi(E') + s_{f_k}(E)\delta_{ik}$$

for k = 1,2 (II-1)

where, regions 1 and 2 correspond to the fuel and moderator regions respectively. The fission source is $s_{f_k}(E)$, and it is given by:

$$s_{f(1)} = \sum_j \int_{E'} \chi^j(E)\nu^j(E')\Sigma^i_{f(1)}(E')\bar{\phi}'(E')dE'$$

where the summation is taken over all fissionable isotopes within the fuel region. The fact that fission sources exist only in region (1) may be represented by multiplying $s_{f(k)}$ by the Kronecker delta δ_{1k},

$$\delta_{1k} = \begin{cases} 1 & \text{for } k=1 \\ 0 & \text{otherwise} \end{cases} .$$

Integrating equation (II-1) over the volume and applying Gauss law yields the following:

$$\int_{A_k} \vec{J} \cdot \hat{n}_k dA + \Sigma_{t(k)} V_k \bar{\phi}^k = \int_{E'} dE' \; \Sigma_{S(k)}(E' \to E) V_k \bar{\phi}^k(E') + s_{f(k)}(E)\delta_{lk}$$

for k=1,2.

The volume averaged variables are represented as follows:

$$\bar{\phi}^k = \frac{1}{V_k} \int_{V_k} \phi(\vec{r},E) dV$$

and

$$s_{f(l)}(E) = V_l s_{f(l)}(E) = \int_{V_l} s_{f_{(l)}}(\vec{r},E) dV \; .$$

Furthermore, considering the fluxes and currents, $\phi_k(E)$ and $\vec{J}_k(E)$ respectively, due to a source in region k, the sum total of the fluxes and currents is given by:

$$\phi(E) = \phi_1(E) + \phi_2(E)$$

$$\vec{J}(E) = \vec{J}_1(E) + \vec{J}_2(E) \; . \qquad \text{(II-2)}$$

Subsequently, the steady-state continuity equation may be written as specialized in terms of $\phi_k(E)$ and $\vec{J}_k(E)$, i.e.,

$$\vec{\nabla} \cdot \vec{J}_k + \Sigma_t(E)\phi_k(E) = \int_{E'} dE' \; \Sigma_{S_i}(E' \to E)\phi(E')\delta_{ik} + s_{f_i}(E)\delta_{li} \qquad \text{(II-3)}$$

for k=1,2 and i=1,2

where,

$$\delta_{\alpha\beta} = \begin{cases} 1 & \text{for } \alpha=\beta \\ 0 & \text{for } \alpha\neq\beta \end{cases} .$$

The fuel and moderator regions are coupled via the following condition:

$$\int_{A_1} \vec{J}\cdot\hat{n}_1 dA = - \int_{A_2} \vec{J}\cdot\hat{n}_2 dA \quad . \tag{II-4}$$

Integrating equation (II-3) over the volume and invoking Gauss law, yields the following system of equations:

$$\int_{A_1} \vec{J}_1\cdot\hat{n}_1 dA + \Sigma_{t(1)}(E)\bar{\phi}_1^1 V_1 = \int_{E'} dE' \; \Sigma_{s(1)}(E'\to E)\bar{\phi}^1(E')V_1 + s_{f(1)}(E)$$

$$\int_{A_1} \vec{J}_2\cdot\hat{n}_1 dA + \Sigma_{t(1)}(E)\bar{\phi}_2^1 V_1 = 0$$

$$\int_{A_2} \vec{J}_1\cdot\hat{n}_2 dA + \Sigma_{t(2)}(E)\bar{\phi}_1^2 V_2 = 0$$

$$\int_{A_2} \vec{J}_2\cdot\hat{n}_2 dA + \Sigma_{t(2)}(E)\bar{\phi}_2^2 V_2 = \int_{E'} dE' \; \Sigma_{s(2)}(E'\to E)\bar{\phi}^2(E')V_2 . \tag{II-5}$$

Interactions between the fuel and moderator regions may be described by making use of the escape probability functions $p_1(E)$ and $P_2(E)$ in the following manner:

$$\int_{A_1} \vec{J}_1(\vec{r},E)\cdot\hat{n}_1 dA = P_1(E)\{V_1 \int_{E'} dE' \, \Sigma_{S_{(1)}}(E' \to E)\bar{\phi}^1(E') + S_{f_1}(E)\}$$

$$\int_{A_2} \vec{J}_2(\vec{r},E)\cdot\hat{n}_2 dA = P_2(E)V_2 \int_{E'} dE' \, \Sigma_{S(2)}(E'\to E)\bar{\phi}^2(E')dE' \, .$$

Therefore, the expressions for $P_1(E)$ and $P_2(E)$ may be written by making use of equation (II-5) and from the fact that $\hat{n}_1 = -\hat{n}_2$, i.e.,

$$P_1(E) = \frac{V_2\Sigma_{t(2)}(E)\bar{\phi}^2{}_1(E)}{V_1 \int_{E'} \Sigma_{S(1)}(E'\to E)\bar{\phi}^1(E)dE' + S_{f_1}(E)}$$

$$P_2(E) = \frac{V_1\Sigma_{t(1)}(E)\bar{\phi}^1_2(E)}{V_2 \int_{E'} \Sigma_{s(2)}(E'\to E)\bar{\phi}^2(E')dE'} \, . \qquad \text{(II-6)}$$

The work by Compton[18] has dealt extensively with the development and verification of empirical relations for the escape probabilities $P_i(E)$. In addition, the physical and geometrical implications of $P_i(E)$ are well described by Henry[19] and Schwenk[6]. The results for the empirical relationships of the escape probabilities for square and hexagonal lattice configurations as developed by Compton are given in Appendix II.

Furthermore, coupling equations (II-4), (II-5) and (II-6) and performing some detailed algebra yields the following specialized system of equations:

$$\Sigma_{t(1)}(E)\bar{\phi}^{1}(E) = [1 - p_1(E)]\{ \int_{E'} dE' \; \Sigma_{s(1)}(E' \to E)\bar{\phi}^{1}(E') + S_{f(1)}(E)\}$$

$$+ \frac{P_2(E)}{\rho} \int_{E'} dE' \; \Sigma_s(E' \to E)\bar{\phi}^{2}(E')$$

$$\Sigma_{t(2)}(E)\bar{\phi}^{2}(E) = [1 - P_2(E)] \int_{E'} dE' \; \Sigma_{t(2)}(E' \to E)\bar{\phi}^{2}(E') +$$

$$\rho P_1(E)\{ \int_{E'} dE' \; \Sigma_{S(1)}(E' \to E)\bar{\phi}^{1}(E') + S_{f(1)}(E)\}$$

where ρ is the fuel-to-moderator ratio (V_1/V_2). Subsequent transformation into lethargy variable yields the following:

$$F_1^{(n)}(u) = \sum_j \{[1 - P_1^{(n)}(u)][\int_{u_{n_j}}^{u} R_{S_1}^{(n)^j}(u') \frac{F_1^{(n)^j}(u')}{(1-\alpha_j)} e^{-(u-u')} du'$$

$$+ \int_{u-\ell u}^{u_{n_j}} \frac{1}{\alpha_j} R_{S_1}^{(n-1)^j}(u') \frac{F_1^{(n-1)^j}(u')}{(1-\alpha_j)} e^{-(u-u')} du' + S_{f(1)}^{j}(u)]\}$$

$$+ \sum_j \frac{P_2^{(n)}(u)}{\rho} \{ \int_{u_{n_j}}^{u} R_{S_2}^{(n)^j}(u') \frac{F_2^{(n)^j}(u')}{(1-\alpha_j)} e^{-(u-u')} du' +$$

$$\int_{u-\ell n}^{u_{n_j}} \frac{1}{\alpha_j} R_{S_2}^{(n-1)^j}(u') F_2^{(n-1)^j}(u') e^{-(u-u')} du'\} \qquad \text{(II-7-A)}$$

$$F_2^{(n)}(u) = \sum_j \{[1 - P_2^{(n)}(u)][\int_{u_{n_j}}^{u} R_{S_2}^{(n)^j}(u') \frac{F_2^{(n)^j}(u')}{(1-\alpha_j)} e^{-(u-u')} du'$$

$$+ \int_{u-\ell u}^{u_{n_j}} \frac{1}{\alpha_j} R_{S_2}^{(n-1)^j}(u') \frac{F_2^{(n-1)^j}(u')}{(1-\alpha_j)} e^{-(u-u')} du']\}$$

$$+ \sum_j \rho P_1^{(n)}(u) \{ \int_{u_{n_j}}^{u} R_{S_1}^{(n)^j}(u') \frac{F_1^{(n)^j}(u')}{(1-\alpha_j)} e^{-(u-u')} du' +$$

$$\int_{u-\ell u}^{u_{n_j}} \frac{1}{\alpha_j} R_{S_1}^{(n-1)^j}(u') \frac{F_1^{(n-1)^j}(u')}{(1-\alpha_j)} e^{-(u-u')} du' + S_{f_1}^{j}(u)\}$$

$$\text{(II-7-B)}$$

where summation is taken over the isotopes under consideration. The following variables have been introduced in equation (II-7):

$$F_k^{(n)^j}(u) = \Sigma_{t_k}^{(n)^j}(u)\,\bar{\phi}_k^{(n)}(u)$$

$$R_s^{(n)^j}(u) = \Sigma_{s_k}^{(n)^j}(u)/\Sigma_{t_k}^{(n)^j}(u)$$

$$u_{n_j} = n_j \ell u \frac{1}{\alpha_j}$$

$$\rho = V_1/V_2 \cdot$$

The notation utilized is summarized below:

subscript k: refers to region number, i.e. k=1,2

superscript j: refers to the isotope index

superscript (n): refers to the recursion iterate in slowing down.

For analytical purposes, it is convenient to rewrite equation (II-7) in compact form, by introducing new kernels defined by:

$$F_K^{(n)}(u) = \sum_i \sum_j \left\{ \int_{u_{n_j}}^{u} \Gamma_{k_i}^{(n)^j}(u,u') \frac{F_i^{(n)^j}(u')}{(1-\alpha_j)} e^{(u-u')} du' + \right.$$

$$\left. \int_{u-\ell u \frac{1}{\alpha_j}}^{u_{n_j}} \Gamma_{k_i}^{(n-1)^j}(u,u') F_i^{(n-1)^j}(u') e^{-(u-u')} du' \right\}$$

$$+ \sum_j \Gamma_{k_1}^{(n)^j}(u) \left[\Sigma_{s_1}(u)/\Sigma_{t_1}(u)\right]^{-1} S_{f(1)}^j(u) \qquad \text{(II-8)}$$

for k=1,2

The indices i and j denote summation over region and fission isotopes respectively where,

$$\underline{\Gamma}(u,u') = \begin{pmatrix} [1 - P_1(u)][\Sigma_{s_1}(u')/\Sigma_t(u')] & \rho^{-1}P_2(u)[\Sigma_{s_2}(u')/\Sigma_{t_2}(u')] \\ \rho P_1(u)[\Sigma_{s_1}(u')/\Sigma_t(u')] & [1 - P_2(u)][\Sigma_{s_2}(u')/\Sigma_{t_2}(u')] \end{pmatrix}.$$

The fission source may be obtained from the following[22]:

$$S_{f_1}^j(E) = \int_{E'} G^j(E,E')\Sigma_{f1}^j(E')\bar{\phi}^{-1}(E')dE' \simeq \chi(E) \int_{E'} \nu^j(E)\Sigma_{f_1}^j(E')\bar{\phi}^{-1}(E')dE'$$

where $\int_0^\infty \chi(E)dE$ is normalized to unity i.e.,

$$\chi(E) \simeq 0.453e^{-1.036E}\sinh\sqrt{2.29E} \text{ for E in MeV}$$

and

$$\int_0^\infty E\chi(E)dE = 1.98 \text{ MeV} .$$

2.3 Development of Recursion Algorithms for Kernels

This section covers the method utilized to develop the recursion algorithms for the kernels by means of algebraic as well as analytical approaches. The goal has been to obtain an economical set of recursion relations in the form of an algebraic system of equations, or equations that may be readily integrated, minimizing in this manner costly invokations of more involved numerical algorithms.

The implementation of such a method begins by mapping the set of integro- differential equations into a system of algebraic equations by invoking the LaPlace transform and limit theorems as will be detailed below. Differentiating equation (II-8) with respect to lethargy, the following is obtained:

$$\frac{dF_k^{(u)^I}}{du} + \left\{1 - \sum_{i=1}^{2} \frac{\Gamma_{ki}^{(n)^I}(u)}{(1-\alpha_I)}\right\} F_k^{(n)^j}(u) = \sum_j \sum_{j\neq I} \Gamma_{k_i}^{(n)^j}(u) \frac{F_i^{(n)^j}(u)}{(1-\alpha_i)}$$

$$- \sum_i \sum_j \Gamma_{K_i}^{(n-1)^j}(u - \ell u \frac{1}{\alpha_j}) F_i^{(n-1)^j}(u - \ell u \frac{1}{\alpha_j})(\frac{\alpha_i}{1-\alpha_j}) -$$

$$\sum_{j\neq 1} \frac{dF_K^{(n)_j}(u)}{du} + \sum_i \sum_j \left\{ \int_{n\ell u \frac{1}{\alpha_j}}^{u} \frac{\partial \Gamma_{ki}^{(n)_j}(u,u')}{\partial u} \frac{F_i^{(n)^j}(u')}{(1-\alpha_j)} du' + \right.$$

$$\left. \int_{u-\ell u \frac{1}{\alpha_j}}^{n\ell u \frac{1}{\alpha_j}} \frac{\partial \Gamma_{ki}^{(n-1)^j}(u,u')}{\partial u} \frac{F_i^{(n-1)^j}(u')}{(1-\alpha_j)} du' \right\} +$$

$$+ \sum_{j=1} \left[\frac{\partial \Gamma_{Ki}}{\partial u} S_{f1}^j(u) + \Gamma_{k_i}(u) \frac{\partial S_{f1}^j(u)}{\partial u}\right\} \text{ for } k=1,2 \text{ and } I=1,2,\ldots N_I, \text{ where } N_I$$

is the number of isotopes.

Subsequently, taking the LaPlace transform with respect to lethargy of the above set of equations and invoking the initial value theorem yields:

$$\tilde{F}_k^I(s) = \frac{F_k^{I\,(0)}(0)}{(s - A_k)} \{1 - L[\frac{R_{a1}^I(u)B_{k1}(u)}{(1-\alpha_I)}] - L[\frac{R_{a2}^I(u)B_{k2}(u)}{(1-\alpha_I)})\} -$$

$$\sum_{j\neq I} \frac{1}{(s - A_k)}\{L[\frac{R_{a1}^j(u)B_{k1}(u)}{(1-\alpha_j)}] + L[\frac{R_{a2}^j(u)B_{k2}(u)}{(1-\alpha_j)}]\}$$

$$+ L[y_{k1}(S_{f(1)} + \frac{\partial S_{f_1}}{\partial u} + S_{f(1)}(u)\frac{\partial y_{k1}}{\partial u}](\frac{1}{s-A_k^{(0)}}) \qquad \text{(II-9)}$$

for $k=1,2$

$I=1,2,\ldots,N_I$

$s\tilde{F}_k^I(s) > u\ell n \frac{1}{\alpha_I}$

and

$$\tilde{F}_k^I(s) = \frac{F_k^I(n\ell u \frac{1}{\alpha_I})}{(s - A_k^{(n)})} \{1 - L[\frac{R_{a1}^{I\,(n)}(u)B_{K1}(u)}{(1 - \alpha_I)}] - L[\frac{R_{a2}^{I\,(n)}(u)B_{K2}(u)}{(1 - \alpha_I)}] -$$

$$\sum_{j\neq 1} [L(\frac{R_{a1}^{j\,(n)}(u)B_{K1}(u)}{(1 - \alpha_j)}) + L(\frac{R_{a2}^{j\,(n)}(u)B_{K2}(u)}{(1 - \alpha_j)})]\} -$$

$$\sum_i \sum_j L[\Gamma_{K1}^{(n-1)^j}(u-\ell u \frac{1}{\alpha_j})F_i^{(n-1)^j}(u-\ell u \frac{1}{\alpha_j})(\frac{\alpha_j}{1-\alpha_j})(\frac{1}{s-A_k^{(n)}})$$

$$+ \frac{1}{s-A_k^{(n)}} Ly_{k_1}(S_{f1}(u) + \frac{\partial S_{f1}(u)}{\partial u}) \quad . \qquad \text{(II-10)}$$

for $k=1,2$

for $I=1,2,\ldots,N_I$

and $s\tilde{F}_k^I(s) < n\ell n \frac{1}{d_I}$, where $A_k^{(n)} = \sum_i \sum_j \frac{F_i^{\,j}(n\ell n\ 1/\alpha_j)/F_k^{\,I}(n\ell n\ 1/\alpha_I)}{(1 - \alpha_j)} - 1$.

Here $L(\ldots)$ denotes the LaPlace operator, and $\tilde{F}(s)$ denotes the transform

of F(u), and where the following variables have been introduced:

$$\underline{\underline{B}}(u) = \underline{\underline{\Gamma}}(u)\underline{\underline{R}}_S^{-1}(u) = \begin{pmatrix} [1 - P_1(u)] & \rho^{-1}P_2(u) \\ \rho P_1(u) & [1 - P_2(u)] \end{pmatrix}$$

$$y_{k_1}(u) = \begin{cases} 1 - P_1(u) & \text{for } k=1 \\ \rho P_1(u) & \text{for } k=2 \end{cases}$$

and

$$A_k^{(0)} = \sum_i \sum_j \frac{[F_i^j(0)/F_k(0)]B_{ki}(0)}{(1-\alpha_j)} - 1$$

Inverting equation (II-9) into the lethargy domain yields:

$$F_k^{(0)I}(u) \cong F_k^{(0)I}(0)e^{A_k^{(0)}u} * \prod_{\mu=1}^{N_f} \exp\{-\int_o^u \frac{R_{a1}^{\mu}(u')B_{k1}(u')}{(1-\alpha_I)} e^{-(u-u')}du'\}*$$

$$* \prod_{\mu=1}^{N_m} \exp\{-\int_o^u \frac{R_{a2}^{\mu}(u')B_{k2}(u')}{(1 - \alpha_I)} e^{-(u-u')}du'\} +$$

$$+ \int_o^u S_{f1}(u')B_{k1}(u')e^{A_k^{(0)}(u-u')}du' \qquad \text{(II-11)}$$

for k=1,2,

for I=1,2,...N_I,

and $0 < u < \ell n \frac{1}{\alpha_I}$,

where, N_f and N_m are the total number of isotopes in the fuel and moderator regions respectively.

Similarly, inverting equation (II-10) yields the following:

$$F_K^{(n)I}(u) = F_K^I(n\ell n \frac{1}{\alpha_I}) e^{A_K(n\ell n \frac{1}{\alpha_I}} \prod_{J=1}^{N_f} \exp\{-\int_{n\ell n \frac{1}{\alpha_I}}^{u} \frac{R_{a1}^J(u')B_{k1}(u')}{(1-\alpha_I)} e^{-(u-u'} du'\} *$$

$$* \prod_{J=1}^{N^m} \exp\{-\int_{n\ell n \frac{1}{\alpha_I}}^{u} \frac{R_{a2}^J(u')B_{k2}(u')}{(1-\alpha_j)} e^{-(u-u')} du'\}$$

$$- \sum_i \sum_j \int_{n\ell n \frac{1}{\alpha_j}}^{u} \Gamma_{K_1}^{(n-1)^j}(u' - \ell n \frac{1}{\alpha_j}) F_i^{(n-1)^j}(u' - \ell n \frac{1}{\alpha_j}) e^{A_k^{(n-1)}(u-u')} \frac{du'}{(1-\alpha_j)}$$

$$+ \int_{n\ell n \frac{1}{\alpha_I}}^{u} S_{f1}(u') e^{A_k^{(n)}(u-u')} du' \qquad \text{(II-12)}$$

for $k=1,2$

$I=1,2,\ldots,N_I$

$(u - \ell n \frac{1}{\alpha_I}) < u' < u$

where, N^f and N^m are the total number of isotopes in the fuel and moderator regions respectively.

Some useful physical simplifications may be deduced from equations (II-11) and (II-12). Firstly, considering negligible absorption for the moderator isotopes in the range $0 < u < \ell n\, 1/\alpha_j$, we arrive at the following simplification for equation (II-11):

$$F_K^{(0)I}(u) = F_K^{(0)I}(0) e^{A_K u} P_{re}(u) + \int_o^u S_{f1}(u') B_{K1}(u') e^{A_k(u-u')} du'$$

(II-13)

where P_{re} is the net resonance escape probability, given as the product of the resonance escape probabilities over all the fuel isotopes, i.e.,

$$P_{re}(u) = \prod_{\mu=1}^{N_f} P_{re}^{\mu}(u) \quad . \tag{II-14}$$

Also from equation (II-11), $P_{re}(u)$, is the following:

$$P_{re}^{\mu}(u) = \exp\left\{- \int_{u'} \left(\frac{\rho}{1+\rho}\right) \Sigma_a^{\mu}(u')\phi(u')du'\right\} =$$

$$= \exp\left\{- \int_{o}^{u} R_{a_1}^{\mu}(u') \frac{B_{K1}(u')}{(1-\alpha_{\mu})} e^{-(u-u')}du'\right\} \quad . \tag{II-15}$$

In the limit as $u \to 0$, equations (II-14) and (II-15) become:

$$\lim_{u\to 0} P_{re}(u) = 1 \quad . \tag{II-16}$$

Therefore in accordance with the above limit, substituting equation (II-16) into equation (II-13) yields the following limit for equation (II-11):

$$\lim_{u\to 0} F_K^{(0)^I}(u) = F_K^{(0)^I}(0) \text{ for } V_I. \tag{II-17}$$

Furthermore, by considering negligible absorption over all isotopes, and by assuming homogenized media with a preponderant number of scatterer atoms, the coefficient $A_K^{(0)}$ simplifies to

$$A_K^{(0)} \simeq \frac{\alpha_s}{1-\alpha_s} \quad . \tag{II-18}$$

Consequently, by substituting equation (II-18) into equation (II-11), the latter reduces to

$$F^{(0)}(u) = F^{(0)}(0) \exp\left(\frac{\alpha_s}{1-\alpha_s}\right)u \quad . \tag{II-19}$$

Equation (II-19) represents the case for neutron moderation without absorption for homogeneous media[20,21].

Finally, it should also be noted that equation (II-12) reduces in the limit as $u \to n\ell n\ 1/\alpha_I$,

$$\lim_{u \to n\ell n \frac{1}{\alpha_I}} F_K^{(n)^I}(u) = F_K^{(n)^I}\left(n\ell n \frac{1}{\alpha_I}\right) \quad . \tag{II-20}$$

2.3 Thermal Energy Region

The implementation of the transport equation will be presented in two parts. First, the derivation of the transport equation modelling heterogeneous lattice cells will be described, and subsequently, a subsection will follow with a survey of scattering kernels.

2.3.1 Thermal Transport Equations

The derivation of the transport equation begins with the definitions for the Emission Density Function, and for the Transmission Probability Function. The former deals with scattering cross sections in the energy domain, and the latter with transmission probabilities in space. More concisely, these are the following:

$$H(\vec{r},E) = \int_0^\infty dE' \; \Sigma_s(\vec{r},E,E') \; \phi(\vec{r};E) \qquad \text{(II-21)}$$

and

$$T(\vec{r},\vec{r};E) = \frac{1}{4\pi(|r-r'|)^2} \exp\left\{ \int_0^{|\vec{r}-\vec{r}'|} ds\Sigma_t\left(r - s\frac{\vec{r}-\vec{r}'}{(|\vec{r}-\vec{r}'|)^2}\right)\right\} \qquad \text{(II-22)}$$

where equations (II-21) and (II-22) define the emission and the transmission probability functions respectively. Together, the above functions constitute the integrand for the flux in the following manner:

$$\phi(\vec{r},E) = \int_{\vec{r}'} d\vec{r}' T(\vec{r},\vec{r}',E) H(\vec{r}',E) \quad . \qquad \text{(II-23)}$$

In a more concise definition, the emission density describes the distribution of neutrons following a collision, and the transmission probabil-

ity function describes the density at $\vec{r}$ due to a unit point source at $\vec{r}'$. These two together constitute the flux which in terms of equations (II-21) and (II-22) may be written as follows:

$$\phi(\vec{r},E) = \int_{\vec{r}'} d\vec{r}'\ T(\vec{r},\vec{r}',E)\Big\{ \int_{o}^{E_c} dE'\ N\sigma_s(\vec{r}',E,E')\phi(\vec{r}',E') + S(\vec{r}',E)\Big\}. \tag{II-24}$$

The source term appearing in equation (II-24) arises from the down scattering from the fast group, i.e.,

$$S(\vec{r},E) = \int_{E_c}^{\infty} dE' N\sigma_s(\vec{r},E,E')\phi(\vec{r},E')$$

where E_c is the cut-off energy. In addition, equations (II-21) and (II-22) are subject to the following normalization and symmetry conditions:

(i) $\Sigma_s(E) = \int_{o}^{\infty} dE'\Sigma_s(E',E)$

(ii) $\int_{T_l} \vec{r}'\ d\vec{r}'\ T(\vec{r},\vec{r}',E)\Sigma_t(\vec{r}',E) = 1$

(iii) $T(\vec{r},\vec{r}',E) = T(\vec{r}',\vec{r},E)$

(iv) $M(E')\Sigma_s(\vec{r},E,E') = M(E)\Sigma_s(\vec{r},E',E)$.

Condition (iv) above describes the detailed balance, where M(E) is the Maxwellian flux.

Therefore, for a heterogeneous cell configuration, equation (II-24) in conjunction with conditions (i) through (iv) may constitute the specialized system of equations for the moderator and fuel regions. More concisely,

$$\bar{\phi}^{k}_{(E)} = \frac{1}{V_k} \int_{\vec{r}} d\vec{r} \int_{\vec{r}'} d\vec{r}' \; T(\vec{r},\vec{r}',E) \Big\{ \int_{o}^{E_c} dE' \sum_{j \; \varepsilon \; \text{isotopes}} N_j \sigma^{j}_{S_k}(\vec{r}',E',E)\phi(\vec{r}',E)$$

$$+ S(\vec{r}',E)\delta_{kl} \Big\} \quad \text{for } k = 1,2 \qquad \text{(II-25)}$$

where $\delta_{\alpha\beta}$ is the Kronecker delta defined previously, and $\bar{\phi}^{k}$ is the volume-averaged flux for region k, i.e.,

$$\bar{\phi}^{k}_{(E)} = \frac{1}{V_k} \int_{\vec{r}_k} \phi(\vec{r},E)d\vec{r} \; .$$

The next task involves a detailed description of the kernels $\sigma^{j}_{sk}(\vec{r}',E',E)$ in equation (II-25). This will be elaborated further in the following subsection.

2.3.2 Survey of Thermal Energy Scattering Kernels

The differential scattering cross section is strongly related to the detailed dynamics of atomic motion through its dependence on the scattering law $S(\vec{r},\omega)$ as expressed by the following:

$$\frac{d^2\sigma}{dEd\Omega}(\vec{k}_o,\vec{k}) = \frac{\vec{k}}{4\pi\hbar\vec{k}_o}\left[\sigma_{c,b}S_c(\vec{k},\omega) + \sigma_{inc,b}S_{inc}(\vec{k},\omega)\right] \qquad \text{(II-26)}$$

where the subscripts c, inc, and b stand for coherent, incoherent and bound respectively, and $\hbar_2\vec{k}_o$ represents the momentum lost by the neutron.

The essential problem in relating neutron scattering cross sections as expressed by equation (II-26) arises in modelling the atomic dynamics in a manner in which simple numerical calculations or analytical methods would not yield unfeasible results. In addition, the description of the atomic motions that are represented by the formulation should reflect with reasonable accuracy all the features of moderator atomic motion to which the scattering of thermal neutrons is more sensitive. Therefore, the main approximations in calculating scattering in an economic fashion should be the following:

(1) Incoherent approximation for inelastic scattering,

(2) Gaussian approximation to the scattering function, i.e.,

$$\chi_{inc}(\vec{k},t) = \exp[-k^2\gamma(t)]$$

whereby, $\chi_{inc}(\vec{k},t)$ is related to the Nelkin and Honeck functions as will be explained in a later part in this section.

Prior to implementing assumption (1), it should be remarked that the incoherent scattering encompasses the sum total of the scattering contributions of the individual atoms, whereas the coherent component contains, in addition to the interference effect of the scattered waves by different atoms, also the direct terms. Therefore, it is useful to separate the direct terms from the interference terms in equation (II-26) to arrive at the following:

$$\frac{d^2\sigma}{dEd\Omega} = \frac{\vec{k}}{4\pi\hbar\vec{k}_o}\{\sigma_b S_{inc}(\vec{k},\omega) + \sigma_{c,b}[S_c(\vec{k},\omega) - S_{inc}(\vec{k},\omega)]\} \qquad \text{(II-27)}$$

where $\sigma_b = \sigma_{c,b} + \sigma_{inc,b}$.

Equation (II-27) has been obtained by algebraically adding and subtracting the term $\sigma_{c,b}S_{inc}(\vec{k},\omega)$ in equation (II-26) and subsequently regrouping.

Fundamentally, since the cross sections for the interference scattering governing molecules of single species is a highly singular function of the wave vector, $\vec{k}$, of the incident neutron, the simplification of the calculations becomes feasible by assuming the incoherent

approximation for inelastic scattering as established by approximation (1).

The advantage of invoking the second approximation above arises from experimental facts, whereby the non-Gaussian effects associated with anisotropic motions affects only slightly the neutron spectrum in a reactor[24]. Another useful remark regarding the simplification process arises from the definition of the scattering terms $S(\vec{k},\omega)$. This function is defined as the sum over quantities involving the exact eigenstates of the scattering system[25]. Usually, these exact eigenstates are not known. Even if they were known the number of initial and final state contributions to the sum over the states would be so large that explicit summation becomes unfeasible. Therefore, it is preferable to eliminate the appearance of exact eigenstates. This can be done by introducing an intermediate scattering function $\chi_{inc}(\vec{k},t)$ in the following manner:

$$\chi_{inc}(\vec{k},t) = \int_{-\infty}^{\infty} e^{i\omega t} S_{inc}(\vec{k},\omega)dw \ . \qquad \text{(II-28)}$$

After $\chi_{inc}(\vec{k},t)$ in equation (II-28) has been determined via approximation (2), the function $S_{inc}(\vec{k},\omega)$ may be obtained by inverting equation (II-28) i.e.,

$$S_{inc}(\vec{k},\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{-i\omega t} \chi_{inc}(\vec{k},t)dt \qquad \text{(II-29)}$$

where $\chi_{inc} = \exp[-k^2\gamma(t)]$ from approximation (2) is obtainable indirectly from the Nelkin and Honeck approximations.

2.3.3 The Structure of Light and Heavy Water Molecules

The two light atoms in H_2O and oxygen atoms form an isosceles triangle. The oxygen atom is at the vertex of the $\gamma = 104^o$ angle formed by two equal sides of length $\ell = 0.96$[26]. The x and y axes, which intersect at the center of the molecule, are the two principal axes. The third principal axis lies in a direction perpendicular to the x-y plane. The moments of inertia about the x,y, and z axes are[26]:

$$I_x = 1.02 \times 10^{-40} \text{ gm-cm}^2$$

$$I_y = 1.92 \times 10^{-40} \text{ gm-cm}^2$$

$$I_z = 2.95 \times 10^{-40} \text{ gm-cm}^2 \quad .$$

Furthermore, since no two of these moments are equal, the H_2O molecule is an asymmetric rotator, and because of this asymmetry, the rotation spectrum of H_2O is very complex, having many closely spaced energies. The smallest transition energies are about 10^{-4} eV.

The structure and normal vibrations of D_2O are similar to those of H_2O. The bond angle, γ, and the bond length, ℓ, in D_2O are 106 deg. and 1.01 A respectively. Because the deuteron has a greater mass than the proton, the internal vibrations of D_2O are less than those of H_2O. Nevertheless, since the moments of inertia of D_2O are greater than those of H_2O, a very complicated rotation spectrum for D_2O with many closely spaced levels results.

Although H_2O and D_2O are dynamically similar, they scatter neutrons differently. The scattering from H_2O comes predominantly from incoherent scattering by hydrogen, with a small but generally significant direct contribution from oxygen as indicated in Table (II-1). On the other hand, the deuterons and the oxygen contribute a large proportion of the cross sections in the D_2O molecule. Furthermore, the interference effects resulting from scattering by D_2O are very significant for neutron wavelengths which are comparable to the length of the OD bond. This arises from the fact that the coherent scattering lengths of the oxygen and the deuteron are greater than the incoherent scattering length of the deuteron. The fundamental vibrations of the H_2O and the D_2O molecules are shown in Table (II-2). The molecular dynamics of water in the liquid phase is not as well understood as in the vapor phase. Three very significant frequency spectra experiments attempt to incorporate some of the complexities inherent in the molecular clusters of H_2O and D_2O liquids. These experiments yield the

TABLE II-1[27]

Bound-Atom Cross Sections for Moderators[27]
Ref. Hughes et al., USAEC Rep # BNL-325, 2nd ed. (1958).

Isotope	σ_b σ_c (barns)[b]	Sign of coherent (barns)	amplitude
H	81.5 ± 0.4	1.79 ± 0.02	(-)
D	7.6 ± 0.1	5.4 ± 0.3	(+)
O	4.24 ± 0.02	4.2 ± 0.3	(+)

TABLE (II-2)[26]

Fundamental Vibrations, $\bar{h}\omega$, of H_2O and D_2O Molecules.
Ref. Herzberg, "Infrared and Raman Spectra of Polyatomic Molecules"
Molecular Spectra and Molecular Structure, Vol. II,
(Van Nostrand-NY-1945)

Type	H_2O vapor	D_2O vapor
Symmetric (ω_1) Stretching	0.474	0.342
Bending (ω_2)	0.205	0.150
Assymmetric (ω_3)	0.488	0.356

responses of the Delta function singularities constituting $\gamma(t)$ in equation (II-29). Namely, these spectra are the Brown-St. John[27] and Nelkin for H_2O[29], and Honeck[30] for D_2O.

Brown and St. John[27] were the first to consider the effects of molecular binding on neutron thermalization by H_2O. In their calculations the energy distributions of scattered neutrons correspond to that which is characteristic of a rigid, freely rotating H_2O molecule, but the neutron-proton scattering is assumed to depend on the relative velocity in such a way as to reproduce the total scattering cross section. This is a completely unphysical assumption, inasmuch as the nuclear scattering amplitude is velocity dependent at low energies. Furthermore, the Brown-St. John model does not account for the internal molecular vibrations or the hindrance of the rotations produced by the molecular interactions in the liquid state.

Nelkin has introduced a model for H_2O which takes into account, at least in rough approximation, all of the principal dynamic features of the molecule in the liquid state. Nelkin assumes that the internal vibrations and the center-of-mass motion of the molecule in the liquid state are the same as in the vapor state. This model has been calibrated with the following equation:

$$M^{-1}f(\omega) = \sum_{j=1}^{k} M_j^{-1} f_j(\omega) \qquad \text{(II-30)}$$

where M is the mass of the nucleus, and M_j and $f_j(\omega)$ are obtained from experimentally fit data. These responses must also satisfy the following requirements:

(1) Normalization condition, i.e.,

$$\int_0^\infty f_j(\omega)d\omega = 1 \text{ for } V_j$$

(2) $M^{-1} = \sum_{j=1}^{k} M_j^{-1}$, which is the result of imposition (1) above.

(3) $\lim_{\omega\to 0} \omega^{-2} f_j(\omega) = b_j > 0$ for each $f_j(\omega)$ except one.

(4) The remaining $f_j(\omega)$ satisfies either imposition (3) above, or one of the following:

(i) $\lim_{\omega\to 0} f_j(\omega) = f(0) \neq 0$

(ii) $f_j(\omega) = \delta(\omega)$.

Requirements (1) through (4) above arise from the behavior of $f(\omega)$ in the limit $\omega\to 0$. This may be explained from a physical basis, by the behavior due to the mean square displacement of an atom at very long times, and the characterization of the neutron scattering for very small energy transfers.

Requirement (3) represents the case in which the atomic motion is bounded at all times and there is a delta-function peak in $Sinc(\vec{k},\omega)$ at zero energy transfer. This peak strictly corresponds to elastic scattering, where the quantum state of the scatterer does not change.

Impositions (4-i) and (4-ii) relate to mean square displacement at long times. For the case of water fluids, $f(\omega)$ satisfies (4-i). This gives rise to a peak for $Sinc(\vec{k},\omega)$ centered at zero energy transfer and with a finite width which is a function of $\vec{k}$.

In terms of equation (II-30) Nelkin's model may be expressed as follows:

$$f(\omega) = \frac{M}{M_1}\,\delta(\omega) + \frac{M}{M_2}\,\delta(\omega-\omega_2) + \frac{M}{M_3}\,\delta(\omega-\omega_3) + \frac{M}{M_4}\,\delta(\omega-\omega_4) \quad . \tag{II-31}$$

The coefficients M/Mj and the parameters ω_j are detailed in Table (II-3). The above coefficients are determined from simple dynamical arguments. First, since it is assumed that the molecule translates freely, the coefficient $M_1/M=18$, where M_1 is the mass of the H_2O molecule. The coefficient M_2/M is determined from the best fit of the cross section obtained from the mass tensor approximation to the measured free molecule cross section. The vibrational masses M_3/M and M_4/M are chosen from requirement (2), and from the fact that the contribution of any mode to the incoherent, vibrational, intermediate scattering function $\chi_{ss}(\vec{k},t)$ depends on the square of the normal mode amplitude for that mode. The square of this amplitude must be proportional to the inverse of the effective mass for that mode. In the approximation that the oxygen atom is infinitely heavy, the proton amplitude vectors in the

symmetric stretching, the assymetric stretching and bending vibrations all have the same magnitude, and the two stretching modes are combined to give:

$$f_4(\omega) = \delta(\omega-\omega_3) \quad .$$

Consequently, it follows that $M_4^{-1} = 2M_3^{-1}$ from imposition (2) and the previously defined values of M_1 and M_2. The coefficients M_3/M and M_4/M are therefore 5.84 and 2.92 respectively.

In analogy to Nelkin's model for H_2O, Honeck has determined similar parameters for D_2O. These are presented in Table (II-3). In Honeck's calculations $M_1/M=20/2$, which represents the ratio of the mass of the D_2O molecule to the mass of the deuteron, and M_3 is obtained from the Sachs-Teller formula (31). A complementary model presented by Butler (32) invokes essentially all the features of Honeck's model, with the exception that it takes into account interference effects in scattering.

2.3.4 Implementation of Spectra into Scattering Law

Nelkin's approximation, equation (II-31) may be related to the intermediate function in the time domain by the following:[25]

$$\gamma(t) = \int_{-\infty}^{\infty} \{\cosh\left(\frac{\beta}{2}\right) - \cos\left(\frac{\beta}{2}\right)\}\left[\beta \sinh\left(\frac{\beta}{2}\right)\right]^{-1} f(\beta)d\beta \qquad \text{(II-32)}$$

Table (II-3)

Coefficients of Spectral Equation: $f(\omega) = \sum_{j=1}^{4} \frac{M}{M_j} (\omega-\omega_j)$

Moderator/ Coefficient	H_2O	D_2O
M_1/M	18	10
M_2/M	2.32	2.06
M_3/M	5.84	14.52
M_4/M	2.92	7.26
$\hbar\omega_2$ (eV)	0.060	0.050
$\hbar\omega_3$ (eV)	0.205	0.150
$\hbar\omega_4$(eV)	0.481	0.350

where,

$$\beta = \bar{h}\omega/kT \ .$$

Equation (II-32) yields the scattering amplitude by first invoking the Gaussian approximation for the intermediate scattering function, i.e.,

$$\chi_{inc}(\vec{k},t) = e^{-k^2\gamma(t)}$$

and subsequently entering the above in equation (II-29).

The scattering Kernel $\sigma_s^{(2)}(E,E')$, thus is:

$$\sigma_s^{(2)^j} = \frac{1}{4\pi kT}\sqrt{\frac{E}{E'}}\exp(-\frac{\beta}{2})\ \sigma_b^j S_{inc_j}(\alpha,\beta) \qquad \text{(II-33)}$$

for

$$\alpha = (E' + E - 2\sqrt{E'E}\ \hat{\Omega}\cdot\hat{\Omega}')/kT$$

$$\beta = \bar{h}\omega/kT$$

and

$$S_{inc_j}(\alpha,\beta) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{-i\beta t}\exp[-\alpha^2\gamma_j(t)]dt \ .$$

The scattering within the fuel volume may be determined by implementing the specialized Breit-Wigner formula:

$$\sigma_s^{(1)j}(E',E) = \frac{\sigma_o \Gamma_n^j}{4\pi\Gamma} \psi(\xi^j, \chi^j) + \frac{\sigma_o^j \Omega}{4\pi t_o} \chi(\xi^j) + 6.164 \times 10^{-14} \quad \text{(II-34)}$$

for:

$$\chi^j = 2\bar{h}\omega/\Gamma^j$$

and

$$\xi^j = \Gamma/\Gamma_D = \left(\frac{4EkT}{A}\right)^{-1/2} \Gamma^j \ .$$

The Doppler Broadening functions ψ and χ have been tabulated by Beynon[32].

CHAPTER III

RESULTS

3.1 Cell Models Implemented in Benchmark Studies

The lattice types studied in the present work have been designated according to the cell geometry in conjunction with the isotopic composition of the moderator. The fuel types have been categorized according to the isotopic concentrations within the pellets as well as the fuel rod dimensions. The above designations are detailed in Tables (III-1) through (III-12). The energy groups implemented are subsets of the MUFT multigroup structure. These groups are detailed in Table (III-13).

TABLE III-1

FUEL TYPE: 1

Pellet Diameter: 0.9104 cm
Pellet Isotopic Composition:

ISOTOPE (#)	NUMBER DENSITY (1/barn-cm)
U-235	44620-4
U-238	21860-2
O-16	424850-2

The above isotopic composition corresponds to a 2% enriched UO-2 pellet.

(+) Notation: In this Table and in all subsequent Tables numbers such as 44620-4 represent the exponential notation: 4.4620E-4

TABLE III-2

FUEL TYPE: 2

Pellet Diameter: 0.6858 cm

Pellet Isotopic Composition:

ISOTOPE (#)	NUMBER DENSITY (1/barn-cm)
U-235	39712-5
U-238	19816-2
Pu-239	14479-3
Pu-240	73623-4
Pu-241	17179-4
Pu-242	98164-5
O-16	44614-2

The above isotopic concentrations correspond to a PuO-2 / UO-2 pellet at about 0.2% enrichment level and 11% Pu content with 59% Pu-239, 30% Pu-240, 7% Pu-241, and 4% Pu-242.

TABLE III-3

FUEL TYPE: 3

Fuel Diameter: 0.6858 cm.

Pellet Isotopic Composition:

ISOTOPE (#)	NUMBER DENSITY (1/barn-cm)
U-235	37920-5
u-238	18922-2
Pu-239	19765-3
Pu-240	10050-3
Pu-241	23450-4
Pu-242	13400-4
O-16	44614-2

The above isotopic concentrations correspond to a PuO-2 / UO-2 pellet at about 0.2% enrichment and 15% Pu content with 59% Pu-239, 30% Pu-240, 7% Pu-241, and 4% Pu-242.

TABLE III-4

LATTICE TYPE: 1

Cell Type: hexagonal

Cell Pitch: 1.3718 cm.

Moderator Isotopic Composition:

ISOTOPE (#)	NUMBER DENSITY (1/barn-cm)
H-1	46840-2
O-16	23420-2

The cladding and moderator are homogenized. The cladding isotopes are not input.

TABLE III-5

LATTICE TYPE: 2

Cell Type: hexagonal

Cell Pitch: 1.2332 cm.

Moderator Isotopic Composition:

ISOTOPE (#)	NUMBER DENSITY (1/barn-cm)
H-1	46840-2
O-16	23420-2

The cladding and moderator are homogenized. The cladding isotopes are not input.

TABLE III-6

LATTICE TYPE: 3

Cell Type: hexagonal

Cell Pitch: 0.8636 cm.

Moderator Isotopic Composition:

ISOTOPE (#)	NUMBER DENSITY (1/barn-cm)
H-1	46840-2
O-16	23420-2

The cladding and moderator are homogenized. The cladding isotopes are not input.

TABLE III-7

LATTICE TYPE: 4

Cell Type: rectangular

Cell Pitch: 1.3718 cm.

Moderator Isotopic Composition:

ISOTOPE (#)	NUMBER DENSITY (1/barn-cm)
H-1	46840-2
O-16	23420-2

The cladding and moderator are homogenized. The cladding isotopes are not input.

TABLE III-8

LATTICE TYPE: 5

Cell Type: rectangular

Cell Pitch: 0.8636 cm.

Moderator Isotopic Composition:

ISOTOPE (#)	NUMBER DENSITY (1/barn-cm)
H-1	46840-2
O-16	23420-2

The cladding and moderator are homogenized. The cladding isotopes are not input.

TABLE III-9

LATTICE TYPE: 6

Cell Type: hexagonal

Cell Pitch: 1.3718 cm.

Moderator Isotopic Composition:

ISOTOPE (#)	NUMBER DENSITY (1/barn-cm)
H-2	42161-2
O-16	21081-2

The cladding and moderator are homogenized. The cladding isotopes are not input.

TABLE III-10

LATTICE TYPE: 7

Cell Type: hexagonal

Cell Pitch: 0.8636 cm.

Moderator Isotopic Composition:

ISOTOPE (#)	NUMBER DENSITY (1/barn-cm)
H-2	42161-2
O-16	21081-2

The cladding and moderator are homogenized. The cladding isotopes are not input.

TABLE III-11

LATTICE TYPE: 8

Cell Type: rectangular

Cell Pitch: 1.3718 cm.

Moderator Isotopic Composition:

ISOTOPE (#)	NUMBER DENSITY (1/barn-cm)
H-2	42161-2
O-16	21081-2

The cladding and moderator are homogenized. The cladding isotopes are not input.

TABLE III-12

LATTICE TYPE: 9

Cell Type: hexagonal

Cell Pitch: 0.8636 cm.

Moderator and Cladding Isotopic Compositions:

ISOTOPE (#)	NUMBER DENSITY (1/barn-cm)
H-1	46840-2
O-16	23420-2
ZIRC-2	42850-2

TABLE III-13

Subset of fast energy groups implemented from MUFT-group structure.

GROUP SUBSET	LOWER ENERGY (eV)	LETHARGY WIDTH
1	8.2085E+05	0.20
2	4.9787E+05	0.50
3	1.4264E+05	1.25
4	8.6517E+04	0.50
5	5.2475E+04	0.50
6	2.3579E+04	0.80
7	5.5308E+03	1.45
8	2.0347E+03	1.00
9	1.2341E+03	0.50
10	7.4852E+02	0.50
11	4.5400E+02	0.50
12	2.7536E+02	0.50
13	1.6702E+02	0.50
14	1.0130E+02	0.50
15	7.3600E+01	0.32
16	2.5608E+00	0.40
17	1.7261E+00	0.40
18	6.8256E-01	0.50

3.2 Verification of Simulation Runs

The validations of the simulation runs for the fast energy region are detailed in Tables III-14 through III-43. The program used in the CSMP language has been named ECG1 throughout the remainder of this work. The set of variables generated by the ECG1 model in these tables are tabulated with respect to the lethargy widths of 2.50, 5.00 and 8.00, covering the non-resolved and resolved resonance energy regions. These output variables are subsequently compared with the group constants computed by VIM. In addition, the multigroup spectra based on the widths and energy ranges given in Table III-13 are given in Tables III-44 through III-55.

The thermal group constants for the core configurations of the above runs are given in Tables III-56 through III-71. The reactivity analysis data is tabulated at the end of this section (Table III-72). The coded algorithms in CSMP as well as the coupling between the fast and thermal energy modules are detailed in Appendix 2. The integration stepsize in lethargy making optimal utilization of computer time and accuracy has been chosen as 2.50E-4 throughout the remainder of this work. The criteria for this selection are further described in Section 3.4.

3.3 Thermal Energy Group Constants

The thermal energy group constants are presented in Table III-56 through Table III-71.

TABLE III-14

LATTICE TYPE: 1
FUEL TYPE : 1

ENERGY GROUP (eV): ⌜1.0000E+07,8.2085E+05⌝
LETHARGY WIDTH : 2.50

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	2.6758E-01	2.6883E-01	-4.667E-01
sigt-2	1.9491E-01	1.9517E-01	-1.325E-01
siga-1	1.0496E-02	1.0517E-02	-2.011E-01
sigf-1	8.7646E-03	8.7146E-03	5.736E-01
sigt-25	7.2520E+00	7.2203E+00	4.386E-01
siga-25	1.2942E+00	1.2988E+00	-3.535E-01
sigf-25	1.2436E+00	1.2359E+00	6.206E-01
sigt-28	7.2408E+00	7.3564E+00	-1.572E+00
siga-28	4.2903E-01	4.3304E-01	-9.255E-01
sigf-28	3.7540E-01	3.7343E-01	5.267E-01

The fuel and moderator regions are 1 and 2 respectively. The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-15

LATTICE TYPE: 1
FUEL TYPE : 1

ENERGY GROUP (eV): 8.2085E+05,5.5308E+03
LETHARGY WIDTH : 5.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	4.1718E-01	4.1765E-01	-1.125E-01
sigt-2	6.1053E-01	6.1634E-01	-9.427E-01
siga-1	6.4000E-03	6.4589E-03	-9.112E-01
sigf-1	7.3521E-04	7.3662E-04	-1.914E-01
sigt-25	1.0920E+01	1.0916E+01	3.664E-02
siga-25	2.0920E+00	2.0922E+00	-9.559E-03
sigf-25	1.6330E+00	1.6326E+00	2.450E-02
sigt-28	1.0990E+01	1.0949E+01	3.745E-01
siga-28	2.5630E-01	2.5280E-01	1.384E+00
sigf-28	3.7155E-04	2.5280E-01	-4.715E-01

The fuel and moderator regions are 1 and 2 respectively. The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-16

LATTICE TYPE: 1
FUEL TYPE : 1

ENERGY GROUP (eV): [5.5308E+03,1.8554E+00]
LETHARGY WIDTH : 8.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	5.1220E-01	5.1346E-01	-2.454E-01
sigt-2	1.0425E+00	1.0416E+00	8.641E-01
siga-1	7.2406E-02	7.2635E-02	-3.153E-01
sigf-1	9.8850E-03	9.9416E-03	-5.693E-01
sigt-25	4.7096E+01	4.7181E+01	-1.802E-01
siga-25	3.4974E+01	3.5052E+01	-2.225E-01
sigf-25	2.2233E+01	2.2276E+01	-1.930E-01
sigt-28	1.4811E+01	1.4878E+01	-4.503E-01
siga-28	2.6016E+00	2.6072E+00	-2.148E-01
sigf-28	8.8260E-05	8.7395E-05	-9.898E-01

The fuel and moderator regions are 1 and 2 respectively. The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-17

LATTICE TYPE: 2
FUEL TYPE : 1

ENERGY GROUP (eV): [1.0000E+07,8.2085E+05]
LETHARGY WIDTH : 2.50

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	2.6813E-01	2.6870E-01	-2.106E-01
sigt-2	1.9611E-01	1.9592E-01	9.739E-02
siga-1	1.0384E-02	1.0450E-02	-6.307E-01
sigf-1	8.5884E-03	8.6591E-03	-8.160E-01
sigt-25	7.1756E+00	7.2139E+00	-5.313E-01
siga-25	1.3134E+00	1.2997E+00	1.053E+00
sigf-25	1.2485E+00	1.2363E+00	9.861E-01
sigt-28	7.4352E+00	7.3516E+00	1.137E+00
siga-28	4.3302E-01	4.3114E-01	4.366E-01
sigf-28	3.7203E-01	3.7088E-01	3.109E-01

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-18

LATTICE TYPE: 2
FUEL TYPE : 1

ENERGY GROUP (eV): [8.2085E+05,5.5308E+03]
LETHARGY WIDTH : 5.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	4.1613E-01	4.1697E-01	-2.014E-01
sigt-2	6.1700E-01	6.1789E-01	-1.440E-01
siga-1	6.3989E-03	6.4593E-03	-9.351E-01
sigf-1	7.2994E-04	7.3861E-04	-1.174E+00
sigt-25	1.0910E+01	1.0950E+01	-3.653E-01
siga-25	2.1002E+00	2.1000E+00	9.524E-03
sigf-25	1.6330E+00	1.6374E+00	-2.687E-01
sigt-28	1.0990E+01	1.0963E+01	2.463E-01
siga-28	2.5150E-01	2.5262E-01	-4.434E-01
sigf-28	3.5950E-04	3.6643E-04	-1.880E+00

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-19

LATTICE TYPE: 2
FUEL TYPE : 1

ENERGY GROUP (eV): [5.5308E+03,1.8554E+00]
LETHARGY WIDTH : 8.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	5.0385E-01	5.0514E-01	-2.554E-01
sigt-2	1.0410E+00	1.0412E+00	-1.921E-01
siga-1	6.7885E-02	6.8037E-02	-2.234E-01
sigf-1	9.6748E-03	9.7950E-03	-1.227E+00
sigt-25	4.6348E+01	4.6428E+01	-1.723E-01
siga-25	3.4216E+01	3.4293E+01	-2.245E-01
sigf-25	2.1903E+01	2.1949E+01	-2.096E-01
sigt-28	1.4592E+01	1.4513E+01	5.443E-01
siga-28	2.4030E+00	2.4124E+00	-3.897E-01
sigf-28	7.1200E-05	7.0523E-05	9.600E-01

The fuel and moderator regions are 1 and 2 respectively. The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-20

LATTICE TYPE: 3
FUEL TYPE : 2

ENERGY GROUP (eV): [1.0000E+07,8.2085E+05]
LETHARGY WIDTH : 2.50

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	2.7048E-01	2.6656E-01	-1.470E+00
sigt-2	2.0091E-01	1.9875E-01	1.086E+00
siga-1	1.3027E-02	1.3218E-02	-1.445E+00
sigf-1	1.1278E-02	1.1122E-02	1.399E+00
sigt-25	7.1864E+00	7.1116E+00	1.052E+00
siga-25	1.3023E+00	1.2891E+00	1.125E+00
sigf-25	1.2359E+00	1.2494E+00	-1.083E+00
sigt-28	7.3339E+00	7.4101E+00	-1.228E+00
siga-28	4.1515E-01	4.1064E-01	1.098E+00
sigf-28	3.5153E+00	3.5707E+00	-1.552E+00
sigt-29	7.3311E+00	7.4027E+00	-9.667E-01
siga-29	1.8523E+00	1.8689E+00	-8.889E-01
sigf-29	1.8401E+00	1.8595E+00	-1.044E+00
sigt-40	7.2016E+00	7.2618E+00	-8.290E-01
siga-40	1.6528E+00	1.6697E+00	-1.010E+00
sigf-40	1.5907E+00	1.6015E+00	-6.720E-01
sigt-41	7.6348E+00	7.5504E+00	1.118E+00
siga-41	1.7434E+00	1.7300E+00	7.731E-01
sigf-41	1.6512E+00	1.6218E+00	1.812E+00
sigt-42	7.1668E+00	7.2439E+00	-1.065E+00
siga-42	1.5101E+00	1.5341E+00	-1.563E+00
sigf-42	1.4707E+00	1.4906E+00	-1.336E+00

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-21

LATTICE TYPE: 3
FUEL TYPE : 2

ENERGY GROUP (eV): "8.2085E+05,5.5308E+03"
LETHARGY WIDTH : 5.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	4.4783E-01	4.5609E-01	-1.811E+00
sigt-2	6.0943E-01	6.1771E-01	-1.340E+00
siga-1	9.9085E-03	9.7525E-03	1.601E+00
sigf-1	2.9653E-03	2.9946E-03	-9.780E-01
sigt-25	1.0767E+01	1.0972E+01	-1.868E+00
siga-25	2.0658E+00	2.0983E+00	-1.549E+00
sigf-25	1.6096E+00	1.6363E+00	-1.632E+00
sigt-28	1.0792E+01	1.0983E+01	-1.739E+00
siga-28	2.5390E-01	2.5106E-01	1.131E+00
sigf-28	3.3805E-04	3.4425E-04	-1.801E+00
sigt-29	1.0504E+01	1.0691E+01	-1.749E+00
siga-29	2.0026E+00	1.9693E+00	1.691E+00
sigf-29	1.5973E+00	1.6203E+00	-1.419E+00
sigt-40	1.0748E+01	1.0947E+01	-1.817E+00
siga-40	6.2982E-01	6.4110E-01	-1.760E+00
sigf-40	2.4693E-01	2.5138E-01	-1.770E+00
sigt-41	1.2260E+01	1.2028E+01	1.929E+00
siga-41	2.4259E+00	2.4668E+00	-1.658E+00
sigf-41	2.1481E+00	2.1091E+00	1.849E+00
sigt-42	1.1454E+01	1.1236E+01	1.940E+00
siga-42	4.1572E-01	4.0837E-01	1.801E+00
sigf-42	1.5789E-01	1.6059E-01	-1.681E+00

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-22

LATTICE TYPE: 3
FUEL TYPE : 2

ENERGY GROUP (eV): ⌜5.5308E+03,1.8554E+00⌝
LETHARGY WIDTH : 8.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	6.1022E-01	5.9855E-01	1.950E+00
sigt-2	1.0176E+00	1.0390E+00	-2.059E+00
siga-1	9.9144E-02	1.0091E-01	-1.751E+00
sigf-1	2.8721E-02	2.8191E-02	1.880E+00
sigt-25	3.9506E+01	4.0152E+01	-1.609E+00
siga-25	2.7515E+01	2.7911E+01	-1.419E+00
sigf-25	1.7950E+01	1.8236E+01	-1.568E+00
sigt-28	1.4660E+01	1.4225E+01	1.629E+00
siga-28	1.8946E+00	1.9282E+00	-1.743E+00
sigf-28	9.9128E-05	1.0073E-04	-1.591E+00
sigt-29	3.8147E+01	3.8870E+01	-1.860E+00
siga-29	2.5356E+01	2.5816E+01	-1.782E+00
sigf-29	1.4431E+01	1.4713E+01	-1.917E+00
sigt-40	2.7710E+01	2.8247E+01	-1.901E+00
siga-40	9.4871E+00	9.3148E+00	1.849E+00
sigf-40	2.0049E-01	1.9696E-01	1.849E+00
sigt-41	5.6149E+01	5.5368E+01	1.411E+00
siga-41	4.1986E+01	4.2625E+01	-1.489E+00
sigf-41	3.4782E+01	3.4217E+01	1.652E+00
sigt-42	6.1592E+01	6.0319E+01	2.110E+00
siga-42	2.9748E+01	3.0299E+01	-1.818E+00
sigf-42	0.0	0.0	

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-23

LATTICE TYPE: 3
FUEL TYPE : 3

ENERGY GROUP (eV): ⌜1.0000E+07,8.2085E+05⌝
LETHARGY WIDTH : 2.50

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	2.9836E-01	3.0300E-01	-1.532E+00
sigt-2	1.9946E-01	2.0075E-01	-6.411E-01
siga-1	1.6181E-02	1.6016E-02	1.033E+00
sigf-1	1.3796E-02	1.4000E-02	-1.460E+00
sigt-25	7.0613E+00	7.1871E+00	-1.751E+00
siga-25	1.3144E+00	1.3022E+00	9.386E-01
sigf-25	1.2469E+00	1.2361E+00	8.721E-01
sigt-28	7.4081E+00	7.3343E+00	1.006E+00
siga-28	4.1350E-01	4.1693E-01	-8.237E-01
sigf-28	3.5092E-01	3.5360E-01	-7.566E-01
sigt-29	7.2198E+00	7.3315E+00	-1.524E+00
siga-29	1.8747E+00	1.8523E+00	1.212E+00
sigf-29	1.8593E+00	1.8401E+00	1.041E+00
sigt-40	7.1069E+00	7.2012E+00	-1.309E+00
siga-40	1.6752E+00	1.6515E+00	1.433E+00
sigf-40	1.6168E+00	1.5897E+00	1.702E+00
sigt-41	7.5420E+00	7.6345E+00	-1.212E+00
siga-41	1.7164E+00	1.7428E+00	-1.513E+00
sigf-41	1.6316E+00	1.6510E+00	-1.177E+00
sigt-42	7.2676E+00	7.1668E+00	1.406E+00
siga-42	1.4917E+00	1.5122E+00	-1.355E+00
sigf-42	1.4490E+00	1.4728E+00	-1.617E+00

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-24

LATTICE TYPE: 3
FUEL TYPE : 3

ENERGY GROUP (eV): [8.2085E+05,5.5308E+03]
LETHARGY WIDTH : 5.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	4.5815E-01	4.6541E-01	-1.156E-00
sigt-2	6.1331E-01	6.1969E-01	-1.029E-00
siga-1	1.0858E-02	1.1056E-02	-1.791E+00
sigf-1	4.0272E-03	3.9630E-03	1.620E+00
sigt-25	1.0840E+01	1.0995E+01	-1.409E+00
siga-25	2.0657E+00	2.1049E+00	-1.863E+00
sigf-25	1.6091E+00	1.6404E+00	-1.908E+00
sigt-28	1.1169E+01	1.0999E+01	1.546E+00
siga-28	2.4877E-01	2.5256E-01	-1.501E+00
sigf-28	3.3554E-04	3.4110E-04	-1.630E+00
sigt-29	1.0608E+01	1.0714E+01	-9.890E-01
siga-29	2.0072E+00	1.9733E+00	1.718E+00
sigf-29	1.5983E+00	1.6217E+00	-1.443E+00
sigt-40	1.0817E+01	1.0981E+01	-1.494E+00
siga-40	6.3221E-01	6.4106E-01	-1.381E+00
sigf-40	2.4519E-01	2.4900E-01	-1.530E+00
sigt-41	1.1817E+01	1.2048E+01	-1.917E+00
siga-41	2.5185E+00	2.4730E+00	1.840E+00
sigf-41	2.0794E+00	2.1136E+01	-1.618E+00
sigt-42	1.1481E+01	1.1257E+01	1.989E+00
siga-42	4.0103E-01	4.0821E-01	-1.759E+00
sigf-42	1.5632E-01	1.5919E-01	-1.803E+00

The fuel and moderator regions are 1 and 2 respectively. The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-25

LATTICE TYPE: 3
FUEL TYPE : 3

ENERGY GROUP (eV): 5.5308E+03,1.8554E+00
LETHARGY WIDTH : 8.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	6.1470E-01	6.2501E-01	-1.649E+00
sigt-2	1.0243E+00	1.0386E+00	-1.377E+00
siga-1	1.1427E-01	1.1620E-01	-1.661E+00
sigf-1	3.4966E-02	3.4297E-02	1.951E+00
sigt-25	3.8262E+01	3.8999E+01	-1.890E+00
siga-25	2.6324E+01	2.6771E+01	-1.669E+00
sigf-25	1.7293E+01	1.7571E+01	-1.582E+00
sigt-28	1.4272E+01	1.4538E+01	-1.829E+00
siga-28	1.9194E+00	1.8847E+00	1.841E+00
sigf-28	9.2736E-05	9.4580E-05	-1.949E+00
sigt-29	3.6010E+01	3.6629E+01	-1.690E+00
siga-29	2.3991E+01	2.3599E+00	1.661E+01
sigf-29	1.3231E+01	1.3460E+01	-1.702E+00
sigt-40	2.6828E+01	2.7317E+01	-1.790E+00
siga-40	8.6413E+00	8.7845E+00	-1.629E+00
sigf-40	1.8903E-01	1.9265E-01	-1.880E+00
sigt-41	5.3586E+01	5.2571E+01	1.931E+00
siga-41	3.9015E+01	3.9803E+01	-1.978E+00
sigf-41	3.1339E+01	3.1926E+01	-1.839E+00
sigt-42	5.3684E+01	5.2600E+01	2.061E+00
siga-42	2.2979E+01	2.3424E+01	-1.900E+00
sigf-42	0.0	0.0	

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-26

LATTICE TYPE: 4
FUEL TYPE : 1

ENERGY GROUP (eV): [1.0000E+07,8.2085E+05]
LETHARGY WIDTH : 2.50

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	2.8061E-01	2.8023E-01	1.359E-01
sigt-2	1.9664E-01	1.9678E-01	-7.267E-02
siga-1	1.1062E-02	1.1086E-02	-2.120E-01
sigf-1	9.1971E-03	9.1740E-03	2.516E-01
sigt-25	7.2297E+00	7.2080E+00	3.013E-01
siga-25	1.2897E+00	1.2993E+00	-7.358E-01
sigf-25	1.2421E+00	1.2355E+00	5.3221-01
sigt-28	7.3164E+00	7.3475E+00	-4.229E-01
siga-28	4.2769E-01	4.2828E-01	-1.388E-01
sigf-28	3.6528E-01	3.6756E-01	-6.208E-01

The fuel and moderator regions are 1 and 2 respectively. The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-27

LATTICE TYPE: 4
FUEL TYPE : 1

ENERGY GROUP (eV): [8.2085E+05,5.5305E+03]
LETHARGY WIDTH : 5.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	4.3347E-01	4.3464E-01	-2.692E-01
sigt-2	6.1767E-01	6.1823E-01	-9.058E-02
siga-1	6.9420E-03	6.9171E-03	3.600E-01
sigf-1	7.8449E-04	7.8567E-04	-1.502E-01
sigt-25	1.0943E+01	1.0963E+01	-1.824E-01
siga-25	2.1075E+00	2.1029E+00	2.188E-01
sigf-25	1.6365E+00	1.6391E+00	-1.586E-01
sigt-28	1.0945E+01	1.0979E+01	-3.097E-01
siga-28	2.5385E-01	2.5337E-01	1.894E-01
sigf-28	3.5814E-04	3.5864E-04	-1.394E-01

The fuel and moderator regions are 1 and 2 respectively. The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-28

LATTICE TYPE: 4
FUEL TYPE : 1

ENERGY GROUP (eV): ~5.5308E+03,1.8554E+00~
LETHARGY WIDTH : 8.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	5.2592E-01	5.2756E-01	-3.109E-01
sigt-2	1.0400E+00	1.0411E+00	-1.057E-01
siga-1	7.1201E-02	7.0889E-02	4.401E-01
sigf-1	1.0310E-02	1.0334E-02	-2.322E-01
sigt-25	4.6222E+01	4.6148E+01	1.604E-01
siga-25	3.3907E+01	3.3999E+01	-2.706E-01
sigf-25	2.1753E+01	2.1788E+01	1.606E-01
sigt-28	1.4419E+01	1.4489E+01	-4.831E-01
siga-28	2.3512E+00	2.3439E+00	3.114E-01
sigf-28	6.2520E-05	6.2589E-05	-1.102E-01

The fuel and moderator regions are 1 and 2 respectively. The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-29

LATTICE TYPE: 5
FUEL TYPE : 2

ENERGY GROUP (eV): [1.0000E+07,8.2085E+05]
LETHARGY WIDTH : 2.50

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	2.9292E-01	2.9674E-01	-1.287E+00
sigt-2	1.9745E-01	1.9918E-01	-8.691E-01
siga-1	1.4922E-02	1.4676E-02	1.673E+00
sigf-1	1.2909E-02	1.2717E-02	1.512E+00
sigt-25	7.0991E+00	7.2000E+00	-1.402E+00
siga-25	1.2798E+00	1.3008E+00	-1.611E+00
sigf-25	1.2196E+00	1.2358E+00	-1.309E+00
sigt-28	7.4226E+00	7.3438E+00	1.073E+00
siga-28	4.1726E-01	4.2128E-01	-9.533E-01
sigf-28	3.6182E-01	3.5921E-01	-7.265E-01
sigt-29	7.4243E+00	7.3432E+00	1.104E+00
siga-29	1.8312E+00	1.8522E+00	-1.135E+00
sigf-29	1.8651E+00	1.8403E+00	1.348E+00
sigt-40	7.3097E+00	7.2076E+00	1.416E+00
siga-40	1.6715E+00	1.6531E+00	-1.115E+00
sigf-40	1.5725E+00	1.5924E+00	-1.250E+00
sigt-41	7.5183E+00	7.6338E+00	-1.513E+00
siga-41	1.7721E+00	1.7411E+00	1.779E+00
sigf-41	1.6227E+00	1.6500E+00	-1.653E+00
sigt-42	7.2754E+00	7.1717E+00	1.446E+00
siga-42	1.5396E+00	1.5190E+00	1.359E+00
sigf-42	1.4550E+00	1.4805E+00	-1.722E+00

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-30

LATTICE TYPE: 5
FUEL TYPE : 2

ENERGY GROUP (eV): [8.2085E+05,5.5308E+03]
LETHARGY WIDTH : 5.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	4.4989E-01	4.5568E-01	-1.271E+00
sigt-2	4.6788E-01	4.7568E-01	-1.640E+00
siga-1	9.9374E-03	9.7502E-03	1.920E+00
sigf-1	2.9670E-03	3.0000E-03	-1.070E+00
sigt-25	1.0802E+01	1.0960E+01	-1.442E+00
siga-25	2.0767E+00	2.1002E+00	-1.119E+00
sigf-25	1.6096E+00	1.6379E+00	-1.728E+00
sigt-28	1.0850E+01	1.0957E+01	-9.765E-01
siga-28	2.4872E-01	2.5062E-01	-7.581E-01
sigf-28	3.4927E-04	3.5287E-04	-1.020E+00
sigt-29	1.0826E+01	1.0683E+01	1.339E+00
siga-29	1.9500E+00	1.9729E+00	-1.161E+00
sigf-29	1.6010E+00	1.6221E+00	-1.301E+00
sigt-40	1.0798E+01	1.0937E+01	-1.271E+00
siga-40	6.3737E-01	6.4518E-01	-1.210E+00
sigf-40	2.5890E-01	2.5492E-01	1.563E+00
sigt-41	1.2169E+01	1.2012E+01	1.307E+00
siga-41	2.4290E+00	2.4642E+00	-1.428E+00
sigf-41	2.0717E+00	2.1071E+00	-1.680E+00
sigt-42	1.1436E+01	1.1222E+01	1.907E+00
siga-42	4.0413E-01	4.1162E-01	-1.819E+00
sigf-42	1.6075E-01	1.6363E-01	-1.760E+00

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-31

LATTICE TYPE: 5
FUEL TYPE : 2

ENERGY GROUP (eV): [5.5308E+03,1.8554E+00]
LETHARGY WIDTH : 8.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	6.0248E-01	6.1327E-01	-1.759E+00
sigt-2	8.7832E-01	8.8827E-01	-1.120E+00
siga-1	1.1155E-01	1.1313E-01	-1.40xE+00
sigf-1	3.1103E-02	3.1541E-02	-1.389E+00
sigt-25	1.0112E-02	9.9906E-03	1.215E+00
siga-25	7.0446E-03	7.1483E-03	-1.451E+00
sigf-25	4.5656E-03	4.6281E-03	-1.350E+00
sigt-28	1.7094E+00	1.6893E+00	1.189E+00
siga-28	2.4394E-01	2.4658E-01	-1.071E-00
sigf-28	8.2530E-06	8.0227E-06	2.872E+00
sigt-29	4.2044E+01	4.1521E+01	1.259E+00
siga-29	2.8951E+01	2.8594E+01	1.248E+00
sigf-29	1.6180E+01	1.6403E+01	-1.360E+00
sigt-40	2.9482E+01	2.9907E+01	-1.421E+00
siga-40	1.0336E+01	1.0482E+01	-1.393E+00
sigf-40	1.8779E-01	1.9077E-01	-1.562E+00
sigt-41	6.0016E+01	6.1029E+01	-1.658E+00
siga-41	4.9194E+01	4.8343E+01	1.760E+00
sigf-41	3.9751E+01	3.9048E+01	1.800E+00
sigt-42	6.8621E+01	6.9680E+01	-1.520E+00
siga-42	4.0829E+01	4.0238E+01	1.469E+00
sigf-42	0.0	0.0	

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-32

LATTICE TYPE: 5
FUEL TYPE : 3

ENERGY GROUP (eV): ⌜1.0000E+07,8.2085E+05⌝
LETHARGY WIDTH : 2.50

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	2.6961E-01	2.7380E-01	-1.529E+00
sigt-2	1.9861E-01	1.9634E-01	1.157E+00
siga-1	1.3232E-02	1.3061E-02	1.310E+00
sigf-1	1.1494E-02	1.1335E-02	-1.402E+00
sigt-25	7.1935E+00	7.2517E+00	-8.020E-01
siga-25	1.4284E+00	1.4425E+00	-9.741E-01
sigf-25	1.2380E+00	1.2251E+00	1.050E+00
sigt-28	7.3364E+00	7.4269E+00	-1.219E+00
siga-28	4.2404E-01	4.3060E-01	-1.523E+00
sigf-28	3.6199E-01	3.6565E-01	-1.001E+00
sigt-29	7.3367E+00	7.4225E+00	-1.156E+00
siga-29	1.8553E+00	1.8309E+00	1.331E+00
sigf-29	1.8435E+00	1.8640E+00	-1.098E+00
sigt-40	7.2026E+00	7.2853E+00	-1.135E+00
siga-40	1.6547E+00	1.6860E+00	-1.856E+00
sigf-40	1.5940E+00	1.5818E+00	7.690E-01
sigt-41	7.6247E+00	7.7180E+00	-1.209E+00
siga-41	1.7448E+00	1.7727E+00	-1.572E+00
sigf-41	1.6536E+00	1.6709E+00	-1.033E+00
sigt-42	7.1656E+00	7.0940E+00	1.009E+00
siga-42	1.5176E+00	1.5432E+00	-1.662E+00
sigf-42	1.4789E+00	1.4979E+00	-1.269E+00

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-33

LATTICE TYPE: 5
FUEL TYPE : 3

ENERGY GROUP (eV): "8.2085E+05,5.5308E+03"
LETHARGY WIDTH : 5.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	4.5772E-01	4.6947E-01	-1.559E+00
sigt-2	4.7097E-01	4.7587E-01	-1.029E+00
siga-1	1.1185E-02	1.1025E-02	1.451E+00
sigf-1	3.9136E-03	3.9647E-03	-1.289E+00
sigt-25	1.0830E+01	1.0960E+01	-1.186E+00
siga-25	2.0749E+00	2.0978E+00	-1.092E+00
sigf-25	1.6554E+00	1.6363E+00	1.167E+00
sigt-28	1.0856E+01	1.0972E+01	-1.057E+00
siga-28	2.5442E-01	2.5163E-01	1.109E+00
sigf-28	3.4539E-04	3.5104E-04	-1.601E+00
sigt-29	1.0822E+01	1.0677E+01	1.358E+00
siga-29	1.9402E+00	1.9687E+00	-1.448E+00
sigf-29	1.6455E+00	1.6207E+00	1.530E+00
sigt-40	1.0774E+01	1.0915E+01	-1.292E+00
siga-40	6.3553E-01	6.4410E-01	-1.331E+00
sigf-40	2.5086E-01	2.5437E-01	-1.379E+00
sigt-41	1.1835E+01	1.2010E+01	-1.457E+00
siga-41	2.4220E+00	2.4611E+00	-1.589E+00
sigf-41	2.1395E+00	2.1046E+00	1.658E+00
sigt-42	1.1426E+01	1.1226E+01	1.782E+00
siga-42	4.0509E-01	4.1168E-01	-1.601E+00
sigf-42	1.6064E-01	1.6307E-01	-1.490E+00

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-34

LATTICE TYPE: 5
FUEL TYPE : 3

ENERGY GROUP (eV): ⌜5.5308E+03,1.8554E+00⌝
LETHARGY WIDTH : 8.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	6.3188E-01	6.4053E-01	-1.459E+00
sigt-2	8.7669E-01	8.8622E-01	-1.075E+00
siga-1	1.2520E-01	1.2689E-01	-1.332E+00
sigf-1	3.8840E-02	3.9288E-02	-1.140E+00
sigt-25	4.1490E+01	4.1991E+01	-1.193E+00
siga-25	2.9394E+01	2.9760E+01	-1.229E+00
sigf-25	1.9525E+01	1.9303E+01	1.150E+00
sigt-28	1.4570E+01	1.4780E+01	-1.421E+00
siga-28	2.1057E+00	2.1289E+00	-1.090E+00
sigf-28	7.7575E-05	7.8997E-05	-1.806E+00
sigt-29	3.9147E+01	3.9687E+01	-1.361E+00
siga-29	2.6416E+01	2.6756E+01	-1.271E+00
sigf-29	1.5542E+01	1.5364E+01	1.158E+00
sigt-40	2.8024E+01	2.8370E+01	-1.220E+00
siga-40	9.3522E+00	9.4908E+00	-1.460E+00
sigf-40	1.9386E-01	1.9043E-01	1.802E+00
sigt-41	5.9833E+01	5.9027E+01	1.450E+00
siga-41	4.5509E+01	4.6324E+01	-1.759E+00
sigf-41	3.7830E+01	3.7341E+01	1.310E+00
sigt-42	6.3435E+01	6.2547E+01	1.419E+00
siga-42	3.1601E+01	3.2177E+01	-1.790E+00
sigf-42	0.0	0.0	

The fuel and moderator regions are 1 and 2 respectively. The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-35

LATTICE TYPE: 6
FUEL TYPE : 1

ENERGY GROUP (eV): "1.0000E+07,8.2085E+05"
LETHARGY WIDTH : 2.50

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	2.8507E-01	2.8335E-01	6.062E-01
sigt-2	1.7259E-01	1.7168E-01	5.312E-01
siga-1	1.0455E-02	1.0551E-02	-9.076E-01
sigf-1	8.5267E-03	8.6189E-03	-1.070E+00
sigt-25	7.1014E+00	7.1842E+00	-1.152E+00
siga-25	1.3151E+00	1.3025E+00	9.655E-01
sigf-25	1.2274E+00	1.2350E+00	-6.121E-01
sigt-28	7.3895E+00	7.3356E+00	7.350E-01
siga-28	4.1257E-01	4.0862E-01	9.662E-01
sigf-28	3.4233E-01	3.4381E-01	-4.311E-01

The fuel and moderator regions are 1 and 2 respectively. The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-36

LATTICE TYPE: 6
FUEL TYPE : 1

ENERGY GROUP (eV): [8.2085E+05,5.5308E+03]
LETHARGY WIDTH : 5.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	4.5154E-01	4.5122E-01	7.092E-02
sigt-2	5.5608E-01	5.5018E-01	9.088E-02
siga-1	8.7279E-03	8.7550E-03	-3.095E-01
sigf-1	8.8576E-04	8.9003E-04	-4.798E-01
sigt-25	1.2322e+01	1.2206E+01	9.504E-01
siga-25	2.4535E+00	2.4723E+00	-7.604E-01
sigf-25	1.8602E+00	1.8671E+00	-3.696E-01
sigt-28	1.1883E+01	1.1874E+01	7.580E-02
siga-28	3.2421E-01	3.2453E-01	-9.860E-02
sigf-28	1.9909E-04	1.9628E-04	-1.406E+00

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-37

LATTICE TYPE: 6
FUEL TYPE : 1

ENERGY GROUP (eV): [5.5308E+03,1.8554E+00]
LETHARGY WIDTH : 8.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	5.0771E-01	5.0675E-01	1.894E-01
sigt-2	8.7108E-01	8.7318E-01	-2.405E-01
siga-1	3.8590E-02	3.8741E-02	-3.898E-01
sigf-1	5.7782E-03	5.7523E-03	4.5025-01
sigt-25	3.0083E+01	3.0011E+01	2.399E-01
siga-25	1.7749E+01	1.7818E+01	-3.872E-01
sigf-25	1.2217E+01	1.2124E+01	7.671E-01
sigt-28	1.3904E+01	1.3929E+01	-1.795E-01
siga-28	1.2952E+01	1.2964E+01	-9.256E-02
sigf-28	1.1942E-04	1.1817E-04	1.058E+00

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-38

LATTICE TYPE: 8
FUEL TYPE : 1

ENERGY GROUP (eV): [1.0000E+07,8.2085E+05]
LETHARGY WIDTH : 2.50

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	2.7634E-01	2.7922E-01	-1.031E-01
sigt-2	1.6774E-01	1.6885E-01	5.311E-01
siga-1	1.1068E-02	1.1146E-02	-6.973E-01
sigf-1	9.1624E-03	9.2495E-03	-9.418E-01
sigt-25	7.1260E+00	7.2177E+00	-1.271E+00
siga-25	1.3127E+00	1.2990E+00	1.055E+00
sigf-25	1.2247E+00	1.2355E+00	-8.763E-01
sigt-28	7.2996E+00	7.2549E+00	-7.514E-01
siga-28	4.2839E-01	4.3110E-01	-6.296E-01
sigf-28	3.6887E-01	3.7079E-01	-5.166E-01

The fuel and moderator regions are 1 and 2 respectively. The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-39

LATTICE TYPE: 8
FUEL TYPE : 1

ENERGY GROUP (eV): [8.2085E+05,5.5308E+03]
LETHARGY WIDTH : 5.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	4.5051E-01	4.5209E-01	-3.495E-01
sigt-2	2.3950E-01	2.3991E-01	-1.709E-01
siga-1	9.0690E-03	9.0140E-03	6.102E-01
sigf-1	9.0024E-04	9.0723E-04	-7.705E-01
sigt-25	1.2303E+01	1.2347E+01	-3.564E-01
siga-25	2.5177E+00	2.5316E+00	-5.491E-01
sigf-25	1.9077E+00	1.9037E+00	2.101E-01
sigt-28	1.1919E+01	1.1911E+01	6.716E-02
siga-28	3.3381E-01	3.3441E-01	-1.794E-01
sigf-28	1.8788E-04	1.8980E-04	-1.012E+00

The fuel and moderator regions are 1 and 2 respectively. The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-40

LATTICE TYPE: 8
FUEL TYPE : 1

ENERGY GROUP (eV): [5.5308E+03,1.8554E+00]
LETHARGY WIDTH : 8.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	5.0608E-01	5.0172E-01	8.690E-01
sigt-2	2.4293E-01	2.4454E-01	-6.600E-01
siga-1	4.4186E-02	4.4301E-02	-2.596E-01
sigf-1	7.3025E-03	7.2345E-03	9.399E-01
sigt-25	3.5041E+01	3.5136E+01	-2.704E-01
siga-25	2.2985E+01	2.2930E+01	2.399E-01
sigf-25	1.5228E+01	1.5225E+01	-1.508E-01
sigt-28	1.3582E+01	1.3609E+01	-1.984E-01
siga-28	1.4312E+00	1.4301E+00	7.692E-02
sigf-28	9.5029E-05	9.6125E-05	-1.140E+00

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-41

LATTICE TYPE: 9
FUEL TYPE : 1

ENERGY GROUP (eV): "1.0000E+07,8.2085E+05"
LETHARGY WIDTH : 2.50

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	2.8367E-01	2.8329E-01	1.358E-01
sigt-2	2.0070E-01	2.0257E-01	-9.237E-01
siga-1	1.0566E-02	1.0625E-02	-5.563E-01
sigf-1	8.7952E-03	8.7123E-03	9.521E-01
sigt-25	7.0753E+00	7.1869E+00	-1.553E+00
siga-25	1.3148E+00	1.3017E+00	1.004E+00
sigf-25	1.2252E+00	1.2348E+00	-7.762E-01
sigt-28	7.3992E+00	7.3366E+00	8.527E-01
siga-28	4.1465E-01	4.1196E-01	6.522E-01
sigf-28	3.4618E-01	3.4782E-01	-4.716E-01

The fuel and moderator regions are 1 and 2 respectively. The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-42

LATTICE TYPE: 9
FUEL TYPE : 1

ENERGY GROUP (eV): [8.2085E+05,5.5308E+03]
LETHARGY WIDTH : 5.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	4.3180E-01	4.3429E-01	-5.727E-01
sigt-2	6.1957E-01	6.2170E-01	-3.425E-01
siga-1	6.9649E-03	6.9139E-03	7.377E-01
sigf-1	7.7545E-04	7.8761E-04	-1.544E+00
sigt-25	1.1051E+01	1.1016E+01	3.218E-01
siga-25	2.1295E+00	2.1113E+00	8.631E-01
sigf-25	1.6380E+00	1.6442E+00	-3.755E-01
sigt-28	1.0900E+01	1.1005E+01	-9.517E-01
siga-28	2.5121E-01	2.5306E-01	-7.308E-01
sigf-28	3.4218E-04	3.3736E-04	1.430E+00

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-43

LATTICE TYPE: 9
FUEL TYPE : 1

ENERGY GROUP (eV): ~5.5308E+03,1.8554E+00~
LETHARGY WIDTH : 8.00

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	5.1520E-01	5.1964E-01	-8.539E-01
sigt-2	1.0322E+00	1.0402E-01	-7.735E-01
siga-1	6.2589E-02	6.2432E-02	2.516E-01
sigf-1	9.6206E-03	9.5298E-03	9.533E-01
sigt-25	4.3052E+01	4.3285E+01	-5.386E-01
siga-25	3.0973E+01	3.1126E+01	-4.931E-01
sigf-25	2.0212E+01	2.0091E+01	6.005E-01
sigt-28	1.4181E+01	1.4208E+01	-1.901E-01
siga-28	2.0587E+00	2.0403E+00	9.010E-01
sigf-28	8.0227E-05	8.1088E-05	-1.062E+00

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-44
Macroscopic Cross Sections

Lattice Type: 3
Fuel Type : 2

GROUP	ENERGY (+)	SIGT-1	SIGT-2	SIGA-1	SIGF-1
1	8.2085E+05	2.7048E-01 (-1.470)	2.0091E-01 (1.086)	1.3027E-02 (-1.445)	1.1278E-02 (1.399)
2	4.9787E+05	3.1293E-01 (-1.793)	3.2307E-02 (-1.148)	5.8797E-01 (-1.536)	3.3620E-03 (-1.487)
3	1.4264E+05	4.3195E-01 (-1.400)	5.0459E-01 (-1.151)	5.5747E-03 (1.701)	2.6608E-03 (-1.621)
4	8.6517E+04	4.2434E-01 (0.780)	6.5766E-01 (-1.092)	6.9465E-03 (1.600)	2.7506E-03 (1.538)
5	5.2475E+04	4.4281E-01 (1.050)	7.5929E-01 (0.976)	8.8847E-03 (-1.108)	2.8489E-03 (1.267)
6	2.3579E+04	4.5681E-01 (-0.855)	8.6659E-01 (-0.731)	1.2223E-02 (-0.997)	2.9059E-03 (-1.082)
7	5.5308E+03	4.8122E-01 (0.526)	9.7315E-01 (1.261)	1.8736E-02 (1.366)	3.4415E-03 (-1.476)
8	2.0347E+03	5.2509E-01 (1.626)	1.0245E+00 (-1.109)	3.0602E-02 (-1.617)	5.6020E-03 (-1.591)
9	1.2341E+03	5.0920E-01 (-1.5129)	1.0359E+00 ((-1.215)	3.7477E-02 (1.499)	7.8801E-03 (1.373)
10	7.4852E+02	5.1071E-01 (-1.334)	1.0398E+00 (1.117)	5.2295E-02 (-1.368)	1.1284E-02 (-1.309)
11	4.5400E+02	5.0509E-01 (-1.601)	1.0414E+00 (-1.397)	6.4287E-02 (-1.881)	1.6206E-02 (-1.522)
12	2.7536E+02	5.1076E-01 (1.268)	1.0426E+00 (1.563)	6.9778E-02 (-1.098)	1.8231E-02 (-1.156)
13	1.6702E+02	6.0780E-01 (1.391)	1.0439E+00 (-1.329)	1.0081E-01 (1.271)	2.8907E-02 (-1.279)
14	1.0130E+02	6.4077E-01 (-1.372)	1.0451E+00 (1.651)	1.3733E-01 (1.353)	3.1881E-02 (1.449)
15	1.7360E+02	5.1402E-01 (-1.556)	1.0459E+00 (1.367)	1.7391E-01 (-1.606)	7.6758E-02 (-1.627)
16	2.5608E+00	6.3429E-01 (1.822)	1.0468E+00 (-1.692)	2.1765E-01 (1.729)	6.9272E-02 (-1.553)
17	1.7261E+00	4.5478E-01 (-1.639)	1.0567E+00 (1.038)	8.2970E-02 (-1.518)	2.8036E-02 (1.326)

The fuel and moderator regions are 1 and 2 respectively. The quantities in parenthesis represent percent deviation from VIM.

(+) Values represent group lower bounds.

TABLE III-45
Macroscopic Cross Sections

Lattice Type: 5
Fuel Type : 3

GROUP	ENERGY (+)	SIGT-1	SIGT-2	SIGA-1	SIGF-1
1	8.2085E+05	2.6961E-01 (-1.529)	1.9861E-01 (1.157)	1.3232E-02 (1.310)	1.1494E-02 (-1.402)
2	4.9787E+05	3.1275E-01 (-1.653)	3.2283E-01 (-1.187)	5.8826E-03 (-1.455)	3.3388E-03 (-1.577)
3	1.4264E+05	4.3308E-01 (1.730)	5.0469E-01 (0.962)	5.5717E-03 (-1.716)	2.6621E-03 (-1.561)
4	8.6517E+04	4.2436E-01 (-0.960)	6.5775E-01 (-1.002)	6.9468E-03 (-1.688)	2.7510E-03 (1.732)
5	5.2475E+04	4.4436E-01 (-1.329)	7.5969E-01 (1.099)	8.9006E-03 (-1.359)	2.8498E-03 (1.516)
6	2.3579E+04	4.5650E-01 (-0.828)	8.6616E-01 (-1.632)	1.2205E-02 (1.512)	2.9063E-03 (-1.314)
7	5.5308E+03	4.8281E-01 (1.716)	9.7318E-01 (0.736)	1.8712E-02 (-1.629)	3.4490E-03 (1.779)
8	2.0347E+03	5.3187E-01 (-1.555)	1.0246E+00 (-1.261)	3.1000E-02 (-1.366)	5.6045E-03 (-1.655)
9	1.2341E+03	5.2505E-01 (-1.462)	1.0359E+00 (-1.538)	3.9739E-02 (1.793)	7.9897E-03 (-1.438)
10	7.4852E+02	5.2202E-01 (1.321)	1.0398E+00 (-1.256)	5.4984E-02 (-1.506)	1.1454E-02 (0.736)
11	4.5400E+02	5.1064E-01 (1.176)	1.0414E+00 (-1.020)	6.7036E-02 (-1.208)	1.6974E-02 (1.222)
12	2.7536E+02	5.1225E-01 (-1.406)	1.0426E+00 (1.539)	6.8803E-02 (1.417)	1.8265E-02 (-1.347)
13	1.6702E+02	6.1763E-01 (1.733)	1.0439E+00 (-1.096)	1.0287E-01 (-1.517)	2.8356E-02 (1.916)
14	1.0130E+02	6.5653E-01 (-1.588)	1.0452E+00 (1.031)	1.4143E-01 (-1.432)	3.2435E-02 (-1.612)
15	1.7360E+02	5.1402E-01 (-1.656)	1.0459E+00 (-1.515)	1.7511E-01 (1.588)	7.7792E-02 (1.490)
16	2.5608E+00	6.4813E-01 (1.329)	1.0469E+00 (-1.312)	2.3165E-01 (1.513)	7.2308E-02 (-1.317)
17	1.7261E+00	4.5511E-01 (1.702)	1.0568E+00 (1.570)	8.3164E-02 (-1.655)	2.8113E-02 (-1.488)

The fuel and moderator regions are 1 and 2 respectively. The quantities in parenthesis represent percent deviation from VIM.

(+) Values represent group lower bounds.

TABLE III-46
Macroscopic Cross Sections

Lattice Type: 7
Fuel Type : 2

GROUP	ENERGY (+)	SIGT-1	SIGT-2	SIGA-1	SIGF-1
1	8.2085E+05	2.7148E-01 (1.722)	1.5416E-01 (-0.833)	1.2920E-02 ((-1.651)	1.1152E-02 (-1.767)
2	4.9787E+05	3.1429E-01 (-1.378)	1.9002E-01 (1.531)	5.8589E-03 (-1.502)	3.3195E-03 (-1.445)
3	1.4264E+05	4.2257E-01 (-1.696)	2.2520E-01 (-1.737)	5.6422E-03 (1.556)	2.6486E-03 (1.301)
4	8.6517E+04	4.2470E-01 (1.535)	2.1207E-01 (1.433)	6.9605E-03 (-1.405)	2.7517E-03 (-1.617)
5	5.2475E+04	4.4463E-01 (-1.787)	2.1480E-01 (-1.411)	8.9552E-03 (1.453)	2.8517E-03 (1.660)
6	2.3579E+04	4.5559E-01 (-1.256)	2.1694E-01 (0.806)	1.2185E-02 (-0.908)	2.9062E-03 (-1.138)
7	5.5308E+03	4.7641E-01 (-1.387)	2.1883E-01 (1.110)	1.8301E-02 (-1.005)	3.4192E-03 (-1.312)
8	2.0347E+03	5.1518E-01 (-1.070)	2.1981E-01 (-1.321)	2.9472E-02 (1.212)	5.5332E-03 (-1.227)
9	1.2341E+03	4.9253E-01 (-1.153)	2.2010E-01 (1.229)	3.5871E-02 (-1.283)	7.8307E-03 (-1.406)
10	7.4852E+02	4.9334E-01 (1.211)	2.2020E-01 (-1.122)	4.8562E-02 (-1.311)	1.1239E-02 (1.477)
11	4.5400E+02	4.9105E-01 (-1.133)	2.2023E-01 (-0.879)	5.9514E-02 (1.052)	1.5600E-02 (-1.531)
12	2.7536E+02	4.9743E-01 (-1.588)	2.2024E-01 (1.054)	6.3855E-02 (-1.312)	1.7684E-02 (1.603)
13	1.6702E+02	5.8229E-01 (-1.607)	2.2024E-01 (1.311)	9.4573E-02 (-1.602)	2.8698E-02 (-1.400)
14	1.0130E+02	5.9750E-01 (1.661)	2.2025E-01 (-1.601)	1.2148E-01 (1.308)	3.1318E-02 (1.513)
15	1.7360E+02	4.7925E-01 (1.769)	2.2025E-01 (-1.808)	1.4850E-01 (1.730)	6.9841E-02 (1.651)
16	2.5608E+00	6.2864E-01 (1.501)	2.2025E-01 (1.755)	1.8602E-01 (-1.677)	6.0361E-02 (-1.544)
17	1.7261E+00	4.5703E-01 (-1.873)	2.2069E-01 (-1.487)	8.4914E-02 (1.512)	2.8162E-02 (-1.673)

The fuel and moderator regions are 1 and 2 respectively. The quantities in parenthesis represent percent deviation from VIM.

(+) Values represent group lower bounds.

TABLE III-47
Fuel Isotopes Total Microscopic Cross Sections

Lattice Type: 3
Fuel Type : 2

GROUP (#)	SIGF-25	SIGF-28	SIGF-29	SIGF-40	SIGF-41	SIGF-42
1	7.1864E+00	7.3339E+00	7.3311E+00	7.2016E+00	7.6348E+00	7.1668E+00
	(1.052)	(-1.028)	(-0.966)	(-0.829)	(1.118)	(-1.065)
2	7.6405E+00	8.0322E+00	7.7755E+00	7.5564E+00	9.0658E+00	7.7021E+00
	(-1.179)	(1.143)	(-1.020)	(-1.055)	(-1.201)	(-1.174)
3	9.5627E+00	1.0074E+01	9.5533E+00	9.6349E+00	1.0946E+01	9.2673E+00
	(-1.136)	(-0.667)	(-1.301)	(-1.158)	(-1.507)	(1.365)
4	1.1496E+01	1.1977E+01	1.1262E+01	1.1321E+01	1.2714E+01	1.1239E+01
	(-1.282)	(-1.177)	(-1.371)	(-1.349)	(-1.412)	(-1.344)
5	1.2535E+01	1.2716E+01	1.2110E+01	1.2275E+01	1.3527E+01	1.2462E+01
	(0.802)	(1.531)	(-1.414)	(-1.408)	(1.322)	(1.559)
6	1.3622E+01	1.3102E+01	1.2952E+01	1.3490E+01	1.3918E+01	1.4201E+01
	(-1.379)	(1.722)	(-1.506)	(-1.302)	(-1.053)	(1.634)
7	1.5508E+01	1.4017E+01	1.4383E+01	1.5585E+01	1.5808E+01	1.7485E+01
	(-1.676)	(-1.857)	(1.305)	(-1.607)	(-1.334)	(1.574)
8	1.8337E+01	1.5718E+01	1.8493E+01	1.8120E+01	2.0760E+01	2.3532E+01
	(1.556)	(-1.479)	(-1.574)	(1.083)	(1.404)	(-1.189)
9	2.1678E+01	1.4595E+01	2.0117E+01	2.1635E+01	2.4115E+01	2.9020E+01
	(-0.942)	(-0.722)	(0.997)	(-1.136)	(1.712)	(-0.956)
10	2.5363E+01	1.4192E+01	2.3833E+01	2.5453E+01	2.7075E+01	3.4363E+01
	(-1.311)	(1.135)	(-1.009)	(-1.532)	(-1.440)	(-1.709)
11	3.0556E+01	1.3541E+01	3.0361E+01	2.0287E+01	3.3096E+01	3.8669E+01
	(-1.517)	(-1.412)	(1.177)	(1.228)	(1.515)	(-1.351)
12	3.2061E+01	1.3022E+01	3.2403E+01	3.4314E+01	4.2082E+01	4.9282E+01
	(1.406)	(1.317)	(-1.282)	(-1.545)	(-1.316)	(-1.504)
13	4.3594E+01	1.7281E+01	4.5581E+01	2.5993E+01	4.9741E+01	2.8086E+01
	(1.510)	(-1.325)	(-1.676)	-(1.606)	(1.721)	(1.833)
14	4.6277E+01	1.7529E+01	4.9696E+01	5.4297E+01	5.4334E+01	3.1645E+01
	(-1.307)	(-1.506)	(1.411)	(-1.309)	(-1.766)	(1.809)
15	4.9430E+01	9.0241E+00	8.7869E+01	3.1064E+01	6.7895E+01	4.3459E+01
	(1.778)	(-1.414)	(1.676)	(1.516)	(-1.536)	(-1.906)
16	8.5028E+01	1.4876E+01	6.9227E+01	3.9934E+01	1.3911E+02	1.5659E+02
	(-1.990)	(-1.856)	(-1.404)	(-1.919)	(-1.629)	(1.773)
17	3.4975E+01	9.0900E+00	2.8622E+01	5.9442E+01	3.6272E+01	1.4883E+02
	(-1.800)	(1.898)	(1.906)	(-2.061)	(-1.537)	(1.612)

The quantities in parenthesis represent percent deviation from the VIM results.

TABLE III-48
Fuel Isotopes Total Microscopic Cross Sections

Lattice Type: 5
Fuel Type : 3

GROUP (#)	SIGF-25	SIGF-28	SIGF-29	SIGF-40	SIGF-41	SIGF-42
1	7.1935E+00	7.3364E+00	7.3367E+00	7.2026E+00	7.6247E+00	7.1656E+00
	(-0.802)	(-1.219)	(-1.156)	(-1.135)	(-1.209)	(1.009)
2	7.6373E+00	8.0289E+00	7.7727E+00	7.5548E+00	9.0626E+00	7.6999E+00
	(-0.912)	(-0.815)	(-0.791)	(-1.721)	(-1.512)	(-1.202)
3	9.5529E+00	1.0063E+01	9.5445E+00	9.6242E+00	1.0936E+00	9.2585E+00
	(-1.512)	(1.390)	(0.615)	(-1.901)	(-1.772)	(1.308)
4	1.1496E+01	1.1977E+01	1.1263E+01	1.1322E+01	1.2715E+01	1.1240E+01
	(-1.616)	(-1.663)	(-1.326)	(-1.251)	(-1.577)	(1.529)
5	1.2539E+01	1.2719E+01	1.2114E+01	1.2880E+01	1.3530E+01	1.2468E+01
	(1.327)	(1.727)	(-1.529)	(-1.188)	(1.449)	(-1.331)
6	1.3619E+01	1.3088E+01	1.2951E+01	1.3477E+01	1.3909E+01	1.4192E+01
	(-1.504)	(-1.650)	(-1.018)	(1.537)	(0.735)	(-1.766)
7	1.5494E+01	1.4096E+01	1.4393E+01	1.5608E+01	1.5806E+01	1.7347E+01
	(-1.312)	(-1.729)	(1.533)	(1.217)	(-1.821)	(-1.614)
8	1.8348E+01	1.6060E+01	1.8473E+01	1.8168E+01	2.0869E+01	2.3269E+01
	(0.716)	(-1.530)	(1.726)	(-1.087)	(-1.656)	(1.212)
9	2.1681E+01	1.5348E+01	2.0407E+01	2.2328E+01	2.4203E+01	2.8928E+01
	(1.521)	(1.155)	(1.608)	(-1.412)	(-1.200)	(0.956)
10	2.5343E+01	1.4739E+01	2.4191E+01	2.5561E+01	2.7260E+01	3.3422E+01
	(1.312)	(1.715)	(-1.542)	(1.568)	(1.403)	(-1.542)
11	3.0737E+01	1.3714E+01	3.1932E+01	1.9623E+01	3.3891E+01	4.0722E+01
	(-1.507)	(-1.131)	(-1.309)	(-1.449)	(1.208)	(-1.861)
12	3.2446E+01	1.3100E+01	3.2660E+01	3.3036E+01	4.2385E+01	5.3961E+01
	(-0.992)	(1.721)	(1.196)	(-1.517)	(1.302)	(1.557)
13	4.4092E+01	1.7841E+01	4.4686E+01	2.5872E+01	4.9915E+01	2.8712E+01
	(-1.008)	(1.101)	(-1.509)	(-1.346)	(-1.110)	(1.501)
14	4.6651E+01	1.8109E+01	4.9661E+01	5.9309E+01	5.5626E+01	3.5702E+01
	(1.431)	(-0.956)	(1.723)	(-1.375)	(-1.992)	(-1.721)
15	5.0797E+01	2.8870E+00	8.9721E+01	3.0657E+01	7.0630E+01	4.1156E+01
	(1.629)	(1.823)	(-1.441)	(1.511)	(1.553)	(-1.669)
16	8.4831E+01	1.5199E+01	7.2575E+01	3.9263E+01	1.4300E+02	1.8142E+02
	(-1.548)	(1.778)	(-1.324)	(1.815)	(-2.102)	(-1.719)
17	3.5156E+01	9.0913E+00	2.8708E+01	6.0147E+01	3.6257E+01	1.4527E+02
	(1.928)	(1.897)	(-1.909)	(1.539)	(-1.671)	(-1.702)

The quantities in parenthesis represent percent deviation from the VIM results.

TABLE III-49
Fuel Isotopes Total Microscopic Cross Sections

Lattice Type: 7
Fuel Type : 2

GROUP (#)	SIGF-25	SIGF-28	SIGF-29	SIGF-40	SIGF-41	SIGF-42
1	7.1777E+00	7.3292E+00	7.3235E+00	7.1977E+00	7.6410E+00	7.1656E+00
	(-1.017)	(0.876)	(1.026)	(1.543)	(-1.351)	(1.412)
2	7.6625E+00	8.0551E+00	7.7943E+00	7.5665E+00	9.0886E+00	7.7155E+00
	(1.002)	(-0.908)	(0.913)	(-1.107)	(1.712)	(-1.561)
3	9.7133E+00	1.0237E+01	9.6900E+00	9.7919E+00	1.1092E+01	9.4101E+00
	(1.277)	(1.712)	(-1.376)	(-1.515)	(1.532)	(-1.161)
4	1.1512E+01	1.1991E+01	1.1275E+01	1.1335E+01	1.2727E+01	1.1257E+01
	(1.549)	(-0.708)	(1.156)	(1.140)	(-1.261)	(1.389)
5	1.2556E+01	1.2729E+01	1.2128E+01	1.2296E+01	1.3544E+01	1.2490E+01
	(1.688)	(-1.512)	(-1.717)	(-1.350)	(-1.926)	(1.328)
6	1.3623E+01	1.3040E+01	1.2956E+01	1.3475E+01	1.3906E+01	1.4203E+01
	(-1.244)	(-1.566)	(1.307)	(-1.525)	(0.956)	(-1.421)
7	1.5439E+01	1.3878E+01	1.4346E+01	1.5569E+01	1.5723E+01	1.7345E+01
	(1.156)	(-1.071)	(1.610)	(-1.712)	(1.717)	(-1.835)
8	1.8246E+01	1.5233E+01	1.8352E+01	1.8068E+01	2.0672E+01	2.3021E+01
	(0.911)	(-0.605)	(0.917)	(-1.338)	(-1.312)	(-1.975)
9	2.1738E+01	1.3763E+01	2.0116E+01	2.1465E+01	2.4144E+01	2.8431E+01
	(-1.153)	(1.416)	(-1.011)	(1.566)	(-1.762)	(-1.513)
10	2.5404E+01	1.3326E+01	2.3786E+01	2.5439E+01	2.7216E+01	3.3441E+01
	(0.756)	(-1.106)	(-1.572)	(-1.319)	(-1.492)	(1.628)
11	3.0559E+01	1.2892E+01	2.9837E+01	1.9520E+01	3.3482E+01	3.9572E+01
	(0.649)	(-1.541)	(1.449)	(-1.517)	(-1.207)	(-1.516)
12	3.2092E+01	1.2509E+01	3.1432E+01	3.1677E+01	4.1877E+01	5.1671E+01
	(-1.329)	(-1.092)	(1.739)	(-1.554)	(1.565)	(-1.323)
13	4.3810E+01	1.6047E+01	4.5631E+01	2.4449E+01	4.9849E+01	2.7837E+01
	(1.306)	(-1.716)	(-1.782)	(1.609)	(2.026)	(1.496)
14	4.6426E+01	1.5621E+01	4.8952E+01	4.8091E+01	5.3744E+01	3.4657E+01
	(1.619)	(-1.329)	(-1.891)	(-1.716)	(1.945)	(-1.721)
15	5.0261E+01	8.1199E+00	7.8298E+01	2.7921E+01	6.7928E+01	3.6161E+01
	(1.999)	(-1.539)	(-1.689)	(-1.960)	(-1.812)	(-1.272)
16	8.3453E+01	1.4920E+01	6.7451E+01	5.3986E+01	9.8907E+01	8.2056E+01
	(-1.813)	(-0.916)	(-1.703)	(-1.933)	(1.910)	(-1.697)
17	3.5989E+01	9.0923E+00	2.8754E+01	6.0415E+01	3.6196E+01	1.6178E+02
	(-1.956)	(1.732)	(-1.808)	(-1.895)	(-1.716)	(-2.018)

The quantities in parenthesis represent percent deviation from the VIM results.

TABLE III-50
Fuel Isotopes Absorbtion Microscopic Cross Section

Lattice Type: 3
Fuel Type : 2

GROUP (#)	SIGF-25	SIGF-28	SIGF-29	SIGF-40	SIGF-41	SIGF-42
1	1.3023E+00	4.1515E-01	1.8523E+00	1.6528E+00	1.7434E+00	1.5101E+00
	(1.025)	(1.098)	(-0.888)	(-1.010)	(0.773)	(-1.563)
2	1.2944E+00	1.1696E-01	1.7092E+00	9.4025E-01	1.6249E+00	6.5504E-01
	(-1.214)	(-1.053)	(-1.313)	(1.255)	(1.081)	(-1.333)
3	1.5533E+00	1.2496E-01	1.6932E+00	3.2444E-01	1.8995E+00	2.0409E-01
	(-1.005)	(1.723)	(-1.551)	(1.067)	(-1.161)	(-1.293)
4	1.9595E+00	1.8058E-01	1.8075E+00	3.2228E-01	2.4311E+00	1.8655E-01
	(-0.804)	(1.510)	(1.337)	(-1.206)	(1.221)	(-1.056)
5	2.3145E+00	2.5949E-01	1.9817E+00	3.9042E-01	2.7251E+00	2.6243E-01
	(1.673)	(-1.336)	(-1.558)	(-1.479)	(-1.115)	(1.317)
6	2.6781E+00	4.0557E-01	2.0847E+00	6.6627E-01	3.0508E+00	4.3763E-01
	(-1.537)	(-1.193)	(0.933)	(1.515)	(-1.317)	(1.225)
7	3.9150E+00	6.3912E-01	2.9102E+00	1.2177E-01	4.2829E+00	7.0662E-01
	(-0.759)	(-1.120)	(1.401)	(1.389)	(1.315)	(-1.451)
8	6.4600E+00	9.7230E-01	5.5073E+00	2.1214E-01	8.2058E+00	1.3562E-01
	(1.350)	(-1.181)	(1.919)	(1.421)	(-1.166)	(1.808)
9	9.5758E+00	1.0981E+00	7.4559E+00	3.1958E+00	1.1419E+01	2.3029E+00
	(-1.793)	(1.325)	(-1.469)	(1.588)	(-1.212)	(1.775)
10	1.2911E+01	1.4952E+00	1.0701E+01	5.2549E+00	1.4315E+00	3.3819E+00
	(-1.565)	(0.773)	(-1.483)	(-1.340)	(-1.173)	(-1.911)
11	1.8129E+01	1.6637E+00	1.5827E+01	5.1371E+00	1.9876E+01	4.9444E+00
	(1.906)	(-1.733)	(-1.347)	(-1.599)	(1.667)	(-1.522)
12	1.9755E+01	1.5145E+00	1.8222E+01	9.4418E+00	2.8235E+01	8.1099E+00
	(-1.559)	(-1.092)	(1.455)	(1.186)	(-1.787)	(-1.933)
13	3.0666E+01	2.0846E+00	3.0425E+01	1.0117E+01	3.5931E+01	6.1979E+00
	(1.596)	(-1.516)	(-1.272)	(-1.585)	(1.114)	(-1.860)
14	3.3743E+01	2.9919E+00	3.4676E+01	2.4706E+01	4.1005E+01	1.2932E+01
	(1.399)	(-1.912)	(-1.886)	(-2.021)	(1.566)	(1.778)
15	3.6787E+01	2.3616E+00	7.0915E+01	1.6066E+01	5.4022E+01	1.8976E+01
	(-1.919)	(1.933)	(-1.897)	(-1.720)	(-1.901)	(-1.675)
16	7.2976E+01	4.1257E+00	5.9127E+01	1.9069E+01	1.2728E+01	1.1695E+02
	(-1.886)	(1.429)	(-1.814)	(1.948)	(-1.565)	(1.778)
17	2.2995E+01	4.8905E-01	1.9004E+01	3.5403E+01	2.7653E+01	1.4297E+02
	(-1.818)	(-1.450)	(-1.718)	(-1.892)	(1.951)	(1.969)

The quantities in parenthesis represent percent deviation from the VIM results.

TABLE III-51
Fuel Isotopes Absorbtion Microscopic Cross Sections

Lattice Type: 5
Fuel Type : 3

GROUP (#)	SIGF-25	SIGF-28	SIGF-29	SIGF-40	SIGF-41	SIGF-42
1	1.3029E+00	4.2404E-01	1.8553E+00	1.6547E+00	1.7448E+00	1.5176E+00
	(-0.974)	(-1.523)	(1.331)	(-1.856)	(-1.572)	(-1.662)
2	1.2942E+00	1.1702E-01	1.7094E+00	9.4223E-01	1.6247E+00	6.5711E-01
	(1.103)	(-0.879)	(-1.354)	(1.323)	(-1.423)	(-1.445)
3	1.5517E+00	1.2479E-01	1.6934E+00	3.2525E-01	1.8975E+00	2.0478E-01
	(0.663)	(-0.527)	(-1.765)	(1.201)	(-1.387)	(-1.551)
4	1.9604E+00	1.8059E-01	1.8075E+00	3.2229E-01	2.4312E+00	1.8651E-01
	(-1.677)	(-1.433)	(0.944)	(-1.331)	(-1.465)	(1.321)
5	2.3173E+00	2.6018E-01	1.9825E+00	3.9104E-01	2.7278E+00	2.6309E-01
	(0.912)	(-1.109)	(1.776)	(-1.815)	(-1.706)	(1.517)
6	2.6774E+00	4.0483E-01	2.0873E+00	6.6239E-01	3.0464E+00	4.3701E-01
	(1.533)	(-1.316)	(1.509)	(-1.636)	(1.513)	(-1.311)
7	3.9052E+00	6.3746E-01	2.9164E+00	1.2191E+00	4.2826E+00	7.0013E-01
	(-1.617)	(1.455)	(-1.312)	(-1.650)	(-1.909)	(-1.110)
8	6.4740E+00	9.9264E-01	5.5001E+00	2.1103E+00	8.2830E+00	1.3466E+00
	(1.512)	(-1.976)	(-1.963)	(-1.701)	(0.911)	(-1.231)
9	9.5668E+00	1.1963E+00	7.6215E+00	3.2929E+00	1.1469E+00	2.2684E+00
	(-1.439)	(1.302)	(1.329)	(-1.233)	(-1.097)	(-1.560)
10	1.2898E+01	1.6197E+00	1.0908E+01	5.1178E+00	1.4453E+00	3.3690E+00
	(-1.771)	(0.914)	(-1.510)	(-1.516)	(1.390)	(-1.371)
11	1.8289E+01	1.7255E+00	1.6779E+01	5.1508E+00	2.0502E+01	5.1779E+00
	(-1.915)	(-0.871)	(1.471)	(-1.326)	(-1.455)	(1.956)
12	2.0113E+01	1.4722E+00	1.8342E+01	8.8860E+00	2.8508E+01	8.4991E+00
	(-1.609)	(-1.019)	(-1.708)	(1.802)	(1.373)	(1.739)
13	3.1071E+01	2.2410E+00	2.9696E+01	1.0071E+01	3.6030E+01	6.3816E+00
	(-1.312)	(-1.444)	(-1.228)	(1.897)	(1.220)	(-1.522)
14	3.4074E+01	3.0740E+00	3.4830E+01	2.7129E+01	4.2212E+01	1.5358E+01
	(1.701)	(1.436)	(-1.571)	(1.339)	(-1.561)	(1.693)
15	3.8110E+01	2.2928E+00	7.2665E+01	1.5677E+01	5.6368E+01	1.7536E+01
	(-1.697)	(-1.317)	(1.667)	(-1.706)	(-1.713)	(-1.502)
16	7.2791E+01	4.4531E+00	6.2435E+01	1.8662E+01	1.3130E+02	1.4077E+02
	(-1.912)	(1.955)	(-1.309)	(1.959)	(1.519)	(1.613)
17	2.3173E+01	4.8881E-01	1.9087E+01	3.5966E+01	2.7630E+01	1.3951E+02
	(1.602)	(-1.907)	(2.071)	(-1.899)	(1.619)	(-1.720)

The quantities in parenthesis represent percent deviation from the VIM results.

TABLE III-52
Fuel Isotopes Absorbtion Microscopic Cross Sections

Lattice Type: 7
Fuel Type : 2

GROUP (#)	SIGF-25	SIGF-28	SIGF-29	SIGF-40	SIGF-41	SIGF-42
1	1.3034E+00	4.1008E-01	1.8514E+00	1.6511E+00	1.7433E+00	1.5060E+00
	(-1.060)	(-1.552)	(-0.877)	(1.130)	(-1.116)	(0.982)
2	1.2691E+00	1.1657E-01	1.7077E+00	9.2700E-01	1.6263E+00	6.4127E-01
	(1.029)	(0.459)	(-1.028)	(-1.454)	(-1.337)	(1.565)
3	1.5797E+00	1.2834E-01	1.6931E+00	3.1675E-01	1.9337E+00	1.9654E-01
	(-1.722)	(0.918)	(1.067)	(-1.283)	(-1.445)	(-1.072)
4	1.9630E+00	1.8114E-01	1.8085E+00	3.2290E-01	2.4360E+00	1.8709E-01
	(-1.449)	(-1.423)	(1.651)	(-1.729)	(-1.120)	(-1.300)
5	2.3233E+00	2.6260E-01	1.9850E+00	3.9287E-01	2.7351E+00	2.6525E-01
	(0.905)	(-0.778)	(-0.961)	(1.531)	(-1.466)	(-1.321)
6	2.6775E+00	4.0358E-01	2.0891E+00	6.6597E-01	3.0443E+00	4.3775E-01
	(1.332)	(-1.556)	(-1.527)	(-1.947)	(-1.810)	(-1.429)
7	3.8646E+00	6.2044E-01	2.8819E+00	1.2039E+00	4.2219E+00	6.9667E-01
	(-1.279)	(-1.833)	(-1.427)	(1.666)	(1.328)	(-1.501)
8	6.3808E+00	9.2471E-01	5.4121E+00	2.0827E+00	8.1209E+00	1.3257E+00
	(-1.537)	(-1.182)	(-1.450)	(-1.377)	(1.414)	(-1.522)
9	9.6195E+00	1.0186E+00	7.4381E+00	3.1949E+00	1.1436E+01	2.2221E+00
	(-1.728)	(1.466)	(-1.921)	(1.628)	(-1.535)	(-1.097)
10	1.2942E+01	1.3146E+00	1.0631E+01	5.1630E+00	1.4429E+01	3.3036E+00
	(1.256)	(-0.912)	(1.145)	(-1.401)	(1.771)	(-1.936)
11	1.8110E+01	1.4678E+00	1.5360E+01	4.7817E+00	2.0165E+01	4.9334E+00
	(-1.903)	(1.273)	(-1.781)	(-1.539)	(-1.491)	(1.831)
12	1.9781E+01	1.2951E+00	1.7488E+01	8.7691E+00	2.8004E+01	8.3277E+00
	(-1.588)	(-1.387)	(-1.995)	(-1.921)	(1.629)	(-1.533)
13	3.0791E+01	1.8098E+00	3.0300E+01	9.2646E+00	3.5978E+01	6.2569E+00
	(-1.817)	(-1.538)	(1.837)	(-1.741)	(-1.638	(1.735)
14	3.3689E+01	2.3510E+00	3.3929E+01	2.1775E+01	4.0444E+01	1.4776E+01
	(1.339)	(-1.672)	(-1.756)	(1.1377)	(1.060)	(-1.722)
15	3.7598E+01	1.7957E+00	6.2445E+01	1.3966E+01	5.4004E+01	1.4775E+01
	(-1.877)	(1.962)	(-1.989)	(-1.338)	(-1.592)	(-1.768)
16	7.1086E+01	3.2045E+00	5.6765E+01	2.6151E+01	8.6334E+01	3.4881E+01
	(-2.056)	(-1.805)	(1.967)	(-1.878)	(1.761)	(-1.980)
17	2.4010E+01	4.8865E-01	1.9130E+01	3.6164E+01	2.7612E+01	1.5493E+02
	(1.672)	(-1.773)	(-1.913)	(1.312)	(2.587)	(-1.435)

The quantities in parenthesis represent percent deviation from the VIM results.

TABLE III-53
Fuel Isotopes Fission Microscopic Cross Sections

Lattice Type: 3
Fuel Type : 2

GROUP (#)	SIGF-25	SIGF-28	SIGF-29	SIGF-40	SIGF-41	SIGF-42
1	1.2359E+00	3.5153E+00	1.8401E+00	1.5907E+00	1.6512E+00	1.4707E+00
	(-1.083)	(-1.552)	(-1.044)	(-0.672)	(1.812)	(-1.336)
2	1.1448E+00	1.3689E-03	1.6342E+00	7.9694E-01	1.4950E+00	5.4952E-01
	(0.952)	(-0.886)	(1.002)	(-1.433)	(-1.152)	(-1.337)
3	1.2953E+00	8.6930E-05	1.5204E+00	1.4437E-01	1.7000E+00	8.0986E-02
	(-0.774)	(1.060)	(1.656)	(-1.237)	(-1.113)	(1.139)
4	1.5468E+00	4.2287E-05	1.5681E+00	7.1466E-02	2.1097E+00	2.9442E-02
	(-1.013)	(1.822)	(-1.331)	(-1.546)	(-1.255)	(0.999)
5	1.7752E+00	4.0000E-05	1.6126E+00	5.6973E-02	2.3144E+00	3.2203E-02
	(-1.333)	(1.511)	(1.828)	(1.213)	(-1.452)	(-1.250)
6	1.9813E+00	6.2194E-05	1.6096E+00	7.9405E-02	2.5184E+00	4.4114E-02
	(1.076)	(1.088)	(-1.822)	(1.454)	(-1.337)	(-1.335)
7	2.7691E+00	5.8379E-05	1.8543E+00	7.6144E-02	3.4103E+00	3.6857E-02
	(-1.082)	(1.010)	(1.532)	(-1.707)	(-1.223)	(-1.383)
8	4.7610E+00	0.0	2.8953E+00	1.6454E-01	6.4012E+00	0.0
	(-0.929)		(1.155)	(1.609)	(1.775)	
9	6.9337E+00	0.0	4.0654E+00	2.6882E-01	8.8510E+00	0.0
	(-1.544)		(1.339)	(1.318)	(-1.577)	
10	8.5399E+00	2.0997E-04	6.0764E+00	3.5109E-01	1.0970E+01	0.0
	(-1.219)	(1.881)	(1.232)	(1.952)	(1.099)	
11	1.3351E+01	9.2544E-04	8.9441E+00	1.6444E-01	1.5055E+01	0.0
	(1.632)	(-1.905)	(-0.966)	(-1.285)	(1.476)	
12	1.3723E+01	1.6428E-08	9.5696E+00	2.2016E-01	2.1355E+01	0.0
	(-1.265)	(2.166)	(-1.578)	(1.553)	(1.129)	
13	2.0506E+01	0.0	1.6055E+01	2.3732E-01	2.7197E+01	0.0
	(-1.263)		(-1.094)	(-1.803)	(1.577)	
14	2.1776E+01	0.0	1.7598E+01	3.2272E-01	3.0849E+01	0.0
	(-1.323)		(1.076)	(-1.976)	(-1.180)	
15	2.3086E+01	0.0	4.7612E+01	9.7985E-02	3.9765E+01	0.0
	(1.400)		(-1.387)	(-1.555)	(1.998)	
16	4.5944E+01	0.0	3.4032E+01	1.0178E-01	1.0535E+02	0.0
	(-1.880)		(-1.595)	(-2.209)	(1.445)	
17	1.3542E+01	0.0	1.5930E+01	7.6197E-03	2.5778E+01	0.0
	(1.348)		(-1.077)	(1.631)	(-1.529)	

The quantities in parenthesis represent percent deviation from the VIM results.

TABLE III-54
Fuel Isotopes Fission Microscopic Cross Sections

Lattice Type: 5
Fuel Type : 3

GROUP (#)	SIGF-25	SIGF-28	SIGF-29	SIGF-40	SIGF-41	SIGF-42
1	1.2380E+00	3.6199E-01	1.8435E+00	1.5940E+00	1.6536E+00	1.4789E+00
	(1.050)	(-1.001)	(-1.098)	(0.769)	(-1.033)	(-1.269)
2	1.1448E+00	1.3833E-03	1.6346E+00	7.9901E-01	1.4949E+00	5.5173E-01
	(1.066)	(-1.345)	(-1.130)	(-1.413)	(1.673)	(0.866)
3	1.2944E+00	8.7524E-05	1.5210E+00	1.4527E-01	1.6985E+00	8.1724E-02
	(1.525)	(-0.466)	(-1.419)	(1.048)	(-1.635)	(-1.837)
4	1.5474E+00	4.2271E-05	1.5683E+00	7.1454E-02	2.1098E+00	2.9433E-02
	(-0.894)	(-1.578)	(1.493)	(-1.238)	(-1.344)	(1.324)
5	1.7772E+00	4.0000E-05	1.6130E+00	5.6979E-02	2.3164E+00	3.2249E-02
	(-1.764)	(-1.982)	(1.293)	(1.382)	(-1.074)	(-1.490)
6	1.9814E+00	6.2057E-05	1.6103E+00	7.9311E-02	2.5151E+00	4.4065E-02
	(-1.575)	(1.990)	(-1.784)	(-1.567)	(-1.217)	(-1.468)
7	2.7617E+00	5.7977E-05	1.8598E+00	7.6086E-02	3.4100E+00	3.6431E-02
	(-1.637)	(-2.335)	(1.018)	(1.946)	(-1.487)	(-1.439)
8	4.7729E+00	0.0	2.8892E+00	1.6483E-01	6.4633E+00	0.0
	(-1.044)		(-0.664)	(-1.582)	(1.044)	
9	6.9032E+00	0.0	4.1376E+00	2.6959E-01	8.8848E+00	0.0
	(1.090)		(-1.107)	(-1.553)	(-1.498)	
10	8.5277E+00	1.4837E-04	6.1815E+00	3.5178E-01	1.1081E+01	0.0
	(1.137)	(-1.664)	(-1.763)	(-1.805)	(-1.190)	
11	1.3474E+01	9.1708E-04	9.4137E+00	1.6380E-01	1.5544E+01	0.0
	(-1.335)	(-1.912)	(-1.286)	(1.797)	(1.352)	
12	1.3972E+01	0.0	9.5644E+00	2.1680E-01	2.1552E+01	0.0
	(-1.888)		(-1.725)	(-1.901)	(-1.291)	
13	2.0722E+01	0.0	1.5662E+01	2.3708E-01	2.7251E+01	0.0
	(-1.599)		(1.276)	(1.629)	(-1.792)	
14	2.1944E+01	0.0	1.7866E+01	3.3688E-01	3.1713E+01	0.0
	(1.314)		(1.713)	(-1.813)	(-1.551)	
15	2.3813E+01	0.0	4.8122E+01	9.6483E-02	4.1329E+01	0.0
	(-1.251)		(1.139)	(-1.766)	(-1.308)	
16	4.5606E+01	0.0	3.5743E+01	1.0033E-01	1.0868E+02	0.0
	(1.517)		(-1.914)	(-1.892)	(-1.793)	
17	1.3608E+01	0.0	1.5984E+01	7.7286E-03	2.5753E+01	0.0
	(-1.929)		(-1.794)	(-2.896)	(1.443)	

The quantities in parenthesis represent percent deviation from the VIM results.

TABLE III-55
Fuel Isotopes Fission Microscopic Cross Sections

Lattice Type: 7
Fuel Type : 2

GROUP (#)	SIGF-25	SIGF-28	SIGF-29	SIGF-40	SIGF-41	SIGF-42
1	1.2361E+00	3.4538E-01	1.8389E+00	1.5880E+00	1.6505E+00	1.4659E+00
	(-1.026)	(-1.658)	(1.189)	(1.116)	(-1.060)	(1.099)
2	1.1456E+00	1.3082E-03	1.6314E+00	7.8303E-01	1.4958E+00	5.3483E-01
	(-0.998)	(1.763)	(-1.546)	(-1.209)	(1.035)	(-1.381)
3	1.3111E+00	7.9742E-05	1.5148E+00	1.3314E-01	1.7265E+00	7.2257E-02
	(1.048)	(-1.309)	(0.596)	(-1.193)	(-1.187)	(-1.091)
4	1.5489E+00	4.2182E-05	1.5684E+00	7.1181E-02	2.1133E+00	2.9403E-02
	(-1.350)	(1.727)	(-1.562)	(-1.115)	(-1.247)	(-1.071)
5	1.7809E+00	4.0000E-05	1.6136E+00	5.6888E-02	2.3217E+00	3.2396E-02
	(-0.623)	(-1.215)	(1.068)	(-1.187)	(-1.205)	(0.932)
6	1.9811E+00	6.2036E-05	1.6106E+00	7.9347E-02	2.5125E+00	4.4123E-02
	(-1.577)	(-0.908)	(1.107)	(-1.662)	(-1.389)	(1.551)
7	2.7369E+00	6.1066E-05	1.8451E+00	7.6156E-02	3.3640E+00	3.8614E-02
	(1.626)	(-1.438)	(-1.239)	(-1.577)	(0.872)	(-1.864)
8	4.7095E+00	2.3540E-10	2.8578E+00	1.6275E-01	6.3362E+00	0.0
	(-1.159)	(-1.317)	(-1.957)	(1.543)	(1.671)	
9	6.9494E+00	0.0	4.0286E+00	2.7056E-01	8.8624E+00	0.0
	(-1.062)		(1.770)	(-1.515)	(-1.806)	
10	8.5690E+00	1.6827E-04	6.0363E+00	3.4618E-01	1.1065E+01	0.0
	(1.921)	(-1.708)	(-1.336)	(1.784)	(-1.145)	
11	1.3291E+01	1.0168E-03	8.5007E+00	1.6145E-01	1.5282E+01	0.0
	(1.649)	(-1.866)	(-1.297)	(-1.528)	(-1.325)	
12	1.3755E+01	0.0	9.2150E+00	2.1510E-01	2.1171E+01	0.0
	(-1.285)		(1.788)	(2.922)	(-1.506)	
13	2.0683E+01	0.0	1.5905E+01	2.3125E-01	2.7227E+01	0.0
	(-1.475)		(-1.953)	(-1.662)	(-1.393)	
14	2.1752E+01	0.0	1.7265E+01	3.0628E-01	3.0444E+01	0.0
	(-1.545)		(-1.783)	(1.839)	(-1.523)	
15	2.3302E+01	0.0	4.2841E+01	8.8853E-02	3.9703E+01	0.0
	(1.409)		(1.658)	(-1.537)	(1.866)	
16	4.6626E+01	0.0	3.1675E+01	1.5198E-01	7.2967E+01	0.0
	(1.733)		(-1.992)	(-1.275)	(-1.756)	
17	1.3810E+01	0.0	1.6014E+01	7.7674E-03	2.5734E+01	0.0
	(-1.696)		(1.893)	(1.863)	(-1.538)	

The quantities in parenthesis represent percent deviation from the VIM results.

TABLE III-56

LATTICE TYPE: 1
FUEL TYPE : 1

ENERGY GROUP (eV): [1.8854E+00,1.0000E-05]

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	5.5028E-01	5.6063E-01	-1.846E+00
sigt-2	1.8217E+00	1.8086E+00	7.239E-01
siga-1	1.9213E-01	1.8903E-01	1.639E+00
sigf-1	1.2998E-01	1.3267E-01	-2.026E+00
sigt-25	3.5781E+02	3.6384E+02	-1.658E+00
siga-25	3.4418E+02	3.4909E+02	-1.407E+00
sigf-25	3.0193E+02	2.9732E+02	1,552E+00
sigt-28	1.0559E+01	1.0462E+01	9.311E-01
siga-28	1.5025E+00	1.5217E+00	-1.263E+00
sigf-28	0.0	0.0	-

The fuel and moderator regions are 1 and 2 respectively. The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-57

LATTICE TYPE: 2
FUEL TYPE : 1

ENERGY GROUP (eV): ⌜1.8854E+00,1.0000E-05⌝

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	5.2802E-01	5.3973E-01	-2.170E+00
sigt-2	1.7245E+00	1.7082E+00	9.561E-01
siga-1	1.6592E-01	1.6886E-01	-1.749E+00
sigf-1	1.1992E-01	1.1793E-01	1.687E+00
sigt-25	3.3118E+02	3.2523E+02	1.828E+00
siga-25	3.0645E+02	3.1064E+02	-1.350E+00
sigf-25	2.5974E+02	2.6431E+02	-1.729E+00
sigt-28	1.0426E+01	1.0311E+01	1.115E+00
siga-28	1.3634E+00	1.3840E+00	-1.488E+00
sigf-28	0.0	0.0	

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-58

LATTICE TYPE: 3
FUEL TYPE : 2

ENERGY GROUP (eV): "1.8854E+00,1.0000E-05"

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	1.3550E+00	1.3269E+00	2.118E+00
sigt-2	1.2412E+00	1.2245E+00	1.364E+00
siga-1	8.7318E-01	8.9584E-01	-2.529E+00
sigf-1	3.0184E-01	3.1050E-01	-2.780E+00
sigt-25	1.0631E+02	1.0425E+02	1.976E+00
siga-25	9.3058E+01	9.0992E+01	2.271E+00
sigf-25	7.6339E+01	7.7541E+01	-1.554E+00
sigt-28	9.2846E+00	9.4896E+00	-2.160E+00
siga-28	6.9383E-01	6.7645E-01	2.569E+00
sigf-28	0.0	0.0	
sigt-29	3.1241E+02	3.0804E+02	1.419E+00
siga-29	2.9214E+02	2.9774E+00	-1.881E+00
sigf-29	1.8921E+02	1.9325E+02	-2.091E+00
sigt-40	5.9425E+02	6.0762E+02	-2.200E+00
siga-40	5.6373E+02	5.5393E+02	1.769E+00
sigf-40	1.0983E-01	1.0689E-01	2.752E+00
sigt-41	2.2675E+02	2.1970E+02	3.209E+00
siga-41	2.0409E+02	2.0866E+02	-2.190E+00
sigf-41	1.5432E+02	1.5691E+02	-1.653E+00
sigt-42	1.6794E+01	1.7205E+01	-2.388E+00
siga-42	1.0734E+01	1.0462E+01	2.600E+00
sigf-42	0.0	0.0	

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-59

LATTICE TYPE: 3
FUEL TYPE : 3

ENERGY GROUP (eV): "1.8854E+00,1.0000E-05"

VARIABLE (#)	OUTPUT (ECG1)	OUTPUT (VIM)	DIFF (%)
sigt-1	1.5027E+00	1.5239E+00	-1.391E+00
sigt-2	1.2351E+00	1.2149E+00	1.663E+00
siga-1	1.0974E+00	1.0755E+00	2.036E+00
sigf-1	3.5696E-01	3.6630E-01	-2.549E+00
sigt-25	9.6509E+01	9.4682E+01	1.930E+00
siga-25	8.0111E+01	8.1505E+01	-1.710E+00
sigf-25	6.7763E+01	6.9422E+01	-2.389E+00
sigt-28	9.7155E+00	9.4527E+00	2.781E+00
siga-28	6.5736E-01	6.4816E-01	1.419E+00
sigf-28	0.0	0.0	
sigt-29	2.6883E+02	2.7457E+02	-2.090E+00
siga-29	2.5916E+02	2.6426E+02	-1.928E+00
sigf-29	1.7446E+02	1.7185E+02	1.519E+00
sigt-40	5.8070E+02	5.6587E+02	2.621E+00
siga-40	5.2763E+02	5.1346E+02	2.760E+00
sigf-40	9.7191E-02	9.9144E-02	-1.970E+00
sigt-41	1.8725E+02	1.9280E+02	-2.878E+00
siga-41	1.8644E+02	1.8180E+02	2.552E+00
sigf-41	1.3413E+02	1.3719E+02	-2.231E+00
sigt-42	1.6998E+01	1.7363E+01	-2.102E+00
siga-42	1.0933E+01	1.0734E+01	1.854E+00
sigf-42	0.0	0.0	

The fuel and moderator regions are 1 and 2 respectively.
The cross sections representing these regions are macroscopic, while the isotopic cross sections are microscopic.

TABLE III-60
Macroscopic Thermal Cross Sections

Lattice Type: 3
Fuel Type : 2

ENERGY (+) (eV)	OUTPUT	SIGT-1	SIGT-2	SIGA-1	SIGF-1
6.82526E-01	ECG1:	1.1172E+00	1.1073E+00	7.2223E-01	5.0101E-02
	VIM:	1.1365E+00	1.0835E+00	7.0876E-01	5.1544E-02
	diff (%):	-1.698	2.197	1.901	-2.800
1.00000E-05	ECG1:	1.6584E+00	1.3834E+00	1.3627E+00	7.5692E-01
	VIM:	1.7009E+00	1.4160E+00	1.3360E+00	7.4357E-01
	diff (%):	-2.499	-2.302	1.998	1.795

(+): Values represent group lower bounds.

TABLE III-61
Macroscopic Thermal Cross Sections

Lattice Type: 5
Fuel Type : 2

ENERGY (+) (eV)	OUTPUT	SIGT-1	SIGT-2	SIGA-1	SIGF-1
6.82526E-01	ECG1:	1.1986E+00	1.1059E+00	7.7334E-01	5.2723E-02
	VIM:	1.2231E+00	1.0853E+00	7.9155E-01	5.4075E-02
	diff (%):	-2.003	1.898	-2.301	-2.500
1.00000E-05	ECG1:	1.8241E+00	1.5049E+00	1.3828E+00	8.2071E-01
	VIM:	1.7787E+00	1.4739E+00	1.4139E+00	8.0011E-01
	diff (%):	2.401	2.103	-2.199	2.575

(+): Values represent group lower bounds.

TABLE III-62
Macroscopic Thermal Cross Sections

Lattice Type: 7
Fuel Type : 2

ENERGY (+) (eV)	OUTPUT	SIGT-1	SIGT-2	SIGA-1	SIGF-1
6.82526E-01	ECG1:	8.9086E-01	2.1673E-01	4.6468E-01	4.0238E-02
	VIM:	8.7110E-01	2.2138E-01	4.5391E-01	4.1322E-02
	diff (%):	2.200	-2.101	2.373	-2.623
1.00000E-05	ECG1:	1.3323E+00	2.2198E-01	1.0321E+00	5.0496E-01
	VIM:	1.3721E+00	2.2784E-01	1.0071E+00	5.1608E-01
	diff (%):	-2.901	-2.572	2.478	-2.155

(+): Values represent group lower bounds.

TABLE III-63
Fuel Isotope Microscopic Total Thermal Cross Sections

Lattice Type: 3
Fuel Type : 2

GROUP (+)	SIGT-25	SIGT-28	SIGT-29	SIGT-40	SIGT-41	SIGT-42
1 ECG1:	1.8398E+01	9.9049E+00	5.1339E+01	9.2819E+02	4.2936E+01	1.6502E+01
VIM:	1.7914E+01	9.7202E+00	5.2280E+01	9.4907E+02	4.4062E+01	1.6983E+01
diff(%):	2.702	1.900	-1.799	2.200	-2.555	-2.835
2 ECG1:	2.0199E+02	9.6104E+00	7.5208E+02	2.3589E+02	4.8983E+02	1.5310E+01
VIM:	1.9784E+02	9.8662E+00	7.4024E+02	2.3062E+02	5.0332E+02	1.5770E+01
diff(%):	2.098	-2.593	1.601	2.286	-2.661	-2.917

(+): The lower bounds of groups 1 and 2 are 6.8256-1 eV and 1.-5 eV respectively.

TABLE III-64
Fuel Isotope Microscopic Total Thermal Cross Sections

Lattice Type: 5
Fuel Type : 3

GROUP (+)	SIGT-25	SIGT-28	SIGT-29	SIGT-40	SIGT-41	SIGT-42
1 ECG1:	5.1594E+01	9.4381E+00	5.3202E+01	1.0349E+03	4.3814E+01	1.7226E+01
VIM:	5.0545E+01	9.2803E+00	5.4678E+01	1.0614E+03	4.4872E+01	1.6757E+01
diff(%):	2.076	1.700	-2.699	-2.497	-2.358	2.798
2 ECG1:	2.2892E+02	9.7237E+00	8.0030E+02	2.3156E+02	5.6720E+02	1.5832E+01
VIM:	2.2417E+02	9.9628E+00	7.8461E+02	2.2629E+02	5.8234E+02	1.6317E+01
diff(%):	2.117	-2.410	1.998	2.329	-2.601	-2.972

(+): The lower bounds of groups 1 and 2 are 6.8256-1 eV and 1.-5 eV respectively.

TABLE III-65
Fuel Isotope Microscopic Total Thermal Cross Sections

Lattice Type: 7
Fuel Type : 2

GROUP (+)	SIGT-25	SIGT-28	SIGT-29	SIGT-40	SIGT-41	SIGT-42
1 ECG1:	3.7843E+01	9.3996E+00	4.3775E+01	5.9436E+02	4.2049E+01	1.8020E+01
VIM:	3.8738E+01	9.2336E+00	4.2578E+01	6.0980E+02	4.0936E+01	1.7612E+01
diff(%):	-2.310	1.798	2.881	-2.532	2.718	2.315
2 ECG1:	1.1574E+02	9.3854E+00	5.5197E+02	2.4356E+02	2.6753E+02	1.3771E+01
VIM:	1.1827E+02	9.5796E+00	5.3790E+02	2.5156E+02	2.6118E+02	1.4185E+01
diff(%):	-2.135	-2.2027	2.615	-3.180	2.433	-2.917

(+): The lower bounds of groups 1 and 2 are 6.8256-1 eV and 1.-5 eV respectively.

TABLE III-66
Fuel Isotope Microscopic Absorbtion Thermal Cross Sections

Lattice Type: 3
Fuel Type : 2

GROUP (+)	SIGA-25	SIGA-28	SIGA-29	SIGA-40	SIGA-41	SIGA-42
1 ECG1:	3.4467E+01	5.1327E-01	4.3186E+01	8.7567E+02	3.2453E+01	6.0369E+00
VIM:	3.5206E+01	5.0469E-01	4.2133E+01	8.5515E+02	3.3221E+01	6.2188E+00
diff(%):	-2.099	1.715	2.498	2.402	-2.311	-2.925
2 ECG1:	1.8806E+02	9.3532E-01	7.0984E+02	2.2359E+02	5.0265E+02	7.8029E+00
VIM:	1.8355E+02	9.5356E-01	7.2954E+02	2.2855E+02	4.9156E+02	8.0179E+00
diff(%):	2.455	-1.913	-2.701	-2.171	2.256	-2.681

(+): The lower bounds of groups 1 and 2 are 6.8256-1 eV and 1.-5 eV respectively.

TABLE III-67
Fuel Isotope Microscopic Absorbtion Thermal Cross Sections

Lattice Type: 5
Fuel Type : 3

GROUP (+)	SIGA-25	SIGA-28	SIGA-29	SIGA-40	SIGA-41	SIGA-42
1 ECG1:	3.8692E+01	5.1906E-01	4.5430E+01	9.3128E+02	3.3124E+01	1.0687E+01
VIM:	3.7801E+01	5.0849E-01	4.4488E+01	9.6259E+02	3.3993E+01	1.0446E+01
diff(%):	-2.356	2.079	2.118	-3.253	-2.556	2.309
2 ECG1:	2.1440E+02	1.0640E+00	7.5310E+02	2.1754E+02	5.8487E+02	8.0809E+00
VIM:	2.0976E+02	1.0434E+00	7.7426E+02	2.2407E+02	5.7082E+02	8.2594E+00
diff(%):	2.210	1.971	-2.733	-2.916	2.462	-2.158

(+): The lower bounds of groups 1 and 2 are 6.8256-1 eV and 1.-5 eV respectively.

TABLE III-68
Fuel Isotope Microscopic Absorbtion Thermal Cross Sections

Lattice Type: 7
Fuel Type : 2

GROUP (+)		SIGA-25	SIGA-28	SIGA-29	SIGA-40	SIGA-41	SIGA-42
1	ECG1:	2.5578E+01	4.8139E-01	3.3229E+01	5.1534E+02	2.9454E+01	1.1967E+01
	VIM:	2.6165E+01	4.8967E-01	3.2597E+01	5.2921E+02	3.0240E+01	1.1688E+01
	diff(%):	-2.244	-1.691	1.902	-2.621	-2.599	2.387
2	ECG1:	1.0667E+02	6.9861E-01	5.3525E+02	2.5611E+02	2.5737E+02	6.1422E+00
	VIM:	1.0437E+02	6.8771E-01	5.2620E+02	2.5001E+02	2.4909E+02	6.3080E+00
	diff(%):	2.203	1.585	-1.720	2.439	3.326	-2.628

(+): The lower bounds of groups 1 and 2 are 6.8256-1 eV and 1.-5 eV respectively.

TABLE III-69
Fuel Isotope Microscopic Fission Thermal Cross Sections

Lattice Type: 3
Fuel Type : 2

GROUP (+)	SIGF-25	SIGF-28	SIGF-29	SIGF-40	SIGF-41	SIGF-42
1 ECG1:	2.9672E+01	0.0	3.0513E+01	1.6875E-01	3.0197E+01	0.0
VIM:	2.9196E+01	0.0	3.1221E+01	1.6433E-01	2.9449E+01	0.0
diff(%):	1.630		-2.268	2.690	2.541	
2 ECG1:	1.5487E+02	0.0	4.7841E+02	4.3898E-02	3.5468E+02	0.0
VIM:	1.5777E+02	0.0	4.6622E+02	4.4896E-02	3.6219E+02	0.0
diff(%):	-1.838		2.615	-2.223	-2.074	

(+): The lower bounds of groups 1 and 2 are 6.8256-1 eV and 1.-5 eV respectively.

TABLE III-70
Fuel Isotope Microscopic Fission Thermal Cross Sections

Lattice Type: 5
Fuel Type : 3

GROUP (+)	SIGF-25	SIGF-28	SIGF-29	SIGF-40	SIGF-41	SIGF-42
1 ECG1:	3.0919E+01	0.0	3.2086E+01	9.7982E+02	2.9087E+01	0.0
VIM:	3.1592E+01	0.0	3.2831E+01	9.6240E+02	2.9966E+01	0.0
diff(%):	-2.130		-2.269	1.811	-2.933	
2 ECG1:	1.8263E+02	0.0	4.8827E+02	2.2928E+02	4.1116E+02	0.0
VIM:	1.7983E+02	0.0	4.9762E+02	2.2403E+02	4.2160E+02	0.0
diff(%):	1.557		-1.879	2.343	-2.476	

(+): The lower bounds of groups 1 and 2 are 6.8256-1 eV and 1.-5 eV respectively.

TABLE III-71
Fuel Isotope Microscopic Fission Thermal Cross Sections

Lattice Type: 7
Fuel Type : 2

GROUP (+)		SIGF-25	SIGF-28	SIGF-29	SIGF-40	SIGF-41	SIGF-42
1	ECG1:	2.1276E+01	0.0	2.4171E+01	1.0471E-01	2.6833E+01	0.0
	VIM:	2.0848E+01	0.0	2.4649E+01	1.0205E-01	2.7531E+01	0.0
	diff(%):	2.053		-1.939	2.607	-2.535	
2	ECG1:	9.3157E+01	0.0	3.2522E+02	5.0190E-02	1.7284E+02	0.0
	VIM:	9.1590E+01	0.0	3.3277E+02	4.9004E-02	1.7810E+02	0.0
	diff(%):	1.711		-2.269	2.420	-2.953	

(+): The lower bounds of groups 1 and 2 are 6.8256-1 eV and 1.-5 eV respectively.

3.4 Reactivity Calculations

The reactivity data corresponding to the lattice and fuel configurations of Tables 14 through 71 is presented in Table 72. The percent delta rho is defined as follows:

$$\text{delta RHO (\%)} = 100 \left(K_{\infty}^{ECG1} - K_{\infty}^{VIM} \right) / \left(K_{\infty}^{ECG1} K_{\infty}^{VIM} \right)$$

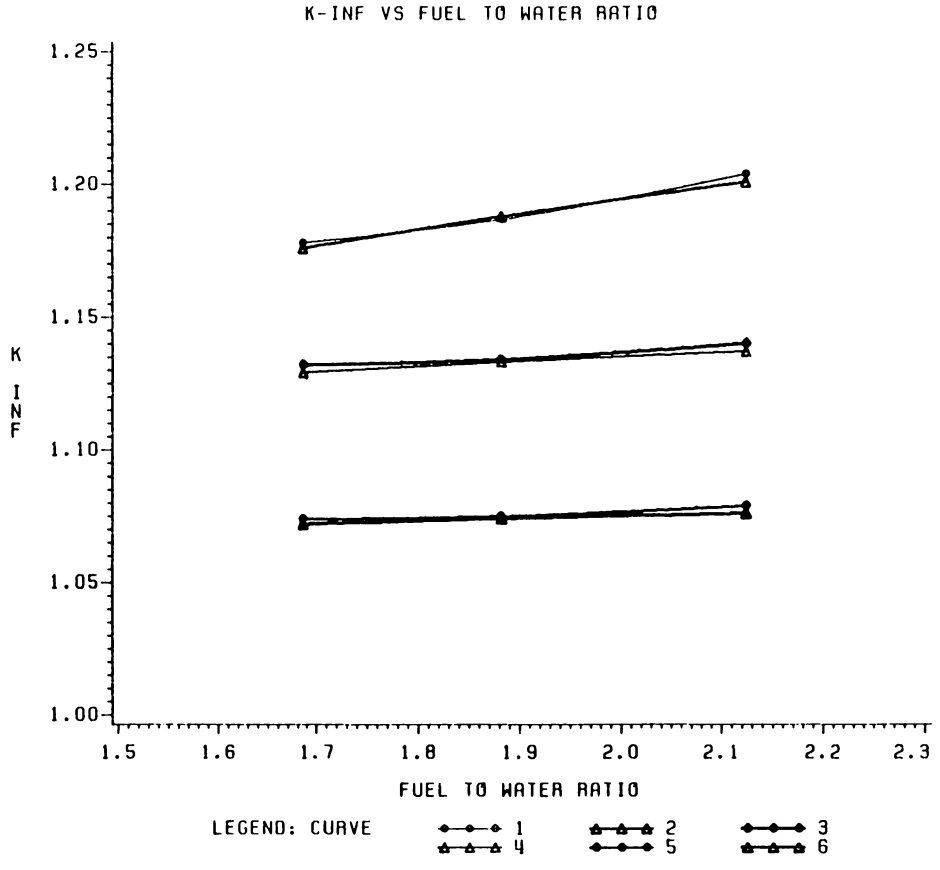
TABLE III-72
Reactivity Results

LATTICE TYPE	FUEL TYPE	K-INF ECG1	K-INF VIM	DELTA-RHO (%)
1	1	0.12040E+01	0.12044E+01	-0.27584E-01
2	1	0.11108E+01	0.11112E+01	-0.32406E-01
3	2	0.99183E+00	0.98947E+00	0.24048E+00
3	3	0.10725E+01	0.10747E+01	-0.19087E+00
4	1	0.11024E+01	0.11033E+01	-0.73996E-01
5	2	0.10139E+01	0.10128E+01	0.10712E+00
5	3	0.10772E+01	0.10754E+01	0.15538E+00
6	1	0.46604E+00	0.46611E+00	-0.32224E-01
8	1	0.55102E+00	0.55094E+00	0.26352E-01
7	2	0.87276E+00	0.87379E+00	-0.13506E+00

3.5 Applications of Economical Model to Compact Lattice Studies

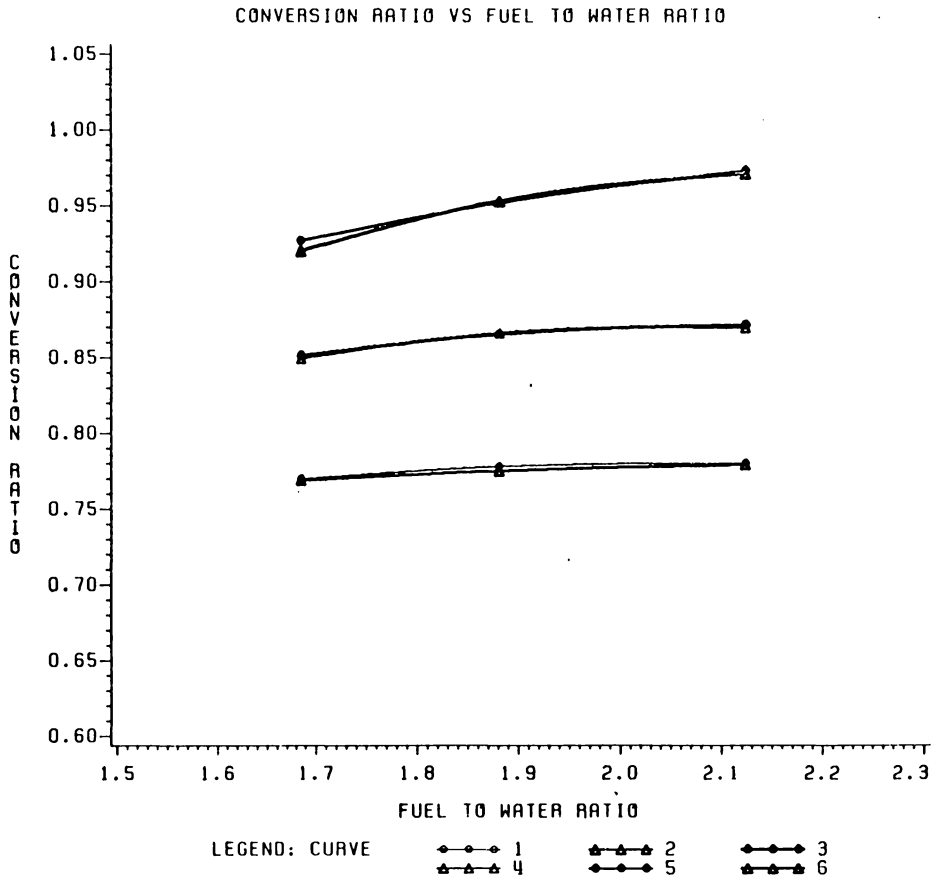
The objective of this section is to demonstrate a relationship between the infinite multiplication factor and conversion ratio as a function of the Fuel-to-Water ratio for compact lattice configurations. In order to accomplish this objective, three separate runs with 11% Pu, 13% Pu, and 15% Pu have been implemented. The above are weight percent of Plutonium within a PuO_2-UO_2 pellet with 0.2 w/o enrichment of U-235. The Fuel Rods have been modelled as an infinitely repetitive hexagonal lattice structure. The Fuel-to-Water ratio has been varied by adjusting the lattice pitch. The results of these runs, showing the responses of K-INF and C.R. versus Fuel-to-Water ratio, are depicted in Fig. III-1 and Fig. III-2 respectively.

The latter of the above figures shows that as the pitch is decreased, the spectrum is hardened. Consequently, the C.R. is increased, since more neutrons are captured by the Plutonium. Furthermore, as depicted in Fig. 1, an increase in the weight percent of Plutonium leads to an increased value of K-INF and to a decrease of the C.R. (Fig. 2). These curves are utilized in establishing the correct values of K-INF and C.R. in the Burnup cycles of high conversion lattices.



ODD LEGEND NUMBERS: ECG1, (1) = 15%PU, (3) = 13%PU, (5) = 11%PU
EVEN LEGEND NUMBERS: VIM, (2) = 15%PU, (4) = 13%PU, (6) = 11%PU

BENCHMARK ECG1 VS VIM
FIG III-1



ODD LEGEND NUMBERS: ECG1, (1) = 11%PU, (3) = 13%PU, (5) = 15%PU
EVEN LEGEND NUMBERS: VIM, (2) = 11%PU, (4) = 13%PU, (6) = 15%PU

BENCHMARK ECG1 VS VIM
FIG III-2

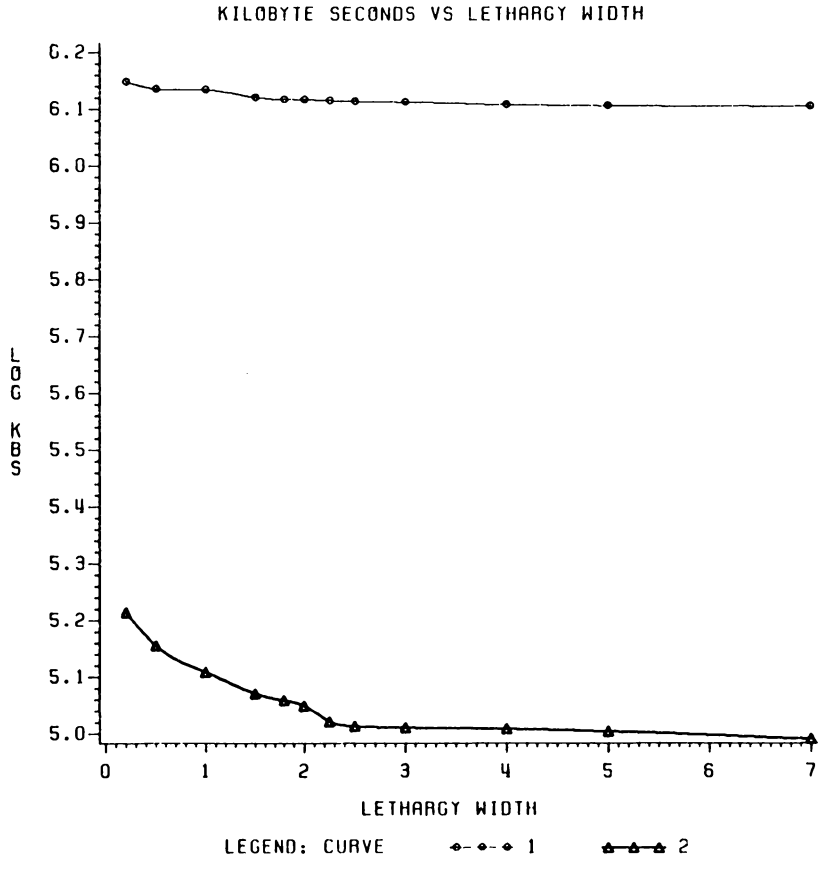
3.6 Sensitivity Analyses

This section considers the determination of the effective CPU times and memory allocations as function of two type of parameters, namely:

(1) lethargy width

(2) integration step size

Implementation of the sensitivity analysis runs as a function of the lethargy width provides the characterization of the cost-effectiveness of the code structure. The determination of cost-effectiveness is given in terms of kilobytes-seconds, since dollar costs of computational resources are frequently represented in units of Kilobyte-seconds. The plots of kilobyte-seconds versus lethargy width for the CSMP and VIM models are depicted by Fig. 3. Furthermore, the CSMP model also allows for the choice of integration step size in lethargy. A study has been made in this section with the CSMP model by implementing lattice type 9 with fuel type 2. Subsequently the results have been compared for a variety of integration step sizes with the VIM output. The outcome of these analyses are detailed in Table III-70. The value of 2.50E-4 has been chosen as the optimal integration step size throughout this work.



CURVE 1: VIM
CURVE 2: ECG1

KILOBYTE SEC EXPENDED VS LETHARGY WIDTH
FIG III-3

TABLE III-73
Effect of Integration Step Size Variation

INTEGRATION STEPZIZE (lethargy *1.0E-06)	RELATIVE CPU TIME	(*) SIGA-1 (% diff.)	(**) RHO (%diff.)
10.00	8.23	1.15E-01	9.32E-03
50.00	4.14	-3.70E-01	1.88E-02
100.00	2.87	-8.26E-01	-5.07E-02
150.00	2.04	-1.27E+00	6.25E-02
250.00	1.00	-1.71E+00	8.53E-02
500.00	0.46	9.12E+00	-2.45E+00

(*) : $100(SIGA\text{-}1^{ECCI} - SIGA\text{-}1^{VIM})/(SIGA\text{-}1^{VIM})$

(**) : $100(K_{\infty}^{ECCI} - K_{\infty}^{VIM})/(K_{\infty}^{ECCI} K_{\infty}^{VIM})$

Chapter IV

CONCLUSIONS

1. The results of this study show that the scheme for the implementation of the economical solution of the Transport Equation is an efficient method for the calculation of the group constants and multiplication factor for heterogeneous lattices of either hexagonal or square cell configurations. Almost all the results from the implemented solution are within the statistical errors of the VIM calculations. These are typically 1-2% for the group constants averaged over the fast energy groups, and about 2% for the thermal energy groups. These results are very good compared to the differences with VIM obtained from MUFT type codes which approach 20% for group cross sectional values for tight lattices[8]. The additional accuracy obtained from the implemented code is procured with little increased costs.

2. A typical three-region problem implemented in CSMP, involving four groups and H_2O moderator, has a CPU running time of about 3 1/2 minutes. The same problem implemented in VIM will spend approximately 30 minutes of CPU time for a 50-batch run in an IBM 4341 environment. Furthermore utilizing D_2O as a moderator will increase the CPU running times of VIM to about 56 minutes for a 50-batch run, while the CPU expenditures of the CSMP model will not increase. Therefore, the CPU running time efficiency of the CSMP code is about 9 times faster for H_2O

moderated systems and about 16 times faster for D_2O moderated systems.

3. The benchmark VIM code[12] invokes scattering tables prepared from the FLANGEX and KERINTX codes. These codes were developed from the FLANGE and KERINT codes of Honeck and Finch[17]; they are still in the development stage. The thermal neutron scattering law, $S(\alpha,\beta)$, is represented in VIM as tabulated parts plus analytic parts of the free gas or diffusive motion forms. On the other hand, the constructed economical model invokes the Nelkin and Honeck Kernels within the thermal neutron scattering. The somewhat higher percent differences between the constructed model and VIM in the thermal energy region arises due to the different representations of the scattering law in these models.

4. The detailed energy solution of the Transport Equation treats properly the complex effects of resonance overlap and interference. The spatial solution, even for tight lattices, is adequately treated using escape probabilities in a two-region problem.

5. The empirical relations for the escape probabilities in either hexagonal or square cells obtained by Compton[18] may be utilized directly in the kernels of the transport equation with satisfactory results.

6. The group constants obtained from the implemented economical solution of the transport equation may further be utilized for procuring the fuel region isotopics in a nuclear fuel cycle depletion calculation

for high conversion lattices. The calculation of isotopics for tight lattices requires a very accurate mapping of the cross sections as functions of fuel-to-water ratio. The cross sections calculated by the code meet the accuracy requirements of the fuel depletion codes.

7. It is recommended that the implemented code be developed into a production type computer program. This could be done in a stand-alone code, or coupled with fuel depletion codes such as RFD-2[2].

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APPENDIX I

ESCAPE PROBABILITY RELATIONS

The analytical expressions for the escape probabilities and the empirical formula for the Dancoff correction factor utilized in this work will be presented in this Appendix.

The fuel and moderator escape probability functions of equations (II-7-A) and (II-7-B) are found to be the following:

$$P_f(u) = \frac{(1 - \langle G_f \rangle)(1-C)}{\bar{\ell}_f \, \Sigma_{t(f)}(u)(1 - \langle G_f \rangle C)}$$

$$P_m(u) = \left(\frac{V_f}{V_m}\right)\left(\frac{\Sigma_{t(f)(u)}}{\Sigma_{t(m)(u)}}\right) P_f(u)$$

where,

$\langle G_f \rangle$: is the average transmission probability through the fuel.

$\bar{\ell}_f$: is the average cord length

C: is the Dancoff correction factor

Furthermore, the empirical relation for the Dancoff correction factor is the following:

$$c = (1 + A_c \tau_c^2)\exp(-2\alpha_c \tau_c)(1 + A_m \tau_m^2)\exp(-\alpha_m \tau_m)$$

The parameters α_c, α_m, A_c and A_m had been determined empirically by

Compton[18] from best fit Monte Carlo data. These parameters are detailed in TABLE (A-1-1) for hexagonal and rectangular lattices. The non-dimensional quantities τ_c and τ_m are given by:

$$\tau_c = \Sigma_c \frac{\bar{\ell}_c}{\alpha_c}$$

$$\tau_m = \Sigma_m \frac{\bar{\ell}_m}{\alpha_m}$$

The average cord lengths $\bar{\ell}_i$ are given by:

$$\bar{\ell}_i = \alpha_i \left(\frac{4V_i}{S_i}\right) .$$

where, V_i and S_i are the volume and surface area of region i respectively. Furthermore, the average transmission probability for the fuel region is given by:

$$\langle G_f \rangle = (1 - 0.445(\Sigma_f \bar{\ell}_f)^2)\exp(-\Sigma_f \bar{\ell}_f).$$

TABLE A-1-1

Parameters of Empirical Formula for Dancoff Correction

Parameter	Best Fit Value	
	Hexagonal Lattice	Rectangular Lattice
α_c	1.050	1.050
α_m	0.904	0.906
A_c	0.180	0.180
A_m	0.140	0.130

APPENDIX II

Coded Program in CSMP

TABLE A2-1
Input Variables

CARD (#)	WORD (#)	VARIABLE	DESCRIPTION	FORMAT
1	1	NISO	Total No. of Isotopes.	I2
1	2	NISOF	Total No. of Fissile Isotopes.	I2
1	3	NGROUP	Total No. of Groups.	I2
1	4	LATYPE	Type of Lattice. (1=Rectangular,2=hexagonal)	I2
2A	1-6	Q(j) 1<=j<=6	Isotopic Number Density (See Table A2-2)	6E12.5
2B	1-6	Q(j) 7<=j<=12	Isotopic Number Density (See Table A2-2)	6E12.5
2C	1-2	Q(j) 13<=j<=14	Isotopic Number Density (See Table A2-2)	6E12.5
3A	1	LETGRP(i)	Lower Bound of i-th lethargy group	E12.5
3N	(Use as many cards as necessary to define group structure)			
4	1	V1	Volume of Region 1	E12.5
4	2	V2	Volume of Region 2	E12.5
4	3	V3	Volume of Clad Region	E12.5
4	4	A1	Area of Region 1	E12.5
4	5	A2	Area of Region 2	E12.5
4	6	A3	Area of Clad Region	E12.5
5	1	RHO	FTW - Ratio	E12.5

TABLE A2-2
Input Isotopes Nomenclature

ISOTOPE NUMBER	ISOTOPE
1	U-235
2	U-238
3	Pu-239
4	Pu-240
5	Pu-241
6	Pu-242
7	O-16
8	ZR-2
9	Ni
10	Cr
11	Fe
12	H&H2O
13	D&D2O
14	O&UO2

```
          //B092432A JOB 217A9,TK40-L32,REGION=1100K,TIME=5
          /*JOBPARM LINES=50
          /*PRIORITY IDLE
          /*ROUTE PRINT VPIMVS1
          //*CSMPX PROC LIB='VPI.DUMMYLIB',LINKMEM='VICTLCDS'
          //*X     EXEC PGM=THERM,ACCT=CSMPX1,
          //*           PARM=('FORTPGM=1FEAAB'),
          //*           'FORTOPT=(OPTIMIZE(2),NOTERM))'
          //*            'LINKOPT=(LET,CALL)',
          //*            'TRANPGM=DEJTM1D')
          //*CSMPLIB DD DSN=VPI.CSMP.LIBRARY.SYSTEM,DISP=SHR
          //*FT01F001 DD UNIT=VIO,SPACE=(3500,(20,20)),DSN=&&SYSIN,
          //*             DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
          //*FT02F001 DD SYSOUT=B
          //*STEBLIB DD DSN=VPI.CSMP.LOAD.SYSTEM,DISP=SHR
          //*        DD DSN=&LIB,DISP=SHR
          //*  PEND
          //STEP1 EXEC CSMPX
          //*SYSLIN DD UNIT=SYSDA,DSN=&&TEMP
          //*
-------------------------------------------------------------------
          //* I           CONTINUOUS SYSTEM MODELING PROGRAM FOR

          //* I           TRANSPORT EQUATION

          //* I           LETHARGY RANGE: 0.0 TO 20.0 UNITS

          //* I           FTW RATIO 0.8636  LATTICE 2   FUEL 1

          //* I          (FILE: TEK40-2 CSMP A1 / A2V2)

          //* I           02/19/84


-------------------------------------------------------------------
          //* 2
          //*
          //SYSIN DD *
          /     DIMENSION XF(4,6),XA(4,6),XT(4,6),Q(14)
          FIXED
.,IP3,IP4,IP6,IP12,IP9,K,ISO,NISO,NISO1,NN,NOG,LBOUND,NGT
          FIXED LATYPE,ICL1,ICL2,ISO2,IGROUP,NSET,NISOF,ISTRTG,NNSET,NTABG
          SYSTEM NPOINT=810
          STORAGE
9),N(9),DLY(9),Q1(9),Q2(9),LETGRP(5),XSECF1(9),Y(5),...

0(9),XSECA(9),XSECT0(9),XSECT(9),U10(9),XSECA1(9),...

),F02(9),F1(9),F2(9),UREL1(9),XSECF0(9),XSECF(9),...

4),CNT2(4),CNT3(4),CNT4(4),SIGF(2),XSECT1(9),VS(12),...
                  XCRF(8),XCRA(8),XCRT(8),GSMF1(9),GSMA1(9),GSMT1(9),...
                  SIGT(3),SIGA(2),XCRF1(27),XCRA1(27),XCRT1(27)
          MACRO N=DETRMN (ALFA,NN,NISO)
          PROCEDURAL
                DO 100 I=1,NN
```

```
      IM1=I-1
      IP1=I+1
      DO 90 K=1,NISO
      INTVL1=IM1*ALOG(1./ALFA(K))
      INTVL2=IP1*ALOG(1./ALFA(K))
      POINT=U
   90 IF ((POINT.GE.INTVL1).AND.(POINT.LT.INTVL2)) N(K)=I
```

```
  100 CONTINUE
ENDMACRO
MACRO GRPN=DETGRP (LETGRP,NOG)
      DO 100 I=1,NOG
      IP1=I+1
      IF ((U.GE.LETGRP(I)).AND.(U.LT.LETGRP(IP1))) GRPN=I
  100 CONTINUE
ENDMACRO
MACRO SIGT,SIGA,SIGF=DETSIG (Q1,Q2,XSECT1,XSECA1,XSECF1,NISO)
      DO 100 I=1,2
      SIGT(I)=0.0
      SIGA(I)=0.0
  100 SIGF(I)=0.0
      NISO1=NISO+1
      DO 110 ISO=1,NISO1
      SIGT(1)=SIGT(1)+Q1(ISO)*XSECT1(ISO)
      SIGT(2)=SIGT(2)+Q2(ISO)*XSECT1(ISO)
      SIGA(1)=SIGA(1)+Q1(ISO)*XSECA1(ISO)
      SIGA(2)=SIGA(2)+Q2(ISO)*XSECA1(ISO)
      SIGF(1)=SIGF(1)+Q1(ISO)*XSECF1(ISO)
      SIGF(2)=SIGF(2)+Q2(ISO)*XSECF1(ISO)
**    SSIGT(2)=SSIGT(2)+XSECT(ISO)
**    SSIGA(1)=SSIGA(1)+XSECA(ISO)
**    SSIGA(2)=SSIGA(2)+XSECA(ISO)
  110 CONTINUE
      SIGT(3)=0.347
ENDMACRO
MACRO XCRF,XCRA,XCRT=DETX (XCRF1,XCRA1,XCRT1,GRPN,NNSET)
PROCEDURAL
      CL1=(GRPN-1)*9+1
      CL2=CL1+7
      DO 100 I=1,NNSET
      IF (CL1.EQ.I) ICL1=I
  100 IF (CL2.EQ.I) ICL2=I
*     WRITE (6,5) ICL1,CL1,ICL2,CL2
*   5 FORMAT (10X,I2,1X,F4.1,1X,I2,1X,F4.1)
      DO 200 I=ICL1,ICL2
      IP1=I-ICL1+1
      XCRF(IP1)=XCRF1(I)
      XCRA(IP1)=XCRA1(I)
  200 XCRT(IP1)=XCRT1(I)
ENDMACRO
MACRO G2,DENU,PU1,PU2=ESCPRB (SIGT,VS,RHO,LATYPE)
      DO 100 I=1,3
      IP3=I+3
      IP6=I+6
      IP9=I+9
      VS(IP6)=4*VS(I)/VS(IP3)
  100 VS(IP9)=SIGT(I)*VS(IP6)
      TAU1=VS(10)
      TAU2=VS(11)
      TAU3=VS(12)
      P1OU=(1./TAU1)*(1-(1+0.09832*(TAU1**2))*EXP(-TAU1))
```

```
      GG=(1.+0.18*(TAU3**2))*EXP(-2.1*TAU3)
      GG1=(1.+0.14*(TAU2**2))*EXP(-0.94*TAU2)
      GG2=(1.+0.13*(TAU2**2))*EXP(-0.906*TAU2)
      IF (LATYPE.EQ.1) G2=GG*GG1
      IF (LATYPE.EQ.2) G2=GG*GG2
      DENU=1-(1-TAU1*P10U)*G2
      PU1=P10U*(1.-G2)/DENU
      PU2=RHO*(SIGT(1)/SIGT(2))*PU1
ENDMACRO
MACRO DETEND=ENDCND (N,NISO,NN)
      DETEND=0.0
      DO 100 I=1,NISO
      IF (N(I).EQ.NN) DETEND=DETEND+1.0
  100 CONTINUE
ENDMACRO
MACRO Y=DETY (LETGRP,GRPN)
PROCEDURAL
      WIDTH=0.1
      DO 100 I=1,NOG
      IP1=I+1
      L1=LETGRP(I)+WIDTH
      L2=LETGRP(IP1)-WIDTH
      Y(I)=-1.0
      IF ((U.GT.L1).AND.(U.LT.L2)) Y(I)=1.0
  100 CONTINUE
ENDMACRO
MACRO N1,N2=DETN12 (X,X1,X2)
      IF (X.LT.X1) N1=1
      IF (X.GT.X1) N1=7
      IF (X.LT.X1) N2=6
      IF (X.GT.X1) N2=9
ENDMACRO
MACRO DELTX=DELTAF (X,Y)
      IF (X.EQ.Y) DELTX=1.0
      IF (X.NE.Y) DELTX=0.0
ENDMACRO
INITIAL
NOSORT
```

```
-----------------------------------------------------------------
*** I           CONTINUOUS SYSTEM MODELING PROGRAM FOR

*** I           TRANSPORT EQUATION

*** I           FAST RANGE

*** I           02/19/84


-----------------------------------------------------------------
*2
*
*
*
*                    -------------------------
*                    I (I) INITIALIZATION:   I
*                    -------------------------
```

```
PARAMETER RHO=0.9773,STRTU=0.0,ENDU=15.5,ETA=1.0E-6,NGT=3
CONSTANT NISO=8,E0=1.0,NN=999,ISTRTG=1,NOG=4,NNSET=5,LATYPE=1
```

```
CONSTANT PI=3.1414,HEIGHT=366.0,V1=238.25,V3=56.14,NTABG=27
CONSTANT A1=1046.8,A3=116.82,NISOF=2,ETA2=1.05,SCALE1=1.0E-24
RENAME TIME=U,DELT=DELU,FINTIM=FINU
      READ (6,5001) NISO,NISOF,NGROUP,LATYPE
      READ (6,5002) (Q(J),J=1,6)
      READ (6,5002) (Q(J),J=7,12)
      READ (6,5003) (Q(J),J=13,14)
      READ (6,5002) V1,V2,V3,A1,A2,A3
      NGL=NGROUP+1
      DO 5010 I=1,NGL
      READ (6,5004) LETGRP(I)
   31 READ (31,1) XL,XF25,XA25,XT25
*     WRITE (91,1) XL,XF25,XA25,XT25
      IF (XL.LT.0) GOTO 311
      CALL FGLOAD (FXSF1,XL,XF25,1)
      GOTO 31
  311 END FILE 31
      REWIND 31
 3111 READ (31,1) XL,XF25,XA25,XT25
      IF (XL.LT.0) GOTO 312
      CALL FGLOAD (FXSA1,XL,XA25,1)
      GOTO 3111
  312 END FILE 31
      REWIND 31
 3121 READ (31,1) XL,XF25,XA25,XT25
      IF (XL.LT.0) GOTO 32
      CALL FGLOAD (FXST1,XL,XT25,1)
      GOTO 3121
   32 READ (32,1) XL,XF28,XA28,XT28
*     WRITE (92,1) XL,XF28,XA28,XT28
      IF (XL.LT.0) GOTO 321
      CALL FGLOAD (FXSF2,XL,XF28,1)
      GOTO 32
  321 END FILE 32
      REWIND 32
 3211 READ (32,1) XL,XF28,XA28,XT28
      IF (XL.LT.0) GOTO 322
      CALL FGLOAD (FXSA2,XL,XA28,1)
      GOTO 3211
  322 END FILE 32
      REWIND 32
 3221 READ (32,1) XL,XF28,XA28,XT28
      IF (XL.LT.0) GOTO 41
      CALL FGLOAD (FXST2,XL,XT28,1)
      GOTO 3221
   41 READ (41,1) XL,XFOX1,XAOX1,XTOX1
*     WRITE (93,1) XL,XFOX1,XAOX1,XTOX1
      IF (XL.LT.0) GOTO 411
      CALL FGLOAD (FXSF3,XL,XFOX1,1)
      GOTO 41
  411 END FILE 41
      REWIND 41
 4112 READ (41,1) XL,XFOX1,XAOX1,XTOX1
```

```
      IF (XL.LT.0) GOTO 412
      CALL FGLOAD (FXSA3,XL,XAOX1,1)
      GOTO 4112
  412 END FILE 41
      REWIND 41
 4121 READ (41,1) XL,XFOX1,XAOX1,XTOX1
      IF (XL.LT.0) GOTO 42
      CALL FGLOAD (FXST3,XL,XTOX1,1)
      GOTO 4121
   42 READ (42,1) XL,XFOX2,XAOX2,XTOX2
*     WRITE (94,1) XL,XFOX2,XAOX2,XTOX2
      IF (XL.LT.0) GOTO 421
      CALL FGLOAD (FXSF4,XL,XFOX2,1)
      GOTO 42
  421 END FILE 42
      REWIND 42
 4211 READ (42,1) XL,XFOX2,XAOX2,XTOX2
      IF (XL.LT.0) GOTO 422
      CALL FGLOAD (FXSA4,XL,XAOX2,1)
      GOTO 4211
  422 END FILE 42
      REWIND 42
 4221 READ (42,1) XL,XFOX2,XAOX2,XTOX2
      IF (XL.LT.0) GOTO 43
      CALL FGLOAD (FXST4,XL,XTOX2,1)
      GOTO 4221
   43 READ (43,1) XL,XFMDR,XAMDR,XTMDR
*     WRITE (94,1) XL,XFMDR,XAMDR,XTMDR
      IF (XL.LT.0) GOTO 431
      CALL FGLOAD (FXSF5,XL,XFMDR,1)
      GOTO 43
  431 END FILE 43
      REWIND 43
 4311 READ (43,1) XL,XFMDR,XAMDR,XTMDR
      IF (XL.LT.0) GOTO 432
      CALL FGLOAD (FXSA5,XL,XAMDR,1)
      GOTO 4311
  432 END FILE 43
      REWIND 43
 4321 READ (43,1) XL,XFMDR,XAMDR,XTMDR
      IF (XL.LT.0) GOTO 51
      CALL FGLOAD (FXST5,XL,XTMDR,1)
      GOTO 4321
   51 READ (51,1) XL,XF29,XA29,XT29
*     WRITE (95,1) XL,XF29,XA29,XT29
      IF (XL.LT.0) GOTO 511
      CALL FGLOAD (FXSF6,XL,XF29,1)
      GOTO 51
  511 END FILE 51
      REWIND 51
  512 READ (51,1) XL,XF29,XA29,XT29
      IF (XL.LT.0) GOTO 513
      CALL FGLOAD (FXSA6,XL,XA29,1)
```

```
      GOTO 512
  513 END FILE 51
      REWIND 51
  514 READ (51,1) XL,XF29,XA29,XT29
      IF (XL.LT.0) GOTO 52
      CALL FGLOAD (FXST6,XL,XT29,1)
      GOTO 514
   52 READ (52,1) XL,XF40,XA40,XT40
*     WRITE (96,1) XL,XF40,XA40,XT40
      IF (XL.LT.0) GOTO 521
      CALL FGLOAD (FXSF7,XL,XSF40,1)
      GOTO 52
  521 END FILE 52
      REWIND 52
  522 READ (52,1) XL,XF40,XA40,XT40
      IF (XL.LT.0) GOTO 523
      CALL FGLOAD (FXSA7,XL,XA40,1)
      GOTO 522
  523 END FILE 52
      REWIND 52
  524 READ (52,1) XL,XF40,XA40,XT40
*     WRITE (97,1) XL,XF40,XA40,XT40
      IF (XL.LT.0) GOTO 53
      CALL FGLOAD (FXST7,XL,XT40,1)
      GOTO 524
   53 READ (53,1) XL,XF41,XA41,XT41
*     WRITE (97,1) XL,XF41,XA41,XT41
      IF (XL.LT.0) GOTO 531
      CALL FGLOAD (FXSF8,XL,XF41,1)
      GOTO 53
  531 END FILE 53
      REWIND 53
  532 READ (53,1) XL,XF41,XA41,XT41
*     WRITE (99,1) XL,XF41,XA41,XT41
      IF (XL.LT.0) GOTO 533
      CALL FGLOAD (FXSA8,XL,XA41,1)
      GOTO 532
  533 END FILE 53
      REWIND 53
  534 READ (53,1) XL,XF41,XA41,XT41
      IF (XL.LT.0) GOTO 61
      CALL FGLOAD (FXST8,XL,XT41,1)
      GOTO 534
   61 READ (61,1) XL,XF42,XA42,XT42
*     WRITE (98,1) XL,XF42,XA42,XT42
      IF (XL.LT.0) GOTO 611
      CALL FGLOAD (FXSF9,XL,XF42,1)
      GOTO 61
  611 END FILE 61
      REWIND 61
  612 READ (61,1) XL,XF42,XA42,XT42
      IF (XL.LT.0) GOTO 613
      CALL FGLOAD (FXSA9,XL,XA42,1)
```

```
      GOTO 612
  613 END FILE 61
      REWIND 61
  614 READ (61,1) XL,XF42,XA42,XT42
      IF (XL.LT.0) GOTO 9
      CALL FGLOAD (FXST9,XL,XT42,1)
      GOTO 614
    9 READ (62,3) NSET
      DO 10 I=1,NTABG
   10 READ (62,2) XCRF1(I),XCRA1(I),XCRT1(I)
      DO 11 I=1,NOG
      READ (63,4) (XF(I,K),K=1,6)
      READ (63,4) (XA(I,K),K=1,6)
   11 READ (63,4) (XT(I,K),K=1,6)
      V2=V1/RHO
      R2=SQRT (V2/(PI*HEIGHT))
      A2=2*V2/R2
    1 FORMAT (4(1X,E11.4))
    2 FORMAT (3(1X,E11.4))
    3 FORMAT (I2)
    4 FORMAT (6(1X,E9.2))
 5001 FORMAT (4I2)
 5002 FORMAT (6E7.5)
 5003 FORMAT (2E7.5)
 5004 FORMAT (E7.5)
DYNAMIC
NOSORT
      CALL ARRAY (0.9831,0.9832,0.9833,0.9834,0.9835,0.9836,...
      0.7786,0.7786,0.0,ALFA)
      CALL ARRAY (Q(1),Q(2),Q(3),Q(4),Q(5),Q(6),0.,0.,0.,0.,...
      0.,0.,0.,Q(14),Q1)
      CALL ARRAY
0.,0.,0.,0.,0.,Q(7),Q(8),Q(9),Q(10),Q(11),...
      Q(12),Q(13),0.,Q2)
*     CALL ARRAY (0.0,0.1974,5.1970,13.1816,LETGRP)
      CALL ARRAY (V1,V2,V3,A1,A2,A3,6*0.0,VS)
*
*-----------
PROCEDURE UON,U1,GRPN,N,DETEND,J,JP1=UPDATE (ALFA,LETGRP)
      N=DETRMN (ALFA,NN,NISO)
      DETEND=ENDCND (N,NISO,NN)
      IF (DETEND.GE.1.0) CALL FINISH
      IF (U.EQ.STRTU) GRPN=1
      GRPN1=GRPN
      GRPN=DETGRP (LETGRP,NOG)
      DO 500 I=1,NOG
  500 IF (GRPN.EQ.I) J=I
      JP1=J+1
      ETA1=(1.0E+5)*ETA
      U1=LETGRP (JP1)
      UL=LETGRP (J)+ETA1
      ULL=STRTU+ETA1+0.5
      UOON=U-LETGRP (J)
      UON=AMAX1 (ETA1,UOON)
```

```
      IF (U.LT.ULL) UON=1.0E+6
ENDPROCEDURE
* ----------
SORT
PROCEDURE U10,DLY=GENERT...
      (Q1,Q2,ALFA,NISO,N,ULL)
      DLY(9)=U-STRTU
      IF (U.LT.ULL) DLY(9)=1.0E+6
      DO 1010 ISO=1,NISO
      DLY(ISO) = ALOG (1./ALFA(ISO))
      IF (U.LT.ULL) DLY(ISO)=1.0E+6
 1010 CONTINUE
      DO 1015 ISO=1,NISO
      U10(ISO)=(N(ISO)-1)*ALOG (1.0/ALFA(ISO))
      IF (U10(ISO).LT.STRTU) U10(ISO)=STRTU
 1015 CONTINUE
      U10(9)=STRTU
      U00=STRTU
      XSECF0(1)=FUNGEN (FXSF1,1,U10(1))
      XSECF0(2)=FUNGEN (FXSF2,1,U10(2))
      XSECF0(3)=FUNGEN (FXSF3,1,U10(3))
      XSECF0(4)=FUNGEN (FXSF4,1,U10(4))
      XSECF0(5)=FUNGEN (FXSF5,1,U10(5))
      XSECF0(6)=FUNGEN (FXSF6,1,U10(6))
      XSECF0(7)=FUNGEN (FXSF7,1,U10(7))
      XSECF0(8)=FUNGEN (FXSF8,1,U10(8))
      XSECF0(9)=FUNGEN (FXSF9,1,U10(9))
      XSECF1(1)=FUNGEN (FXSF1,1,U1)
      XSECF1(2)=FUNGEN (FXSF2,1,U1)
      XSECF1(3)=FUNGEN (FXSF3,1,U1)
      XSECF1(4)=FUNGEN (FXSF4,1,U1)
      XSECF1(5)=FUNGEN (FXSF5,1,U1)
      XSECF1(6)=FUNGEN (FXSF6,1,U1)
      XSECF1(7)=FUNGEN (FXSF7,1,U1)
      XSECF1(8)=FUNGEN (FXSF8,1,U1)
      XSECF1(9)=FUNGEN (FXSF9,1,U1)
      XSECF(1)=FUNGEN (FXSF1,1,U)
      XSECF(2)=FUNGEN (FXSF2,1,U)
      XSECF(3)=FUNGEN (FXSF3,1,U)
      XSECF(4)=FUNGEN (FXSF4,1,U)
      XSECF(5)=FUNGEN (FXSF5,1,U)
      XSECF(6)=FUNGEN (FXSF6,1,U)
      XSECF(7)=FUNGEN (FXSF7,1,U)
      XSECF(8)=FUNGEN (FXSF8,1,U)
      XSECF(9)=FUNGEN (FXSF9,1,U)
      XSECA0(1)=FUNGEN (FXSA1,1,U10(1))
      XSECA0(2)=FUNGEN (FXSA2,1,U10(2))
      XSECA0(3)=FUNGEN (FXSA3,1,U10(3))
      XSECA0(4)=FUNGEN (FXSA4,1,U10(4))
      XSECA0(5)=FUNGEN (FXSA5,1,U10(5))
      XSECA0(6)=FUNGEN (FXSA6,1,U10(6))
      XSECA0(7)=FUNGEN (FXSA7,1,U10(7))
      XSECA0(8)=FUNGEN (FXSA8,1,U10(8))
```

```
XSECA0(9)=FUNGEN (FXSA9,1,U10(9))
XSECA1(1)=FUNGEN (FXSA1,1,U1)
XSECA1(2)=FUNGEN (FXSA2,1,U1)
XSECA1(3)=FUNGEN (FXSA3,1,U1)
XSECA1(4)=FUNGEN (FXSA4,1,U1)
XSECA1(5)=FUNGEN (FXSA5,1,U1)
XSECA1(6)=FUNGEN (FXSA6,1,U1)
XSECA1(7)=FUNGEN (FXSA7,1,U1)
XSECA1(8)=FUNGEN (FXSA8,1,U1)
XSECA1(9)=FUNGEN (FXSA9,1,U1)
XSECA(1)=FUNGEN (FXSA1,1,U)
XSECA(2)=FUNGEN (FXSA2,1,U)
XSECA(3)=FUNGEN (FXSA3,1,U)
XSECA(4)=FUNGEN (FXSA4,1,U)
XSECA(5)=FUNGEN (FXSA5,1,U)
XSECA(6)=FUNGEN (FXSA6,1,U)
XSECA(7)=FUNGEN (FXSA7,1,U)
XSECA(8)=FUNGEN (FXSA8,1,U)
XSECA(9)=FUNGEN (FXSA9,1,U)
XSECT0(1)=FUNGEN (FXST1,1,U10(1))
XSECT0(2)=FUNGEN (FXST2,1,U10(2))
XSECT0(3)=FUNGEN (FXST3,1,U10(3))
XSECT0(4)=FUNGEN (FXST4,1,U10(4))
XSECT0(5)=FUNGEN (FXST5,1,U10(5))
XSECT0(6)=FUNGEN (FXST6,1,U10(6))
XSECT0(7)=FUNGEN (FXST7,1,U10(7))
XSECT0(8)=FUNGEN (FXST8,1,U10(8))
XSECT0(9)=FUNGEN (FXST9,1,U10(9))
XSECT1(1)=FUNGEN (FXST1,1,U1)
XSECT1(2)=FUNGEN (FXST2,1,U1)
XSECT1(3)=FUNGEN (FXST3,1,U1)
XSECT1(4)=FUNGEN (FXST4,1,U1)
XSECT1(5)=FUNGEN (FXST5,1,U1)
XSECT1(6)=FUNGEN (FXST6,1,U1)
XSECT1(7)=FUNGEN (FXST7,1,U1)
XSECT1(8)=FUNGEN (FXST8,1,U1)
XSECT1(9)=FUNGEN (FXST9,1,U1)
XSECT(1)=FUNGEN (FXST1,1,U)
XSECT(2)=FUNGEN (FXST2,1,U)
XSECT(3)=FUNGEN (FXST3,1,U)
XSECT(4)=FUNGEN (FXST4,1,U)
XSECT(5)=FUNGEN (FXST5,1,U)
XSECT(6)=FUNGEN (FXST6,1,U)
XSECT(7)=FUNGEN (FXST7,1,U)
XSECT(8)=FUNGEN (FXST8,1,U)
XSECT(9)=FUNGEN (FXST9,1,U)
FUNCTION FXSF1
FUNCTION FXSF2
FUNCTION FXSF3
FUNCTION FXSF4
FUNCTION FXSF5
FUNCTION FXSF6
FUNCTION FXSF7
```

```
      FUNCTION FXSF8
      FUNCTION FXSF9
      FUNCTION FXSA1
      FUNCTION FXSA2
      FUNCTION FXSA3
      FUNCTION FXSA4
      FUNCTION FXSA5
      FUNCTION FXSA6
      FUNCTION FXSA7
      FUNCTION FXSA8
      FUNCTION FXSA9
      FUNCTION FXST1
      FUNCTION FXST2
      FUNCTION FXST3
      FUNCTION FXST4
      FUNCTION FXST5
      FUNCTION FXST6
      FUNCTION FXST7
      FUNCTION FXST8
      FUNCTION FXST9
 1017 CONTINUE
*     WRITE (6,555) (XSECF0(I),I=1,5)
*     WRITE (6,555) (XSECF(I),I=1,5),U
*     WRITE (6,555) (XSECA0(I),I=1,5)
*     WRITE (6,555) (XSECA(I),I=1,5)
*     WRITE (6,555) (XSECT0(I),I=1,5)
*     WRITE (6,555) (XSECT(I),I=1,5)
* 555 FORMAT (/,5(1X,E9.2),F5.1)
      E=E0*EXP(-U)
      SF1U=0.453*(SINH(SQRT(2.2*E)))*EXP(-1.0356*E)
      NISO1=NISO+1
      FLXIT1=FLUX(1)
      FLXIT2=FLUX(2)
      DO 100 ISO=1,NISO1
      F01(ISO)=Q1(ISO)*XSECT0(ISO)*FLUX0(1)
      F02(ISO)=Q2(ISO)*XSECT0(ISO)*FLUX0(2)
      F1(ISO)=Q1(ISO)*XSECT1(ISO)*FLUX(1)
      F2(ISO)=Q2(ISO)*XSECT1(ISO)*FLUX(2)
      XS0=XSECT0(ISO)-XSECA0(ISO)
      XS=XSECT1(ISO)-XSECA1(ISO)
      DEN=1.0-ALFA(ISO)
      R0DEN=(XS0/XSECT0(ISO))/DEN
      RDEN=(XS/XSECT1(ISO))/DEN
      X01(ISO)=R0DEN*F01(ISO)
      X02(ISO)=R0DEN*F02(ISO)
      X1(ISO)=RDEN*F1(ISO)
      X2(ISO)=RDEN*F2(ISO)
  100 CONTINUE
*
      XINT1=INTGRL (X01,X1,9)
      XINT2=INTGRL (X02,X2,9)
ENDPROCEDURE
*
```

```
* ----------------
*
PROCEDURE FN0,FN,FLUX0,FLUX,MULTF0,MULTF,MULTA0,MULTA=CONVRG...
      (DLY,U10,UON,NISO,ETA1)
      NISO1=NISO+1
      DO 900 ISO=1,NISO1
      UREL1(ISO)=U-U10(ISO)
      IF (UREL1(ISO).LE.ETA1) UREL1(ISO)=ETA1
      IF (U.LT.ULL) UREL1(ISO)=1.0E+6
      IF (DLY(ISO).LE.ETA1) DLY(ISO)=ETA1
      IF (U.LT.ULL) DLY(ISO)=1.0E+6
      DLF1R1=DELAY (1000,UREL1(ISO),XINT1(ISO))
      DLF1R2=DELAY (1000,UREL1(ISO),XINT2(ISO))
      DLF2R1=DELAY (1000,DLY(ISO),XINT1(ISO))
      DLF2R2=DELAY (1000,DLY(ISO),XINT2(ISO))
      XIRG1=XINT1(ISO)-DLF1R1
      XIRG2=XINT2(ISO)-DLF1R2
      XIRG1D=DLF1R1-DLF2R1
      XIRG2D=DLF1R2-DLF2R2
*     XIRG1(ISO)=AMAX1 (0.0,XIRG1(ISO))
*     XIRG2(ISO)=AMAX1 (0.0,XIRG2(ISO))
*     XIRG1D(ISO)=AMAX1 (0.0,XIRG1D(ISO))
*     XIRG2D(ISO)=AMAX1 (0.0,XIRG2D(ISO))
  900 CONTINUE
*
      DO 1022 I=1,4
      TERM1=0.0
      TERM2=0.0
      TERM3=0.0
 1022 TERM4=0.0
      DO 1030 ISO=1,NISO
      TERM1=TERM1+(EXP(-U))*XIRG1
      TERM2=TERM2+(EXP(-U))*XIRG1D
      TERM3=TERM3+(EXP(-U))*XIRG2
      TERM4=TERM4+(EXP(-U))*XIRG2D
 1030 CONTINUE
* ---------------
      SIGT,SIGA,SIGF=DETSIG (Q1,Q2,XSECT1,XSECA1,XSECF1,NISO)
      G2,DENU,PU1,PU2=ESCPRB (SIGT,VS,RHO,LATYPE)
      FN(1)=(1.0-PU1)*(TERM1+TERM2+SF1U)+...
      (PU2/RHO)*(TERM3+TERM4)
      FN(2)=(1.0-PU2)*(TERM3+TERM4)+...
      (RHO*PU1)*(TERM1+TERM2+SF1U)
      DO 2001 I=1,2
      IF (SIGT(I).LT.ETA) SIGT(I)=2*ETA
      FLUX(I)=FN(I)/SIGT(I)
      MULTA(I)=FLUX(I)*SIGA(I)
      MULTF(I)=FLUX(I)*SIGF(I)
      FN0(I)=DELAY (1000,UON,FN(I))
      FLUX0(I)=DELAY (1000,UON,FLUX(I))
      MULTA0(I)=DELAY (1000,UON,MULTA(I))
      MULTF0(I)=DELAY (1000,UON,MULTF(I))
```

```
 2001 CONTINUE
*     WRITE (6,111) (FLUX(I),I=1,2)
* 111 FORMAT (/,2(2X,E9.2))
ENDPROCEDURE
* ----------------------
NOSORT
      TFN=INTGRL (FN0,FN,2)
      TFLX=INTGRL (FLUX0,FLUX,2)
      TMULTA=INTGRL (MULTA0,MULTA,2)
      TMULTF=INTGRL (MULTF0,MULTF,2)
*     IF (U.LT.UL) GOTO 2003
      TTLFN1=TFN(1)-DELAY (1000,UON,TFN(1))
      TTLFN2=TFN(2)-DELAY (1000,UON,TFN(2))
      TTLFX1=TFLX(1)-DELAY (1000,UON,TFLX(1))
      TTLFX2=TFLX(2)-DELAY (1000,UON,TFLX(2))
      TTLMA1=TMULTA(1)-DELAY (1000,UON,TMULTA(1))
      TTLMA2=TMULTA(2)-DELAY (1000,UON,TMULTA(2))
      TTLMF1=TMULTF(1)-DELAY (1000,UON,TMULTF(1))
      TTLMF2=TMULTF(2)-DELAY (1000,UON,TMULTF(2))
      DGRP=GRPN-GRPN1
      IF ((DGRP.GT.0).AND.(TTLFX1.GT.ETA)) ...
      GSIGF1=(TTLMF1/TTLFX1)*SCALE1
      IF ((DGRP.GT.0).AND.(TTLFX2.GT.ETA)) ...
      GSIGF2=(TTLMF2/TTLFX2)*SCALE1
      IF ((DGRP.GT.0).AND.(TTLFX1.GT.ETA)) ...
      GSIGA1=(TTLMA1/TTLFX1)*SCALE1
      IF ((DGRP.GT.0).AND.(TTLFX2.GT.ETA)) ...
      GSIGA2=(TTLMA2/TTLFX2)*SCALE1
      IF ((DGRP.GT.0).AND.(TTLFX1.GT.ETA)) ...
      GSIGT1=(TTLFN1/TTLFX1)*SCALE1
      IF ((DGRP.GT.0).AND.(TTLFX2.GT.ETA)) ...
      GSIGT2=(TTLFN2/TTLFX2)*SCALE1
* ------------
      DO 2002 ISO=1,NISO
      MFIS1(ISO)=XSECF1(ISO)*FLUX(1)
      MAIS1(ISO)=XSECA1(ISO)*FLUX(1)
      MTIS1(ISO)=XSECT1(ISO)*FLUX(1)
*     MMFIS(ISO)=MFIS1(ISO)*Q1(ISO)
*     MMAIS1(ISO)=MAIS1(ISO)*Q1(ISO)
*     MMTIS1(ISO)=MTIS1(ISO)*Q1(ISO)
*     MMFIS1(ISO)=AMAX1 (ETA,MMFIS1(ISO))
*     MMAIS1(ISO)=AMAX1 (ETA,MMAIS1(ISO))
*     MMTIS1(ISO)=AMAX1 (ETA,MMTIS1(ISO))
      MFIS10(ISO)=DELAY (1000,UON,MFIS1(ISO))
      MAIS10(ISO)=DELAY (1000,UON,MAIS1(ISO))
      MTIS10(ISO)=DELAY (1000,UON,MTIS1(ISO))
*     MMFI10(ISO)=DELAY (1000,UON,MMFIS1(ISO))
*     MMAI10(ISO)=DELAY (1000,UON,MMAIS1(ISO))
*     MMTI10(ISO)=DELAY (1000,UON,MMTIS1(ISO))
*     MMFI10(ISO)=AMAX1 (ETA,MMFI10(ISO))
*     MMAI10(ISO)=AMAX1 (ETA,MMAI10(ISO))
*     MMTI10(ISO)=AMAX1 (ETA,MMTI10(ISO))
 2002 CONTINUE
```

```
      TMFI1=INTGRL (MFIS10,MFIS1,8)
      TMAI1=INTGRL (MAIS10,MAIS1,8)
      TMTI1=INTGRL (MTIS10,MTIS1,8)
*     TMMFI1=INTGRL (MMFI10,MMFIS1,8)
*     TMMAI1=INTGRL (MMAI10,MMAIS1,8)
*     TMMTI1=INTGRL (MMTI10,MMTIS1,8)
*     IF (U.LT.UL) GOTO 2016
      XCRF,XCRA,XCRT=DETX (XCRF1,XCRA1,XCRT1,GRPN,NTABG)
      DO 2004 ISO=1,NISO
      TTMF1=TMFI1(ISO)-DELAY (1000,UON,TMFI1(ISO))
      TTMA1=TMAI1(ISO)-DELAY (1000,UON,TMAI1(ISO))
      TTMT1=TMTI1(ISO)-DELAY (1000,UON,TMTI1(ISO))
*     TTMMF1(ISO)=TMMFI1(ISO)-DELAY (1000,UON,TMMFI1(ISO))
*     TTMMA1(ISO)=TMMAI1(ISO)-DELAY (1000,UON,TMMAI1(ISO))
*     TTMMT1(ISO)=TMMTI1(ISO)-DELAY (1000,UON,TMMTI1(ISO))
*     TTMF1(ISO)=AMAX1 (0.0,TTMF1(ISO))
*     TTMA1(ISO)=AMAX1 (0.0,TTMA1(ISO))
*     TTMT1(ISO)=AMAX1 (0.0,TTMT1(ISO))
*     TTMMF1(ISO)=AMAX1 (0.0,TTMMF1(ISO))
*     TTMMA1(ISO)=AMAX1 (0.0,TTMMA1(ISO))
*     TTMMT1(ISO)=AMAX1 (0.0,TTMMT1(ISO))
 2004 CONTINUE
      DO 2015 ISO=1,NISOF
      ISO2=ISO+2
      IF ((DGRP.GT.0).AND.(TTLFX1.GT.ETA))...
      GSMF1(ISO)=(TTMF/TTLFX1)*SCALE1
      IF ((DGRP.GT.0).AND.(TTLFX1.GT.ETA))...
      GSMA1(ISO)=(TTMA1/TTLFX1)*SCALE1
      IF ((DGRP.GT.0).AND.(TTLFX1.GT.ETA))...
      GSMT1(ISO)=(TTMT1/TTLFX1)*SCALE1
*     IF ((DGRP.GT.0).AND.(TTLFX1.GT.ETA))...
*     GSMMF1(ISO)=TTMMF1/TTLFX1
*     IF ((DGRP.GT.0).AND.(TTLFX1.GT.ETA))...
*     GSMMA1(ISO)=TTMMA1/TTLFX1
*     IF ((DGRP.GT.0).AND.(TTLFX1.GT.ETA))...
*     GSMMT1(ISO)=TTMMT1/TTLFX1
 2012 CONTINUE
      GSMF1(ISO)=AMAX1 (XCRF(ISO2),GSMF1(ISO))
      GSMA1(ISO)=AMAX1 (XCRA(ISO2),GSMA1(ISO))
      GSMT1(ISO)=AMAX1 (XCRT(ISO2),GSMT1(ISO))
*     GSMMF1(ISO)=AMAX1 (XCRF(ISO2),GSMMF1(ISO))
*     GSMMA1(ISO)=AMAX1 (XCRA(ISO2),GSMMA1(ISO))
*     GSMMT1(ISO)=AMAX1 (XCRT(ISO2),GSMMT1(ISO))
 2015 CONTINUE
      GSIGF1=AMAX1 (XCRF(1),GSIGF1)
      GSIGF2=AMAX1 (XCRF(2),GSIGF2)
      GSIGA1=AMAX1 (XCRA(1),GSIGA1)
      GSIGA2=AMAX1 (XCRA(2),GSIGA2)
      GSIGT1=AMAX1 (XCRT(1),GSIGT1)
      GSIGT2=AMAX1 (XCRT(2),GSIGT2)
 2016 FE1=FN(1)*1.0E-6*EXP (U)
      FE2=FN(2)*1.0E-6*EXP (U)
      Y=DETY (LETGRP,GRPN)
```

```
            DO 30 I=1,NOG
            IF (Y(I).EQ.1) CNT1(I)=Y(I)*GSIGF1
            IF (Y(I).EQ.1) CNT2(I)=Y(I)*GSIGA1
            IF (Y(I).EQ.1) CNT3(I)=Y(I)*GSIGT1
            IF (Y(I).EQ.1) CNT4(I)=Y(I)*GSIGT2
         30 CONTINUE
            DO 34 I=1,NOG
            DO 33 K=1,NISOF
            IF (Y(I).EQ.1) XF(I,K)=Y(I)*GSMF1(K)
            IF (Y(I).EQ.1) XA(I,K)=Y(I)*GSMA1(K)
         33 IF (Y(I).EQ.1) XT(I,K)=Y(I)*GSMT1(K)
         34 CONTINUE
      TERMINAL
      *TIMER U=0.0,FINU=15.5,DELU=3.023E-4,DELMIN=1.0E-07
      TIMER U=0.0,FINU=15.5
            PRINT GSIGF1,GSIGA1,GSIGT1,GSMF1(1-2),GSMA1(1-2),GSMT1(1-

            GRPN,CNT1(1-4),Y(1-4)
            OUTPUT GSIGF1,GSIGA1,GSIGT1
            WRITE (6,5001)
            WRITE (6,5051)
            DO 6000 I=ISTRTG,NGT
            LBOUND=I+1
       6000 WRITE (6,5002)
:P(LBOUND),CNT1(I),CNT2(I),CNT3(I),CNT4(I)
            WRITE (6,5003)
            WRITE (6,5053)
            DO 6002 I=ISTRTG,NGT
            LBOUND=I+1
            WRITE (6,5004) LETGRP(LBOUND),(XF(I,K),K=1,6)
            WRITE (6,5004) LETGRP(LBOUND),(XA(I,K),K=1,6)
       6002 WRITE (6,5004) LETGRP(LBOUND),(XT(I,K),K=1,6)
       5001 FORMAT (10(/),30X,'END OF RUN GROUP AVERAGED CONSTANTS:')
       5051 FORMAT (/,2X,'COLUMN: (U,SIGF-1,SIGA-1,SIGT-1,SIGT-2)')
       5003 FORMAT (4(/),30X,'MICROSCOPIC X-SEC FOR ISOTOPES:')
       5053 FORMAT (/,X,'ROW
:,SIGA,SIGT)',/,X,'COL:(25,28,29,40,41,42)')
       5002 FORMAT (/,2X,5(2X,E11.4))
       5004 FORMAT (/,2X,7(2X,E11.4))
            END
      ENDJOB
      //**** JCL LIBLINK,MEMBER=
      //* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      //*                                                               *
      //*                        THERMAL ENERGY REGION                  *
      //*                              AND                              *
      //*                        INTEGRAL KERNELS                       *
      //*                                                               *
      //* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      RENAME TIME=E,FINTIM=FINE
      DYNAMIC
      SORT
      PROCEDURE FLUXE1,FLUX10=ONEA(E)
      RENAME E=R,FINE=FINR
      CONSTANT PI=3.1414,L=1.0E+2,RA=0.3929,RB=0.8636
      DYNAMIC
```

```
NOSORT
PROCEDURE FLUX1=TWO1 (E,R,RA,RB)
RENAME R=R1, FINR=FINR1
DYNAMIC
SORT
PROCEDURE T=THREEA (E,R,R1,RA,RB)
STORAGE XSECT (9)
RENAME R1=S,FINR1=FINS
      S1=R-R1
      S1F=RB-RA
      IF (R.GT.RA) GOTO 100
      XSECT(1)=TWOVAR (FXST1,S1,E)
      XSECT0(1)=TWOVAR (FXST1,S1,0)
      XSECT(2)=TWOVAR (FXST2,S1,E)
      XSECT0(2)=TWOVAR (FXST2,S1,0)
      XSECT(3)=TWOVAR (FXST3,S1,E)
      XSECT0(3)=TWOVAR (FXST3,S1,0)
      XSECT(4)=TWOVAR (FXST4,S1,E)
      XSECT0(4)=TWOVAR (FXST4,S1,0)
      XSECT(5)=TWOVAR (FXST5,S1,E)
      XSECT0(5)=TWOVAR (FXST5,S1,0)
      XSECT(6)=TWOVAR (FXST6,S1,E)
      XSECT0(6)=TWOVAR (FXST6,S1,0)
      GOTO 101
  100 XSECT(7)=TWOVAR (FXST7,S1,E)
      XSECT0(7)=TWOVAR (FXST7,S1,0)
      XSECT(8)=TWOVAR (FXST8,S1,E)
      XSECT0(8)=TWOVAR (FXST8,S1,0)
      XSECT(9)=TWOVAR (FXST9,S1,E)
      XSECT0(9)=TWOVAR (FXST9,S1,0)
  101 CONTINUE
DYNAMIC
NOSORT
      XT1=0.0
      XT10=0.0
      N1,N2=DETN12 (R,RA,RB)
      DO 102 I=N1,N2
      XT1=XT1+XSECT(I)
  102 XT10=XT10+XSECT0(I)
      T1=INTGRL (XT10,XT1)
      T2=EXP (T1)
      T=(1/4*PI*(R-R1)**2))*T2
TIMER S=0.0,FINS=S1F
ENDPROCEDURE
PROCEDURE SIGS1=THREEB (E,R1)
CONSTANT EC=1.8102,HBAR=1.05459E-34,C=3.0E+10
CONSTANT K=1.38062E-23,T=1.0E+3,INF=1.0E+24
RENAME E=E1,FINE=FINE1
PROCEDURE SSIGS1=FOUR1 (E1,E)
STORAGE XXSI(6),XXSI0(6),XXXSI(6),XXXSI0(6)
STORAGE SSIGS1(6),TAUN(6),TAU(6),SIGB0(6),A(6),RJ(6)
CONSTANT CK=6.164E-14
      READ (81,1) (TAUN(I),I=1,6)
```

```
      READ (82,1) (TAU(I),I=1,6)
      READ (83,1) (SIGBO(I),I=1,6)
      READ (84,1) (A(I),I=1,6)
      READ (85,1) (RJ(I),I=1,6)
    1 FORMAT (6E11.4)
      DO 10 I=1,10
      READ (86,2) (XXZI(I,J),J=1,10)
      READ (87,2) (XXXZI(I,J),J=1,10)
   10 CONTINUE
      READ (88,2) (XARR(I),I=1,10)
      READ (89,2) (ZARR(I),I=1,10)
    2 FORMAT (10F6.4)
      DO 20 J=1,10
      YARR1(J)=XXZI(1,J)
      YYARR1(J)=XXXZI(1,J)
      YARR2(J)=XXZI(2,J)
      YYARR2(J)=XXXZI(2,J)
      YARR3(J)=XXZI(3,J)
      YYARR3(J)=XXXZI(3,J)
      YARR4(J)=XXZI(4,J)
      YYARR4(J)=XXXZI(4,J)
      YARR5(J)=XXZI(5,J)
      YYARR5(J)=XXXZI(5,J)
      YARR6(J)=XXZI(6,J)
      YYARR6(J)=XXXZI(6,J)
      YARR7(J)=XXZI(7,J)
      YYARR7(J)=XXXZI(7,J)
      YARR8(J)=XXZI(8,J)
      YYARR8(J)=XXXZI(8,J)
      YARR9(J)=XXZI(9,J)
      YYARR9(J)=XXXZI(9,J)
      YARR0(J)=XXZI(10,J)
      YYARR0(J)=XXXZI(10,J)
   20 CONTINUE
      DO 100 I=1,6
      XSI(I)=2*E1/TAU(I)
  100 ZETA(I)=TAU(I)/(SQRT(4*E1*K*T/A(I)))
      CALL TVLOAD (FXXSI,XARR,YARR1,10,1,0.05)
      CALL TVLOAD (FXXSI,XARR,YARR2,10,2,0.10)
      CALL TVLOAD (FXXSI,XARR,YARR3,10,3,0.15)
      CALL TVLOAD (FXXSI,XARR,YARR4,10,4,0.20)
      CALL TVLOAD (FXXSI,XARR,YARR5,10,5,0.25)
      CALL TVLOAD (FXXSI,XARR,YARR6,10,6,0.30)
      CALL TVLOAD (FXXSI,XARR,YARR7,10,7,0.35)
      CALL TVLOAD (FXXSI,XARR,YARR8,10,8,0.40)
      CALL TVLOAD (FXXSI,XARR,YARR9,10,9,0.45)
      CALL TVLOAD (FXXSI,XARR,YARR0,10,10,0.50)
      CALL TVLOAD (FXXSI,XARR,YYARR1,10,1,0.05)
      CALL TVLOAD (FXXSI,XARR,YYARR2,10,2,0.10)
      CALL TVLOAD (FXXSI,XARR,YYARR3,10,3,0.15)
      CALL TVLOAD (FXXSI,XARR,YYARR4,10,4,0.20)
      CALL TVLOAD (FXXSI,XARR,YYARR5,10,5,0.25)
      CALL TVLOAD (FXXSI,XARR,YYARR6,10,6,0.30)
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```
              CALL TVLOAD (FXXSI,XARR,YYARR7,10,7,0.35)
              CALL TVLOAD (FXXSI,XARR,YYARR8,10,8,0.40)
              CALL TVLOAD (FXXSI,XARR,YYARR9,10,9,0.45)
              CALL TVLOAD (FXXSI,XARR,YYARR0,10,10,0.50)
              XXSI(1)=TWOVAR (FXXSI,ZETA(1),XSI(1))
              XXSI(2)=TWOVAR (FXXSI,ZETA(2),XSI(2))
              XXSI(3)=TWOVAR (FXXSI,ZETA(3),XSI(3))
              XXSI(4)=TWOVAR (FXXSI,ZETA(4),XSI(4))
              XXSI(5)=TWOVAR (FXXSI,ZETA(5),XSI(5))
              XXSI(6)=TWOVAR (FXXSI,ZETA(6),XSI(6))
              XXXSI(1)=TWOVAR (FYYSI,ZETA(1),XSI(1))
              XXXSI(2)=TWOVAR (FYYSI,ZETA(2),XSI(2))
              XXXSI(3)=TWOVAR (FYYSI,ZETA(3),XSI(3))
              XXXSI(4)=TWOVAR (FYYSI,ZETA(4),XSI(4))
              XXXSI(5)=TWOVAR (FYYSI,ZETA(5),XSI(5))
              XXXSI(6)=TWOVAR (FYYSI,ZETA(6),XSI(6))
              FXXSI
              FXXSI
              FYYSI
              FYYSI
              DO 200 J=1,6
              SSIGS1(J)=SIGBO(J)*TAUN(J)*XXSI(J)/(4*PI*TAU(J))+...
              SIGBO(J)*RJ(J)*XXXSI(J)*E1/(4*PI*HBAR*C)+CK
            200 CONTINUE
          ENDPROCEDURE
          PROCEDURE SSIGS2=FOUR2 (E1,E,K,T,R1)
          STORAGE SSIGS2(2)
          RENAME R1=TX
          CONSTANT PI=3.1414,INF=1.0E+24
          CONSTANT MM11=0.0556,MM21=0.4310,MM31=0.1712,MM41=0.3425
          CONSTANT MM12=0.10,MM22=0.4854,MM32=0.0689,MM42=0.1377
          CONSTANT
0.0,CE21=4.3459E+18,CE31=1.4848E+19,CE41=3.4839E+19
          CONSTANT
0.0,CE22=3.6216E+18,CE32=1.0865E+19,CE42=2.5351E+19
              READ (91,1) (SIGB(I),I=1,2)
            1 FORMAT (2E11.4)
          DYNAMIC
          NOSORT
              ALFA=(E1+E-2*SQRT(E*E1))/(K*T)
              BETA=E1/(K*T)
              DELTA1=DELTAF (BETA,CE11)
              DELTA2=DELTAF (BETA,CE21)
              DELTA3=DELTAF (BETA,CE31)
              DELTA4=DELTAF (BETA,CE41)
              DELTA5=DELTAF (BETA,CE12)
              DELTA6=DELTAF (BETA,CE22)
              DELTA7=DELTAF (BETA,CE32)
              DELTA8=DELTAF (BETA,CE42)
              FB1=MM11*DELTA1+MM21*DELTA2+MM31*DELTA3+MM41*DELTA4
              FB2=MM12*DELTA5+MM22*DELTA6+MM32*DELTA7+MM42*DELTA8
              FF1=COSH (BETA/2)-COS (BETA/2)
              FF2=1.0/(BETA*SINH(BETA/2))
              GAMT1=FF1*FF2*FB1
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```
      GAMT2=FF1*FF2*FB2
PROCEDURE GAMAT1,GAMAT2=INTERIM (GAMT1,GAMT2,TX)
RENAME TX=BBETA
DYNAMIC
NOSORT
      GAMAT1=INTGRL (0.0,GAMT1)
      GAMAT2=INTGRL (0.0,GAMT2)
TIMER=-INF,FINTX=INF
ENDPROCEDURE
      FN1=COS (BETA*TX)
      FN21=EXP (-(ALFA**2)*GAMAT1)
      FN22=EXP (-(ALFA**2)*GAMAT2)
      FNN1=FN1*FN21
      FNN2=FN1*FN22
      SINC1=INTGRL (0.0,FNN1)
      SINC2=INTGRL (0.0,FNN2)
      CKL=(1.0/*PI*K*T)*SQRT (E/E1)*EXP (-BETA/2)
      SSIGS2(1)=CKL*SINC1
      SSIGS2(2)=CKL*SINC2
ENDPROCEDURE
DYNAMIC
NOSORT
      SIGS=0.0
      IF (R1.GT.RA) GOTO 100
      DO 10 I=1,6
   10 SIGS=SIGS+Q1(I)*SSIGS(I)
      GOTO 101
  100 CONTINUE
      DO 20 I=7,9
      SIGS=SIGS+Q2(I)*SSIGS2(1)
   10 SIGS=SIGS+Q2(I)*SSIGS2(2)
  101 CONTINUE
      SIGS1=INTGRL (0.0,SIGS)
TIMER FINE1=EC
ENDPROCEDURE
SORT
      TT=T*(SIGS1*FLUXE1+SF)
      FLUXE1=INTGRL (FLUX10,TT)
      FLUX10=DELAY (1000,E1,FLUXE1)
TIMER FINR1=RA
ENDPROCEDURE
PROCEDURE FLUXE2,FLUX20=ONEB(E)
RENAME E=R,FINE=FINR
CONSTANT PI=3.1414,L=1.0E+2,RA=0.3929,RB=0.8636
DYNAMIC
NOSORT
PROCEDURE FLUX2=TWO2 (E,R,RA,RB)
RENAME R=R1, FINR=FINR1
DYNAMIC
SORT
PROCEDURE T=THREEA (E,R,R1,RA,RB)
STORAGE XSECT (9)
RENAME R1=S,FINR1=FINS
```

```
            S1=R-R1
            S1F=RB-RA
            XSECT(7)=TWOVAR (FXST7,S1,E)
            XSECT0(7)=TWOVAR (FXST7,S1,0)
            XSECT(8)=TWOVAR (FXST8,S1,E)
            XSECT0(8)=TWOVAR (FXST8,S1,0)
            XSECT(9)=TWOVAR (FXST9,S1,E)
            XSECT0(9)=TWOVAR (FXST9,S1,0)
      DYNAMIC
      NOSORT
            XT1=0.0
            XT10=0.0
            N1,N2=DETN12 (R,RA,RB)
            DO 102 I=N1,N2
            XT1=XT1+XSECT(I)
        102 XT10=XT10+XSECT0(I)
            T1=INTGRL (XT10,XT1)
            T2=EXP (T1)
            T=(1/4*PI*(R-R1)**2))*T2
      TIMER S=0.0,FINS=S1F
      ENDPROCEDURE
      PROCEDURE SIGS1=THREEB (E,R1)
      CONSTANT EC=1.8102,HBAR=1.05459E-34,C=3.0E+10
      CONSTANT K=1.38062E-23,T=1.0E+3,INF=1.0E+24
      RENAME E=E1,FINE=FINE1
      ENDPROCEDURE
      PROCEDURE SSIGS2=FOUR2 (E1,E,K,T,R1)
      STORAGE SSIGS2(2)
      RENAME R1=TX
      CONSTANT PI=3.1414,INF=1.0E+24
      CONSTANT MM11=0.0556,MM21=0.4310,MM31=0.1712,MM41=0.3425
      CONSTANT MM12=0.10,MM22=0.4854,MM32=0.0689,MM42=0.1377
      CONSTANT
0.0,CE21=4.3459E+18,CE31=1.4848E+19,CE41=3.4839E+19
      CONSTANT
0.0,CE22=3.6216E+18,CE32=1.0865E+19,CE42=2.5351E+19
            READ (91,1) (SIGB(I),I=1,2)
          1 FORMAT (2E11.4)
      DYNAMIC
      NOSORT
            ALFA=(E1+E-2*SQRT(E*E1))/(K*T)
            BETA=E1/(K*T)
            DELTA1=DELTAF (BETA,CE11)
            DELTA2=DELTAF (BETA,CE21)
            DELTA3=DELTAF (BETA,CE31)
            DELTA4=DELTAF (BETA,CE41)
            DELTA5=DELTAF (BETA,CE12)
            DELTA6=DELTAF (BETA,CE22)
            DELTA7=DELTAF (BETA,CE32)
            DELTA8=DELTAF (BETA,CE42)
            FB1=MM11*DELTA1+MM21*DELTA2+MM31*DELTA3+MM41*DELTA4
            FB2=MM12*DELTA5+MM22*DELTA6+MM32*DELTA7+MM42*DELTA8
            FF1=COSH (BETA/2)-COS (BETA/2)
            FF2=1.0/(BETA*SINH(BETA/2))
            GAMT1=FF1*FF2*FB1
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```
      GAMT2=FF1*FF2*FB2
PROCEDURE GAMAT1,GAMAT2=INTERIM (GAMT1,GAMT2,TX)
RENAME TX=BBETA
DYNAMIC
NOSORT
      GAMAT1=INTGRL (0.0,GAMT1)
      GAMAT2=INTGRL (0.0,GAMT2)
TIMER=-INF,FINTX=INF
ENDPROCEDURE
      FN1=COS (BETA*TX)
      FN21=EXP (-(ALFA**2)*GAMAT1)
      FN22=EXP (-(ALFA**2)*GAMAT2)
      FNN1=FN1*FN21
      FNN2=FN1*FN22
      SINC1=INTGRL (0.0,FNN1)
      SINC2=INTGRL (0.0,FNN2)
      CKL=(1.0/*PI*K*T)*SQRT (E/E1)*EXP (-BETA/2)
      SSIGS2(1)=CKL*SINC1
      SSIGS2(2)=CKL*SINC2
ENDPROCEDURE
DYNAMIC
NOSORT
      SIGS=0.0
      IF (R1.GT.RA) GOTO 100
      DO 10 I=1,6
   10 SIGS=SIGS+Q1(I)*SSIGS(I)
      GOTO 101
  100 CONTINUE
      DO 20 I=7,9
      SIGS=SIGS+Q2(I)*SSIGS2(1)
   10 SIGS=SIGS+Q2(I)*SSIGS2(2)
  101 CONTINUE
      SIGS1=INTGRL (0.0,SIGS)
TIMER FINE1=EC
ENDPROCEDURE
SORT
      TT=T*(SIGS1*FLUXE2+SF)
      FLUXE2=INTGRL (FLUX10,TT)
      FLUX20=DELAY (1000,E1,FLUXE2)
TIMER R1=RA,FINR1=RB
ENDPROCEDURE
      MULTF=FLUXE1*SIGF(1)
      MULTA(1)+FLUXE1*SIGA(1)
      MULTT(1)=FLUXE1*SIGT(1)
      MULTF0(1)=FLUX10*SIGF(1)
      MULTA0(1)=FLUX10*SIGA(1)
      MULTT0(1)=FLUX10*SIGT(1)
      MULTT(2)=FLUXE2*SIGT(2)
      MULTT0(2)=FLUX20*SIGT(2)
      TMLTF=INTGRL (MULTF0,MULTF,2)
      TMLTA=INTGRL (MULTA0,MULTA,2)
      TMLTT=INTGRL (MULTT0,MULTT,2)
      CUM1=INTGRL (FLUX10,FLUXE1)
```

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      CUM2=INTGRL (FLUX20,FLUXE2)
      GSIGT1=TMLTT(1)/CUM1
      GSIGT2=TMLTT(2)/CUM2
      GSIGA1=TMLTA(1)/CUM1
      GSIGF1=TMLTF(1)/CUM1
      DO 3002 ISO=1,NISO
      MFIS1(ISO)=XSECF1(ISO)*FLUXE1
      MAIS1(ISO)=XSECA1(ISO)*FLUXE1
      MTIS1(ISO)=XSECT1(ISO)*FLUXE1
      MFIS10(ISO)=XSECF1(ISO)*FLUX10
      MAIS10(ISO)=XSECA1(ISO)*FLUX10
      MTIS10(ISO)=XSECT1(ISO)*FLUX10
 3002 CONTINUE
      TMFI1=INTGRL (MFIS10,MFIS1,8)
      TMAI1=INTGRL (MAIS10,MAIS1,8)
      TMTI1=INTGRL (MTIS10,MTIS1,8)
      DO 3015 ISO=1,NISOF
      GSMF1(ISO)=TMFI1(ISO)/CUM1
      GSMA1(ISO)=TMAI1(ISO)/CUM1
      GSMT1(ISO)=TMTI1(ISO)/CUM1
 3015 CONTINUE
TERMINAL
      TIMER FINE=1.8602,PRDEL=0.1
      PRINT GSMT1(1-6),GSMA1(1-6),GSMF(1-6),GSIGT1,GSIGT2,...
      GSIGA1,GSIGF1
ENDJOB
/*
//FT31F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//            DSN=A217A9.U25C1RX,DISP=(OLD,KEEP),
//            VOL=SER=USER03,
//            DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT32F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//            DSN=A217A9.U28C1RX,DISP=(OLD,KEEP),
//            VOL=SER=USER04,
//            DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT41F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//            DSN=A217A9.OX1C1RX,DISP=(OLD,KEEP),
//            VOL=SER=USER07,
//            DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT42F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//            DSN=A217A9.OX2C1RX,DISP=(OLD,KEEP),
//            VOL=SER=USER04,
//            DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT43F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//            DSN=A217A9.MDRC1RX,DISP=(OLD,KEEP),
//            VOL=SER=USER03,
//            DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT51F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//            DSN=A217A9.P39C1RX,DISP=(OLD,KEEP),
//            VOL=SER=USER08,
//            DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT52F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//            DSN=A217A9.P40C1RX,DISP=(OLD,KEEP),
```

```
//             VOL=SER=USER03,
//             DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT53F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//             DSN=A217A9.P41C1RX,DISP=(OLD,KEEP),
//             VOL=SER=USER03,
//             DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT61F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//             DSN=A217A9.P42C1RX,DISP=(OLD,KEEP),
//             VOL=SER=USER08,
//             DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT62F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//             DSN=A217A9.ZLD45RX,DISP=(OLD,KEEP),
//             VOL=SER=USER09,
//             DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT63F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//             DSN=A217A9.XVAR6N,DISP=(OLD,KEEP),
//             DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT83F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//             DSN=A217A9.SIGB0,DISP=(NEW,KEEP),
//             DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT84F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//             DSN=A217A9.AFILE,DISP=(NEW,PASS),
//             DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT85F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//             DSN=A217A9.RJFIL,DISP=(NEW,PASS),
//             DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT86F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//             DSN=A217A9.XXZI,DISP=(NEW,PASS),
//             DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT87F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//             DSN=A217A9.XXXZI,DISP=(NEW,PASS),
//             DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT88F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//             DSN=A217A9.XARR,DISP=(NEW,PASS),
//             DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//FT89F001 DD UNIT=SYSDA,SPACE=(TRK,(5,5)),
//             DSN=A217A9.ZARR,DISP=(NEW,PASS),
//             DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136)
//
```

APPENDIX III

Function Blocks of CSMP Language[34]

CSMP III STATEMENT

INTEGRATOR

Y = INTGRL (IC,X).

where: $IC = y|_{t=t_s}$

Alternative 'Specification' Form:

Y = INTGRL (IC, X, N)

where: Y = output array
IC = initial condition array
X = integrand array
N = number of elements in the integrator array
(N must be coded as a literal integer constant)

DERIVATIVE

Y = DERIV (IC, X)

where: $IC = \frac{dx}{dt}\Big|_{t=t_s}$

1ST ORDER LAG (REAL POLE)

Y = REALPL (IC, P, X)

where: $IC = y|_{t=t_s}$

LEAD-LAG

Y = LEDLAG (P1, P2, X)

2ND ORDER LAG (COMPLEX POLE)

Y = CMPXPL (IC1, IC2, P1, P2, X)

where: $IC1 = y|_{t=t_s}$

$IC2 = \frac{dy}{dt}\Big|_{t=t_s}$

GENERAL LAPLACE TRANSOFRM

Y = TRANSF (N, B, M, A, X)

where: N and B are, respectively, the degree and coefficients array in the numerator polynomial in S
M and A are, respectively, the degree and coefficient array in the denominator polynomial in S

Arrays A and B may be set up by statements:

STORAGE A(m+1), B(n+1)
TABLE A(1 - M) = $a_1, a_2, \ldots, a_M, A(m+1) = a_o$
TABLE B(1 - N) = $b_1, b_2, \ldots, b_N, B(n+1) = b_o$

where: 1 - M and 1 - N represent subscript ranges and the 0th coefficients follow the highest numbered

Equivalent Mathematical Expression

$$y(t) = \int_{t_s}^{t} x\,dt + y(t_s)$$

where: t_s = start time

t = time

$$\hat{y} = \int_{t_s}^{t} x\,dt + \hat{y}(t_s)$$

Equivalent Laplace Transfer Function:

$$\frac{Y(s)}{X(s)} = \frac{1}{s}$$

$$y = \frac{dx}{dt}$$

Equivalent Laplace Transfer Function:

$$\frac{Y(s)}{X(s)} = s$$

$$p\frac{dy}{dt} + y = x$$

Equivalent Laplace Transfer Function:

$$\frac{Y(s)}{X(s)} = \frac{1}{ps + 1}$$

$$p_2\frac{dy}{dt} + y = p_1\frac{dx}{dt} + x$$

Equivalent Laplace Transfer Function:

$$\frac{Y(s)}{X(s)} = \frac{p_1 s+1}{p_2 s+1}$$

$$\frac{d^2y}{dt^2} + 2p_1p_2\frac{dy}{dt} + p_2^2y = x$$

Equivalent Laplace Transfer Function:

$$\frac{Y(s)}{X(s)} = \frac{1}{s^2 + 2p_1p_2s + p_2^2}$$

$$\frac{Y(s)}{X(s)} = \frac{\sum_{i=1}^{m} a_i s^i + a_o}{\sum_{j=1}^{n} b_j s^j + b_o}$$

where: $m < n$

CSMP III Statement	Equivalent Mathematical Expression
ARBITRARY FUNCTION GENERATOR (LINEAR INTERPOLATION)	
Y = AFGEN(FUNCT, X)	$y = f(x)$
ARBITRARY FUNCTION GENERATOR (QUADRATIC INTERPOLATION)	
Y = NLFGEN(FUNCT, X)	$y = f(x)$
FUNCTION GENERATOR WITH DEGREE OF INTERPOLATION CHOSEN BY USER Y = FUNGEN(FUNCT, N, X) where: FUNCT = function name N = degree of interpolation to be used. May be 1, 2, 3, 4, or 5 X = value of abscissa	$y = f(x)$
ARBITRARY FUNCTION OF 2 VARIABLES Y = TWOVAR (FUNCT, X, Z)	$y = f(x,z)$
SLOPE OF A CURVE Y = SLOPE (FUNCT, N, X) where: FUNCT = name of curve N = degree of interpolation to be used X = value of abscissa	$y = \frac{df}{dx}$ at x
SAMPLING INTERVAL SWITCH Y = SAMPLE (P1, P2, P3) N where: P_1 = start time for sampling to occur P_2 = last time for sampling to occur P_3 = time interval between samples if entered as a floating-point number N = number of sampling intervals if entered as a fixed-point number	$y = 1.0$; TIME = $p_1 + k\ p_3 < p_2$ $k = 0,1,2,\ldots$ or $y = 1.0$; TIME = $p_1 + k(p_2 - p_1)/n < p_2$ $k = 0,1,2,\ldots$ $y = 0.0$ otherwise

CSMP III Statement	Equivalent Mathematical Expression
HYSTERESIS LOOP Y = HSTRSS(IC, P1, P2, X) where: IC = $y\|_{t_0}$	$y = x - p_2$; $(x-x(t-\Delta t))>0$ and $y(t-\Delta t)<(x-p_2)$ $y = x-p_1$; $(x-x(t-\Delta t))<0$ and $y(t-\Delta t)>(x-p_1)$ otherwise: $y = y(t-\Delta t)$
STEP FUNCTION Y = STEP(P)	$y = 0$; $t<p$ $y = 1$; $t>p$
RAMP FUNCTION Y = RAMP(P)	$y = 0$; $t<p_1$ $y = 1$; $(t-p_1) = kp_2$ $y = 0$; $(t-p_1) \neq kp_2$ $k = 0,1,2,3,\ldots$
IMPULSE GENERATOR Y = IMPULS(P1,P2) where: P1 = time of first pulse P2 = interval between pulses	$y = 0$; $t < p_1$ $y = 1$; $(t-p_1) = kp_2$ $y = 0$; $(t-p_1) \neq kp_2$ $k = 0,1,2,3,\ldots$
PULSE GENERATOR **(WITH X > 0 AS TRIGGER)** Y = PULSE(P,X) where: P = minimum pulse width	$y = 1$; $t_t \leq t < (t_t + p)$ or $x>0$ $y = 0$; otherwise (t_t = time of trigger)

CSMP III Statement	Equivalent Mathematical Expression
SCALAR-TO-ARRAY CONVERTOR	
CALL ARRAY (V1, V2,...,VN, X)	x(1) = v1 x(2) = v2 x(3) = v3 . . . x(n) = vn
ARRAY-TO-SCALAR CONVERTOR	
Y1, Y2,...,YM = SCALAR (X(2))	y1 = x(2) y2 = x(3) . . . ym = x(m + 1)
DOUBLE PRECISION FLOATING-POINT TO SINGLE PRECISION	
Y = ZZRND (DNUMBR) where: DNUMBR is a double precision floating-point number. Y = rounded single precision value of DNUMBR	To convert the double precision floating-point number, DNUMBR, to single precision, rounding to hexadecimal digit.
LIMITER	
Y = LIMIT(P1,P2,X)	$y = p_1$; $x < p_1$ $y = p_2$; $x > p_2$ $y = x$; $p_1 < x < p_1$
DEAD SPACE	
Y = DEADSP(P1,P2,X)	$y = 0$; $p_1 < x < p_2$ $y = x - p_2$; $x > p_2$ $y = x - p_1$; $x < p_1$
QUANTIZER	
Y = QNTZR(P,X)	$y = kp$; $(k - 1/2)\ p < x < (k + 1/2)p$ $k = 0, \pm 1, \pm 2, \pm 3, \ldots$

CSMP III Statement

Equivalent Mathematical Expression

DEAD TIME (DELAY)

Y = DELAY (N, P, X)

where: P = delay time
N = number of points sampled in interval p (integer constant) and must be > 3, and < 16,378.

$y = x(t-p);\ t > p$

$y = 0;\ t < p$

Equivalent Laplace Transfer Function:

$$\frac{Y(s)}{X(s)} = e^{-ps}$$

ZERO-ORDER HOLD

Y = ZHOLD (X1, X2)

$y = x_2 ;\ x_1 > 0$

$y = \text{last output} ;\ x_1 < 0$

$y|_{t=t_s} = 0$

Equivalent Laplace Transfer Function:

$$\frac{Y(s)}{X(s)} = \frac{1}{s}(1 - e^{st})$$

MODE-CONTROLLED INTEGRATOR

Y = MODINT (IC, X1, X3, X3)

$$y = \int_{t_s}^{t_f} x_3 dt + ic ;\ x_1 > 0, \text{ any } x_2$$

$y = ic ;\ x_1 < 0, x_2 > 0$

$y = \text{last output} ;\ x_1 < 0, x_2 < 0$

$$fv = \int_{s}^{t} x_1\, dt$$

VARIABLE FLOW TRANSPORT DELAY

Y = PIPE (N, IC, P, X1, X2, ND)

$$q = \int_{t_s}^{t} x_2 x_1\, dt$$

where:

N = number of intervals necessary to define holdup quantity (integer constant)

IC = initial condition of entire pipeline

P = holdup quantity

X1 = flow rate

X2 = delayed characteristic

ND = degree of interpolation for retrieving delayed characteristic. May be 1 or 2 (integer variable or constant).

$y = ic;\ fv < p$

$$y = \frac{q(fv - p) - q(fv(t-\Delta t) - p)}{fv - fv(t - \Delta t)} ;\ fv > p$$

where: fv = flow volume
q = weighted volume

IMPLICIT FUNCTION

$y = f(y)$

Y = IMPL (IC, P, FOFY)

$|y - f(y)| < p|y|$

where: IC = first guess

P = error bound

FOFY = output name from final statement in algebraic loop definition

CSMP III Statement

TRIGONOMETRIC SINE WAVE WITH DELAY,
FREQUENCY AND PHASE PARAMETERS

```
Y = SINE(P1,P2,P3
```

where: P1 = delay
P2 = frequency (in radians per unit time)
P3 = phase shift in radians

Equivalent Mathematical Expression

$y = 0$; $t < p_1$

$y = \sin(p_2(t-p_1)+p_3)$; $t \geq p_1$

NOISE (RANDOM NUMBER) GENERATOR
WITH NORMAL DISTRIBUTION

```
Y = GAUSS (S,P1,P2)
```

where: S = seed (S is first truncated to an integer if real valued, then its absolute value is used once to initialize the generator)
P1 = desired mean of values of Y
P2 = desired standard deviation of values of Y

Normal Distribution of Variable y

p(y) = probability density function

NOISE (RANDOM NUMBER) GENERATOR
WITH UNIFORM DISTRIBUTION

```
Y = RNDGEN(S)
```

where: S = seed (S is first truncated to an integer if real valued, then its absolute value is used once to initialize the generator)

Uniform Distribution of Variable y

p(y) = probability density function

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AN ECONOMICAL METHOD FOR DETERMINATION OF GROUP CONSTANTS FOR REACTOR LATTICES

by

Ricardo Rogow

(ABSTRACT)

The development of an economical method for determining accurately group constants of hexagonal and rectangular cells is considered in this dissertation. The mathematical model constructed for this purpose has the capability to characterize the group constants for the entire range of the neutron spectrum. Furthermore, this model is also rigorous enough to predict the group constants with the required accuracy for a specific range of interest in the energy spectrum and for a variety of energy group configurations.

The model is implemented separately for the fast and thermal energy regions. These regions are subsequently coupled via the source term. The construction of the model for the fast energy range has been pursued by implementing the transport equation specialized in a two-region cell. The regions are coupled via the escape probability functions. The model for the thermal energy range has been attained by implementing the appropriate Nelkin and Honeck amplitude functions within the kernels of the transport equation. The Nelkin amplitude function is utilized for treating light water moderated systems, and the Honeck amplitude

function relates to heavy water moderated systems.

The group constants calculated with the economical model have been benchmarked with those computed by the VIM Monte Carlo code. The values obtained for the group constants agree within 1-2% with those computed by VIM for the fast energy region. The agreements for the thermal energy region are within 2-3%. The CPU running time of the implemented model is about 3 1/2 minutes for a four group configuration. On the other hand a typical VIM run comprising 25,000 neutron histories and a four-group structure expends about 30 minuts of CPU time for light water moderated systems. Moreover, similar VIM runs utilizing heavy water as moderator require over one hour of CPU time. Therefore, the implemented model makes utilization of computer resources with a cost advantage of a factor of 10 or better as compared to VIM. This economical benefit of the implemented model enables it to be coupled directly with fuel depletion codes, whereby the group constants and the fuel isotopics are updated at relatively short time intervals. On the other hand, the coupling of VIM with burnup codes would result in prohibitively expensive CPU costs.