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TEST ENGINEERING

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Subject The Neutron Balance Code
For PLMG, BAL.-1.

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INTRODUCTION

Bal-1 is a program in Fortran for the IBM 7090 to solve the neutron balance for the PLMG code reported in reference 1. This code accounts for the neutron events by region and over the whole system based on PLMG code output fluxes. The types of events considered are described by the basic PLMG equation, as follows:

$$\nabla \cdot \bar{j} \Delta \mu^m + \sum_a \phi_a^m \Delta \mu^m + (1 - P_a^m) \sum_i q_i^{m-1} + \sum_{in} \phi_{in}^m \Delta \mu^m + \sum_i (q_i^m - q_i^{m-1}) = S \Delta \mu^m$$

where $C \left[\sum_a \Delta \mu^m + (1 - P_a^m) \sum_i q_i^{m-1} \right] \int_{region} \phi_a^m dV =$ absorptions in a region

$C \int_{region} (q_i^m - q_i^{m-1}) dV =$ elastic scatterings in a region

$C \sum_{in} \int_{region} \phi_{in}^m \Delta \mu^m dV =$ inelastic scattering loss in a region

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$$C \int_{\text{region}} \nabla \cdot \vec{J} \Delta \mu^m dV = \text{net leakage in a region}$$

$$C \int_{\text{region}} S^m dV = \text{sources in a region}$$

$$S^m = \chi^m \Delta \mu^m \left[\sum_{\ell=1}^{\infty} \nu \sum_f \phi^{\ell} \Delta \mu^{\ell} + \nu^{\ell} (1 - \rho_f^{\ell}) \sum_i q_{i}^{\ell-1} \right] + \sum_{\ell=1}^{m-1} \sum_{in} \Delta \mu^{\ell}$$

= fission + inelastic sources

$$C = \frac{1}{\int_{\text{all regions}} (\nu^m \sum_f \phi^m \Delta \mu^m + \nu_i^m (1 - \rho_f^m) \sum_i q_i^{m-1}) dV}$$

= normalization constant to normalize the fission source to 1 fission neutron

$$C \int_{\text{region}} \nabla \cdot \vec{J} \Delta \mu^m dV \quad \text{can be separated into components depending}$$

on geometry due to the vector properties of the current $\vec{J}$.

Thus for a cylinder, this term is broken up into radial and axial leakage where the axial leakage is given by

$$B_a^m = C B^2 \int_{\text{region}} \frac{\phi^m \Delta \mu^m}{\beta^m} dV = \text{axial leakage}$$

$$B^2 = \text{the total buckling}$$

$$\beta^m = 3 \left[\sum_i \sum_{tr}^m + \frac{\sum_i (\eta \sum_s)_i}{\left(\frac{\Delta \mu^m}{2} + \zeta_i \right)} \right]$$

Each of these terms is calculated and printed by the code. In addition, a calculation by element is done for the absorption, scattering and fission terms. The symbols on the preceding pages are defined in the list following the equations solved by the program (Section 1).

Other descriptions of the symbols used in this report are given in reference 1.

Section 1

The actual equations solved by BAL-1 are as follows:

$$(1) \int_{B_{2J-1}}^{B_{2J}} \phi_m dV = \sum_{n=B_{2J-1}}^{B_{2J}} R_n^y \phi_{n,m} - \left[\frac{(R_{n_{B_{2J-1}}})^y \phi_{B_{2J-1},m} + (R_{n_{B_{2J}}})^y \phi_{B_{2J},m}}{2} \right]$$

$$(2) g_{i,m,n} = \frac{[(\Sigma_s)_{i,j} \phi_n]_m \Delta \mu_m}{\frac{1}{2} \Delta \mu_m + \gamma_{i,m}} - g_{i,n,m-1} \left(\frac{\frac{1}{2} \Delta \mu_m - \gamma_{i,m}}{\frac{1}{2} \Delta \mu_m + \gamma_{i,m}} \right)$$

where $g_{i,m-1} \equiv 0$ for $m=1$; $g_{i,m} \equiv 0$ for $m=51$

$$(3) \int_{B_{2J-1}}^{B_{2J}} g_{m-1} dV = \sum_{n=B_{2J-1}}^{B_{2J}} R_n^y \sum_i g_{i,n,m-1} - \left[\frac{(R_{n_{B_{2J-1}}})^y \sum_i g_{i,B_{2J-1},m-1} + (R_{n_{B_{2J}}})^y \sum_i g_{i,B_{2J},m-1}}{2} \right]$$

$$(4) P_{a_{i,m}} = e^{-(R I_a)_{i,J,m}}$$

$$(5) (RI_a)_{i,j,m} = \sum_{k=1}^K (RI_a)_{i,j,m,k}, K \leq 8$$

$$(6) (RI_a)_{i,j,m,k} = \frac{(Ma_{i,m,k} \cdot L_{i,j,k}) \frac{\pi}{2}}{\sum_{m,j} \sqrt{A_{i,m,j}(A_{i,m,j} + (ra_{i,m,k}))}}$$

$$(7) A_{i,m,j} = \frac{1}{N_{i,j}} \left[\sum_{s_{j,m-1}} + \frac{(B_r^2)_j}{3 \sum_{tr_{j,m-1}}} \right]$$

$$(8) \bar{s}_{j,m} = \frac{u_{j,m}}{\sum_{s_{j,m}}}$$

$$(9) u_{j,m} = \sum_{s_{H_m}} + \sum_{i \neq 1} (\xi \sum_s)_{i,j,m}$$

$$(10) \sum_{s_{j,m}} = \sum_i \sum_{s_{i,j,m}}$$

$$(11) A_{a_{i,j,m}} = C \cdot \Delta R_j \left(\sum_{a_{i,j,m}} \Delta u_m \int_{B_{2j-1}}^{B_{2j}} \phi_m dV + [1 - p_{a_{i,m}}] \int_{B_{2j-1}}^{B_{2j}} q_{m-1} dV \right)$$

$$(12) \quad A_{K_{i,J,m}} = C \cdot \Delta R_J \sum_{K_{i,J,m}} \Delta \mu_m \int_{B_{2J-1}}^{B_{2J}} \phi_m dV$$

$$(13) \quad \beta_{J,m} = 3 \left[\sum_{tr_{J,m}} + \sum_i \left(\frac{\eta_i \sum s_{i,J,m}}{\frac{\Delta \mu_m}{2} + \zeta_i} \right) \right]$$

$$(14) \quad \sum_{tr_{J,m}} = \sum_i \left(\sum_s + \sum_a + \sum_K - \sum_l \right)_{i,J,m}$$

$$(15) \quad B_{a_{J,m}} = C \cdot \Delta R_J \left(\frac{B_J^2}{\beta_{J,m}} \cdot \Delta \mu_m \right) \int_{B_{2J-1}}^{B_{2J}} \phi_m dV$$

$$(16) \quad (D_i^- - D_i^+)_{J,m} = C \cdot \Delta R_J \left\{ \sum_{n=B_{2J-1}}^{B_{2J}} R_n^y (q_{i,n,m} - q_{i,n,m-1}) \right.$$

$$\left. - \left[\frac{(R_{n_{B_{2J-1}}})^y (q_{i,m} - q_{i,m-1})_{B_{2J-1}} + (R_{n_{B_{2J}}})^y (q_{i,m} - q_{i,m-1})_{B_{2J}}}{2} \right] \right\}$$

$$(17) J^-(R_n) = -\frac{C \cdot \Delta \mu_m}{\beta_{J,m} \cdot \Delta R_J} \left(1 - \frac{\Delta R_J}{2 R_n}\right)^2 (\phi_n - \phi_{n-1})_m$$

$$+ \frac{1}{2} \left[\sum_i \sum_{f_{i,n,m}} - (Aa + Ba)_{i,n,m} \right]$$

$$(18) J^+(R_n) = \frac{C \cdot \Delta \mu_m}{\beta_{J,m} \cdot \Delta R_J} \left(1 + \frac{\Delta R_J}{2 R_n}\right)^2 (\phi_n - \phi_{n+1})_m$$

$$- \frac{1}{2} \left[\sum_i \sum_{f_{i,n,m}} - (Aa + Ba)_{i,n,m} \right]$$

$$(19) (E^{J_-} - E^{J_+}) = R_{\beta_{2J}}^y J^-(R_{\beta_{2J}}) - R_{\beta_{2J-1}}^y J^+(R_{\beta_{2J-1}})$$

$$(20) S_{k_{i,J,m}} = C \cdot \Delta R_J \left[\sum_{\ell=1}^{m-1} \sum_{i_n, i, J}^{\ell \rightarrow m} \Delta \mu_\ell \int_{\beta_{2J-1}}^{\beta_{2J}} \phi_\ell dV \right]$$

$$(21) P_{f_{i,J,m}} = e^{-(RI_f)_{i,J,m}}$$

$$(22) \quad (RI_f)_{i,j,m} = \sum_{k=1}^K \alpha_{i,m,k} (RI_a)_{i,j,k,m}$$

$$(23) \quad \chi(n)_{i,m} = \chi_m \Delta \mu_m \left[\sum_{l=1}^{51} [v \Sigma_{f,i,l} \phi_l \Delta \mu_l] + v_{i,l} [1 - p_{f,i,l,j}] \sum_l g_{i,l-1} \right]$$

$$(24) \quad S_{f,i,j,m} = C \cdot \Delta R_j \left\{ \sum_{n=B_{2j-1}}^{B_{2j}} R_n^y \cdot \chi(n)_{i,m} - \frac{(R_{B_{2j-1}})^y \chi(B_{2j-1})_{i,m} + (R_{B_{2j}})^y \chi(B_{2j})_{i,m}}{2} \right\}$$

$$(25) \quad \overline{v \Sigma_f \phi}_n = \sum_{m=1}^{51} \sum_l \left(v \Sigma_{f,i,m} \phi_{n,m} \Delta \mu_m + v_{i,m} [1 - p_{f,i,m}] \sum_l g_{i,m-1} \right)$$

$$(26) \quad C = \frac{1}{\sum_j \Delta R_j \left[\sum_{n=B_{2j-1}}^{B_{2j}} R_n^y \overline{v \Sigma_f \phi}_n - \frac{(R_{B_{2j-1}})^y \overline{v \Sigma_f \phi}_{B_{2j-1}} + (R_{B_{2j}})^y \overline{v \Sigma_f \phi}_{B_{2j}}}{2} \right]}$$

where

m - group number

i - material number

J - region number

y - exponent which is

0 for a plane

1 for a cylinder

2 for a sphere

n - point number

B_{2J-1}^- - lower bound of region J

B_{2J}^- - upper bound of region J

R_n - radial co-ordinate of point n

$\phi_{n,m}$ - group m flux at point n

$(\xi \Sigma_s)_{i,J,m}$ - group m macroscopic slowing down power of element i in region J

$\Delta \mu_m$ - lethargy width of group m

$\gamma_{i,m}$ - age number of element i in group m

$\Sigma_{a_{i,J,m}}$ - group m macroscopic absorption cross section of material i in region J

$\Sigma_{K_{i,J,m}}$ - group m macroscopic inelastic scattering cross section of material i in region J

B_J^2 - total buckling in region J

η_i - eta for element i

$\Sigma_{s_{i,J,m}}$ - group m macroscopic symmetric scattering cross section of material i in region J

ζ_i - zeta for material i

$\Sigma_{l,i,J,m}$ - group m macroscopic sigma l for material i in region J

$\Sigma_{f,i,n,m}$ - group m macroscopic fission cross section of material i at point n

ΔR_J - mesh spacing in region J

$\Sigma_{in,i,J}^{l \rightarrow m}$ - macroscopic inelastic scattering cross section of material i in region J, from group l to group m

χ_m - chi for group m, fraction of fission neutrons emitted in each group m

$\nu \Sigma_{f,i,l}$ - macroscopic nu sigma fission for material i in group l

$\nu_{i,l}$ - nu for material i in group l

$L_{i,J,K}$ - self shielding factor for material i in region J for resonance group K

$M_{a,i,m,K}; r_{a,i,m,K}$ - resonance parameters as obtained from PLMG tape for material i in lethargy group m, resonance group K

$N_{i,J}$ - number density of material i in region J

$(Br^2)_J$ - resonance buckling in region J

The elements presently handled by the neutron balance program are:

(1) hydrogen	(8) uranium 235
(2) carbon	(9) uranium 238
(3) iron	(10) boron 10
(4) nickel	(11) lithium 6
(5) niobium	(12) lithium 7
(6) aluminum	(13) beryllium
(7) chromium	

Section 2

Input Format for BAL-1

Card 1: Problem identification card. Column 1 must contain a 1. Any combination of alpha-numeric data may be used in columns 2-72.

Card 2: Column 4: 0 - Fluxes are to be on cards

1 - Fluxes are to be on tape. (See flux subprogram section of Hic report.)

Column 8: 0 - No elementwise print out is requested

1 - Elementwise print out is requested

Card 3: The words appearing on this card should be in fixed point form, with each word appearing to the right of the indicated field.

Columns 1-4: Total number of points. Note that since the first neutron balance point is 1, whereas the first PLMG point is 0, the number appearing here equals the number of PLMG points plus one.

Limitation: $1 \leq \text{number of points} \leq 200$.

Columns 5-8: Number of regions. This should correspond to the number of PLMG regions.

Limitation: $1 \leq \text{number of regions} \leq 20$.

Column 12: 0 - Slab geometry

1 - Cylindrical geometry

2 - Spherical geometry

The remainder of the input, with the exception of card 5, must appear in floating point form, 6 words per card, (with the possible exception of the last card in each card set, which may contain any number of words, not exceeding six), 12 columns per word, with the first word appearing in columns

1-12, the second word in columns 13-24, the third word in columns 25-36, the fourth word in columns 37-48, the fifth word in columns 49-60, and the sixth in columns 61-72.

Card 4: $\phi_{n,m}$ - Omit this card if fluxes are to be on tape. Otherwise, the 51 group fluxes for each point are to appear here, with group number, m, varying first. That is, they should appear in the order $\phi_{1,1} ; \phi_{1,2} ; \dots \phi_{1,51} ; \phi_{2,1} ; \phi_{2,2} ; \dots \phi_{2,51} ; \dots \phi_{p,1} ; \phi_{p,2} ; \dots \phi_{p,51}$.

Card 5: $B_{2J-1} B_{2J}$ - This is a fixed point card, 4 columns per word, with each word appearing to the right of its field. The first word should appear in columns 1-4, the second word in columns 5-8, the third in columns 9-12, etc. The first word represents the lower bound of region 1, and must be 1. Each succeeding word should represent an upper bound of a region. Therefore, the second word should represent the upper bound of region 1, the third word the upper bound of region 2, the fourth word the upper bound of region 3, etc. Thus, the number of words appearing on this card should be one greater than the number of regions. It should be noted that since the first neutron balance point is 1, whereas the first PLMG point is 0, (upper bound) neutron balance = (upper bound) PLMG + 1.

Card 6: R_j - Mesh spacing in each region. The number of words appearing here should equal the number of regions.

Card 7: $\nu\sigma_{fi,J}^{51}$ - The group 51 microscopic nu sigma fissions should appear here for each of the three elements U^{235} , U^{238} , and beryllium, for each region. They should be listed with material number, i, varying first, where $i=1=U^{235}$, $i=2=U^{238}$, and $i=3=Be$. Thus, the number of words appearing here should be 3 times the number of regions.

Card 8: $\sigma_{ai,J}^{51}$ - Group 51 microscopic absorption cross sections for each of the thirteen elements handled by the program, for each region. They should be listed with material number, i, varying first where $i=1=H$, $i=2=C$, $i=3=Fe$, $i=4=Ni$, $i=5=Nb$, $i=6=Al$, $i=7=Cr$, $i=8=U^{235}$, $i=9=U^{238}$, $i=10=B^{10}$, $i=11=Li^6$, $i=12=Li^7$, and $i=13=Be$. Thus, the number of words appearing here should be 13 times the number of regions.

- Card 9: $N_{i,J}$ - Number density of each of the above mentioned 13 elements for each region. As for Card 8, they should be listed with material number, i , varying first. The number of words appearing in this set should be 13 times the number of regions.
- Card 10: B_J^2 - Total buckling in each region. The number of words appearing here should equal the number of regions.
- Card 11: $(B_R^2)_J$ - Resonance buckling for each region. The number of words appearing here should equal the number of regions.
- Card 12: $L_{i,J,K}$ - Self shielding factors for the two elements U^{235} and U^{238} ($i=1=U^{235}$, $i=2=U^{238}$) for each region for each of the eight resonance groups. These should be listed with resonance group number, K , varying first ($K=1,2, \dots, 8$), with material number, i , varying second ($i=1,2$), and region number, J , varying last. That is, they should appear in the order $L_{U^{235},1,1}; L_{U^{235},1,2}; \dots L_{U^{235},1,8}; L_{U^{238},1,1}; L_{U^{238},1,2}; \dots L_{U^{238},1,8}; L_{U^{235},2,1}; L_{U^{235},2,2}; \dots L_{U^{235},2,8}; L_{U^{238},2,1}; L_{U^{238},2,2}; \dots L_{U^{238},2,8}; \dots L_{U^{235},R,1}; L_{U^{235},R,2}; \dots L_{U^{235},R,8}; L_{U^{238},R,1}; L_{U^{238},R,2}; \dots L_{U^{238},R,8}$. Thus, the number of words appearing here should be 16 times the number of regions.
- Card 13: $L_{Al,J,K=1}$ - One self shielding factor for Aluminum for each region, for the first resonance group. The number of words appearing here should equal the number of regions.
- Card 14: $\sum_{tr,J}^{51}$ - Group 51 sigma transport for each region. The number of words appearing here should equal the number of regions.

Section 3

Output Format for BAL-1

Output for BAL-1 consists of a print out of the problem identification card, and input parameters with self explanatory labels. If an elementwise print has been requested, the absorption, inelastic scatter, inelastic source, fission source, and elastic scattering loss for each of the thirteen elements in each region is printed out, appropriately labelled with element name and the previously mentioned term headings. This is followed by the usual non-elementwise print out which consists of the appropriately labelled absorption, inelastic scatter loss, inelastic scatter source, fission source, inelastic scatter loss, radial leakage loss, and transverse leakage terms in each region. The sum of these terms over all regions is then printed, followed by the sum of all sources over all regions and the sum of all losses over all regions. All parameters are appropriately labelled with element names, region numbers, and term labels.

Section 4

CONCLUSIONS

In reference 2, a comparison study of this P1MG balance code with the DTK code balance check was reported. This comparison showed the P1MG and DTK to agree fairly closely in total absorptions and leakage. However, many differences in absorption rates by material were noted which appear to be due, at least partially, to basic cross section differences. It was also noted in running BAL-1 that the total absorptions and leakage do not quite balance out to 1.0 (the normalized fission source). This is believed to be due to numerical analysis difficulties encountered in calculating the radial leakage term which involves a finite difference approximation of derivatives at boundaries. Since the absorptions and end leakage terms do not involve this approximation, a more accurate determination of the net radial leakage is obtained by subtracting the sum of absorption + end leakage terms.

The code has also never yet been tried for any geometry other than cylindrical. The code should be thoroughly tested for slab and spherical geometry as well as cylindrical geometry before it can be said to be completely operational.

REFERENCES:

1. WAPD-TM-135 - "P1MG - A One Dimensional Multigroup P1 Code for the IBM 704", H. Bohl, E. M. Gilbrand, C. R. Culpepper, P. F. Buerger. July, 1959.
2. RA-572 "Comparison of Neutron Balance by DTK and P1MG", August, 1963. H. Woodsum and P. Sipush.