Westinghouse

No: WANL-TMI-893

Date December 13, 1963

ASTRONUCLEAR LABORATORY

TO: F. D. Retallick
J. G. Gallagher

From P. C. Heiser, Reactor Analysis

cc: H. F. Faught D. E. Thomas
W. H. Esselman W. Henderson, NRDS
W. G. Roman F. W. Henning
W. H. Arnold Dr. Davison, NRDS
M. Johnson J. M. Ravets
J. Kenney H. C. Woodsum
W. M. Jacobi M. A. Capo
H. S. Kirschbaum L. O. Ricks
H. S. McCreary L. D. Stephenson
A. M. Poindexter R. G. Soltesz
G. R. Thomas R. N. Nassano
D. W. Drawbaugh P. C. Heiser

Subject NORMALIZER (For Normalizing HIC One Dimensional Reaction Rates To Two Dimensions)

INFORMATION CATEGORY

MASTER

Unclassified
Authorized Classifier

1/15/64
Date

ABSTRACT

NORMALIZER is a code written for the IBM-7090 which takes reaction rates produced by the one dimensional code (HIC) ⁽¹⁾ and normalizes the data to a two dimensional distribution. The fluxes used for the HIC calculations are obtained from the one dimensional diffusion code P1 MG ⁽²⁾.

The fluxes used in the normalizer program are obtained from CURE ⁽³⁾, a two dimensional diffusion code. Two separate codes, NORMALIZER "A" and "B", were necessary due to computer storage space limitations. Both codes are written in Fortran.

The codes compute for each region the relative radial and axial distribution of heating rate, fission rate, capture gamma rate and inelastic scattering gamma rate.

This report is intended to be a user's manual and the physics of the equations solved by the codes is not described herein. For a discussion of the physics involved, the reader is referred to the description given in WANL-TNR-128, Vol. II ⁽⁴⁾ and program HIC ⁽¹⁾.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

In order to use NORMALIZER the user must be familiar with the following codes: P1 MG, CURE, and HIC all of which must be run prior to running NORMALIZER.

INTRODUCTION

NORMALIZER A and NORMALIZER B are Fortran programs which utilize the two dimensional four group CURE fluxes and the HIC neutron heating rates and 13 gamma group capture and inelastic gamma spectra in the calculation of:

- (1) average heating rates (watts/cc-fission/second) in a region
- (2) radial heating distributions
- (3) axial heating distributions
- (4) radial fission distributions
- (5) relative radial fission distributions
- (6) axial fission distributions
- (7) relative axial fission distributions
- (8) average capture gamma spectra for each of the 13 groups
- (9) axial gamma source strengths
- (10) relative axial gamma source strengths
- (11) average inelastic gamma spectra for each of the 13 groups
- (12) total secondary gamma spectra for each of the 13 groups
- (13) secondary gamma source strengths
- (14) relative secondary gamma source strengths
- (15) prompt gamma ray source density (mev/fission-cc) for each of the 13 groups

- (16) decay gamma ray source density (mev/fission-cc) for each of the 13 groups
- (17) total gamma spectra for each of the 13 groups
- (18) relative axial distribution of fission and secondary gammas
- (19) relative radial distribution of fission and secondary gammas

The CURE four group fluxes as used in these programs may be obtained in data card form by using a HIC option. The inelastic and symmetric scattering four group cross sections required as input may be obtained in data card form from a program (See Section 1) written for this purpose.

This report consists of the following sections:

Section 1 - Generation of cross sections for NORMALIZER

Section 2 - Equations used in NORMALIZER A

Section 3 - Input format for NORMALIZER A

Section 4 - Output format for NORMALIZER A

Section 5 - Equations used in NORMALIZER B

Section 6 - Input format for NORMALIZER B

Section 7 - Output format for NORMALIZER B

Table I - Programmed Constants

Section 1

Generations of Cross Sections for NORMALIZER

A Fortran program which generates the inelastic and symmetric scattering cross sections required as input to the main NORMALIZER program has been written for the IBM-7090. This program uses 51 group neutron fluxes produced by program P1 MG and arranged on tape by a subprogram described in the HIC report. The cross sections are produced by flux weighting with the 51 groups and averaging over the P1MG regions.

The following equations are solved by this program.

$$(1) \bar{\Sigma}_{S_J} = \sum_{i=1}^{14} N_{i,J} \frac{\int_{\chi_l}^{\chi_u} \sum_{m=1}^{10} \sigma_{s_{i,m}} \phi(\chi)_m \Delta \mu_m \chi^y \Delta \chi_J}{\int_{\chi_l}^{\chi_u} \sum_{m=1}^{10} \phi(\chi)_m \Delta \mu_m \chi^y \Delta \chi_J}$$

$$(2) \bar{\Sigma}_{in_J} = \sum_{i=1}^{14} N_{i,J} \frac{\int_{\chi_l}^{\chi_u} \sum_{m=1}^{10} \sigma_{in_{i,m}} \phi(\chi)_m \Delta \mu_m \chi^y \Delta \chi_J}{\int_{\chi_l}^{\chi_u} \sum_{m=1}^{10} \phi(\chi)_m \Delta \mu_m \chi^y \Delta \chi_J}$$

where

- $\bar{\Sigma}_{S_J}$ - macroscopic symmetric scattering cross section in region J
- $\bar{\Sigma}_{in_J}$ - macroscopic inelastic scattering cross section in region J

J - subscript referring to region number

i - subscript referring to material number

m - subscript referring to neutron group number

- $N_{i,J}$ - number density of material i in region J
 $\sigma_{s_{i,m}}$ - microscopic symmetric scattering cross section of material i in group m
 $\sigma_{in_{i,m}}$ - microscopic inelastic scattering cross section of material i in group m
 $\phi(x)_m$ - group m flux at point x
 $\Delta\mu_m$ - lethargy width of group m
 γ - exponent which is 0 for an axial problem and 1 for a radial problem
 x - radial position, r , for a cylindrical geometry or axial position, Z , for slab geometry
 Δx_J - mesh spacing in region J
 x_l - lower bound of the region
 x_u - upper bound of the region

The fourteen materials handled by this program are identical to those handled by the HIC program; the numbers used to refer to these elements also correspond to those used in HIC. They 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	(14) titanium

As in HIC, all microscopic cross sections correspond to those used by P1 MG.

Input to the program consists of the following cards:

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

Card 2: This is a fixed point card. The first two words, appearing in columns 1-4 and 5-8, must be placed to the right of their respective fields.

Columns 1-4: Number of points. Note that since the first point in this program is referred to as 1, whereas the first P1 MG point is zero, the word appearing here should be the number of P1 MG 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 P1 MG regions.

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

Column 12: $y = 0$ for slab geometry (axial problem)

1 for cylindrical geometry (radial problem)

Column 16: 0 - Punched card output is not desired

1 - Punched card output is desired. These cards may then be used as direct input to the main NORMALIZER program if the NORMALIZER problem being run is the special case of one axial subregion.

Column 20: 0 - Fluxes are to be on tape (See flux subprogram section of HIC report)

1 - Fluxes are to be on cards

Card 3: x_l, x_u - This is a fixed point card, 4 columns per word, with each word appearing to the right of its field. Thus, the first word appears in columns 1-4, the second word in columns 5-8, etc. The first word represents the lower bound of region 1, and therefore must be a 1. The succeeding words represent the upper bounds of each region, beginning with region 1. Note that since the first point here is 1, whereas the first P1 MG point is 0, each upper bound appearing here equals a P1 MG bound plus one. The number of words appearing on this card is one greater than the number of regions.

The remainder of the input must appear in floating point form, 5 words per card, with the possible exception of the last card in each card set, which may contain any number of words, not exceeding 5. The first word appears in columns 1-14, the second word in columns 15-28, the third in columns 29-42, the fourth in columns 43-56, and the last in columns 57-70.

- Card 4: Δx_j - mesh spacing in each region. The number of words appearing here should equal the number of regions.
- Card 5: $\phi(x)_m$ - Omit this card if fluxes are to be on tape; i. e., column 20 of card 2 contains a 0. Otherwise, the 51 group fluxes for each point are to appear here, with group number, m , varying first. That is, $\phi(1)_1, \phi(1)_2, \dots, \phi(1)_{51}, \phi(2)_1, \phi(2)_2, \dots, \phi(2)_{51}, \dots, \phi(N)_1, \phi(N)_2, \dots, \phi(N)_{51}$.
- Card 6: $N_{i,j}$ - Number density of each of the 14 materials in each region. These should be listed with material number, i , varying first. That is, $N_{1,1}; N_{2,1}; \dots, N_{14,1}; N_{2,1}; N_{2,2}; \dots, N_{14,2}; \dots, N_{1,j}; N_{2,j}; \dots, N_{14,j}$.

Output to this program consists of the print out of the problem identification card, appropriately labelled input parameters, and the quantities $\sum_{s_j}$ and $\sum_{in_j}$ for each region, labelled as "symmetric scattering cross section" and "inelastic scattering cross section", respectively.

Section 2

Equations used in NORMALIZER A (Heating Distributions)

NORMALIZER A is a Fortran program written for the IBM-7090 which solves

the following equations:

$$(1) \quad B(R_i)_{J'} = \sum_{J=N}^{N'} \int_{Z_{LJ}}^{Z_{UJ}} \sum_{S_{J,I}} \phi_i(R_i, z_i) dz$$

$$(2) \quad S_H(R_i)_{J'} = \frac{\text{HIC Heating Rate}(R_i) \cdot B(R_i)_{J'}}{\sum_{S_{I,Z=Z_n}} \phi_i(R_i, z_n)}$$

$$(3) \quad \bar{S}_{H_{I',J'}} = \frac{2 \sum_{I=M}^{M'} \int_{R_{L,I}}^{R_{U,I}} S_H(R_i)_{J'} \cdot R dR}{\sum_{J=N}^{N'} (Z_U - Z_L)_J (R_{U_{I=M'}}^2 - R_{L_{I=M}}^2)}$$

$$(4) \quad (REL RH)_{i,J'} = \frac{S_H(R_i)_{J'}}{S_H(R_i)_{J'}}$$

$$(5) \quad K_{I',J'} = \frac{(R_{U_{I=M'}}^2 - R_{L_{I=M}}^2)}{2 \sum_{I=M}^{M'} \int_{R_{L,I}}^{R_{U,I}} (REL RH)_{i,J'} \cdot R dR}$$

$$(6) \quad A(R_i)_{J'} = K_{I',J'} \cdot (REL RH)_{i,J'}$$

$$(7) (RELZH)_{j,I'} = \frac{\sum_{I=M}^{M'} \int_{R_{L_I}}^{R_{U_I}} \text{HIC Heating Rate}(R_i) \cdot \frac{\sum_{s_{i,z}} \phi_i(R_i, z_i)}{\sum_{s_{i,z=z_n}} \phi_i(R_i, z_n)} \cdot R dR}{\sum_{I=M}^{M'} \int_{R_{L_I}}^{R_{U_I}} \text{HIC Heating Rate}(R_i) R dR}$$

$$(8) K_{2 I', J'} = \frac{\sum_{J=N}^{N'} (Z_{U_J} - Z_{L_J})}{\sum_{J=N}^{N'} \int_{Z_{L_J}}^{Z_{U_J}} (RELZH)_{j,I'} dz}$$

$$(9) C(Z_j)_{I'} = K_{2 I', J'} \cdot (RELZH)_{j,I'}$$

- where
- J - axial subregion number*
 - N - first axial subregion within a major axial region
 - N' - last axial subregion within a major axial region
 - J' - major axial region number
 - Z_{L_J} - lower bound of axial subregion J
 - Z_{U_J} - upper bound of axial subregion J
 - I - radial subregion number
 - I' - radial major region number

* CURE regions, defined by a given material composition, are subregions. Major regions are combinations of subregions.

- $\sum_{s_{J,I}}$ - symmetric scattering cross section in axial subregion J, radial subregion I
 $\phi_i(R_i, Z_j)$ - Group 1 flux at the point described by the coordinates R_i, Z_j .
 Z_n - axial row chosen as basis for normalization*
 M - first radial subregion within a major radial region
 M' - last radial subregion within a major radial region
 R_{L_I} - lower bound of radial subregion I
 R_{U_I} - upper bound of radial subregion I

* In the event that the row chosen for normalization is an internal boundary point, cross sections used in the normalization by the program are the arithmetical average of the cross sections of the two regions for which $Z=Z_n$ is a boundary.

Section 3

Input Format For NORMALIZER A

Input to the program is as follows:

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

Cards 2-7 must appear in fixed point form, 4 columns per word, with each word appearing to the right of its field. The first word on these cards should appear in Columns 1-4, the second word in Columns 5-8, the third word in Columns 9-12, etc.

Card 2: Columns 1-4: Number of radial points
Limitation: $1 \leq \text{number of radial points} \leq 100$.

Columns 5-8: Number of axial points
Limitation: $1 \leq \text{number of axial points} \leq 100$.

Columns 9-12: Z_n - axial row to which data is to be normalized

Card 3: Columns 1-4: Number of radial subregions
Limitation: $1 \leq \text{number of radial subregions} \leq 50$.

Columns 5-8: Number of axial subregions
Limitation: $1 \leq \text{number of axial subregions} \leq 50$.

Columns 9-12: Number of major radial regions
Limitation: $1 \leq \text{number of major radial regions} \leq 5$.

Columns 13-16: Number of major axial regions
Limitation: $1 \leq \text{number of major axial regions} \leq 5$.

Card 4: $R_{L1} R_{U1}$ - Lower and upper bounds of each radial subregion expressed as a point number; i.e., $R_{L1}, R_{U1}, R_{L2}, R_{U2}, \dots, R_{L1}, R_{U1}$. Thus, the number of words appearing on this card should be twice the number of radial subregions. Note that the lower bound of region 1 should be 1.

Card 5: Z_{L_J}, Z_{U_J} - Lower and upper bounds of each axial subregion expressed as a point number; i. e., $Z_{L_1}, Z_{U_1}, Z_{L_2}, Z_{U_2}, \dots, Z_{L_J}, Z_{U_J}$. Thus, the number of words appearing on this card should be twice the number of axial subregions. Note that the lower bound of region 1 should be 1.

Card 6: R_{L_I}, R_{U_I} - Lower and upper bounds of each major radial region expressed as a point number; i. e., $R_{L_1}, R_{U_1}, R_{L_2}, R_{U_2}, \dots, R_{L_I}, R_{U_I}$. Thus, the number of words appearing here should be twice the number of major radial regions. Note that each bound specified here must correspond to the boundary of some radial subregion as specified on card 4.

Card 7: $Z_{L_{J'}}, Z_{U_{J'}}$ - Lower and upper bounds of each major axial region expressed as a point number; i. e., $Z_{L_1}, Z_{U_1}, Z_{L_2}, Z_{U_2}, \dots, Z_{L_{J'}}, Z_{U_{J'}}$. Thus, the number of words appearing here should be twice the number of major axial regions. Note that each bound specified here must correspond to the boundary of some axial subregion as specified on card 5.

The remainder of the input must appear in floating point form, 6 words per card, with the possible exception of the last card in each set, which may contain any number of words, not exceeding 6. The first word on each card should appear in Columns 1-12, the second word in Columns 13-24, the third in Columns 25-36, the fourth in Columns 37-48, the fifth in Columns 49-60, and the sixth in Columns 61-72.

Card 8: R_m - Radial coordinate of each point. The number of words appearing here should correspond to the number of radial points as specified by word 1 of card 2.

Card 9: Z_m - Axial coordinate of each point. The number of words appearing here should correspond to the number of axial points as specified by word 2 on card 2.

Card 10: $\sum_{J,I} \sigma_{J,I}$ - Symmetric scattering cross section in axial subregion J, radial subregion I. They should be listed with the axial subregion number, J, varying first. The number of words appearing here should equal the product of the number of axial subregions (word 2 on card 3) by the number of radial subregions (word 1 on card 3). In the case of a 1 axial subregion problem, punched card output from the cross section generator described in section 1 may be used here.

- Card 11: $\phi_i(R_i, Z_j)$ - Group I fluxes at the point described by the coordinates R_i, Z_j . These should be listed with j varying first. Fluxes for the first axial position of each radial coordinate should begin on a new card. That is, $\phi_i(R_i, Z_1)$ is the first word on a card for all values of i . Note that these cards can be obtained as punched card output from the HIC program by using the option which converts CURE binary output to decimal form.
- Card 12: HIC Heating Rates (R_i) - The pointwise heating rates as calculated by the HIC program are to appear here. Note that two values should appear for each internal radial subregion boundary point; i.e., the number of words appearing in this set should equal the number of radial points (word 1 on card 2) plus the number of radial subregions (word 1 on card 3) minus one. This set of cards may be obtained as punched card output from HIC.

Section 4

Output Format For NORMALIZER A

Output for this program consists of the print out of the problem identification card, appropriately labelled input parameters, and the results of equations 3, 6, and 9. The quantity $\bar{S}_{H_I, J'}$ (equation 3) is printed for each major region, labelled by radial region number and axial region number, under the heading "average heating rate in watts/cc - fission/second". The quantity $A(R_i)_{J'}$ (equation 6) is printed out under the heading "Relative radial heating distribution for major axial region X". The value at each radial point is labelled by the point number and its radial coordinate. The quantity $C(z_j)_I$ (equation 9) is printed out under the heading "Relative axial heating distribution", labelled with the radial region number, axial point number and axial coordinate.

Section 5

Equations Used in NORMALIZER B

NORMALIZER B is a Fortran program written for the IBM-7090 which

solves the following equations:

$$(1) A(R_i)_{J'} = \sum_{J=N}^{N'} \int_{z_{LJ}}^{z_{UJ}} \sum_{m=1}^4 (\Sigma_a - \Sigma_f)_{m,J,\pm} \phi_m(R_i, z_j) dz$$

$$(2) S(R_i)_{\ell,J'} = \text{HIC capture } \delta \text{ Spectra } (R_i)_{\ell} \cdot \frac{A(R_i)_{J'}}{\sum_{m=1}^4 (\Sigma_a - \Sigma_f)_{m,z=z_n} \phi_m(R_i, z_n)}$$

$$(3) \overline{SR}_{\ell,J',I'} = \frac{2 \sum_{I=M}^{M'} \int_{R_{LI}}^{R_{UI}} S(R_i)_{\ell,J'} \cdot R dR}{\sum_{J=N}^{N'} (z_u - z_L)_J (R_{UI}^2 - R_{LI}^2)}$$

$$(4) F(R_i)_{J'} = \sum_{J=N}^{N'} \int_{z_{LJ}}^{z_{UJ}} \sum_{in_{I,J}} \phi_i(R_i, z_j) dz$$

$$(5) SI(R_i)_{\ell,J'} = \text{HIC Inelastic } \delta \text{ Spectra } (R_i)_{\ell} \cdot \frac{F(R_i)_{J'}}{\sum_{in_{I,z=z_n}} \phi_i(R_i, z_n)}$$

$$(6) \quad \overline{SI}_{\ell, I', J'} = \frac{2 \sum_{I=M}^{M'} \int_{R_{LI}}^{R_{UI}} SI(R_i)_{\ell, J'} \cdot R dR}{\sum_{J=N}^{N'} (Z_u - Z_L)_J (R_{u, I=M'}^2 - R_{L, I=M}^2)}$$

$$(7) \quad C_{\ell, I', J'} = \overline{SR}_{\ell, I', J'} + \overline{SI}_{\ell, I', J'}$$

$$(8) \quad RELR(R_i)_{J'} = \frac{\sum_{\ell=1}^{13} (S(R_i) + SI(R_i))_{\ell, J'}}{\sum_{\ell=1}^{13} (S(R_i) + SI(R_i))_{\ell, J'}}$$

$$(9) \quad K_{I', J'} = \frac{(R_{u, I=M'}^2 - R_{L, I=M}^2)}{2 \sum_{I=M}^{M'} \int_{R_{LI}}^{R_{UI}} RELR(R_i)_{J'} \cdot R dR}$$

$$(10) \quad RELRS(R_i)_{J'} = RELR(R_i)_{J'} \cdot K_{I', J'}$$

$$(11) \quad RELZ(Z_j)_{I'} = \left[\sum_{I=M}^{M'} \int_{R_{LI}}^{R_{UI}} \sum_{\ell=1}^{13} \text{HIC Capture } \gamma \text{ Spectra}(R_i)_{\ell} \cdot \frac{\sum_{m=1}^4 (\Sigma_a - \Sigma_f)_{m, J, I} \phi_m(R_i, Z_j)}{\sum_{m=1}^4 (\Sigma_a - \Sigma_f)_{m, I, Z=Z_n} \phi_m(R_i, Z_n)} \right. \\ \left. + \sum_{\ell=1}^{13} \text{HIC Inelastic } \gamma \text{ Spectra}(R_i)_{\ell} \cdot \frac{\sum_{m, J, I} \phi_m(R_i, Z_j)}{\sum_{m, I, Z=Z_n} \phi_m(R_i, Z_n)} \cdot R dR \right] \\ \div \left[\sum_{I=M}^{M'} \int_{R_{LI}}^{R_{UI}} \sum_{\ell=1}^{13} (\text{HIC Capture } \gamma \text{ Spectra}(R_i)_{\ell} + \text{HIC Inelastic } \gamma \text{ Spectra}(R_i)_{\ell}) \cdot R dR \right]$$

$$(12) \quad K_{2I',J'} = \frac{\sum_{J=N}^{N'} (Z_u - Z_L)_J}{\sum_{J=N}^{N'} \int_{Z_{LJ}}^{Z_{UJ}} \text{RELZ}(Z_j)_{I'} dZ}$$

$$(13) \quad \text{RELZS}(Z_j)_{I'} = \text{RELZ}(Z_j)_{I'} \cdot K_{2I',J'}$$

$$(14) \quad \bar{F}(Z_j)_{I'} = \frac{\sum_{I=M}^{M'} \int_{R_{LI}}^{R_{UI}} \sum_{m=1}^4 \sum_{f_{m,I,J}} \phi_m(R_i, Z_j) R dR}{\sum_{I=M}^{M'} \int_{R_{LI}}^{R_{UI}} \sum_{m=1}^4 \sum_{f_{m,I,Z=Z_n}} \phi_m(R_i, Z_n) R dR}$$

$$(15) \quad K_{3I',J'} = \frac{\sum_{J=N}^{N'} (Z_u - Z_L)_J}{\sum_{J=N}^{N'} \int_{Z_{LJ}}^{Z_{UJ}} \bar{F}(Z_j)_{I'} dZ}$$

$$(16) \quad \text{RELZF}(Z_j)_{I'} = \bar{F}(Z_j)_{I'} \cdot K_{3I',J'}$$

$$(17) \quad \bar{F}(R_i)_{J'} = \frac{\sum_{J=N}^{N'} \int_{Z_{LJ}}^{Z_{UJ}} \sum_{m=1}^4 \sum_{f_{m,I,J}} \phi_m(R_i, Z_j) dZ}{\sum_{J=N}^{N'} \int_{Z_{LJ}}^{Z_{UJ}} \sum_{m=1}^4 \sum_{f_{m,I,J}} \phi_m(R_i, Z_j) dZ}$$

$$(18) \quad K_{4I',J'} = \frac{(R_{uI=M'}^2 - R_{LI=M}^2)}{2 \sum_{I=M}^{M'} \int_{R_{LI}}^{R_{uI}} \bar{F}(R_i)_{J'} R dR}$$

$$(19) \quad RELRF(R_i)_{J'} = \bar{F}(R_i)_{J'} \cdot K_{4I',J'}$$

$$(20) \quad X_{\ell,I',J'} = \frac{P_{\ell}}{\pi(R_{uI=M'}^2 - R_{LI=M}^2)(Z_{uJ=N'} - Z_{LJ=N})}$$

$$(21) \quad Y_{\ell,I',J'} = \frac{D_{\ell}}{\pi(R_{uI=M'}^2 - R_{LI=M}^2)(Z_{uJ=N'} - Z_{LJ=N})}$$

$$(22) \quad \Gamma_{\ell,I',J'} = (X + Y + \bar{S}R + \bar{S}\bar{I})_{\ell,I',J'}$$

$$(23) \quad \Gamma_{tI',J'} = \sum_{\ell=1}^{13} \Gamma_{\ell,I',J'}$$

$$(24) \quad \omega_{1I',J'} = \frac{\sum_{\ell=1}^{13} (X + Y)_{\ell,I',J'}}{\Gamma_{tI',J'}}$$

$$(25) \quad \omega_{2I',J'} = 1 - \omega_{1I',J'}$$

$$(26) \quad \bar{S}(Z'_I)_{I'} = RELZF(Z'_I)_{I'} \cdot W_{I',J'} + RELZS(Z'_I)_{I'} \cdot W_{2I',J'}$$

$$(27) \quad \bar{S}(R'_I)_{I'} = RELRF(R'_I)_{I'} \cdot W_{I',J'} + RELRS(R'_I)_{I'} \cdot W_{2I',J'}$$

where	J	-	axial subregion number*
	N	-	first axial subregion in a major axial region
	N'	-	last axial subregion in a major axial region
	J'	-	major axial region number
	I	-	radial subregion number
	M	-	first radial subregion in a major radial region
	M'	-	last radial subregion in a major radial region
	I'	-	major radial region number
	Z_{LJ}	-	lower bound of axial subregion J
	Z_{UJ}	-	upper bound of axial subregion J
	R_{LI}	-	lower bound of radial subregion I
	R_{UI}	-	upper bound of radial subregion I
	m	-	group number

*CURE regions, defined by a given material composition, are subregions. Major regions are combinations of subregions.

- $\sum_{a_{m,J,I}}$ - macroscopic absorption cross section in group m, axial subregion J, radial subregion I
- $\sum_{f_{m,J,I}}$ - macroscopic fission cross section in group m, axial subregion J, radial subregion I
- $\phi_m(R_i, z_j)$ - group m flux at the point described by the coordinates (R_i, z_j) .
- ℓ - gamma energy group
- HIC capture γ spectra $(R_i)_L$ - capture gamma spectra as obtained from HIC at radial point R_i , gamma energy group L
- $\sum_{in_{I,J}}$ - macroscopic inelastic scattering cross section in radial subregion I, axial subregion J
- HIC inelastic γ spectra $(R_i)_\ell$ - inelastic gamma spectra as obtained from HIC for radial point R_i , gamma energy group L
- P_ℓ - prompt gammas in mev/fission for gamma energy group L
- D_ℓ - delay gammas in mev/fission for gamma energy group L
- Z_n - axial row number chosen as basis for normalization. In the event that the row chosen corresponds to an internal axial region boundary point, the cross sections used in the normalization are the arithmetical averages of the cross sections in the two regions adjacent to the boundary point.

Section 6

Input Format for NORMALIZER B

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

Data cards 2-7 must appear in fixed point form, 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 word in columns 9-12, etc. It should be noted that data cards 3-7 are identical to those used in NORMALIZER A.

Card 2: Columns 1-4: Number of radial points

Limitation: $1 \leq \text{number of radial points} \leq 100$

Columns 5-8: Number of axial points

Limitation: $1 \leq \text{number of axial points} \leq 100$

Columns 9-12: Z_n - axial row chosen as basis for normalization

Column 16: 0 - short print option requested

1 - long print option requested
(See section on output format)

Column 20: 0 - programmed decay constants are to be used (See Table 1)

1 - decay gammas are to be input

Card 3: Columns 1-4: Number of radial subregions

Limitation: $1 \leq \text{number of radial subregions} \leq 50$

Columns 5-8: Number of axial subregions

Limitation: $1 \leq \text{number of axial subregions} \leq 50$

Columns 9-12: Number of major radial regions

Limitation: $1 \leq \text{number of major radial regions} \leq 5$

Columns 13-16: Number of major axial regions

Limitation: $1 \leq \text{number of major axial regions} \leq 5$

- Card 4: R_{L1}, R_{U1} - lower and upper bounds of each radial subregion; i. e., $R_{L1}, R_{U1}, R_{L2}, R_{U2}, \dots, R_{LJ}, R_{UJ}$. The number of words appearing here should be twice the number of radial subregions as specified by word 1 on card 3. It should be noted that the lower bound of radial subregion 1 is 1.
- Card 5: Z_{LJ}, Z_{UJ} - lower and upper bounds of each axial subregion; i. e., $Z_{L1}, Z_{U1}, Z_{L2}, Z_{U2}, \dots, Z_{LJ}, Z_{UJ}$. The number of words appearing here should be twice the number of axial subregions as specified by word 2 on card 3. Note that the lower bound of axial subregion 1 is 1.
- Card 6: R_{L1}, R_{U1} - lower and upper bounds of each major radial region; i. e., $R_{L1}, R_{U1}, R_{L2}, R_{U2}, \dots, R_{L1}, R_{U1}$. The number of words appearing here should be twice the number of major radial regions as specified by word 3 on card 3. Note that the bounds appearing here should correspond to the boundary of same radial subregion appearing on card 4.
- Card 7: Z_{LJ}, Z_{UJ} - lower and upper bounds of each major axial region. The number of words appearing here should be twice the number of major axial regions as specified by word 4 on card 3. Note that the bounds appearing here should correspond to the boundary of same axial subregion appearing on card 5.

The remainder of the input must appear in floating point form, 6 words per card, 12 columns per word. The first word should appear 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 word in columns 61-72.

- Card 8: R_i - radial coordinate of each point. The number of words appearing here should correspond to the number of radial points as specified by word 1 on card 2.
- Card 9: Z_i - axial coordinate of each point. The number of words appearing here should correspond to the number of axial points as specified by word 2 on card 2.

- Card 10: $\Sigma_{a,m,I,J}$ - macroscopic absorption cross section of each of the 4 groups in radial subregion I, axial subregion J. They should be listed with group number, m, varying first; axial subregion number, J, varying second; and radial subregion number, I, varying last.
- Card 11: $\Sigma_{f,m,I,J}$ - macroscopic fission cross section of each of the 4 groups in radial subregion I, axial subregion J. They should be listed with group number, m, varying first; axial subregion number, J, varying second; and radial subregion number, I, varying last.
- Card 12: $\Sigma_{in,I,J}$ - macroscopic inelastic scattering cross section of radial subregion I, axial subregion J. They should be listed with axial subregion number, J, varying first. In the special case problem of one axial subregion, these cards may be obtained directly from the cross section generator program.

Note that cards 13, 14, 15, and 16 can be obtained as punched card output from HIC and used directly in this program by using the routine which converts CURE binary output to decimal form.

- Card 13: $\phi_1(R_i, Z_j)$ - Group 1 flux at the point described by the coordinates R_i, Z_j . These fluxes should be listed with j varying first. The first axial position of each radial coordinate (each R_i, Z_1) should begin on a new card.
- Card 14: $\phi_2(R_i, Z_j)$ - Group 2 flux at the point described by the coordinates R_i, Z_j . These fluxes should be listed with j varying first. The first axial position of each radial coordinate (each R_i, Z_1) should begin on a new card.
- Card 15: $\phi_3(R_i, Z_j)$ - Group 3 flux at the point described by the coordinates R_i, Z_j . These fluxes should be listed with j varying first. The first axial position of each radial coordinate (each R_i, Z_1) should begin on a new card.

Card 16: $\Phi_4(R_i, Z_j)$ - Group 4 flux at the point described by the coordinates R_i, Z_j . These fluxes should be listed with j varying first. The first axial position of each radial coordinate (each R_i, Z_1) should begin on a new card.

Card 17: HIC capture gamma spectra $(R_i)_L$ - Capture gamma spectra as obtained from HIC for group 1 at radial point R_i . They should be listed with group number, L , varying first. Each set of 13 (each $(R_i)_1$) should begin on a new card. A double set of values should appear at all internal radial subregion boundary points. Note that this set of cards can be obtained as punched card output from HIC.

Card 18: HIC inelastic gamma spectra $(R_i)_L$ - Inelastic gamma spectra as obtained from HIC for gamma energy group 1 at radial point R_i . They should be listed with group number, L , varying first. Each set of 13 (each $(R_i)_1$) should begin on a new card. A double set of values should appear at all internal radial subregion boundary points. Note that this set of cards can be obtained as punched card output from HIC.

Card 19: D_L - This card may be omitted if the requestor wishes to use the decay gammas (See Table I) already in the program (word 5 on card 2 contains a 0). Otherwise, the decay gammas should appear here for $L = 1, 2, \dots, 13$.

Card 19 is the last input card required for this program.

Section 7

Output Format for NORMALIZER B

NORMALIZER B prints out the problem identification card and the input parameters with self-explanatory labels. The results of equations 3, 6, 7, 10, 13, 16, 19, 22, 26, and 27 are printed when choosing the short print option. In addition to these, the long print option yields the results of equations 8, 11, 14, 17, 20 and 21.

The quantity $\bar{F}(R_i)_{j,i}$ (equation 17) is printed out under the heading "Unnormalized radial fission distribution". Each value is labelled with the axial region number, point number, and radial coordinate.

The quantity $RELRF(R_i)_{j,i}$ (equation 11) appears under the heading "Relative radial fission distribution". Each value is labelled with the axial region number, point number, and radial coordinate.

The quantity $\bar{F}(Z_i)_{j,i}$ (equation 14) is printed out under the heading "Unnormalized axial fission distribution". Each value is labelled with the radial region number, point number, and axial coordinate.

The quantity $RELZF(Z_i)_{j,i}$ (equation 16) is printed out under the heading "Relative axial fission distribution", with each value labelled with radial region number, point number, and axial coordinate.

The quantity $\bar{SR}_{l,j,i}$ (equation 3) is printed out under the heading "Average capture gamma spectra for gamma energy group X". Each value is labelled with the radial region number and axial region number.

The quantity $RELZ (Z_i)_{I_i}$ (equation 11) is printed out under the heading "Unnormalized axial gamma source strength for major radial region X". Each value is labelled with its point number and axial coordinate.

The quantity $RELZS (Z_i)_{I_i}$ (equation 13) is printed out under the heading "Relative axial gamma source strength", with each value labelled with its radial region number, point number, and axial coordinate.

The quantity $\overline{ST}_{I_i, I_i', J_i}$ (equation 6) is printed out under the heading "Average inelastic gamma spectra for gamma energy group X". Each value is labelled with the radial region number and axial region number.

The quantity C_{I_i, I_i', J_i} (equation 7) is printed out under the heading "Total secondary gamma spectra for gamma energy group X". Each value is labelled with the radial region number and axial region number.

The quantity $RELR (R_i)_{J_i}$ (equation 8) appears under the heading "Unnormalized secondary source strength for major axial region X". Each value is labelled with its point number and radial coordinate.

The quantity $RELRS (R_i)_{J_i}$ (equation 10) appears under the heading "Relative secondary gamma source strength for major axial region X". Each value is labelled with its point number and radial coordinate.

The quantity X_{I_i, I_i', J_i} (equation 20) appears under the heading "Prompt gamma ray source density (mev/fission-cc) for gamma energy group X". Each value is labelled with the radial region number and axial region number.

The quantity $Y_{I, I', J'}$ (equation 21) is printed out under the heading "Decay gamma ray source density (mev/fission-cc) for gamma energy group X", labelled with the radial region number and axial region number.

The quantity $\Gamma_{I, I', J'}$ (equation 22) is printed out under the heading "Total gamma spectrum for gamma energy group X", again labelled with the radial region number and axial region number.

The quantity $\bar{S}(Z_i)_{I'}$ (equation 26) is printed out under the heading "Relative axial distribution of fission and secondary gammas combined for major radial region X". Each value is labelled with its point number and axial coordinate.

The quantity $\bar{S}(R_i)_{J'}$ (equation 27) is printed out under the heading "Relative radial distribution of fission and secondary gammas combined for major axial region X". Each value is labelled with its point number and radial coordinate.

SIGNED P. C. Heiser
P. C. Heiser

Table I

Gamma Energy Group	Energy (Mev)	Prompt Gamma (Mev/Fission)	Decay Gammas* (Mev/Fission)
1	0 - 0.4	1.235	0.226
2	0.4 - 0.9	2.053	0.984
3	0.9 - 1.35	1.389	0.871
4	1.35 - 1.8	0.947	0.739
5	1.8 - 2.2	0.708	0.516
6	2.2 - 2.6	0.503	0.435
7	2.6 - 3.0	0.363	0.338
8	3.0 - 4.0	0.559	0.538
9	4.0 - 5.0	0.252	0.222
10	5.0 - 6.0	0.111	0.041
11	6.0 - 7.0	0.04	0
12	7.0 - 7.5	0.015	0
13	> 7.5	0.003	0

*Based on a 20 Minute Reactor Run

Bibliography

1. WANL-TMI-903, "HIC, Program For Calculation of Neutron Heating, Capture and Inelastic Scattering Rates from Multigroup Diffusion Theory Fluxes", R. N. Nassano, P. C. Heiser, December 23, 1963.
2. WAPD-TM-135 "PIMG-A One Dimensional Multigroup PI Code for the IBM-704", Westinghouse Electric Corp., BAPD, H. Bohl, Jr., E. M. Gelbard, G. R. Culpepper, P. F. Buerger, July 1959.
3. APEX-452 "CURE-A Two-Space-Dimension, Multigroup Code for the IBM-704" General Electric Co. ANPD, F. M. Trantham, August 1958.
4. WANL-TNR-128 Vol. II, "Reactor Analysis of NRX-A Radiation Analysis" September, 1963. CRD