A CODE FOR REDUCING MANY-GROUP CROSS SECTIONS TO FEW GROUPS
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A CODE FOR REDUCING MANY-GROUP CROSS SECTIONS TO FEW GROUPS*

by

Ralph S. Cooper

*This report supersedes LAMS-2747.
ABSTRACT

A code (ZOT) has been written which will produce few-group neutron cross sections from many-group sets based on a given flux spectrum or one computed for an infinite medium. The cross-section format is that of S_n transport theory including the possibility of upscattering in energy. The code is written in the Floco II system for use on the IBM 704 or IBM 7090.
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INTRODUCTION

While many-group cross sections are necessary for computing a large variety of problems with a single set of cross section parameters, it is often desirable to reduce the number of groups used for particular problems. Multidimensional $S_n$ and diffusion codes are becoming available but are time-consuming with many energy groups. Where many $S_n$ one-dimensional problems must be run for parameter studies, for temperature or perturbation effects, or when coupled to hydrodynamic codes, specially tailored few-group cross sections would be advantageous.

George Bell has suggested (internal memo, July 3, 1958) recipes for collapsing many-group parameters assuming a many-group flux spectrum. This can be obtained from a single many-group calculation for the system or approximated, for example by solving the infinite medium (space independent) equations.

A code (ZOT) has been written which will collapse groups according to a given flux spectrum or using a self-generated infinite medium flux. Code details and the results of several test cases are given.
CROSS SECTION INPUT

The code is designed for the standard Los Alamos $S_n$ transport cross section format. For each energy group (denoted by subscript or superscript $g$ and running from $g = 1$ for the highest energy to $G$ for the lowest) the neutron cross sections are entered in the following order:

\[
\begin{align*}
\sigma_{ac1} \\
\sigma_{ac2} \\
\vdots \\
\vdots \\
\sigma_{ac_i} \\
\nu\sigma_f & \quad \nu(\text{neutrons/fission}) \times \text{the fission cross section} \\
\sigma_{tr} & \quad \text{the transport cross section (occasionally labeled } \sigma_g \text{)} \\
\vdots \\
\sigma_{g+2, g} & \quad \text{upsattering from groups of lower energy (higher } g \text{ indices) to the group } g \\
\sigma_{g+1, g} \\
\sigma_{gg} & \quad \text{scattering within the group} \\
\sigma_{g-1, g} \\
\sigma_{g-2, g} & \quad \text{downsattering from groups of higher energy to the group } g \\
\vdots \\
\vdots
\end{align*}
\]
The activity $\sigma$'s are not used in the solution of the transport equation, but are available for calculation of activities from the results of criticality calculations. The most commonly appearing one is $\sigma_a$ (absorption).* In the solution of the transport equation the absorption is accounted for implicitly in the transport cross section $\sigma_{tr}$, which includes $\sigma_a$. Note that through error or intent, the absorption used by the transport code may be different from that which may appear as one of the activity $\sigma$'s. We shall always deal with the $\sigma_a$ derived from the transport and scattering $\sigma$'s:

$$\sigma_a^g = \sigma_{tr}^g - \sum_{all \, g',g} \sigma_{g',g}$$  \hfill (1)

where all $g'$ includes $g' = g$. The number of activity $\sigma$'s and up- and downscattering for each group will be given implicitly by noting the position in the table of $\sigma_{tr}$, $\sigma_{gg'}$, and the last $\sigma_{g',g}$. If these are called $h_t$, $h_s$, and $h_l$ respectively, then:

- number of activity $\sigma$'s = $h_t - 2$
- number of upscattering $\sigma$'s = $h_s - h_t - 1$
- number of downscattering $\sigma$'s = $h_l = h_s$.

*This one is required by the Los Alamos DTK transport code.
The ZOT code will take the many-group cross sections for elements or mixtures and reduce the number of groups to \( K(K \leq G) \) by combining some of the groups according to equations given later. The new groups must have energy limits which are a subset of the many-group limits. We shall use \( k \) to denote the few-group energy index (and \( i \) for the \( \sigma \) position, analogous to \( h \) for the many-group set). Thus each group \( k \) will be composed of one or more of the groups \( g \) of the input \( \sigma \)'s. For example, the first of the few-group set \( (k = 1) \) might be composed of \( g = 1, 2, \) and \( 3 \) of the input many-group set. Our equations will use a simple summation sign to indicate a summation over all \( g \) in a particular \( k \) group.

**THE EQUATIONS FOR GROUP COLLAPSING**

Fission spectrum (fraction of fission neutrons out in each energy group)

\[
X_k = \sum_{g \text{ in } k} X_g = \sum X_g
\]  

(2)

Activity and fission cross sections are weighted linearly by the flux \( \phi \)

\[
\sigma_{ac}^k = \frac{\sum \phi_g \sigma_{ac}^g}{\sum \phi_g}
\]  

(3)
Transport cross section

\[ \sigma_{tr}^k = \sigma_k = \frac{\sum \phi_g}{\sum \phi_g / \sigma_g} \]  \hspace{1cm} (4)

or

\[ \sigma_k = \sum \phi_g \sigma_g / \sum \phi_g \]  \hspace{1cm} (5)

Both options (inverse and linear averaging) are available.

Transfer cross sections from group \( k' \) to group \( k \)

\[ \sigma_{k',k} = \sum_{g' \text{ in } k'} \phi_{g',k'} \sigma_{g',g} / \sum_{g \text{ in } k' \text{ and } g \text{ in } k} \phi_{g'} \]  \hspace{1cm} (6)

For the many-group set, absorption cross sections \( (\sigma_a) \) are found from Eq. (1) and are collapsed with linear averaging

\[ \sigma_a^k = \sum \phi_g \sigma_a^g / \sum \phi_g \]  \hspace{1cm} (7)

These are sufficient to define the new set. The elastic scattering \( \sigma_{kk} \) is determined from the other few-group constants by

\[ \sigma_{kk} = \sigma_k - \left( \sum_{k' \neq k} \sigma_{k,k'} \right) - \sigma_a^k \]  \hspace{1cm} (8)
For conciseness in annotating the code, we define

\[ \varphi_k = \sum \varphi_g \]  

(9)

Different cross sections may be computed for each region (i.e., core and reflector) separately, but a single velocity spectrum is used for a given problem, and this must be weighted by the total fluxes in each region. The region volumes are used as a measure of the total flux.

\[ v_k = \frac{\left( \sum_r v_r \sum \varphi_{g,r} \right)}{\left( \sum_r v_r \sum \varphi_{gr} / v_g \right)} \]  

(10)

The infinite medium fluxes \( \varphi^0 \) can be generated by

\[ (\sigma_g - \sigma_{gg}) \varphi^0_g = x_g + \sum_{g' \neq g} \sigma_{g' \rightarrow g} \varphi^0_{g'} \]  

(11)

These are solved successively from the highest energy group until groups with nonzero upscattering are reached, upon which the remaining equations are solved simultaneously.
The code is written for the Floco II assembly system* (LAMS-2339) and is intended to be fully compatible with the Floco II assembled SNG routines. The code accepts multigroup cross sections and input data on atomic composition and computes collapsed group parameters for the mixtures described for each special region. An option allows collapsing the element microscopic cross sections separately. The code will accept flux spectra as input, will compute infinite medium fluxes, or can use the flux used in the previous spacial region (mixture) regardless of its source. The volumes can be given directly or can be computed from the coordinates for planes, infinite cylinders, or spheres. The code assumes there has been sufficient size allotted to the up- and downscattering in the output groups and will stop with an on-line comment if this is not true. The many-group set is divided into a few groups, each containing one or more of the original groups according to the wishes of the user.

The input and output are printed off-line (on-line if sense switch #6 is down), and the output fission spectrum, velocities, and cross sections are punched on-line, suitable for direct inclusion in the new $S_n$ codes. (They may be used in the Floco I version of SNG by placing nine punches in columns 3 and 21.) The code will normally average $(\sigma_{tr})^{-1}$ but will

---

*This will run on the IBM 704 or IBM 7090 with the appropriate Floco II assembly program. The standard deck is for the 704; modifications for 7090 operation are discussed in a later section.
average $\sigma_{tr}$ if requested. In either case, a comment will be printed describing which was done.

CODE DETAILS

Input

The input is divided into two parts: the parameters which precede the code and the data which follow it.

The parameters determine the sizes of data storage blocks and are used in determining exits and loop lengths in the code. They consist of information on the size of the problem (e.g., number of mixtures), options such as the method of transport weighting, and the cross section table size. Parameters are put on Floco cards, following a "load parameters" pseudo-instruction (*0000000, see IAM5-2339 and example in Appendix I). There are three sets labeled P00, G00, and K00, each requiring a load parameters instruction. All are fixed point numbers. The code was designed originally to form mixture macroscopic cross sections in a manner similar to the SNG code. This requires two tables which we shall label NO and MO. The NO table contains a fixed point identification number (ID#) for each region, followed by the ID numbers of the elements in that particular region. The elements are numbered implicitly by the order in which they are input. The MO block contains the atomic densities corresponding to the elements in each region and zeros in the positions
occupied by the mixture numbers in the NO table. This is illustrated in the example (Appendix I). The lengths of the NO and MO blocks are required for input parameter P05.

One could get σ's for collapsed microscopic elements with this arrangement by placing each element in a separate region with an atom density of 1.0. However, since this is a common use of the code, an alternate way to obtain these σ's with simpler input has been built into the code. This is signaled by letting the mixture specification parameter P05 (or N) be zero. The number of regions R (P02) is put equal to the number of elements E, and P03 is input as 2E. There is no need for certain of the data blocks (NO, MO, FO), and only one set of weighting fluxes need be entered for all elements.

1. Parameters

<table>
<thead>
<tr>
<th>Position</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>P01</td>
<td>PID</td>
<td>Problem identification number.</td>
</tr>
<tr>
<td>P02</td>
<td>R</td>
<td>Number of regions (or number of elements for element calculation).</td>
</tr>
<tr>
<td>P03</td>
<td>M</td>
<td>Number of mixtures + number of elements (or twice number of elements for element calculation).</td>
</tr>
<tr>
<td>P04</td>
<td>W</td>
<td>Volume specification, described later.</td>
</tr>
<tr>
<td>P05</td>
<td>N</td>
<td>Number of mixture specifications, i.e., length of NO and MO tables (N = 0 for element calculations).</td>
</tr>
<tr>
<td>P06</td>
<td>T</td>
<td>Transport σ averaging 0 for inverse, 1 for linear average.</td>
</tr>
</tbody>
</table>
### Parameters, continued

<table>
<thead>
<tr>
<th>Position</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>G01</td>
<td>G</td>
<td>Number of input groups.</td>
</tr>
<tr>
<td>G02</td>
<td>( h_t )</td>
<td>Position of ( \sigma_{tr} ) in ( \sigma ) table.</td>
</tr>
<tr>
<td>G03</td>
<td>( h_s )</td>
<td>Position of ( \sigma_{gg} )</td>
</tr>
<tr>
<td>G04</td>
<td>( h_l )</td>
<td>Position of last ( \sigma ) in a group (number of ( \sigma )'s per group).</td>
</tr>
<tr>
<td>G05</td>
<td>U</td>
<td>Number of groups with nonzero upscattering, assumed to occur in the lowest energy groups.</td>
</tr>
<tr>
<td>K01</td>
<td>K</td>
<td>Output cross section parameters (similar to input group parameters, but may have smaller values except for ( i_t )). The equivalent of G05 is not needed.</td>
</tr>
<tr>
<td>K02</td>
<td>( i_t )</td>
<td></td>
</tr>
<tr>
<td>K03</td>
<td>( i_s )</td>
<td></td>
</tr>
<tr>
<td>K04</td>
<td>( i_l )</td>
<td></td>
</tr>
</tbody>
</table>

### W, Volume Specification

<table>
<thead>
<tr>
<th>W</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Volumes are supplied in W0 data block.</td>
</tr>
<tr>
<td>1</td>
<td>Planar distances of regions are supplied in W0 data block; code will compute volumes ( V = (r_{i+1} - r_i) ) and place them in W0 data block.</td>
</tr>
<tr>
<td>2</td>
<td>Cylindrical radii supplied in W0; code computes ( V = (r_{i+1}^2 - r_i^2) ), etc.</td>
</tr>
<tr>
<td>3</td>
<td>Spherical radii supplied; ( V = (r_{i+1}^3 - r_i^3) ), etc.</td>
</tr>
<tr>
<td>4</td>
<td>Volumes are not supplied; velocities are computed separately for each region.</td>
</tr>
</tbody>
</table>
2. Data

The data follow the code and are on Floco cards preceded by Floco "load data" pseudo-instructions (*OOOOSO). The order of the data blocks is immaterial. Binary cards (e.g., flux dumps) may be loaded behind a Floco "load data" card if they contain the data in the correct number and order. Binary card addresses will be ignored.

<table>
<thead>
<tr>
<th>Block</th>
<th>Description</th>
<th>Type</th>
<th>Number of Entries</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>Group separation, a table giving the largest value of $g$ in each output group.</td>
<td>fixed</td>
<td>$K$</td>
</tr>
<tr>
<td>FC</td>
<td>The flux source for each region</td>
<td>fixed</td>
<td>$R$</td>
</tr>
<tr>
<td></td>
<td>0 -- flux supplied</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 -- calculate = medium flux</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 -- use flux from previous region.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F2†</td>
<td>The weighting fluxes for each region.</td>
<td>floating</td>
<td>GXR</td>
</tr>
<tr>
<td>NO*</td>
<td>The mixture specifications, similar to the SNG input. For each region there is an identifying number, followed by the labels of the elements in that region.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MO*</td>
<td>The atomic densities ($10^{-24}$) of the elements in the order given in NO. Zeros in the positions corresponding to region numbers in NO serve to delimit the regions.</td>
<td>floating</td>
<td>$N$</td>
</tr>
<tr>
<td>W0</td>
<td>Volume or radius input.</td>
<td>floating</td>
<td>$R$</td>
</tr>
<tr>
<td>S0</td>
<td>Input fission neutron spectrum.</td>
<td>floating</td>
<td>$G$</td>
</tr>
<tr>
<td>V0</td>
<td>Input group velocities.</td>
<td>floating</td>
<td>$G$</td>
</tr>
</tbody>
</table>

*Can be omitted for microscopic element calculation.
†Only one set (G entries) needed for microscopic element calculation.
<table>
<thead>
<tr>
<th>Block</th>
<th>Description</th>
<th>Type</th>
<th>Number of Entries</th>
</tr>
</thead>
<tbody>
<tr>
<td>PO</td>
<td>The input (and mixture) cross section block. The elements are numbered implicitly by the order in which they are placed in the input deck. The regions are labeled by consecutive numbers beginning with E + 1, as in the DSN code. See example (Appendix I).</td>
<td>floating</td>
<td>Input = ( h_x \times G \times E )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total = ( h_x \times G \times M )</td>
</tr>
</tbody>
</table>

Output

The output includes off-line (on-line if sense switch \#6 is down) listing of all of the input blocks, descriptively labeled and of the mixture cross sections (in the PO block) and the mixture absorption cross sections. This is followed by a print of the output fission spectrum, velocities, absorption cross sections, and mixture cross sections.

The fission spectrum, velocities, and mixture cross sections for each region are punched in that order on separate cards (or blocks of cards), ready for direct insertion into the DSN code. Cards may also be used in the Floco I SNG code by putting nine punches in columns 3 and 19. Should trouble arise, one can obtain an input print by transferring manually to \((1016)_8\) and pressing start twice. One can obtain an on-line output print by setting sense switch \#6 down and transferring manually to \((1017)_8\) and pushing start twice.

When the calculation is finished, an on-line statement to that effect will be printed. Pushing start will then result in an on-line print of the storage map giving locations of all code and data blocks.
Operation

The present deck (10-30-62) has all necessary loading and transfer cards in it. The three parameter cards follow ZOT card number 001, and the data cards follow card number 076.* The ZOT deck should be preceded by an on-line identification card to identify the user on the off-line listing. ZOT card OOD calls Floco II from the Los Alamos utility tape 1, and may be replaced by a Floco II card deck.

Running time -- ≤ 1 minute per case + readin time, unless there are more than 10 upscattering groups.

Problem size -- for the 8K machine about \((4000)_{10}\) words are available for data. The largest block will be the input and mixture cross sections \((P0)\) which will be \(h_t \times G \times (E + R)\) numbers. Almost all problems can thus be done on an 8K 704.

Stops -- the only programmed stops are for the cases in which insufficient down- or upscattering has been allowed in the output groups. The code will print an on-line comment and stop. One can then transfer to \((1016)_{8}\) to obtain an input print. There is an error stop (usually insufficient space) in the matrix solver subroutine, and three possible divide checks which are described in Appendix II.

Sense switches -- setting sense switch \#6 down causes on-line printing of both input and output. An on-line print of the results can be obtained by transferring manually to \((1017)_{8}\) and pushing start twice (with sense switch \#6 down).

---

*This is a change from the earlier (9-09-59) deck.
Operation on IBM 7090

The ZOT deck (001 to 080) will work without modification on the 7090. However the appropriate Floco II assembly system must be used, and therefore the ZOT 000 card, which is an XX Floco 2 card for calling the 704 version from tape, must be replaced by the equivalent for the 7090. This is a set of two cards (2-FL2 01 and 2-FL2 02) for calling Floco from tape, or a master set of cards containing Floco for use if it is not already on the utility tape in the Los Alamos format. Note that header or identification cards follow the Floco II cards, making the deck arrangement

\[
\begin{align*}
2\text{-FL2 01} & \quad \text{Floco II, call in from Los Alamos 7090 utility tape.} \\
2\text{-FL2 02} & \\
\text{Header Card} & \quad * \text{ in column 1, followed by name, phone, etc.} \\
\text{ZOT 001} & \quad \text{Initialize} \\
& \quad \text{Input, etc., as in 704 version.}
\end{align*}
\]

RESULTS

A series of DSN transport calculations were made to investigate the accuracy of the reduced cross section sets. Few-group results are typically within 2% of the many-group results, but each new situation should be checked, especially where the spectrum changes rapidly in
space. Some typical results obtained in 1959 with $S_4$ SNG transport calculations are listed in Table I. Further calculations are presently under way to study the extent of application and the effects of varying the group spacing, the method of averaging the transport cross section, etc. For example, a 3 group calculation of the C/U = 2400 base sphere with different group aggregations (6, 11, 1) gave only 0.4% error using fluxes generated in an 18 group DTK transport code, compared to 2.5% error with the spacing (6, 6, 6) as listed in Table I. However, the (6, 11, 1) spacing with infinite medium fluxes appears to give a larger error (7%) although this result is difficult to understand and may be in error.
Table I

**Bare U\textsuperscript{235} Sphere**

<table>
<thead>
<tr>
<th># Groups*</th>
<th>Flux Source</th>
<th>Sign, % Error</th>
<th># Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>-</td>
<td>+0.53</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>SNG 6 group</td>
<td>+0.53</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>(\infty) medium</td>
<td>+0.65</td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>SNG 6 group</td>
<td>+1.03</td>
<td>19</td>
</tr>
<tr>
<td>1</td>
<td>(\infty) medium</td>
<td>+0.75</td>
<td>16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th># Groups*</th>
<th>Flux Source</th>
<th>(k_{\text{eff}})</th>
<th>Sign, % Error</th>
<th># Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>-</td>
<td>0.9700</td>
<td>-</td>
<td>119</td>
</tr>
<tr>
<td>6</td>
<td>18 group SNG</td>
<td>0.9634</td>
<td>-0.7</td>
<td>127</td>
</tr>
<tr>
<td>6</td>
<td>(\infty) medium</td>
<td>0.9778</td>
<td>+0.8</td>
<td>126</td>
</tr>
<tr>
<td>3</td>
<td>18 group SNG</td>
<td>0.9582</td>
<td>-1.15</td>
<td>136</td>
</tr>
<tr>
<td>3</td>
<td>(\infty) medium</td>
<td>0.9883</td>
<td>+1.9</td>
<td>122</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th># Groups*</th>
<th>Flux Source</th>
<th>(k_{\text{eff}})</th>
<th>Sign, % Error</th>
<th># Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>-</td>
<td>0.967</td>
<td>-</td>
<td>51</td>
</tr>
<tr>
<td>6</td>
<td>18 group SNG</td>
<td>0.934</td>
<td>-3.4</td>
<td>77</td>
</tr>
<tr>
<td>6</td>
<td>(\infty) medium</td>
<td>0.950</td>
<td>-1.7</td>
<td>75</td>
</tr>
<tr>
<td>3</td>
<td>18 group SNG</td>
<td>0.943</td>
<td>-2.5</td>
<td>111</td>
</tr>
<tr>
<td>3</td>
<td>(\infty) medium</td>
<td>0.984</td>
<td>+1.7</td>
<td>112</td>
</tr>
</tbody>
</table>

*Each of the collapsed groups contained equal numbers (3 or 6) of groups of the 18 group set.*
Appendix I

Example

Consider an $\text{H}_2\text{O}$ reflected, $\text{H}_2\text{O}$ moderated sphere, for which it is desired to reduce the Hansen-Mills 18 group cross sections to 3 groups. There are thus two regions with the following composition:

<table>
<thead>
<tr>
<th>Atom density $\times 10^{-24}$</th>
<th>Core</th>
<th>Reflector</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{H}$</td>
<td>0.0663</td>
<td>0.0668</td>
</tr>
<tr>
<td>$\text{O}$</td>
<td>0.0332</td>
<td>0.0334</td>
</tr>
<tr>
<td>$\text{U}^{235}$</td>
<td>$1.288 \times 10^{-4}$</td>
<td></td>
</tr>
</tbody>
</table>

Assume one wishes to compute the infinite medium fluxes for the core and reflector compositions to use in weighting the 18 group cross sections and that the core and reflector radii will be supplied for weighting the velocities. The three output groups are chosen to contain 6, 9, and 3 input groups, respectively, starting from the high energy end. Parameters and data for the above problem follow on Floco coding forms and are included in the ZOT decks.
<table>
<thead>
<tr>
<th>C</th>
<th>OPERATION</th>
<th>ADDRESS</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>9 * load instr.</td>
<td>P O 0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>16 G</td>
<td>2 pos.</td>
<td>* 0 6 63 N</td>
</tr>
<tr>
<td>2</td>
<td>18 G</td>
<td>2 pos.</td>
<td>0 mixture</td>
</tr>
<tr>
<td>3</td>
<td>20 G</td>
<td>3 pos.</td>
<td>* 0 3 2 2 N</td>
</tr>
<tr>
<td>4</td>
<td>22 G</td>
<td>2 pos.</td>
<td>0 mixture</td>
</tr>
<tr>
<td>5</td>
<td>24 G</td>
<td>0 # upscattering</td>
<td>0 6 68 N</td>
</tr>
<tr>
<td>6</td>
<td>26 G</td>
<td>G 0 0</td>
<td>* 0 3 3 4 M</td>
</tr>
<tr>
<td>7</td>
<td>28 G</td>
<td>G 0 0</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>9 * load instr.</td>
<td>K O 0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>14 K</td>
<td>3 pos.</td>
<td>1 fixed pt. flux</td>
</tr>
<tr>
<td>2</td>
<td>18 K</td>
<td>2 pos.</td>
<td>1 source</td>
</tr>
<tr>
<td>3</td>
<td>29 K</td>
<td>3 pos.</td>
<td>1 source</td>
</tr>
<tr>
<td>4</td>
<td>37 K</td>
<td>5 last σ_k</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>39 K</td>
<td>X 0 0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>41 K</td>
<td>G 0 0</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>9 * load data</td>
<td>C 0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>16 table of last</td>
<td>1.6 radii</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>15 g in each k</td>
<td>31 27</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>48</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>52</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>24</td>
<td>0 0</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>OPERATION</td>
<td>ADDRESS</td>
<td>REMARKS</td>
</tr>
<tr>
<td>---</td>
<td>-----------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>0</td>
<td>9 *</td>
<td>S 0</td>
<td></td>
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<tr>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>This card followed by 18 group</td>
<td>2 G</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>fission spectrum</td>
<td>3 22</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>This card followed by 18 group</td>
<td>2 G</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>velocity set</td>
<td>4 47</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>This card followed by 18 group</td>
<td>2 G</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>cross sections in the order, H, q, y</td>
<td>3 25</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix II

ZOT Code Listings and Flow Diagrams

The coding is relatively simple and straightforward except perhaps where the transfer cross sections $g_{ij}$ are involved. Flow diagrams are given for those cases and for the master or flow code. Annotated listings are given for all code blocks, as well as summaries of the data and code blocks.

Summary of Data and Code Blocks

<table>
<thead>
<tr>
<th>Data</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AO (A1)</td>
<td>Input absorption cross sections by region.</td>
</tr>
<tr>
<td>A2 (A3)</td>
<td>Output absorption cross sections by region.</td>
</tr>
<tr>
<td>C0</td>
<td>Separation of output groups.</td>
</tr>
<tr>
<td>F0</td>
<td>Flux source table.</td>
</tr>
<tr>
<td>F2 (F3)</td>
<td>Many-group flux by region.</td>
</tr>
<tr>
<td>F4 (F5)</td>
<td>Few-group flux by region.</td>
</tr>
<tr>
<td>G0</td>
<td>Table of the output group corresponding to each input group.</td>
</tr>
<tr>
<td>M0</td>
<td>Atomic density table.</td>
</tr>
<tr>
<td>ML (M2)</td>
<td>Matrix for flux with upscattering.</td>
</tr>
<tr>
<td>NO</td>
<td>Mixture composition table.</td>
</tr>
</tbody>
</table>
Data (contd.)

P0 (P1, P2)  Many-group cross sections by element and mixture.
Q0 (Q1, Q2)  Output cross sections by mixture.
V0          Many-group velocities.
V1          Few-group velocities average over volume.
V2 (V3)     Few-group velocities for each region.
W0          Volume or radius table.

Code

801  Flow code (master code).
803  Data assignment.
804  Form mixture σ's.
805  Calculate many-group fluxes, \( \phi^g \).
806  Set region addresses.
807  Calculate many-group absorption \( \sigma^g_a \).
810  Calculate transfer cross sections \( \sigma^g_{kk'} \).
811  Collapse cross sections \( \sigma_{ac}, \ \nu \sigma_f, \ \sigma_{tr}, \ \sigma_a \).
812  Calculate few-group self-scattering \( \sigma_{kk} \).
813  Generate code constants.
814  Calculate fission spectrum \( \chi_k^f \).
815  Calculate velocities.
816  Input print.
817  Output print and punch.
Code (contd.)

822 Place element σ's in region blocks.
823 Set flux for element calculation.
843 - 867 and 871 Print remarks and headings.
870 Matrix solver subroutine LA-885.

Use of Temporary Storage Block TOO

T01-T07 Temporary use only.
T10 \( \sigma_t^g \) region base address and region index in decrement.
T11 \( \phi_g \) region base address.
T12 \( \sigma_t^k \) region base address.
T13 \( \phi_k \) region base address.
T14 \( v_k \) region base address.
T15 \( \sigma_a \) region base address.
T16 \( \sigma_a \) region base address.
T17 Not used.
T20 \( h_s - h_l \)
T21 # elements
T22 \( h_s - h_t - l \)
T23 \( h_s - h_t \)
T24 \( h_t + l \)
T25 \( i_t + l \)
## Error Stops

### Location

<table>
<thead>
<tr>
<th>Octal</th>
<th>Region</th>
<th>Symbolic</th>
<th>Type</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>5314</td>
<td>805</td>
<td>X47</td>
<td>divide check</td>
<td>$\sigma_g - \sigma_{gg} = 0$. Not allowed in calculating flux.</td>
</tr>
<tr>
<td>5427</td>
<td>805</td>
<td>Y62</td>
<td>halt</td>
<td>Matrix error. Stop, check size.</td>
</tr>
<tr>
<td>5461</td>
<td>805</td>
<td>Z14</td>
<td>divide check</td>
<td>$\varphi_k = \sum \varphi_g = 0$. Check flux input.</td>
</tr>
<tr>
<td>5617</td>
<td>810</td>
<td>X46</td>
<td>halt</td>
<td>Too few upscattering cross sections allowed in output (on-line print).</td>
</tr>
<tr>
<td>5674</td>
<td>810</td>
<td>X53</td>
<td>halt</td>
<td>Too few downscattering cross sections allowed in output (on-line print).</td>
</tr>
<tr>
<td>6304</td>
<td>815</td>
<td>X50</td>
<td>divide check</td>
<td>$\sum V_r v_k^F = 0$. Check volume and velocity inputs.</td>
</tr>
</tbody>
</table>

### ZOT Deck

- **XX Floco 2**
  - Floco II tape calling card.
- **ZOT 000**
  - Initialize, allow space for parameters.
- **Input**
  - Parameters P00, G00, K00 cards.
- **ZOT 002**
  - Assigns temporary storage T00, 308 spaces.
- **003**
  - Assigns formula space 1008 for 801, 15008 for 804, 508 for 803, and 4208 for 870.
- **004 to 025**
  - Remarks for printing headings.

-30-
ZOT Deck, continued

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>026</td>
<td>Load data assign code (803).</td>
</tr>
<tr>
<td>027, 028</td>
<td>Data assign code (symbolic binary).</td>
</tr>
<tr>
<td>029</td>
<td>Execute data assign code.</td>
</tr>
<tr>
<td>030</td>
<td>Load matrix solver (870).</td>
</tr>
<tr>
<td>031 - 041</td>
<td>Matrix solver (binary).</td>
</tr>
<tr>
<td>042</td>
<td>Load formulas 804 to 823.</td>
</tr>
<tr>
<td>043 - 073</td>
<td>Formulas in symbolic binary.</td>
</tr>
<tr>
<td>074</td>
<td>Load flow code 801.</td>
</tr>
<tr>
<td>75, 76</td>
<td>Flow code.</td>
</tr>
<tr>
<td>Input</td>
<td>Data.</td>
</tr>
<tr>
<td>77</td>
<td>Transfer to flow code.</td>
</tr>
<tr>
<td>78, 79</td>
<td>Blank.</td>
</tr>
</tbody>
</table>
801 FLOW CODE

Print input 816
Generate code constants 813
Calc. \( X_k \) 814

**Element calc.1**

- **YES**
  - Place element \( \sigma \)'s in region blocks 823
  - Form mixture \( \sigma \)'s 804

- **NO**
  - Print input and mixture \( \sigma \)'s

Set region index
Save index

Set region constants 806

**Element calc.2**

- **YES**
  - Set fluxes 822
  - Calc. fluxes 805

- **NO**
  - Calc. \( \varphi \) 807

Calc. \( \sigma_{k} \), \( \beta_{x} \), \( \alpha_{x} \), \( \gamma_{x} \), 811
Calc. \( \sigma_{k \to k} \) 810
Calc. \( \sigma_{x} \) 812

Advance region index

**All regions done?**

- **YES**
  - Calc. \( v_{x} \) 815
  - Output 817
  - PRINT CONCLUSION
  - STOP
  - PRINT STORAGE MAP

- **NO**

**STOP**

-32-
SIO $g', \overline{g}$ COLLAPSE

1. $l \rightarrow g$ (index 2)
   - Set addresses
   - Save $g$
   - Set addresses
   - $k^* \rightarrow$ index $k$
   - Set addresses
   - $h_t \rightarrow l \rightarrow h$ (index 1)
   - Set decrement on $h$
   - $g + h_n \rightarrow g$
   - $g + h_n - h \leq 0$
     - NO
     - Set decrement on $h$
   - $g' = g + h_n - h$
   - $g' > GT$
     - YES
     - $k' = k$
   - NO
   - $i = k - k' + 1$ (index 4)
     - $i > i_k$
       - YES
       - ON-LINE PRINT STOP
     - NO
     - $i < i_k$
       - YES
       - ON-LINE PRINT STOP
     - NO

$g' \overline{g'} \sum \rightarrow \sum$
- Restore $g$

$k_g$ is the output group corresponding to an input group $g$. 

-34-
X00 8 Bu1
X01 TSX4816
X02 TSX4813
X03 TSX4814
X04 CLA PC6
X05 TFE X11
X06 TSX6974
X07 *47000846
X10 TRA X13
X11 TSX4974
X12 40C00846
X13 CLA PC5
X14 TRA X17
X15 TSX4822
X16 TRA X20
X17 TSX48C4
X20 TSX4974
X21 00000861
X22 40000PC
X23 LXA24C1
X24 X0D21C
X25 TSX48C6
X26 CLA PC5
X27 TRA X32
X30 TSX4823
X31 TRA X35
X32 CLA2FC
X33 TZE X35
X34 TSX48C5
X35 TSX48C7
X36 TSX4811
X37 TSX4810
X40 TSX4812
X41 LX2D210
X42 10012X43
X43 TPE22X24
X44 TSX4815
X45 TSX4817
X46 HPR
X47 TSX4976
X50 4801

FLOW CODE

Linear $\sigma_{tr}$?

NO

Element calc.?
Transfer on "no".

Print input and mixture sigmas.

l $\rightarrow$ region index.
Save.

Element calc.?

NO

Fluxes supplied?
Transfer on "yes".
Calc. flux.

$\sigma_{tr}$, $\sigma_{tr}$, $\sigma_k$

$\sigma_k$, $\rightarrow k$

All regions done?

Normal program stop.
Print storage map.

Transfer to flow code.
X00 8 RC4
X01 LXA14C1
X02 CLA1NC
X03 STA TC1
X04 CLA1PC
X05 TNZ X14
X06 LXA2T01
X07 CLA PGC
X10 SUB2P2
X11 STA X26
X12 STA X27
X13 TRA X31
X14 STC TC2
X15 LXA4TC1
X16 CLA P0*
X17 SUB4P2
X20 STA X24
X21 LXA2402
X22 CLA2P2
X23 PAX2
X24 LCO2CCO
X25 FMP T02
X26 FAC2CC
X27 STO20CC
X30 20012X24
X31 10011X32
X32 7P051X02
X33 LXD4457
X34 TRA4001

FORM MIXTURE e's
1 \rightarrow 1
N_i \leftarrow
N_i atom density.

N_i \rightarrow j
Set address
for region sigmas.

N_i \rightarrow \text{index.}
Set address.

Put h_i x G
in index.

Form M_i x a.

Advance i.
X00 8 805
X01 SUB 4C1
X02 TNZ Z21
X03 CLA T11
X04 STA X42
X05 STA X50
X06 CLA GC1
X07 SUB GC5
X10 ALS 022
X11 STD X52
X12 LXA1401
X13 CLA T10
X14 SUB1P1
X15 STA X37
X16 SUB GC2
X17 STA X23
X20 ACD GC2
X21 SUB GC3
X22 STA X24
X23 CLA GCC
X24 FSR GCC
X25 STO TC3
X26 CLAISO
X27 STO T02
X30 SXD1TC1
X31 LX021C1
X32 20012X34
X33 TRA X46
X34 LXX4GC3
X35 1CO14X36
X36 GO04X46
X37 CLA40CC
X40 TZE X46
X41 LRS 043
X42 FMP2CC0
X43 FAD T02
X44 STO TC2
X45 20012X35
X46 CLA TC2
X47 FCH TC3
X50 STQ1000
X51 10011X52
X52 T0CO1X13
X53 CLA GC5
X54 TZE 201
X55 CLA T11
X56 STA Y35
X57 STA Y77
X60 STI T04
X61 LXD1T04
X62 ICO11X63
X63 CLA N1
X64 SLB1W2
X65 STA Y10
X66 STA Y23
X67 STA Y24

CALCULATE FLUXES

Use flux from previous region?

NO, calc. flux.

\( \sigma_{\text{base}} \)

\( \sigma(g) \text{ base.} \)

\( \sigma_g \)

\( \sigma_{gb} \)

\( \sigma_g - \sigma_{gb} \)

\( g \to \text{index 2.} \)

\( g' = g - 1 \)

\( g' = 0 \)

\( h_\text{h} \to h \)

\( h > h_f? \)

\( \text{NO, } \sigma_g \to g \)

\( g' \to g = \text{OT NO} \)

\( \sum \sigma_g' \sigma_g' g \)

\( \sum \sigma_{g'} \sigma_{g'} g' \)

\( g' = 1 \to g', g' = \text{OT} \)

\( \sum \sigma_{g'} \sigma_{g'} g' \)

\( g + 1 \to g \)

\( g < G_d? \)

\( \text{NO} \)

\( \text{Upscattering present?} \)

\( \text{YES} \)

\( \text{Set up matrix solution.} \)

\( j = 0 \)

\( \text{Save } j. \)

\( \text{Set addresses on } j. \)
\[ X70 \text{ SUB GC5} \]
\[ X71 \text{ SUB 4C1} \]
\[ X72 \text{ STA Y12} \]
\[ X73 \text{ STA Y36} \]
\[ X74 \text{ STA Y37} \]
\[ X75 \text{ SXD1T04} \]
\[ X76 \text{ LXDT2T04} \]
\[ X77 \text{ TO002YCO} \]
\[ Y00 \text{ SXD1T05} \]
\[ Y01 \text{ 3GO12Z32} \]
\[ Y02 \text{ CLA T1C} \]
\[ Y03 \text{ SUBP1} \]
\[ Y04 \text{ STA Y07} \]
\[ Y05 \text{ STA Y15} \]
\[ Y06 \text{ LXAGGC2} \]
\[ Y07 \text{ CLAAGCC} \]
\[ Y10 \text{ STO1CG0} \]
\[ Y11 \text{ CLA2SC} \]
\[ Y12 \text{ STO CCO} \]
\[ Y13 \text{ 1CC14Y14} \]
\[ Y14 \text{ 3G044X61} \]
\[ Y15 \text{ CLA44CC0} \]
\[ Y16 \text{ STO TCI} \]
\[ Y17 \text{ SXD4Y21} \]
\[ Y20 \text{ LGC31Y21} \]
\[ Y21 \text{ 6GO01Y27} \]
\[ Y22 \text{ TRA Z34} \]
\[ Y23 \text{ FAD10CC} \]
\[ Y24 \text{ STO10CC} \]
\[ Y25 \text{ LXDT1T04} \]
\[ Y26 \text{ TRA Y13} \]
\[ Y27 \text{ LXDT2T05} \]
\[ Y30 \text{ SXD4Y32} \]
\[ Y31 \text{ LGG32Y32} \]
\[ Y32 \text{ GGO2X61} \]
\[ Y33 \text{ LXDT1T04} \]
\[ Y34 \text{ LFO TCI} \]
\[ Y35 \text{ FAO 000} \]
\[ Y36 \text{ FAD 000} \]
\[ Y37 \text{ STO CCO} \]
\[ Y40 \text{ TRA Y13} \]
\[ Y41 \text{ ARS 001} \]
\[ Y42 \text{ STD Y57} \]
\[ Y43 \text{ ARS C21} \]
\[ Y44 \text{ CLA} \]
\[ Y45 \text{ ADD M1} \]
\[ Y46 \text{ STA Y64} \]
\[ Y47 \text{ LXAI401} \]
\[ Y50 \text{ LXDT2M2} \]
\[ Y51 \text{ CLA1401} \]
\[ Y52 \text{ LFO2M1} \]
\[ Y53 \text{ STO2M1} \]
\[ Y54 \text{ STO1M1} \]
\[ Y55 \text{ 2GO12Y56} \]
\[ Y56 \text{ 1GO11Y57} \]

**Index**: 2.

\[ g = g + M_{i,j} \]

Save \( g^* \).

\[ g > G? \text{ Exit of matrix set.} \]

\[ h = h_{tr} \]

\[ g_{i,j} \rightarrow g \]

Index \( i = j + h_8 \)

\[ g_{i,j} = h_{g} - h \]

\[ g_{i,j} < G? \text{ from } 235 \]

\[ g_{i,j} + M_{i,j} \rightarrow M_{i,j} \]

Restore \( j \).

\[ g \rightarrow \text{ index 2}. \]

\[ g + h_8 \]

\[ g + h_8 - h = g' < G? \text{ NO, restore } j \].

\[ g_{i,j} g_{i,j} \rightarrow g + M_{i+1,j} \rightarrow M_{i+1,j} \]

From 235.

Store matrix to agree with subroutine input requirements.

-38-
X00 8C6  SET REGION ADDRESSES
X01 LX6D210  r → index 2.
X02 CLA F2*  *φg base address.
X03 SUB2F3  φg base address.
X04 STA T11  φg base address.
X05 PX02
X06 PCX4
X07 1T214X10  r + E → index 4.
X10 CLA PO*  φg base address.
X11 SUB4P2  φg base address.
X12 STA T10
X14 CLA F4*  *φk base address.
X14 SUB2F5
X15 STA T13  φkr
X16 CLA Q0*  φk
X17 SUB2Q2
X20 STA T12  φkr
X21 CLA V2*  *φk
X22 SUB2V3
X23 STA T14  *φk
X24 CLA A0*  *φa(φ)
X25 SUB2A1
X26 STA T15  *φar(φ)
X27 CLA A2*  *φa(k)
X30 SUB2A3
X31 STA T16  *φar(k)
X32 LX64457
X33 TRA 4001
X34 80002X04
X35 CLA T21
X36 ALS 022
X37 STD X07  } Patch to
X40 TRA X05  get E in
decrement.

-40-
X00 8 807  CALCULATE $g'$
X01 CLA T15  $g'_{sa}$ address base.
X02 STA X16
X03 STA X17 
X04 STA X33
X05 STA X34
X06 LXA24C1  $l \rightarrow g$
X07 SX02T01  Save $g$.
X10  CLA T10  
X11 SUB2P1  $s(g,r)$ address.
X12 STA X31
X13 SUB G02
X14 STA X16
X15 CLA 000
X16 FAD2000  $g'_{sa} + g'_{sa} + g'_{sa}$ 
X17 ST02000
X20 LXA1T24  $h_{sa} + 1 \rightarrow h$
X21 SX01X23  $i \rightarrow dec.$
X22 LC32X23  $g + h_{sa}$
X23 6000?X37  $g + h_{sa} \rightarrow h = g'_{sa}$
X24 PX02
X25 ARS. 022
X26 SUB U01  $g'_{sa} \rightarrow G$
X27 TZE X31  $g'_{sa} = G$
X30 TPL X35  $NO, g'_{sa} \geq G$
X31 CLS1000  $NO g'_{sa}$
X32 TZE X35  $= G$
X33 FAD2000  $NO g'_{sa} \rightarrow g'_{sa} \rightarrow G$
X34 ST02000
X35 10011X36  $h + 1 \rightarrow h$
X36 7GO4X43  $h \leq h_{sa}$
X37 LXD2T01  Restore $g$.
X40 10012X41  $g + 1 \rightarrow g$
X41 7GO12X07  $g < G$
X42 TRA4001  Return to flow code.
X43 LXD2T01  Restore $g$.
X44 TRA X21
X00 8 810  
X01 LX4A401  
X02 TNO X04  
X03 TRA XC4  
X04 CLA T11  
X05 STA X63  
X06 STZ T01  
X07 STZ TC2  
X10 CLA T13  
X11 STA X64  
X12 SXD2TC1  
X13 CLA T10  
X14 SLB2P1  
X15 STA X62  
X16 CLA2G0  
X17 STO TC2  
X20 LX4A4T02  
X21 CLA T12  
X22 SUB4Q1  
X23 STA X71  
X24 STA X73  
X25 STA T30  
X26 LX4A1T24  
X27 SX01X31  
X30 LG032X31  
X31 60002X77  
X32 3GC12X74  
X33 CLA2G0  
X34 STO TC3  
X35 SUB TC2  
X36 TZE X74  
X37 CHS  
X40 ADD KC3  
X41 STO T04  
X42 LX4A4T04  
X43 3K024X47  
X44 TSX4975  
X45 4G000847  
X46 HTR Y02  
X47 3K044X51  
X50 TRA X54  
X51 TSX4975  
X52 4G000846  
X53 HTR YC2  
X54 CLA T04  
X55 NOP  
X56 NOP  
X57 NOP  
X60 STO TC4  
X61 LX4A4T03  
X62 L0Q1000  
X63 FDP2000  
X64 FDP4000  
X65 STG T07  
X66 CLA TC7  
X67 NOP  

-42-
X70  LXA4TC4  Restore i.
X71  FAD40C0  \( g' \to g' \to g \div k \)
X72  NOP
X73  ST040C0  \( gk' \to k \)
X74  LX02TC1  Restore g.
X75  10011X76  \( h + 1 \to h \)
X76  TGC41X27  \( h < h_g \)
X77  LX02T01  Restore g.

Y00  10012YC1  \( g + 1 \to g \)
Y01  7GC12X12  \( g > G \) \( \text{NO} \)
Y02  LX04457  Return to flow code.
Y03  TRA4C01
X00 811 CALCULATE $\sigma_{kr}$, $\nu_k$, $\nu_r$, $\sigma_{\nu_k}$
X01 LXA24C1 $l \rightarrow g$
X02 LXA1401 $l \rightarrow k$
X03 CLAIC0
X04 ALS 022
X05 STD Y07
X06 CLA T13 Set addresses.
X07 STA X42
X10 STA X43
X11 STA Y24
X12 STA Y31
X13 STA Y33
X14 STA Y40
X15 CLA T14 $\nu_r$
X16 STA X50
X17 STA X51
X20 CLA T15 $\sigma_{\nu r}$
X21 STA X52
X22 CLA T16 $\sigma_r$
X23 STA X54
X24 STA X55
X25 STA Y23
X26 STA Y25
X27 CLA T11 $\nu_r$
X30 STA X40
X31 CLA T12 $\sigma_r$ base.
X32 SUB101
X33 STA Y02
X34 STA Y03
X35 SUB K02
X36 STA X75
X37 STA X76
X40 CLA20C0
X41 STO TC1 $\varphi_r$
X42 FAD10C0 $\varphi = \sum \varphi_r$
X43 STO1000
X44 CLA T01
X45 FDP2VC $\varphi g / \nu g$
X46 STQ T07
X47 CLA T07
X50 FAD10C0 $\varphi = \sum \varphi_r / \nu g$
X51 STO1000
X52 LEO2000 $\sigma_{\nu r}$
X53 FMP T01
X54 FAD10C0
X55 STO1000
X56 CLA T10
X57 SUB2P1 $\sigma r$ base.
X60 STA YC0
X61 SUB GC2
X62 STA X67 $\sigma_{\nu r}$ base.
X63 STA X72
X64 CLA PC6 Linear $\sigma_{\nu r}$? 
X65 TZE X71
X66 LOQ T01 YES
X67 FMP GC0 $\sigma g \sigma_{\nu r}$

-44-
Inverse $\sigma_{tr}$

$$\sum \phi_{G} \sigma_{E}^{F} \phi_{R}^{G} \sum \phi_{G} \sigma_{E}^{F} \phi_{R}^{G}$$

1. $l \rightarrow \text{index i, } l$ for $\sigma_{ac}(i)$.

2. $k + 1 \rightarrow k$

3. $l \rightarrow k$

4. $\phi_{E}$ base.

5. $\phi_{tr}$ base.

6. $\phi_{k} = \sum \phi_{E} \sigma_{a}^{G} \phi_{k}^{E}$

7. Linear $\sigma_{tr}$

8. $\sum \phi_{E} \sigma_{tr}^{G}$

9. Inverse $\sigma_{tr} = \phi_{k} / \sum \phi_{E} / \phi_{tr}^{G}$

10. $i + 1 \rightarrow i$ or $i + 1 \rightarrow i$

11. $k + 1 \rightarrow k$

12. $k > k_{t}$

13. Return to flow code.

Dec. - $l \rightarrow$ dec. of Y05.

Dec. - $l \rightarrow$ dec. of Y43.
X00 8 812 \( \sigma_{lk} \) CALC.
X01 STZ 1C1 \( \sigma_k \) address.
X02 CLA 16 \( \sigma_a \) address.
X03 STA X20
X04 LXA2+C1 \( i \rightarrow k \)
X05 SXD2TC1 Save \( k \).
X06 CLA 112
X07 SUB2G1
X10 STA X42 \( \sigma_k \) address.
X11 SUB K02 \( \sigma_a \) address.
X12 STA X17
X13 ACD X02
X14 SUB KC3
X15 STA X21 \( \sigma_{kk} \) address.
X16 STA X22
X17 CLA 000 \( \sigma_k \)
X20 FS82000 \( \sigma_k - \sigma_a \)
X21 RAD 000 \( +\sigma_{kk} \)
X22 STO 000 \( \rightarrow \sigma_{kk} \)
X23 LXA1T25 \( i \rightarrow k \)
X24 LXO2TC1 \( \) Restore \( k \).
X25 SX01X27
X26 1K032X27 \( k \) + i
X27 6C002X51 \( k \) + i - i = \( k' \)
X30 3X012X47 \( k' \leq k ? \)
X31 CLM NO
X32 PXD2
X33 SUB TC1
X34 TZE X47 \( k' = k ? \)
X35 CLA 112 NO,
X36 SUB2G1
X37 SUB K03
X40 STA X44
X41 STA X45
X42 CLS1CC0 \( \sigma_{kk} \)
X43 NOP \( +\sigma_{kk} \)
X44 RAD 000 \( \rightarrow \sigma_{kk} \)
X45 STO 6CC
X46 NOP
X47 10011X50 \( i + 1 \rightarrow i \)
X50 7K041X24 \( i > i' ? \) NO
X51 LXO2TC1 \( \) YES, restore \( k \).
X52 10012X53 \( k + 1 \rightarrow k \)
X53 7K012X05 \( k > K ? \) NO
X54 LX04457 \( \) YES, return to flow code.
X55 TRA4C1

-46-
GENERATE CODE CONSTANTS

X00 8 813
X01 LXA24C1
X02 LXA1401
X03 CLA 4G1
X04 STO T01
X05 CLA1CC
X06 ALS 022
X07 STO X13

X10 CLA TC1
X11 STO2G0
X12 10012X13
X13 70002X11
X14 ADD 4C1
X15 10011X16
X16 .7X011X04
X17 CLA 604

X20 SUB 803
X21 STO T20
X22 CLA P03
X23 SUB PG2
X24 STO T21
X25 CLA 603
X26 SUB 802
X27 STO T23
X30 SUB 401
X31 STO T22
X32 CLA GC2
X33 ADD 401
X34 STO T24
X35 CLA KD2
X36 ADD 4C1
X37 STO T25
X40 TRA4001

Form a table of k corresponding to each g.

-47-
x00 8 814 CALC. \( \chi_l \) (fission spectrum)
x01 LXA2401 \( l \rightarrow \text{index 2} \)
x02 LXA14C1 \( l \rightarrow \text{index 1} \)
x03 CLAQ10 \( \text{Group limits} \)
x04 ALS O22
x05 STD X12
x06 CLA25C
x07 FAD151

\[ \chi_k = \sum_{n} \chi_n \]

x10 STD1S1
x11 10012X12
x12 7C002X06
x13 10011X14
x14 7KQ01X03
x15 TRA4001
X00  0  815       CALC. \( v_k \)
X01  CLA PC4       Volume specification \( W \).
X02  SUB 464
X03  TBE X54       \( W = 4 \), calc. \( v \) for each region.
X04  CLA PC4
X05  TBE X24       \( W = 0 \), volumes supplied.
X06  LXA24L1      Generate volumes, \( l \rightarrow 2 \).
X07  STZ 102

X10  LXA1P04       \( n \rightarrow \text{index } l = 1 \) (region index).
X11  LCO 421       1.0
X12  FMP2W0
X13  LRS 043
X14  20011X12
X15  STO T01
X16  FSB T02
X17  STO2W0

X20  CLA T01
X21  STO T02
X22  10012X23       \( r_1 \rightarrow r_1 - 1 \)
X23  7P022X10

X24  LXA1K01       \( k \rightarrow k \) (index 1).
X25  LXA2P02       \( R \rightarrow \text{index } 2 \).
X26  STZ TC1
X27  STZ T02

X30  CLA F4*       \( \phi \) base address.
X31  SUB2F5
X32  STA X33
X33  LCO1000
X34  FMP2W0
X35  FAD T01
X36  STO T01
X37  CLA V2*       \( v \) base.
X40  SUB2Y3
X41  STA X42
X42  LCO1000
X43  FMP2W0
X44  FAD T02
X45  STO TC2
X46  20012X30       Regions done.
X47  CLA T01

X50  FDM TC2       \( \psi_k \).
X51  STQ1V1
X52  20011X25       \( k - 1 \rightarrow k \)
X53  TRA4001       Calc. done, return to flow code.
X54  LDQ XC1       \( v_k \) for each region.
X55  MPY P02
X56  STQ T01
X57  LXA1T01       \( R \times K \) in index 1.

X60  CLA1F4
X61  FDP1V2
X62  STQ1V2
X63  20011X60       \( \psi_k / \sum \psi_i / v_i \)
X64  TRA4001       Return to flow code.
X65  80002X15       Patch, LRS not reliable.
X66  STQ T01
X67  CLA T01
X70  TRA X16

-49-
X00 8 816
X01 THX4974
X02 00000850
X03 00000851
X04 00000852
X05 00061PC0
X06 00000853
X07 00051G00
X10 00000854
X11 00051K00
X12 00000855
X13 0000050
X14 00000VC0
X15 000000CO
X16 00000N0
X17 00000FO
X20 00000856
X21 000COF0
X22 00000WO
X23 00000R7
X24 40000F2
X25 LX04457
X26 TRA4001

INPUT PRINT

Parameters.

Fission spectrum.

Velocities.

Few-group spacing.

Elements for mixtures.

Atom densities.

Flux source.

Volumes or radii.

Flux input.

Return.
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<td>TRA4001</td>
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PLACE ELEMENTS IN REGION BLOCKS

X00 8  822
X01  LXA2P02  E \to index 2.
X02  I0C12X03  E + 1
X03  _CLA_PQs_
X04  STA X11  PO block address.
X05  SUB2P2
X06  STA X12  PO - h_{ij} \times G \times E
X07  CLA2P2
X10  _PAX1_  D_{ij} \times G \times E in index l = i.
X11  CLA1000  \sigma' element.
X12  STO1000  \sigma . region.
X13  70011X11  i - l \rightarrow i
X14  TRA4Q01  Return
X00 B 823
X01 LXD2T10  r = 12
X02 70012X13  If yes, flux supplied, exit.
X03 CLA T11  NO
X04 STA X11  Set φ address.
X05 AND C61
X06 STA X10  φ_{F-1} address.
X07 LXA1601  g \rightarrow g
X10 CLA1000C  \text{Place } \phi \rightarrow \phi_{F-1}
X11 ST01000
X12 20011X10  g - 1 \rightarrow g
X13 TRA4001  g = 0, return.
X14 B 801