AUSTRALIAN ATOMIC ENERGY COMMISSION

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MULGA – A COMPLEX OF CODES FOR THE DETERMINATION OF MULTIGROUP AVERAGED NEUTRON CROSS SECTION DATA

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ABSTRACT

A complex of computer programmes called MULGA is described which will produce multigroup cross sections in a format suitable for input into a selection of reactor codes. Always bearing in mind that the spatial variation of flux will frustrate any determination of "exact" cross sections the maximum accuracy has been striven for within the limitations of urgency and feasibility.

The programmes, together with an associated microscopic data library tape, and a specialised monitor system, have been coded for an IBM 1620 computer with 4 magnetic tapes. The basic programmes MULGA 1 and MULGA 2 have already been adapted for an IBM 7090 and the whole series will be modified for the new site computer in 1964.

CONTENTS

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CONTENTS (continued)

1. INTRODUCTION

Efficient use of multigroup neutron diffusion and transport codes for the study of the high temperature gas-cooled reactor concept is hampered by the lack of dependable group cross section data. Few group sets are oriented towards calculations on specific systems and the use of an excessively large number of groups wastes machine time. Added to this there is little information in the literature on the best choice of group boundaries or even on a reasonable criterion for the number of groups required to give a specified accuracy. The subject is covered by Hansen and Roach (1961), Yiftah et al. (1960), and Argonne National Laboratory (1963).

Confronted with various sets of multigroup cross sections not designed for the intermediate thermal BeO systems being studied by the Australian Atomic Energy Commission, we initiated an extensive investigation into the whole question.

The immediate requirement is reliable numbers for use in a variety of calculations. Continued study will then be directed towards determining a balance between the minimum number of multigroup cross section sets and the minimum number of groups required to calculate reactivity to a reasonable accuracy within the limitations imposed by the microscopic cross section data.

Towards satisfying the twofold objective of immediate utility and ultimate understanding we have written the MULGA programmes. They are being used for the study of the dependence of k_{eff} on the number and position of group boundaries and the effect of the choice of the spectrum for obtaining the group cross sections in the reflector. Work on temperature coefficients in bare and reflected systems is also in hand although an auxiliary calculation of the Doppler coefficient for the fertile material is required at this stage.

When obtaining a neutron energy spectrum for group averaging it must be borne in mind that for energies where the spatial variation of spectrum is unimportant it will be advantageous to determine a spectrum as near as possible to that in the actual reactor system under study, since fewer groups will then be needed in this energy range. However, for energy ranges where the spatial variation of the spectrum is appreciable we will have to account for the variation by taking closer group boundaries and therefore will gain little from excessive accuracy in the initial calculation.

Another important consideration is that the systems to be studied in the H.T.G.C.R. project as outlined by Roberts (1963), are all moderated by beryllia so that the major features of this moderator should be included in the spectrum calculation. Added complications arise from the decision to obtain a thorough understanding of the Pu–Th cycle preparatory to a comparison with uranium fuelled systems.

Most of the important spatial spectrum changes will take place at or near thermal energies. For this reason it seems unrealistic to strive for too high an accuracy for the first approximation to the thermal and epithermal spectra since there will be variations that cannot be included in a single spectrum calculation and the number of groups will have to be sufficiently numerous to allow for these unaccountable effects. However, we can allow for some major features of the systems such as spectrum hardening and the absorption by the 0.3 eV resonance of plutonium, when this isotope is present in the system. The inclusion of these effects should help to reduce the number of groups required.

Spatial variation of the spectrum above the epithermal region should not be so important and a more precise spectrum calculation is worthwhile, particularly at high energies where the beryllium (n,2n) reaction and some oxygen resonances occur.

1.1 Outline of the Codes

MULGA 1 is a space independent spectrum calculation and produces a flux at lethargy intervals of 0.1 from 0 to 23 where zero lethargy corresponds to 10 MeV. It also produces resonance fission emission and resonance absorption probabilities, certain reaction rates to give a check on the neutron balance, and a k_{eff} which is not meant to be any more than a rough estimate.

MULGA 2 produces multigroup cross sections for almost any selection of groups by averaging a library of microscopic data taken from the A.A.E.C. nuclear data card library (Doherty 1963a) given at 0.1 lethargy units, over the corresponding MULGA 1 Spectrum.

The group averaging process is mainly straightforward evaluation of reaction rates but special consideration has been given to transfer cross sections, the beryllium (n,2n) reaction, resonance reactions, and inelastic scattering.

MULGA 3 has been written to automate the process of obtaining multigroup input data for the various codes being used for production runs. Accepting the output of MULGA 2 this programme then produces a deck of cards in the correct order and format for input into either Carlson DSN (Carlson et al. 1960), DSN FORTRAN (Clancy and Scott, 1963) or CRAM (Hassitt 1962) with the possibility of including further programme blocks for other codes. A special input-output routine has been incorporated in the programme to cope with those codes which do not have normal FORTRAN input.

By using MULGA 4 a set of group averaged cross sections obtained by MULGA 2 can be condensed to fewer groups having their boundaries as a subset of the original. The process is by straightforward averaging.

MULGA 5 converts the MULGA 1 tape output into a format suitable for the E.A.T. variplotter (1100-E).

MULGA 6 was found desirable because MULGA 2 will only produce group averaged cross sections for those nuclides present in the original MULGA 1 spectrum calculation. MULGA 6 is not so restricted. In particular, MULGA 6 is used to compute group averaged cross sections from discrete lethargy cross section tabulations or from previously compiled group data with different lethargy boundaries. Averaging is performed over a chosen MULGA 1 output spectrum which is assumed to be unperturbed by the presence of the material for which the cross sections are being averaged.

The information for the MULGA library tape is obtained from the A.A.E.C. nuclear data card library. Considerations of computer time and storage have limited the number of nuclides available in a single run of the MULGA programmes to nine. The original library tape contains the nuclides Be9, O16, Th232, U233, U235, U238, Pu239, Pu240 and a 1 barn 1/v absorber.

MULGA 0 and MULGA 7 are used to cover a larger range of fuel systems, provision being made for nuclide changes in the library subject to the conventions outlined in Section 8.1. Microscopic cross sections from the nuclear data card library must be entered at the card reader; the information will be interpolated and transferred to tape by the programme MULGA 0. Once the nuclide is present on one tape the programme MULGA 7 may be used to transfer the information to any other tape with a changed nuclide position if the latter is required. It is hoped that the use of these programmes will offset the disadvantage of having only nine nuclides present in any MULGA library and make the MULGA codes sufficiently flexible to handle most core survey calculations.

The MULGA monitor controls a collection of MULGA runs by means of "load" and "control" cards. It uses a tape monitor system which allows any programme to be called into core from magnetic tape, and effects the tape editing required for a series of programme runs without operator intervention. The monitor is not available for the IBM 7090 but MULGA 1 and MULGA 2 are available in a single programme written entirely in FORTRAN II.

1.2 Future Extensions of the Codes

A number of extensions and improvements to the MULGA system are under consideration but it has been decided to postpone any amendments until 1964. The proposed installation of a larger computer at the Research Establishment late in 1964 will afford us the opportunity to rewrite the whole MULGA series which will be modified in accordance with the experience gained from the current version.

The deficiencies already noted are:

(i) There is no allowance for crystal binding in the spectrum calculation of MULGA 1. This could be overcome by a modification of the average logarithmic energy decrement.

(ii) The transfer coefficients are calculated by MULGA 2 from the free gas kernel and extensions to other models are desirable.

(iii) For resolved resonances above 454 eV and for all unresolved resonances there is no allowance for the Doppler coefficient. Although this is of little consequence for the spectrum calculation in MULGA 1 there is a need for some allowance for temperature variation in the group averaged cross sections obtained in MULGA 2.

(iv) Self shielding for fertile and fissile material dispersed as small particles is only included very roughly and some refinement is needed.

(v) MULGA 6 cannot deal with resonance absorbers.

2. MULGA 1

2.1 Method

The calculation of the neutron flux spectrum over the whole lethargy range 0 to 23.0, requires a division into 3 different regions: the high energy region from 0 to 10.0 lethargy, the resolved resonance region, and the thermal region.

It is felt that between 0 and 10 lethargy units the group averaged cross sections will not have significant spatial variation and that we can minimise the number of groups required in this range by an accurate first approximation to the spectrum. It is also important to obtain the (n,2n) reaction rate as accurately as possible. For this reason the microscopic cross section data are read in at 0.1 lethargy intervals and Greuling Goertzel slowing down theory is used. Resonances are not treated individually in this range and the calculation is temperature independent.

With so many variables unaccounted for above 10 lethargy units, we have thought it reasonable to calculate the flux from 10 to 23 lethargy units from the heavy gas equation. Absorption cross sections are assumed to follow a 1/v variation and initially resonances have been neglected, except that the 0.3 eV Pu239 resonance is included in the solution of the heavy gas equation. Finally individual resonance reaction rates are calculated from Goldstein and Cohen's theory (1962) with allowance for Doppler broadening and a correction for thermalisation. They are included as a discontinuity at the nearest point of the calculation. The spectrum from 10 to 23 lethargy units is then renormalised to give continuity with the high energy spectrum at 10 lethargy units.

2.1.1 High energy region

For the high energy region the equation to be solved for each lethargy u is:

$$\left(\bar{\xi}\,\Sigma_s + \bar{\xi}\,\bar{\gamma}_0\,\Sigma_a\right)\phi(u) = \int_0^u S_1(u')\,du' + \bar{\xi}\,\bar{\gamma}_0\,S_1(u) - \int_0^u \Sigma_a^*\,\phi(u')\,du' \quad , \tag{2.1}$$

where $\bar{\xi}\,\Sigma_s$, $\bar{\xi}\,\bar{\gamma}_0$, calculated for beryllium and oxygen only, and with due allowance for anisotropic scattering (Keane and Pollard 1962), are given by:

$$\bar{\xi}\,\Sigma_s = N_{Be}(\xi\sigma_s)_{Be} + N_O(\xi\sigma_s)_O \quad ,$$

and

$$\bar{\xi}\,\bar{\gamma}_0 = \frac{1}{\bar{\xi}\,\Sigma_s}\left[N_{Be}\,(\xi\sigma_s)_{Be}(\xi\gamma_0)_{Be} + N_O(\xi\sigma_s)_O\,(\xi\gamma_0)_O\right] \quad ,$$

where ξ is the average logarithmic decrement per collision and γ_0 allows for the Greuling Goertzel correction.

In Equation 2.1 :

$$\Sigma_a^* = DB^2 + \sum_i N_i \cdot \sigma_{a_i} \quad ,$$

summed over all nuclides present.

where

B^2 = buckling coefficient

D = diffusion coefficient of BeO

and

$S_1(u)$ = fission source $S(u)$ + 2β [Be(n,2n) source $s(u)$] ,

where

$$\beta = \int_0^{1.6} \Sigma_{n,2n}\, \phi(u')\, du' \ .$$

For $0 \leqslant u \leqslant 1.6$, β has been taken as 0.1 in the calculation since this is a reasonable guess for the integral which cannot be evaluated in this range and since, in any case, the contribution of the emission spectrum to the range $0 \leqslant u \leqslant 1.6$ is small.

(The fission spectrum $\int_0^u S(u')\, du'$, and the Be(n,2n) spectrum $\int_0^u s(u')\, du'$ are given in the input data).

Using the trapezoidal rule for integration,

$\int_0^u \Sigma_a^*\, \phi(u')\, du'$ may be written:

$$du \left\{ \tfrac{1}{2}\, \Sigma^*_{a_1}\, \phi(u_1) + \Sigma^*_{a_2}\, \phi(u_2) + \ldots + \Sigma^*_{a_{n-1}}\, \phi(u_{n-1}) + \tfrac{1}{2}\, \Sigma^*_{a_n}\, \phi(u_n) \right\} .$$

Hence, the flux at the point u_n is given by:

$$\phi(u_n) = \left\{ \int_0^u S(u')\, du' + 2\beta \int_0^u s(u')\, du' + \bar{\xi}\, \bar{\gamma}_o \left(S(u) + 2\beta\, s(u) \right) \right.$$

$$\left. - du \left(\tfrac{1}{2}\, \Sigma^*_{a_1}\, \phi(u_1) + \Sigma^*_{a_2}\, \phi(u_2) + \ldots + \Sigma^*_{a_{n-1}} \phi(u_{n-1}) \right) \right\}$$

$$\times \left\{ \bar{\xi}\, \Sigma_s + \bar{\xi}\, \bar{\gamma}_o\, \Sigma_a^* + \frac{du}{2}\, \Sigma_a^* \right\}^{-1} \ .$$

2.1.2 Thermal region

The thermal flux may be calculated from the solution of the heavy gas equation following Rubbra and Pollard (1963). The recurrence relation of the flux is given by the expression:

$$\phi^*(u_j) = \frac{p^*_{j-1} + \left(\frac{du}{2\xi}\, g_{j-1} + \frac{y_j}{du} \right) \phi^*(u_{j-1})}{1 - \frac{du}{2\xi}\, g_j + \left(\frac{1}{du} - 2 \right) y_j} \quad , \ j > 1 \ ,$$

where

$$g_j = \frac{\Sigma_a^*(u_j)}{\bar{\xi}\, \Sigma_s}$$

$$p_j^* = \int_{u_j}^{u_1} g\, \phi^*(u')\, du'$$

$$= p^*_{j-1} + (g_j \phi^*_j + g_{j-1} \phi^*_{j-1}) \frac{du}{2}$$

$$\Sigma^*_a = \frac{B^2}{(\frac{N}{D})_{BeO} + 3\Sigma_a} + \left(\frac{E_t}{E}\right)^y \sum_{i=1}^{9} N_i \sigma_{a_i}(E_t) + \Sigma_a(res)$$

$$y_j = \frac{T}{E_j} = .10^{-7} T e^{u_j} \quad .$$

The temperature T is expressed in eV, E_t denotes thermal energy (= 0.0253 eV), and:

$$\Sigma_a(res) = \frac{\Gamma_a}{\Gamma} N_{Pu239} \sigma_o \frac{1}{1+x_j^2} \left[1 + \frac{2}{\theta^2} \frac{(3x_j^2 - 1)}{(1+x_j^2)^2} \right],$$

thus allowing approximately for the Doppler broadening of the 0.3 eV resonance of Pu239. In this last equation σ_o is the peak height of the resonance, Γ_a and Γ the absorption and total widths, $x_j = \frac{2}{\Gamma}(E - E_r)$, and $\theta = \sqrt{(\Gamma^2 A / 4TE_r)}$ where E_r is the resonance energy, T the temperature in eV, and A the ratio of the mass of a Pu239 nucleus to that of a neutron.

Fluxes are calculated by the above method from u = 23 to 10.

2.1.3 Resonance region

In the resonance region the flux must be modified to allow for slowing down of neutrons into and past the resonances.

This modified flux is given by:

$$\phi_k(u_j) = r \left(\prod_{i=1}^{k} p_i \right) \phi^*(u_j) \quad ,$$

where

$\phi^*(u_j)$ is the low energy flux calculated, neglecting resonances,

$p_i = \exp\{-I_i / \xi \sigma_s\}$ where I_i is the resonance integral given by Goldstein and Cohen (1962) and evaluated using Doherty's (1963b) approximation to the J function,

$\bar{\xi} \sigma_s = \frac{\bar{\xi} \Sigma_s}{N}$, where N is the atomic density ($\times 10^{-24}$) of the resonance absorber,

k = number of resonances with lethargies $\leqslant u_j$, and

r = $\phi(10) / \phi^*(10)$ to give a continuous flux at u = 10 from the high energy and low energy method of calculation.

Including the effects due to other absorptions and thermalization, the resonance reaction rates are found to be:

$$r_{1j} = \int_j \Sigma_a \phi(u)\, du = (1 - p_j)\, \bar{\xi} \Sigma_s \phi_{k-1}(u_j) \quad ,$$

and

$$r_{2j} = \int_j \nu \Sigma_f \phi(u)\, du = \nu \left(\frac{\Gamma_f}{\Gamma_a}\right)_j (1 - p_j)\, \bar{\xi} \Sigma_s \phi_{k-1}(u_j) \quad ,$$

where

$$\Gamma_a = \Gamma_\gamma + \Gamma_f \quad .$$

2.1.4 Remaining reaction rates

The 1/v and leakage reaction rates are not properly included for the resonance region (10 to 15 lethargy units) as they are based on the flux $\phi^*(u)$ calculated without resonances. It is possible, however, to preserve the neutron balance for the total lethargy range by introducing the factor d, defined by:

$$d = \left[1 + 2\beta - \left(\int_0^{10} \Sigma_a^* \phi(u)du + pr\int_{15}^{23} \Sigma_a^* \phi^*(u)\, du + \Sigma(r_{1j}) \right) \right]$$

$$x \left(r \int_{10}^{15} \Sigma_a^* \phi^*(u)\, du \right)^{-1} ,$$

thus ensuring that the non-resonance absorption reaction rate in the lethargy interval from 10 to 15 is equal to that fraction of the neutrons not otherwise absorbed.

If all resonances are at $u = u_p$, then

$$d = \left(r \int_{10}^{u_p} \Sigma_a^* \phi^*(u)\, du + rp \int_{u_p}^{15} \Sigma_a^* \phi^*(u)\, du \right) \left(r \int_{10}^{15} \Sigma_a^* \phi^*(u)\, du \right)^{-1} .$$

Using this procedure the total fission emission:

$$k_{eff} = f + \Sigma(r_{2j}) + rd \int_{10}^{15} (\nu\Sigma_f)\, \phi^*(u)\, du + rp\int_{15}^{23} (\nu\Sigma_f)\, \phi^*(u)du ,$$

where f is the fast fission emission rate.

The number of neutrons emitted from fast fission is only included very roughly by using, for example, the formula:

$$f_{U238} = \frac{N_{U238}}{\bar{\xi}\Sigma_p} F_{U238} ,$$

where

$$F_{U238} = \int_0^{10} \left(\nu\sigma_f(u)\right)_{U238} \left[\bar{\xi}\, \Sigma_p\, \phi(u)\right]_{BeO} du .$$

That is, the fast fission rate of U238, or any other nuclide, is calculated on the assumption that the flux is not perturbed from that in a system of pure BeO containing a source of neutrons with the same energy distribution as obtained from fission of U235.

2.1.5 k_∞

Assuming that leakage will not greatly change the spectrum (this could introduce considerable error), then:

$$k_\infty = k_{eff} \left\{ 1 - \frac{\int_0^{23} DB^2 \phi(u)\, du}{\int_0^{23} \Sigma_a^* \phi(u)\, du} \right\}^{-1} .$$

It should be noted that k_∞ and k_{eff} are only given as a guide and neither can be expected to be accurate owing to the very approximate cross section data used in MULGA 1, especially at the low energy end of the spectrum.

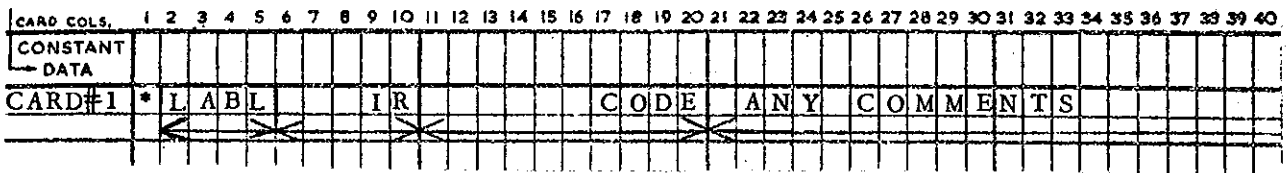
2.2 Operating Instructions

2.2.1 Preparation of input data

The input for MULGA 1 consists of a variable card input deck and a standard tape library. The

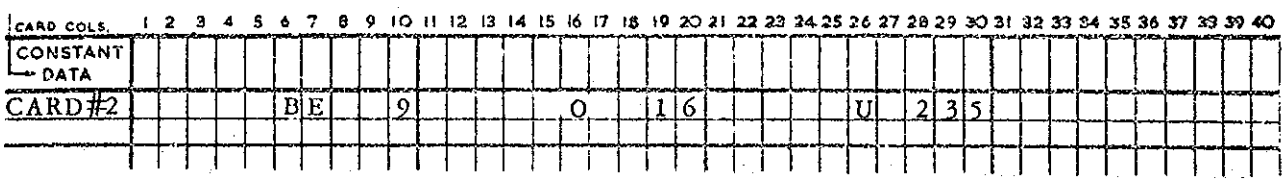
card input consists of 8 cards per problem. These cards contain information on the particular system under consideration, and are punched out at the beginning of the problem to furnish part of the input for MULGA 2 which calculates group averaged cross sections. Details of the contents and format of these 8 cards are set out below:

Card (1), the indicative card, is



where LABL may be any Hollerith information in columns 2–5 and will be reproduced in cols. 73–76 of the output cards. CODE may be any of the codes: DSN, DSNFORTRAN, CRAM, or other codes yet to be decided upon, and is used by MULGA 3 to produce group data in the correct format for the code specified here. IR (with format I5 in cols. 6–10) is used to supply information to MULGA 2. Normally, (IR = 0 or left blank), MULGA 2 will include resonance reactions in the group averaging process. However, if IR is any non–zero number, then the resonance reactions will not be included in the calculations.

Card (2), the nuclides card, contains the list of nuclides in the system in any order but with format (7(5X2A1,I3)): for example



9 vector spaces are set aside for the constituents of the mixture in the reactor system; however, the input is limited to 7 nuclides only. The nuclides on the first library tape prepared are given in the following order:

Be^{9}, O^{16}, Th^{232}, U^{233}, U^{235}, U^{238}, Pu^{239}, Pu^{240}, plus a library spare.

Card (3) contains the atomic densities ($x10^{-24}$) of the nuclides given on cards (2) in the order specified above, and with format (1P7E10.3)

for example

X.XXXE±NN etc.

Card (4) contains five items of information with format (1P5E10.3). The first three are data for MULGA 1:

(i) the temperature in degrees Kelvin,
(ii) the buckling coefficient B^2 in cm^{-2} for the system,
(iii) the coefficient y to be used with thermal absorption ($\Sigma_a \propto E^{-y}$). If the space is left blank, then a value of 0.5 is used for y in the programme.
(iv) This item, supplying data for MULGA 2, is the lethargy above which thermalisation is considered to be significant. If the allotted columns are left blank, then the lethargy u corresponding to 2eV is used by the programme MULGA 2.
(v) There is provision for the approximate treatment of resonance absorption in particles of fissile or fertile material dispersed in an otherwise homogeneous mixture by using a simple formula. Defining Σ_m as the scattering cross section of the moderator per fuel particle and $\bar{l}$ as the mean chord length of a particle, the value of a $\Sigma_m \bar{l}$ (where a is a parameter, usually between 9/16 and 3/4, depending on the particular fertile and fissile isotopes and the particle size) is punched in columns 41–50. This information may be omitted for a completely homogeneous system.

Cards (5) to (8) contain the number of groups and the group boundaries used in MULGA 2, with format (1X2I2,13F5.1/ (5X13F5.1)).

There must always be 4 cards for this group information. If the data fit onto fewer than 4 cards, the remaining cards are blank.

Groups for which MULGA 2 supplies information can be numbered serially, starting from any desired number. If a fixed point number M is punched in columns 2 to 3 on the fifth data card, the first set of information produced by MULGA 2 will be labelled as output for group M + 1. Thus, by simply performing a short MULGA 2 run, altered information may be obtained for a few groups which may replace information for these groups in a previous set of output.

The MULGA 1 library tape, mounted on tape unit 3, contains all the basic nuclear data necessary for the calculation. Further details of the library are given in Section 8.

The calculation takes approximately 30 minutes per problem on the IBM 1620 and 19 seconds on the IBM 7090.

2.2.2 MULGA 1 output

The output consists of 242 records, the first 8 being a reproduction of the input cards. These are followed by a heading record containing β with format (57X1PE11.4), then 231 records (u = 0(0.1) 23.0) containing:

u ϕ(u) LABL

or

u ϕ(u) 5x(i,j,r_{ij}) m LABL

in format (F5.1, 1PE10.3,1X5(I2,E9.2)I1,4A1) ,

where

u = lethargy,

ϕ(u) = flux per unit lethargy from a unit fission source,

r_{ij} = resonance reaction rate of reaction i for nucleus j at lethargy u ,

and

i = 1 for absorption i.e. γ + f ,

i = 2 for fission emission,

m = number of non-zero r's.

The last 2 records in the output contain the following quantities in format (1P5E12.4,12X4A1).

(1) β, k_{eff}, $\int_{10}^{23} (\nu\Sigma_f)\ \phi(u)\ du$, $\int_{0}^{23} DB^2\ \phi(u)\ du$, p, LABL.

(2) $\int_{0}^{10} \Sigma_a^*\ \phi(u)\ du$, k_∞, $\int_{10}^{18.5} (\nu\Sigma_f)_{\text{resonances}}\ \phi(u)\ du$, $\int_{0}^{10} DB^2\ \phi(u)\ du$, d, LABL.

3. MULGA 2

3.1 Method

3.1.1 Modification of group boundaries

To facilitate use of the library data, the group lethargy boundaries specified in the MULGA

input cards will be modified by the code so that each group boundary falls midway (in lethargy) between the lethargies at which the MULGA 1 spectrum is calculated. A boundary lethargy UGP specified in the range $7.20 \leqslant \text{UGP} \leqslant 7.30$, for example, will be changed to 7.25.

3.1.2 Group averaging methods

The method used for averaging within groups is a neutron flux averaging as follows:

$$\sigma_{x,g} = \frac{\int_{(g)} \sigma_x(u)\,\phi(u)\,du}{\phi_g} \quad , \tag{3.1}$$

where the group flux:

$$\phi_g = \int_{(g)} \phi(u)\,du \quad , \tag{3.2}$$

and the integrations are taken over the group (g). In Equation 3.1, σ_x may be any of σ_a, σ_s, $\sigma_{(n,n')}$, $\sigma_{(n,2n)}$, and $\nu\sigma_f$, that is, absorption, scattering, inelastic scattering, (n,2n) cross sections, and nu times fission cross sections (all read in from the library tape), while $\phi(u)$ is the neutron spectrum calculated by MULGA 1. The group transport cross sections are obtained by averaging the transport mean free path so that:

$$\frac{1}{\sigma_{tr,g}} = \frac{\int_{(g)} \frac{1}{\sigma_{tr}(u)}\,\phi(u)\,du}{\phi_g} \quad , \tag{3.3}$$

while the average neutron velocity v_g for the group is calculated by averaging the inverse velocity:

$$\frac{1}{v_g} = \frac{\int_{(g)} \frac{1}{v(u)}\,\phi(u)\,du}{\phi_g} \quad . \tag{3.4}$$

In MULGA 2 the integrals in Equations 3.1 to 3.4 are evaluated by trapezoidal rule using the resonance removed cross section on the library tape. The numerator of (3.1) is the reaction rate for the appropriate reaction in group (g) and this is corrected by adding to it any resonance reaction rates calculated in MULGA 1 and available on the spectrum cards. The cross sections produced thus make allowance for the self screening of the resolved resonances. The 0.3 eV resonance in plutonium 239 is treated as a cross section since the spectrum over this resonance is determined by MULGA 1.

3.1.3 Transfer cross sections for moderator nuclides

The cross sections $\sigma_i(g \rightarrow g')$ for transfer of neutrons from group (g) to group (g') by collisions with nuclide i are evaluated in one of two ways depending on the lethargy boundaries of group (g). If the entire group does not have lower lethargy than the lethargy UT at which thermalisation is considered to become significant the group (g) is treated as a thermal group and the transfer cross sections calculated accordingly. It should be remembered that UT is specified in columns 31 to 40 of the fourth MULGA input card; if this is left blank UT is taken to be 15.2.

(a) Thermal Groups

In the thermal region the transfer cross section $\sigma(g \rightarrow g')$ is an average over group (g) of the cross section $\sigma_{\rightarrow g'}(u)$ for scattering from lethargy u into the group (g'). Using the gas kernel and the value of $\sigma_s(u)$ read in from the library, MULGA 2 calculates the cross section $\sigma_{\rightarrow g'}(u)$ and then performs the averaging procedure of (3.1) for the nuclides beryllium and oxygen.

The cross section:

$$\sigma_{\rightarrow g'}(u) = \sigma_{\rightarrow g'}(E) \quad ,$$

can be written:

$$I(E_{g'-1}, E) - I(E_{g'}, E) \quad , \qquad \text{if } E > E_{g'-1} \quad ,$$

or

$$J(E_{g'-1}, E) - J(E_{g'}, E) \quad , \qquad \text{if } E < E_{g'} \quad ,$$

where

$$\left.\begin{aligned} I(E_{g'}, E) &= \int_{0}^{E_{g'}} \sigma(E \rightarrow E')\, dE \\ J(E_{g'}, E) &= \int_{\infty}^{E_{g'}} \sigma(E \rightarrow E')\, dE \end{aligned}\right\} \quad , \tag{3.5}$$

and $E_{g'}$ is the low energy boundary of group (g').

Using the gas kernel, the cross section:

$$\sigma(E \rightarrow E') = \frac{\sigma_s(E)}{2(1-\alpha)E} \{\exp(\epsilon - \epsilon') [\operatorname{erf}(f_2) - \operatorname{erf}(f_1)]$$

$$+ \operatorname{erf}(f_3) + \operatorname{erf}(f_4)\} \text{, if } E > E' \text{,}$$

and

$$= \frac{\sigma_s(E)}{2(1-\alpha)E} \{\exp(\epsilon - \epsilon') [\operatorname{erf}(f_2) + \operatorname{erf}(f_1)]$$

$$+ \operatorname{erf}(f_3) - \operatorname{erf}(f_4)\} \text{, if } E < E' \text{,}$$

where

$\sigma_s(E)$ is the scattering cross section of the scattering nuclide,

$$\alpha = \left(\frac{A-1}{A+1}\right)^2 \quad ,$$

A is the mass number of the nuclide,

$\epsilon = E/T$ and $\epsilon' = E'/T$,

T is the temperature of the moderator in energy units,

$$f_1 = \frac{\sqrt{\epsilon} + \sqrt{\alpha\epsilon'}}{\sqrt{1-\alpha}} \quad ,$$

$$f_2 = \frac{\sqrt{\epsilon} - \sqrt{\alpha\epsilon'}}{\sqrt{1-\alpha}} \quad ,$$

$$f_3 = \frac{\sqrt{\epsilon'} - \sqrt{\alpha\epsilon}}{\sqrt{1-\alpha}} \quad ,$$

$$f_4 = \frac{\sqrt{\epsilon'} + \sqrt{\alpha\epsilon}}{\sqrt{1-\alpha}} \quad ,$$

and $\operatorname{erf}(f_i) = \frac{2}{\sqrt{\pi}} \int_{0}^{f_i} e^{-t^2}\, dt = F_i$.

The integrations in Equations 3.5 can be performed analytically, and yield:

$$I(E_{g'}, E) = \frac{\sigma_s(E)}{2\epsilon(1-\alpha)} \left\{ \frac{(1-\alpha)}{\sqrt{\pi}} \left(f_4 e^{-f_3^2} + f_3 e^{-f_4^2} \right) + (F_1 - F_2) e^{(\epsilon - \epsilon')} \right.$$

$$\left. + (F_3 + F_4)(\epsilon' - \alpha\epsilon - \frac{1-\alpha}{2} - \sqrt{\alpha} \right\} \int ,$$

where $\epsilon' = E_g/T$;

$$J(E_{g'}, E) = \frac{\sigma_s(E)}{2\epsilon(1-\alpha)} \left\{ \frac{1-\alpha}{\sqrt{\pi}} \left(f_4 e^{-f_3^2} - f_3 e^{-f_4^2} \right) - (F_1 + F_2) e^{(\epsilon - \epsilon')} \right.$$

$$\left. + (F_3 - F_4)(\epsilon' - \alpha\epsilon - \frac{1-\alpha}{2} - \sqrt{\alpha}) \right\} \int .$$

These equations give the required analytic formulae for $\sigma_{\rightarrow g'}(u)$ which is computed by the code.

The full scattering matrix is truncated by the code setting limits on the lethargy change on collision. The limits depend on the incident lethargy of the neutrons and are indicated in the following table. Neutrons which would scatter beyond the furthest energy group allowed by the code are released in this last group.

ϵ	Maximum Lethargy Decrease on Scattering	Maximum Lethargy Increase in Scattering
$100 \leqslant \epsilon$	0.1	0.7
$3 \leqslant \epsilon < 100$	0.5	1.1
$0.1 \leqslant \epsilon < 3$	1.4	2.7
$\epsilon < 0.1$	1.7	4.5

(b) Slowing Down Region

In the slowing down region use is made of the requirement that the group boundaries must be so wide apart that neutrons can only slow down by elastic scattering from group (g) to the neighbouring group (g + 1). The only transfer cross sections to be calculated are then $\sigma(g \rightarrow g+1)$ and $\sigma(g \rightarrow g)$.

The removal cross section $\sigma_i(g \rightarrow g+1)$ for nuclide i is calculated as:

$$\sigma_i(g \rightarrow g+1) = \langle (\xi \sigma_s)_i \phi(u) \rangle_{av} / \phi_g ,$$

where the average is taken over the collision interval from which neutrons can leave the group. Removal cross sections for the heavy nuclides are not calculated.

3.1.4 Beryllium (n,2n) reaction

The production of the second neutron by the Be(n,2n) reaction is treated as a negative absorption. The two neutrons thus available should appear at energies lower than that at which the reaction takes place. This is allowed for by adding a contribution to the beryllium transfer cross sections for the group. The appropriate contributions are determined from an average emission spectrum available on the library tape.

3.1.5 Self scattering term

For each nuclide the self scattering cross section $\sigma(g \rightarrow g)$ is calculated as:

$$\sigma(g \rightarrow g) = \sigma_{tr,g} - \sigma_{a,g} - \sum_{g' \neq g} \sigma(g \rightarrow g') ,$$

since this is the interpretation placed on it in most codes.

3.1.6 Inelastic scattering by heavy elements

In the MULGA calculation, neutron moderation by elastic scattering from the heavy nuclides is neglected. However slowing down due to inelastic scattering may be more significant and some allowance for this is made.

While the averaging over the MULGA 1 spectrum is taking place, the reaction rates for inelastic scattering by thorium 232 and/or uranium 238 (if they are present) are calculated and the appropriate neutrons are then supposed to be emitted according to average emission spectra taken from the library. The fraction of the fission spectrum in each group is then diminished by the inelastic scattering reaction rate in the group and is augmented by the emission rate in the group, thus giving the modified fission spectrum punched out at the end of the job.

The inelastic scattering emission spectrum is produced from the secondary energy scattering laws using a typical incident energy spectrum. Variations in the incident spectrum will produce departures from the standard emission spectrum which should not affect the overall reaction rates.

3.2 Operating Instructions

3.2.1 Preparation of input data

The input for MULGA 2 consists of the output of MULGA 1 (as described in Section 2) and comprises the eight MULGA input cards followed by the spectrum and reaction rate records produced by MULGA 1. A standard MULGA 2 library tape is also required, (for details see Section 8), and should be mounted on tape unit 3.

3.2.2 MULGA 2 tape output

The tape output is in three parts:

(i) A reproduction of the eight MULGA input cards written first to supply information for MULGA 3, followed by

(ii) the group averaged cross sections for each group starting with the results for group 1, the group of highest energy. The output for group (g) consists of the following records:

(a) two descriptive records giving the group number (g) and a heading for the group cross sections, followed by

(b) for each nuclide listed in the input, a record giving the nuclide number and cross sections for the reactions (n,2n), (n,n'), scattering, absorption, and transport; ν times the fission cross section and the self scattering cross section. Then

(c) a record giving the total neutron flux in the group and the average velocity of the neutrons in the group, and finally in this portion come,

(d) the non zero transfer cross sections for beryllium and oxygen preceded by descriptive records giving the length of the scattering vector for this group and the position in the vector of the self scatter cross section. The order of the transfer cross sections appearing is:

$$\sigma(g \rightarrow g-n), \ldots, \sigma(g \rightarrow g-1), \sigma(g \rightarrow g), \sigma(g \rightarrow g+1), \ldots \sigma(g \rightarrow g+m) ,$$

if the length of the vector is $n+m+1$ and the position of the self scatter is $n+1$.

(iii) The final portion of the output is a number of records giving for each group, the group number, the group boundaries in both lethargy and energy (as modified by the code) and the proportion of the modified fission spectrum (normalised to unity) falling in the group. These are preceded by a descriptive header and are followed by an end record.

3.2.3 Typewriter output

At the beginning of a job, copies of the first input card and the library header card are typed out for identification purposes. If errors are detected during the running of the job, diagnostics and appropriate messages to the operator are typed. At the end of the job a message to this effect is given.

Time for a coverage of the complete spectrum depends primarily on the range in which thermalisation is considered important. If this range is taken as extending from 10 eV downwards, about 80 minutes on an IBM 1620 is required. If thermalisation is ignored, about 35 minutes is needed.

3.3 Error Messages

Certain input errors are detected by the code. In most cases a diagnostic message is typed and execution of the job is terminated.

The errors detected are:

(i) A data record is missing.

(ii) Tape loaded on unit 3 is not a MULGA library tape.

(iii) A nuclide specified on the nuclides card is not in the library. The name of the wrong nuclide is given in the diagnostic message. If this error is detected the offending nuclide is ignored and the job is continued.

(iv) The number of groups is non-positive or greater than 40.

(v) The group boundaries specified lie outside the allowable lethargy range of 0.0 to 23.0.

(vi) The group boundaries specified are not in increasing order of lethargy or are not sufficiently wide apart.

(vii) The spectrum records from MULGA 1 are not in correct order. To facilitate correcting this error the lethargy for the last correctly read record is included in the diagnostic message.

3.4 Options

Although the number of groups must not exceed 40 and the group boundaries must lie between 0.0 and 23.0 lethargy units it is not necessary that the whole lethargy range be covered in one run. The code will only start calculation from the first specified group boundary and continue to the last boundary; any necessary searching of spectrum records and library tapes is carried out by the code so that the user need not interfere with the MULGA 1 output in any way.

4. MULGA 3

4.1 General

To avoid errors in transcription, the programme MULGA 3 edits the multigroup data obtained from MULGA 2 and MULGA 4 and produces a deck of cards suitable as input cross section data for a selection of codes.

Since the programme is used to reorganise the order of the data and to give the output in various selected formats it was not possible with the limited storage to code MULGA 3 in FORTRAN. It has its own input-output routines written in SPS and is therefore not readily available for other machines.

4.2 Operating Instructions

4.2.1 Input data on Tape 2 (one file)

The input for MULGA 3 consists of the output from MULGA 2 which contains on the first record the choice of output required. The code required is punched in columns 11 – 20.

The following options are at present available:

(i) DSN,

(ii) DSNFORTRAN (a FORTRAN version of DSN, Clancy and Scott 1963),

and (iii) CRAM.

MULGA 3 will be extended as more codes are commissioned.

4.2.2 Input data on cards (3)

(i) The first two cards are the library required for MULGA 3 and consist of a_i (i = 1 to 9) and b_i where the number of neutrons emitted from fission is given by:

$$\nu_i = a_i + b_i E(\text{MeV}),$$

i being the number of the nuclide in the library. For non-fissile nuclides a = 1 and b = 0 is required for the library which is used to convert $\nu \sigma_f$ for each group to σ_f. The format of the cards is 9F8.3 .

(ii) The last card must be present, but is ignored for CRAM, and should be the "G00" card for DSN and DSNFORTRAN. The restrictions imposed on the data on this card are:

(a) the position of σ_{tr} must be 6,

(b) the table length must not exceed 39,

and (c) no more than 40 groups are allowed.

4.2.3 Output on cards

The first eight cards are copies of the first eight records of MULGA 2. These are followed by cards whose format and layout depend on the choice of code.

Examples of output are given in Section 9.3 and should be read in conjunction with the appropriate code reports for DSN (Carlson et al. 1960), CRAM (Hassit 1962) and DSNFORTRAN (Clancy and Scott 1963).

4.3 Error Messages

The error messages all consist of:

L ERROR IN JOB LABL MULGA 3 ,

where L is a code letter indicative of the type of error,

L = 8 indicates an error in one of the first eight records,

L = 0 indicates an error in the order of the data,

L = I indicates an error in the inserted data from the card reader,

L = T indicates an insufficient table length for DSN (and DSNFORTRAN) which would result in the truncation of the scattering matrix,

L = any other character, indicates an * is missing from the first data record – the character in its place being the error indicative, and LABL is the job reference (columns 2 – 5 of the first data record).

5. MULGA 4

5.1 Method

The group averaged data given by MULGA 2 for the groups $g_1, \ldots, g_n$ may be collapsed into a single group $\bar{g}$ by using the formula:

$$\sigma_{x,\,\bar{g}} = \sum_{i=1}^{n} \sigma_{x,\,g_i}\,\phi_{g_i} \Big/ \sum_{i=1}^{n} \phi_{g_i}$$

where x specifies any particular reaction. This expression is used in MULGA 4.

Special treatment is given to the group averaged transport cross sections and to group averaged velocities since the inverses of these quantities have been obtained by the averaging procedure in MULGA 2.

The contributions of the modified fission spectrum falling on each MULGA 2 group are added to produce the appropriate fission component in the condensed group.

5.2 Operating Instructions

5.2.1 Input data

Input, which is taken from tape unit 2, consists of the output of a MULGA 2 job as described in Section 3, together with two cards from the card reader giving the numbers:

NOG

and NV(I) , I = 1 , NGPS

in format (I5,5X20I3/10X20I3).

Here NGPS is the number of groups for which cross sections were calculated by the MULGA 2 job, NOG is the number of groups into which this output is to be condensed, and NV(I) is the condensation vector whose meaning is best described by the following example:

NGPS = 20

NOG = 5

NV(I) = 4, 6, 10, 19, 20.

These data would be used if the MULGA 2 job had been done using 20 groups and this information was to be presented in 5 condensed groups with:

1st condensed group = groups 1 to 4 of MULGA 2 (NV(1) = 4)

2nd condensed group = groups 5 to 6 of MULGA 2 (NV(2) = 6)

3rd condensed group = groups 7 to 10 of MULGA 2 (NV(3) = 10)

4th condensed group = groups 11 to 19 of MULGA 2 (NV(4) = 19)

5th condensed group = group 20 of MULGA 2 (NV (5) = 20) .

5.2.2 Output

The output from MULGA 4 is the same as would have been obtained from MULGA 2 if the condensed group structure had been specified as input data in MULGA 2.

5.3 Error Messages

Any of the following errors will be detected by the programme:

(i) NOG is not positive,

(ii) NOG is not less than NGPS, that is, condensation is not being asked for,

(iii) Elements of the vector NV are not in strictly increasing order, and

(iv) Errors detected by input-output subroutines.

If any error is detected, an appropriate diagnostic message is typed out and execution of the programme is terminated.

6. MULGA 5

6.1 Method

Since the 1100-E variplotter can only handle numbers between -999 and +999 in both directions, the points to be plotted must be converted into the appropriate format. The plotter is set to a fixed position, so that the point (0,0) on the plotter-scale is situated at the centre of the page and the limits at its corners. Consequently, it is necessary to define different scales for each type of paper.

6.1.1 Conversion ratio along x-axis

(a) Centimetre-paper of size = (38 x 25) :

Setting the point (-7,M) equal to (+999, -999) and using a scale of 1 cm per lethargy unit, so that (12,M) corresponds to(0, -999), the conversion ratio becomes:

$$h = \frac{999}{190}$$ for steps of 0.1 lethargy .

(b) Inch-paper of size = (15 x 10):

Setting (-3,M) equivalent to (+999, -999), but using a scale of ½ inch per lethargy unit, so that (12,M) corresponds to (0, -999), the conversion ratio becomes:

$$h = \frac{999}{75}$$ for steps of 0.1 lethargy.

(c) For blank paper, the point (0,M) is set equal to (+999, -999) and (23,M) to (-999, -999), and the whole range divided into equal steps, so that the conversion ratio becomes:

$$h = \frac{1998}{230}$$ for steps of 0.1 lethargy.

6.1.2 Conversion ratio along y-axis

The conversion ratio along the y-axis is completely independent of the type of paper used, but depends only on the lower and upper limits, M and N, of log $\phi(u)$. Setting y=N equivalent to y = +999, and y = M to y = -999, and dividing the range into equal intervals, then the conversion ratio per unit of log $\phi(u)$ is:

$$h = \frac{1998}{N-M}$$.

6.1.3 Formulae for conversion of u and log $\phi(u)$ into plotter-scale

In the range $0 \leqslant u \leqslant 23$,

that is, $999 - 10sh \geqslant I(u) \geqslant 999 - 10(23 + s)h$,

the formula for conversion is :

$$I(u) = 999 - 10(u + s)h \ ,$$

where

$$s = \begin{cases} 7 \ . \ . \ . \text{ for cm-paper} \\ 3 \ . \ . \ . \text{ for inch-paper} \\ 0 \ . \ . \ . \text{ for blank paper} \end{cases} .$$

For $M \leqslant \log \phi(u) \leqslant N$,

that is, $-999 \leqslant I(\phi) \leqslant +999$, the expression becomes:

$$I(\phi) = 999 - Rh + dh \ ,$$

where $0 \leqslant R \leqslant N - M$, and

$dh = h \ dy$,

where dy = decimal part of $\log \phi(u)$.

All numbers are rounded off before they are punched out in fixed mode. If $\log \phi(u)$ should be greater than N , the converted values are punched as +999 and if $\log \phi(u)$ should be less than M the converted values are punched as -999.

6.2 Operating Instructions

6.2.1 Input data from card reader

The first piece of information required by the programme is obtained from an "option" card, containing a code number, ICODE, associated with the type of paper used on the variplotter, and the lower and upper limits (M,N), of $\log \phi(u)$. ICODE, punched starting in column 1, must be one of the following: CM for cm paper, IN for inch paper and blank for plain paper. Then M and N must be punched in columns 11-15 and 16-20 respectively.

6.2.2 Input data from tape 2 (one file)

The MULGA 5 input consists of the MULGA 1 output as contained on tape 2.

6.2.3 Output

The MULGA 5 output consists of a copy of the first 8 data records from tape 2, followed by a copy of the "option card". The rest of the output deck is a set of 33 cards, each containing 7 values of u and $\log \phi(u)$ in the appropriate scale and format for the variplotter (14(*5)2X4A1).

6.3 Error Messages

The programme tests for correct input from tapes and correct code number from the first input card.

Since all MULGA outputs are characterized by an asterisk in column 1 of the first card image, the programme tests for a "*" in this position on tape 2. If the test fails, an appropriate error message is typed out, the current programme ceases and the next programme is loaded.

To ensure that tape 2 contains MULGA 1 output, the programme tests for "U" in column 4 of the 9th card image. Again an error message results on failure of the test and the programme ceases as above.

The test on ICODE is to ascertain whether any characters other than those mentioned in Section 6.2.1, have been used in the input. If an error is detected, a message is typed out and the programme is again terminated.

Note: On termination of the programme, whether due to errors or to a normal exit, the end of file mark will have been detected so that the tape is ready for the next problem.

7. MULGA 6

7.1 Method

Using Equation 3.1 the programme MULGA 6 calculates group averaged cross sections using a MULGA 1 flux output and discrete or group cross section tabulations. Linear interpolation is used for discrete cross sections and integration is performed trapezoidally, removing the necessity for coinciding lethargies.

7.2 Operating Instructions

7.2.1 Input Data

(a) The first card contains an alphameric character in column 1 and the required number of groups in I mode anywhere to column 72. If the character in column 1 is G , the input cross section will be a group cross section; any other character (including blank) will indicate discrete cross section data.

(b) The boundaries for the required groups follow. They may be punched in E or F mode anywhere to column 72 and any number to a card. The range of lethargy for the required groups must be within the MULGA 1 flux range (u = 0.0 to 23.00) and the range of tabulation of the input cross section data. Groups are assumed adjacent requiring one more boundary than the number of groups.

(c) The format for cross section input is read next, allowing a wide range of cross section tabulations to be treated. Only lethargy and cross section are read and the format may be used to bypass unnecessary information (for example, energy on standard data library cross section decks).

(d) The format for output of group cross sections follows.

(e) The next input is the lethargy – cross section tabulation read under the format in (c) above. Point cross sections may be used in the usual data library format using the format (F7.3, 11X E11.3). Group cross section data require the lower lethargy boundary and group cross section. The upper lethargy boundary of any group is taken to be the lower boundary of the next group. The last lethargy of the group tabulation must exceed the highest required group boundary. This usually entails the provision of a last card containing the upper boundary and group cross section of the last input group.

(f) The last card must contain 99.999 in the lethargy field to terminate either a successful or unsuccessful programme run in a manner which meets the MULGA monitor requirements.

(g) The MULGA 1 output containing the flux required for averaging must be the leading file on tape 2.

7.2.2 Output

Output consists of the lower lethargy boundary, upper lethargy boundary, and average cross section for each group, punched in the output format chosen in (d) above. In the event of data errors or chronic tape errors no data will be punched. The first card of the input is typed with each run of the programme to supply identification for the problem.

7.3 Limitations

Only one cross section may be averaged in a single run of the programme. The lethargy requirements of the output group data have been outlined in Section 7.2.1 (b). The accuracy of group averaged estimates depends on the details of the input data, particularly in the group to group problem which requires judicious choice of group boundaries to achieve sensible results.

8. THE MULGA LIBRARIES

8.1 Conventions

The number of nuclides available in a single MULGA library is nine owing to machine storage and calculation time limitations. For convenience of calculation the reactions associated with each nuclide position in the library are subject to the following conventions:

Position 1 may be occupied by a light moderating material, with the inclusion of the (n,n') or $(n,2n)$ emission spectrum for the MULGA 1 spectrum calculation.

Position 2 may be occupied by a light moderator, the secondary (n,n') spectrum being ignored.

Positions 3,6 are reserved for fertile nuclides, present in sufficient quantity to warrant the (n,n') emission spectrum being included in the MULGA 1 calculation.

Positions 4,5 may be occupied by thermally fissile isotopes; inelastic scattering is ignored.

Position 7 may be occupied by a fissile or fertile nuclide; provision is made for inclusion of a thermal resonance for this nuclide; inelastic scattering is ignored.

Position 8 may be occupied by a fertile nuclide; inelastic scattering is ignored.

Position 9 may contain data for a fertile or fissile nuclide; inelastic scattering is ignored.

8.2 Data Procedures

No resonances have been included for any nuclides above 454 eV, cross sections being represented continuously above this arbitrary cutoff. Cross section representation in MULGA 1 consists of resonance parameters of all resolved resonances below 454 eV and a background cross section assumed to be $\frac{1}{v}$, and normalised to the 2200 m/sec 'resonance removed' cross section value. The 0.296 eV resonance in Pu239 is included in the heavy gas calculation of MULGA 1 and parameters are included for that resonance (Pu239 occupies position 7). No other parameters for resonances below 1 eV have been included in the library, owing to the inadequacy of conventional resonance absorption approximations and the interference of absorption and thermalisation effects.

The approach adopted in the MULGA 2 library differs from the MULGA 1 procedures in that the 'resonance removed' cross sections have been calculated with explicit lethargy dependence up to the last resolved resonance or 454 eV, whichever is the lower energy. Above this energy resonances are included as continuous cross sections rather than in the resonance parameter representation.

The interpolation procedure which has been followed to obtain cross sections at lethargy points intermediate between tabulated information is as follows:

1. $\sigma(u)$ has been deduced at the lethargy points $u + 0.05$, $u-0.05$, using linear–linear interpolation against lethargy.

2. The value $\sigma(u)$ has been evaluated from $10 \int_{u-0.05}^{u+0.05} \sigma \, du$ using all tabulated points between $u-0.05$ and $u+0.05$.

The procedure may be seen to give correct reaction rates in a flux $\phi(u) = \text{const.}$, a not unreasonable approximation over a 0.1 range of u .

8.3 Contents of the Original Library Tape

8.3.1 The MULGA 1 library file

Cards	Columns	Information
Heading 1	1 – 8	*MULGAb1
	64 – 70	99ZZ999 other information optional
Heading 2		code representation of nuclides in library
Heading 3		alternate code representation of nuclides in library
1,6,11 ...501:	2 – 7	u(increasing in 0.1 steps from 0.0 to 10.0)
	12 – 20	$(\xi \sigma_s)$ Be9
	22 – 30	$(\xi \sigma_s)$ O16
	32 – 40	$(\xi \gamma_o)$ Be9
	42 – 50	$(\xi \gamma_o)$ O16
	52 – 60	$\sigma_{n,2n}$ Be9
2,7,12...502:	2 – 7	u
	12 – 20	σ_a Be9 ($\sigma_a = \sigma_{tot} - \sigma_{n,n'} - \sigma_{n,n}$)
	22 – 30	σ_a O16
	32 – 40	σ_a Th232
	42 – 50	σ_a U233
3,8,13,18...503:	2 – 7	u
	12 – 20	σ_a U235
	22 – 30	σ_a U238
	32 – 40	σ_a Pu239
	42 – 50	σ_a Pu240
	52 – 60	σ_a spare
4,9,14,19...504	2 – 7	u
	12 – 20	D_{Be9} $\left(\frac{1}{3D} = \sigma_a + \sigma_s(1 - \bar{\mu})\right)$
	22 – 30	D_{O16}

Cards	Columns	Information
5,10,15...505:	2 – 7	u
	12 – 20	S(u) U235 fission source
	22 – 30	$\int_{-\infty}^{u} S(u')\,du'$ U235 spectrum
	32 – 40	S(u) Be (n,2n) source
	42 – 50	$\int_{-\infty}^{u} S(u')\,du'$ Be (n,2n)
506	2 – 7	u = 19.800
	12 – 20	$(\xi \sigma_s)$ Be9
	22 – 30	$(\xi \sigma_s)$ O16
507	2 – 7	u = 19.800
	12 – 20	σ_a Be9
	22 – 30	σ_a O16
	32 – 40	σ_a Th232 (resonance removed)
	42 – 50	σ_a U233 (resonance removed)
508	2 – 7	u = 19.800
	12 – 20	σ_a U235 (resonance removed)
	22 – 30	σ_a U238 (resonance removed)
	32 – 40	σ_a Pu239
	42 – 50	σ_a Pu240 (resonance removed)
	52 – 60	σ_a spare = 1.000E+00
509	2 – 7	u = 18.400
	12 – 20	D_{Be9}
	22 – 30	D_{O16}
510	2 – 7	u = 19.800
	12 – 20	$\nu \sigma_f$ Be9 = 0.0
	22 – 30	$\nu \sigma_f$ O16 = 0.0
	32 – 40	$\nu \sigma_f$ Th232 = 0.0
	42 – 50	$\nu \sigma_f$ U233 (resonance removed)

Cards	Columns	Information	
511	2 – 7	u = 19.800	
	12 – 20	$\nu\sigma_f$ U235	(resonance removed)
	22 – 30	$\nu\sigma_f$ U238 = 0.0	
	32 – 40	$\nu\sigma_f$ Pu239	
	42 – 50	$\nu\sigma_f$ Pu240 = 0.0	
	52 – 60	$\nu\sigma_f$ spare (= 0.0 at present)	
512	2 – 7	u = 17.335	Pu239 0.296 resonance
	41 – 48	ν	
	71 – 72	−1 indicative	
513	2 – 7	u = 17.335	Pu239 0.296 resonance
	11 – 18	E	
	21 – 28	Γ_n	
	31 – 38	Γ_γ	
	41 – 48	Γ_f	
	51 – 58	g(J)	
	64 – 65	Code number 17	
	67 – 68	Z = 94	
	70 – 72	A = 239	
514	2 – 7	u = 13.800	
	12 – 20	$(\xi\sigma_s)$ Be9	
	22 – 30	$(\xi\sigma_s)$ O16	
515	2 – 7	u = 13.800	
	12 – 20	σ_s Be9	
	22 – 30	σ_s O16	
	32 – 40	σ_s Th232	potential scattering
	42 – 50	σ_s U233	potential scattering

Cards	Columns	Information
516	2 – 7	u = 13.800
	12 – 20	σ_s U235
	22 – 30	σ_s U238
	32 – 40	σ_s Pu239
	42 – 50	σ_s Pu240
	52 – 60	σ_s spare
517	2 – 7	u = 13.800
	12 – 20	D_{Be9}
	22 – 30	D_{O16}
518	2 – 7	u = 10.000
	32 – 40	$\int_0^{10} \nu \sigma_f \phi(u)\, du$ for Th232
	42 – 50	$\int_0^{10} \nu \sigma_f \phi(u)\, du$ for U233
519	2 – 7	u = 10.000
	12 – 20	$\int_0^{10} \nu \sigma_f \phi(u)\, du$ for U235
	22 – 30	" U238
	32 – 40	" Pu239
	42 – 50	" Pu240
	52 – 60	" spare
520	2 – 7	u = 13.800
	21 – 28	ν233
	31 – 38	ν235
	41 – 48	ν239
	51 – 58	νspare = 0.0
	71 – 72	−1 (indicative)

potential scattering

521 forward	Data Library Resonance Format	Resonances of Th232, U233, U238, Pu239 and Pu240 in ascending lethargy order starting u = 10.000 to u = 18.421.
LAST	Blank card with MUL1LAST in col. 72 – 80	

END FILE MARK.

8.3.2 The MULGA 2 library file

Cards	Columns	Information
Heading 1	1 – 8	*MULGAb2 other information optional
	66 – 70	ZZ999
Heading 2		field representation of nuclides present
3	2 – 9	α Be9
	11 – 18	α O16
	20 – 27	$1 - \alpha$ Be9
	29 – 36	$1 - \alpha$ O16
	38 – 45	$\sqrt{\alpha}$ Be9
	47 – 54	$\sqrt{\alpha}$ O16
	56 – 63	$\sqrt{1-\alpha}$ Be9
	65 – 72	$\sqrt{1-\alpha}$ O16
4 – 15		$2\int_{-\infty}^{u} s(u')\,du'$ for Be (n,2n) evaluated at consecutive lethargies (−0.05, 0.05, 0.15,..... 7.95) in format (7E10.3).
16,26,36,...2316:	2 – 7	u increasing in 0.1 steps from 0.0 to 23.0
	12 – 20	$\frac{1}{\sigma_{tr}}$ Be9 $\left(\sigma_{tr} = \sigma_a + \sigma_s\ (1-\bar{\mu})\right)$
	22 – 30	σ_a Be9
	32 – 40	$(\xi\,\sigma_s)$ Be9
	42 – 50	σ_s Be9
	52 – 60	$\sigma_{n,2n}$ Be9
17,27,... 2317:	2 – 7	u
	12 – 20	$1/\sigma_{tr}$ O16
	22 – 30	σ_a O16

Cards	Columns	Information
	32 – 40	$(\xi \sigma_s)$ O16
	42 – 50	σ_s O16
	52 – 60	$\sigma_{n,n'}$ O16
18,28,...2318:	2 – 7	u
	12 – 20	$1/\sigma_{tr}$ Th232
	22 – 30	σ_a Th232
	32 – 40	$\nu \sigma_f$ Th232
	42 – 50	σ_s Th232
	52 – 60	$\sigma_{n,n'}$ Th232
19,29...2319:		As per Th232 for U233
20,30,40,...2320:		As per Th232 for U235
21,31,...2321:		As per Th232 for U238
22,32,...2322:		As per Th232 for Pu239
23,33,...2323:		As per Th232 for Pu240
24,34,...2324:		As per Th232 for library spare
		$\sigma_s = 0$
		$\sigma_{n,n'} = 0$
		$\nu \sigma_f = 0$
		$\sigma_a = \frac{1}{v}$ normalised to 1 barn at thermal lethargy
		$1/\sigma_{tr}$ = v normalised to 1 barn^{-1} at thermal lethargy
25,35...2325:	2 – 7	u
	12 – 20	s (u) for Be9 (n,2n)
	22 – 30	s (u) for U235 (n,f)
	32 – 40	s (u) for Th232 (n,n')
	42 – 50	s (u) for U238 (n,n')

LAST END FILE

8.4 MULGA 0

The programme MULGA 0 may be used to change the nuclide in position N1. If N1 = 2 then the parameters required over the range u = -0.05 to u = 23.05 are ξ, γ_o, $\bar{\mu}$, σ_s, σ_{nab}, and $\sigma_{n,n'}$; and if N1 >2 then they are $\bar{\mu}$, σ_s, σ_{nab}, σ_f, $\sigma_{n,n'}$ and ν. Note that for N1 >2, background cross sections for both σ_{nab} and σ_f are required, as well as the resonance parameters for the nuclide in question.

Input Data

(a) A previously compiled library tape must be mounted on tape 3 and a scratch tape on tape 2.

(b) Card 1 contains the proton number Z in cols. 1,2, the chemical symbol in columns 3,4 and the mass number A and nuclide position N1 anywhere to columns 72.

(c) This block is the set of slowing down parameters for the nuclide in the standard nuclear data format. The lethargies must be in ascending order with the first lethargy = 0.05, the second last lethargy 23.05 and the last lethargy = 99.999 to terminate reading.

(d) This block is σ_s with the same lethargy requirements.

(e) This block is σ_{nab} with the same lethargy requirements.

(f) If N1 = 2 the block (c) must be reloaded. If N1 >2 this block will be σ_f with the same lethargy requirements. For fertile nuclei where only fast fission is possible, a card with the terminating lethargy and 0.0 in the cross section field must be present to set the field zero from the terminating lethargy onward.

(g) This block is $\sigma_{n,n'}$ with the requirements outlined in (f) as the inelastic scattering reaction terminates above a specified threshold.

(h) N1 = 2, block (c) must be reloaded. If N1 >2 this block consists of ν with the lethargy requirements of (c).

(i) The next card is a heading card for the MULGA 1 library tape. Any information between columns 8 and 63 inclusive will be included on the library heading card.

(j) If N1 < 2 this block is the set of resonance parameters of the nuclide which is to be inserted in the library, in ascending lethargy order. Any lethargy below 10.000 will terminate reading of the block and any lethargy above 16.000 will not be included, as the absorption cannot be calculated by the conventional resonance approximation. Normal termination of the block would be a blank card.

(k) The final card is a heading card for the MULGA 2 library and is treated in the same manner as the MULGA 1 library card of block (i).

Time

The programme MULGA 0 take approximately 1 hour to replace a nuclide.

8.5 MULGA 7

Having prepared one library tape with a particular nuclide present, the tedious card loading procedure can be eliminated from the preparation of additional tapes containing the nuclide by the use of MULGA 7.

Input Data

Tape 2 contains a MULGA library with the nuclide with proton number Z1, mass number A1 in position N1. Tape 3 contains another MULGA library with nuclide proton number Z2 mass number A2 in position N2. The programme replaces the nuclide in position N2 on tape 3 by the nuclide in position

N1 on tape 2 and outputs the composite tape on tape 4. Input consists of two cards, the first containing Z1, A1, N1 and the second Z2, A2, N2. All fields are I fields and may be anywhere to column 72.

Restrictions

The Be9 information in position N1 = 1 cannot be replaced except by new Be9 data. This restriction will be removed later. Pu239 cannot occupy any position except N1 = 7 on any tape.

Time

Tape transfer time is 10 to 15 minutes.

9. THE MULGA MONITOR SYSTEM

9.1 Description of the Monitor System

A single monitor system tape has been prepared to facilitate the use of the MULGA codes. The monitor uses the tape monitor system of Richardson (unpublished) which allows any programme to be called into core from magnetic tape, and incorporates the set of MULGA codes and MICROBOL (Richardson 1963). With the aid of MICROBOL it is possible to effect the tape editing required for a series of programme runs without operator intervention. The machine operator need only mount tapes at the start of the run, push the "LOAD" button and collect the card output on completion of the monitor run.

In addition to "load" cards which call a specific programme into core, several cards are available to REWIND 4, END FILE 4, TYPE, etc. These cards, MICROBOL instruction cards, and input data cards, form the basic input to the monitor system. Data errors have been trapped to enable each programme to "tidy up" before the "CALL EXIT".

It is possible to run the monitor to suit the particular collection of jobs. However, the usual correct tape practices should be observed (IBM 1962). Table 1 lists the various load cards available and indicates the input and output requirements of each code. Note the difference between CALL MULGA "N" and CONTINUE MULGA "N"; the former rewinds its input tape, while the latter does not. The actual contents of the various "LOAD" cards are set out in Table 2.

9.2 Example of a MULGA Monitor Run

```
260008600067340000002204490006 8                    REWIND2 M900000360000000500
260008600067340000002404490006 8                    REWIND4 M900000360000000500
340000002104360000002100                          CALL MULGA1        N46453474171
*AS01     CRAM        PU/TH/BEO=1/10/2000 AT 300K AND HOMOG.---SCOTT
     TH232     PU239     PU240     BE  9     O  16
 2.046E-04 2.214E-05 4.262E-06 4.178E-02 4.224E-02
 3.000E+02 1.000E-05 0.0       1.760E+01
    4  0.0  6.9 15.2 17.4 23.0


260008600067492210 2                                CONTINUE MULGA1 M900000360000000500
*AS02     CRAM        PU/TH/BEO=1/10/2000 AT 900K AND HOMOG.---SCOTT
     TH232     PU239     PU240     BE  9     O  16
 2.046E-04 2.214E-05 4.262E-06 4.178E-02 4.224E-02
 9.000E+02                       1.760E+01
    4  0.0  6.9 15.2 17.4 23.0


340000002104360000002100                          CALL MULGA5        N46453474175
CM           -3    2
260008600067340Z000001023759855005003959855001004900068 TYPE M900000360000000500
LABEL  AS01  MULGA 5
260008600067480000000004900068                      PAUSE M900000360000000500
260008600067492206 4                              CONTINUE MULGA5 M900000360000000500
CM           -3    2
260008600067340Z000001023759855005003959855001004900068 TYPE M900000360000000500
LABEL  AS02  MULGA 5
260008600067480000000004900068                      PAUSE M900000360000000500
340000002104360000002100                          CALL MULGA2        N46453474172
260008600067491808 2                              CONTINUE MULGA2 M900000360000000500
```

```
340000002104360000002100                          CALL MICROBOL        N44943595642
=REWIND 2
=REWIND 4
=TAPE 4 INPUT
=TAPE 2 OUTPUT
=OUTPUT FROM +0 ON
=SKIP
=*LABEL  AS01  MULGA 1
=PAUSE
=OUTPUT FROM +0 ON
=SKIP
=*LABEL  AS02  MULGA 1
=PAUSE
=OUTPUT FROM +0 ON
=COPY
=*LABEL AS01 MULGA 2
=PAUSE
=END FILE 2
=REWIND 2
=END
340000002104360000002100                               CALL MULGA3        N46453474173
   1.000   1.000   1.870   2.500   2.440   2.300   2.900   2.580   1.000MULGA3 1
   0.0     0.0     0.177   0.126   0.115   0.154   0.154   0.155   0.0  MULGA3 2

2600086000673402000001023759855005003959855001004900068 TYPE M900000360000000500
LABEL  AS01  MULGA  3   CRAM
260008600067480000000004900068                         PAUSE M900000360000000500
340000002104360000002100                          CALL MICROBOL        N44943595642
=TAPE 4 INPUT
=TAPE 2 OUTPUT
=REWIND 2
=OUTPUT FROM +0 ON
=COPY
=* LABEL  AS02  MULGA 2
=PAUSE
=END FILE 2
=REWIND 2
=REWIND 4
=END
```

```
340000002104360000002100                                    CALL MULGA3          N46453474173
   1.000    1.000    1.870    2.500    2.440    2.300    2.900    2.580    1.000MULGA3 1
   0.0      0.0      0.177    0.126    0.115    0.154    0.154    0.155    0.0  MULGA3 2

340000002104360000002100                                  CALL MICROBOL          N44943595642
=*LABEL  AS02  MULGA 3  CRAM
=TAPE 4 INPUT
=REWIND 2
=TAPE 2 OUTPUT
=SKIP 2 FILES
=INSERT
*AS01     DSN          PU/TH/BEO=1/10/2000 AT 300K AND HOMOG.---SCOTT
=DELETE +0
=COPY
=END FILE 2
=REWIND 2
=END
340000002104360000002100                                    CALL MULGA3          N46453474173
   1.000    1.000    1.870    2.500    2.440    2.300    2.900    2.580    1.000MULGA3 1
   0.0      0.0      0.177    0.126    0.115    0.154    0.154    0.155    0.0  MULGA3 2
9*    G00        18          1          6          9         15                    MULGA 3
260008600067340Z000001023759855005003959855001004900068 TYPE M900000360000000500
LABEL  AS01  MULGA 3   DSN
260008600067340000022044900068                          REWIND2 M900000360000000500
260008600067340000024044900068                          REWIND4 M900000360000000500
260008600067480000000004900068                            PAUSE M900000360000000500
260008600067340Z000001023759855005003959855001004900068 TYPE M900000360000000500
END OF MULGA RUN
```

9.3 Sample Output from a MULGA Run

The MULGA 3 output obtained for the problem AS01 in the monitor run of Section 9.2 is given for illustration. Note that an error message is given in the DSN output since this specified eighteen groups when only four had been computed by MULGA 3.

```
*AS01      CRAM          PU/TH/BEO=1/10/2000 AT 300K AND HOMOG.---SCOTT
     TH232      PU239      PU240      BE  9      O  16          0          0       0001
 2.046E-04 2.214E-05 4.262E-06 4.178E-02 4.224E-02 0.0         0.0                0002
 3.000E+02 1.000E-05 0.0       1.760E+01 0.0       0.0           451000230      0003
    4  0.0  6.9 15.2 17.4 23.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0          0004
       0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0          0005
       0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0          0006
       0.0  0.0                                                                 0007
SP                                                                        AS01CRAM
      9.996E-01  4.300E-04  0.000E+00  0.000E+00                         FISCR001
I 1                                                                       AS01CRAM
      3.291E+00  5.556E+00  5.557E+00  5.558E+00                         BE9CR001
      1.824E-01  1.237E-01  3.816E-01  5.142E-03                         BE9CR002
      0.000E+00  0.000E+00  0.000E+00  0.000E+00                         BE9CR003
      0.000E+00  2.011E-01  0.000E+00  0.000E+00                         BE9CR004
      0.000E+00  0.000E+00  1.227E-01  0.000E+00                         BE9CR005
      0.000E+00  0.000E+00  0.000E+00  3.802E-01                         BE9CR006
      0.000E+00  0.000E+00  0.000E+00  0.000E+00                         BE9CR007
     -1.872E-02  1.000E-03  1.421E-03  5.142E-03                         BE9CR008
      0.000E+00  0.000E+00  0.000E+00  0.000E+00                         BE9CR009
      2.798E-02  0.000E+00  0.000E+00  0.000E+00                         BE9CR010
      0.000E+00  0.000E+00  0.000E+00  0.000E+00                         BE9CR011
I 2                                                                       AS01CRAM
      2.618E+00  3.617E+00  3.618E+00  3.751E+00                         O 6CR001
      7.123E-02  4.565E-02  1.286E-01  2.397E-03                         O 6CR002
      0.000E+00  0.000E+00  0.000E+00  0.000E+00                         O 6CR003
      0.000E+00  6.827E-02  0.000E+00  0.000E+00                         O 6CR004
      0.000E+00  0.000E+00  4.494E-02  0.000E+00                         O 6CR005
      0.000E+00  0.000E+00  0.000E+00  1.279E-01                         O 6CR006
      0.000E+00  0.000E+00  0.000E+00  0.000E+00                         O 6CR007
      2.962E-03  7.105E-04  6.984E-04  2.397E-03                         O 6CR008
      0.000E+00  0.000E+00  0.000E+00  0.000E+00                         O 6CR009
      0.000E+00  0.000E+00  0.000E+00  0.000E+00                         O 6CR010
      0.000E+00  0.000E+00  0.000E+00  0.000E+00                         O 6CR011
```

```
I 3
      8.035E+00   1.348E+01   1.288E+01   1.458E+01
      4.196E-01   7.390E+00   1.018E+00   4.768E+00
      4.578E-02   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      3.953E-01   7.390E+00   1.018E+00   4.768E+00
      2.426E-02   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      1.215E+00   0.000E+00   0.000E+00   0.000E+00
I 7
      8.521E+00   2.343E+01   6.055E+01   9.320E+02
      2.306E+00   3.284E+01   4.921E+02   1.077E+03
      5.714E+00   5.362E+01   8.708E+02   2.088E+03
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      3.455E-01   1.435E+01   1.918E+02   3.570E+02
      1.960E+00   1.849E+01   3.003E+02   7.200E+02
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
I 8
      6.597E+00   2.984E+01   1.698E+02   1.371E+02
      7.000E-01   2.204E+01   2.676E+03   1.526E+02
      2.469E-01   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      6.048E-01   2.204E+01   2.676E+03   1.526E+02
      9.515E-02   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
      0.000E+00   0.000E+00   0.000E+00   0.000E+00
```

```
AS01CRAM
TH2CR001
TH2CR002
TH2CR003
TH2CR004
TH2CR005
TH2CR006
TH2CR007
TH2CR008
TH2CR009
TH2CR010
TH2CR011
AS01CRAM
PU9CR001
PU9CR002
PU9CR003
PU9CR004
PU9CR005
PU9CR006
PU9CR007
PU9CR008
PU9CR009
PU9CR010
PU9CR011
AS01CRAM
PU0CR001
PU0CR002
PU0CR003
PU0CR004
PU0CR005
PU0CR006
PU0CR007
PU0CR008
PU0CR009
PU0CR010
PU0CR011
```

```
*AS01      DSN          PU/TH/BEO=1/10/2000 AT 300K AND HOMOG.---SCOTT
     TH232      PU239      PU240      BE  9      O  16          0          0       0001
 2.046E-04 2.214E-05 4.262E-06 4.178E-02 4.224E-02 0.0        0.0                 0002
 3.000E+02 1.000E-05 0.0       1.760E+01 0.0        0.0          451000230      0003
    4  0.0  6.9 15.2 17.4 23.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    0004
       0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    0005
       0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    0006
       0.0  0.0                                                               0007
9*     G00        18         1         6         9        15                  MULGA 3
9*     K7                                                                    AS01DSN
9  9.9957      -01E    4.3000      -04E    0.0000      +00E    0.0000      +00EFISDL001
9*     K6                                                                    AS01DSN
9  9.2950      +01E    1.1030      +02E    1.8590      +01E    9.9140      +00EFLXDL001
9*     V1                                                                    AS01DSN
9  4.2610      +00E    1.0060      -01E    1.2570      -02E    3.4240      -03EVELDL001
9*     C0                                                                    AS01DSN
 I ERROR IN DATA AS01      DSN                                               AS01D002
```

TABLE 1

MULGA MONITOR LOAD CARDS

(Systems tape on 1)

LOAD CARD (special cards designated as below)	INPUT				OUTPUT			
	Card	Tape			Card	Tape		
		2	3	4		2	3	4
CALL MULGA 0	variable	–	(r) old library	–	–	new library	–	–
CALL MULGA 1	8	–	(r) library	–	–	(r) M1(e)	–	M1(e)
CONTINUE MULGA 1	8	–	”	–	–	M1(e)	–	M1(e)
CALL MULGA 2	–	(r) M1(e)	”	–	–	–	–	M2(e)
CONTINUE MULGA 2	–	M1(e)	”	–	–	–	–	M2(e)
CALL MULGA 3	3	(r) M2	–	–	variable	–	–	–
CALL MULGA 4	2	(r) M2	–	–	–	–	–	M4
CONTINUE MULGA 4	2	M2	–	–	–	–	–	M4
CALL MULGA 5	1	(r) M1(e)	–	–	42	–	–	–
CONTINUE MULGA 5	1	M1(e)	–	–	42	–	–	–
CALL MULGA 6	variable	(r) M1(e)	–	–	variable	–	–	–
CONTINUE MULGA 6	”	M1(e)	–	–	”	–	–	–

CALL MICROBOL	follow call card with MICROBOL instruction cards.
REWIND 4	must be used at beginning or end of a run only.
END FILE 4	must be used after MULGA 4.
SEEK END FILE 2	must be used after MULGA 4 if next is CONTINUE MULGA 4.
TYPE	follow call card with one only card to be typed.
PAUSE	

NOTATION:	(r) M1(e)	(r) M1(e)
	indicates that the input tape is rewound at the beginning, file M1 is read by the programme which ends with the file mark just read.	indicates that the output tape is rewound at the beginning, file M1 is created by the programme which ends by placing a file mark on the tape.

NOTE: The absence of (r) or (e) indicates the absence of this option.

TABLE 2

CONTENTS OF "LOAD" CARDS

```
LL MULGA 0 =
0000002104360000002100                    CALL MULGA0        N46453474170
LL MULGA 1 =
0000002104360000002100                    CALL MULGA1        N46453474171
NTINUE MULGA 1 =
00086000674922102                    CONTINUE MULGA1 M900000360000000500
LL MULGA 2 =
0000002104360000002100                    CALL MULGA2        N46453474172
NTINUE MULGA 2 =
00086000674918082                    CONTINUE MULGA2 M900000360000000500
LL MULGA 3 =
0000002104360000002100                    CALL MULGA3        N46453474173
LL MULGA 4 =
0000002104360000002100                    CALL MULGA4        N46453474174
NTINUE MULGA 4 =
00086000674918096                    CONTINUE MULGA4 M900000360000000500
LL MULGA 5 =
0000002104360000002100                    CALL MULGA5        N46453474175
NTINUE MULGA 5 =
00086000674922064                    CONTINUE MULGA5 M900000360000000500
LL MULGA 6 =
0000002104360000002100                    CALL MULGA6        N46453474176
NTINUE MULGA 6 =
00086000674923088                    CONTINUE MULGA6 M900000360000000500
LL MULGA 7 =
0000002104360000002100                    CALL MULGA7        N46453474177
LL MICROBOL =
0000002104360000002100                  CALL MICROBOL        N44943595642
WIND 2 =
000860006734000000 22044900068                  REWIND2 M900000360000000500
WIND 4 =
000860006734000000 24044900068                  REWIND4 M900000360000000500
EK END FILE 2 =
0001201400375983902200M70000001400260009100035470006800 6004900068 360000000500
D FILE 2 =
000860006734000000 22054900068                 ENDFILE2 M900000360000000500
D FILE 4 =
000860006734000000 24054900068                 ENDFILE4 M900000360000000500
PE =
000860006734 0Z000001023759855005003959855001004900068 TYPE M900000360000000500
USE =
000860006748000000000004900068                   PAUSE M900000360000000500
```

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