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SUBJECT: Methods for Applying Transmission and $\eta$-vs-E Corrections in the Determination of $\eta_{2200}$ by the Macklin-deSaussure Experiment

TO: Listed Distribution

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## Abstract

A careful determination of $\eta_{2200}$ from results of the Macklin-deSaussure Mn ~~manganese~~ bath experiment involves corrections for (1) the weak but non-zero transmission of sub-Cd ~~cadmium~~ neutrons through the ~~uranium~~ or Pu ~~plutonium~~ foils, and (2) the small variation of $\eta$ with energy in the sub-Cd ~~cadmium~~ region. This report presents the derivation of a single general expression for applying both these corrections, and then describes two IBM 704 codes (MTC and GTC) which were written especially to facilitate the numerical evaluation of this combined correction factor.

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# METHODS FOR APPLYING TRANSMISSION AND $\eta$-VERSUS-E CORRECTIONS IN THE DETERMINATION OF $\eta_{2200}$ BY THE MACKLIN-deSAUSSURE EXPERIMENT

## A. Introduction: Equation for Applying the Corrections

In the determination of $\eta_{2200}$ from the Macklin-deSaussure manganese bath experiment, allowance must be made for sub-cadmium neutron transmission through the uranium or plutonium foils, and also for the energy-dependent behavior of $\eta$. Corrections for both these effects are incorporated in the following equation:

$$\eta_{2200} = \left(\frac{R_1-R_2}{R_3-R_4}\right)\left[\left(\frac{\eta_M^P}{\eta_{2200}}\right) P_M \left\{1 - \Delta \frac{R_4}{(R_3-R_4)} + H_M \Delta \frac{R_3}{(R_3-R_4)}\right\}\right]^{-1} . \qquad (1)$$

The quantities $R_i$ are those defined by deSaussure and Macklin,[1] except that here $R_3$ and $R_4$ are assumed to be corrected for background effects. The quantity $\Delta$ is given by

$$\Delta = \frac{1-H_F}{H_F-H_M}\left(1 - \frac{\eta_F^P \, P_F}{\eta_M^P \, P_M}\right) . \qquad (2)$$

The remaining quantities $P_M$, etc., in Eqs. (1) and (2) are defined in (11)-(13), Section B of this report*; and each of these remaining quantities can be read directly from the output of two IBM 704 codes, MTC and GTC, which are described in Sections C and D of this report. Section B also

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[1] G. deSaussure and R. L. Macklin, Absolute Measurement of Eta by the Manganese Bath Technique, ORNL CF-59-1-70 (Jan. 20, 1959).

*The ratio $(\eta_M^P/\eta_{2200})$ depends on the energy variation of $\eta$ but is independent of its normalization. The Macklin-deSaussure experiment provides information about this normalization factor.

presents a derivation of Eq. (1). Listings of the Fortran source programs for both MTC and GTC are given in an Appendix.

## B. Derivation of the Equation for Applying Both Corrections

Let the incident flux be $\phi(E)$. Let $t_{Cd}$ = the thickness of the cadmium foil, and $t_m$ = the combined thickness of the uranium or plutonium foils (the "multiplying" foils). Let $\Sigma^{Cd}(E)\, t_{Cd} = \ell_{Cd}$, and $\Sigma^{m}(E)\, t_m = \ell_m$. We ignore all corrections except those pertaining to transmission and to $\eta$-vs-E variation; in particular, all neutron collisions in a given foil are assumed to result in absorptions in that foil*. Then

$$R_1 = K \left[ \int_0^{\infty} dE\, \phi(E)\, (1 - e^{-\ell_m})\, \eta(E) + \int_0^{\infty} dE\, \phi(E)\, e^{-\ell_m - \ell_{Cd}} \right], \tag{3}$$

$$R_2 = K \left[ \int_0^{\infty} dE\, \phi(E)\, e^{-\ell_{Cd}} (1 - e^{-\ell_m})\, \eta(E) + \int_0^{\infty} dE\, \phi(E)\, e^{-\ell_{Cd}}\, e^{-\ell_m} \right], \tag{4}$$

$$R_1 - R_2 = K \left[ \int_0^{\infty} dE\, \phi(E)\, (1 - e^{-\ell_m})\, (1 - e^{-\ell_{Cd}})\, \eta(E) \right], \tag{5}$$

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*Later investigation has shown that the correction for scattering out of cadmium may be as important as the correction term

$$\Delta \frac{R_4}{R_3 - R_4}$$

of Eq. (1). The two corrections have opposite signs. A report is now being written to describe a procedure for including this cadmium scattering correction.

Scattering out of the multiplier will be taken into account in a separate correction to the experimental results.

$$R_3 = K \int_0^{\infty} dE\ \phi(E), \tag{6}$$

$$R_4 = K \int_0^{\infty} dE\ \phi(E)\ e^{-\ell_{Cd}}. \tag{7}$$

K is a constant depending on the counter efficiencies, etc.

It is convenient to treat separately the Maxwellian and non-Maxwellian parts of the incident flux. Let

$$\phi(E) = \phi_M(E) + \phi_F(E), \tag{8}$$

$$\phi_M = \int_0^{\infty} \phi_M(E)\ dE, \tag{9}$$

$$\phi_F = \int_0^{\infty} \phi_F(E)\ dE. \tag{10}$$

Here $\phi_M(E)$ is a Maxwellian flux associated with most probable energy $E_o$; it is equal to $\phi(E)$ at $E = E_o$. Since $\phi_F(E)$ is just $\phi(E) - \phi_M(E)$, the flux $\phi_F(E)$ may have non-zero magnitude at sub-cadmium energies as well as at high energies.

Let

$H_M$ = the fraction of the Maxwellian flux transmitted by the cadmium foil,

$$= \int_0^{\infty} dE\ \phi_M(E)\ e^{-\ell_{Cd}}/\phi_M. \tag{11}$$

Neutrons that do not penetrate the cadmium foil will hereafter be referred to as <u>sub-cadmium</u> neutrons. Thus a sub-cadmium <u>Maxwellian flux</u> is a (hypothetical) flux having the same energy distribution as that of the collection of Maxwellian neutrons which collide in the cadmium foil.

$P_M$ = the fraction of the sub-cadmium Maxwellian flux colliding in the multiplying foils,

$$= \int_0^\infty dE\ \phi_M(E)\ (1 - e^{-\ell_m})(1 - e^{-\ell_{Cd}}) \Big/ \int_0^\infty dE\ \phi_M(E)(1 - e^{-\ell_{Cd}}). \tag{12}$$

$\eta_M^P$ = the average $\eta$ for sub-cadmium Maxwellian neutrons colliding in the multiplying foils,

$$= \int_0^\infty dE\ \phi_M(E)(1 - e^{-\ell_m})(1 - e^{-\ell_{Cd}})\ \eta(E) \Big/ \int_0^\infty dE\ \phi_M(E)(1-e^{-\ell_m})(1-e^{-\ell_{Cd}}). \tag{13}$$

Quantities $H_F$, $P_F$, and $\eta_F^P$ are defined analogously to (11)-(13): $\phi_F$ simply replaces $\phi_M$.

The substitution of definitions (11)-(13) and their analogues into Eqs. (5)-(7) yields

$$R_1 - R_2 = K\ \phi_M(1 - H_M)\ \eta_M^P\ P_M + K\ \phi_F(1 - H_F)\ \eta_F^P\ P_F, \tag{14}$$

$$R_3 = K(\phi_M + \phi_F), \tag{15}$$

$$R_4 = K(H_M\ \phi_M + H_F\ \phi_F) \tag{16}$$

Thus

$$K\ \phi_M = \frac{H_F}{H_F - H_M} R_3 - \frac{1}{H_F - H_M} R_4, \tag{17}$$

$$K\ \phi_F = -\frac{H_M}{H_F - H_M} R_3 + \frac{1}{H_F - H_M} R_4. \tag{18}$$

Then from (14), (17), and (18) we have

$$\eta_M^P = \frac{R_1 - R_2}{K\,\phi_M(1 - H_M)\,P_M + K\,\phi_F(1 - H_F)\left(\frac{\eta_F^P}{\eta_M^P}\right)P_F}$$

$$= \frac{R_1 - R_2}{R_3\left[\frac{H_F(1-H_M)}{H_F-H_M}\,P_M - \frac{H_M(1-H_F)}{(H_F-H_M)}\,\frac{\eta_F^P}{\eta_M^P}\,P_F\right] - R_4\left[\frac{(1-H_M)}{H_F-H_M}\,P_M - \frac{(1-H_F)}{(H_F-H_M)}\,\frac{\eta_F^P}{\eta_M^P}\,P_F\right]} \qquad (19)$$

A rearrangement of terms in (19), together with the introduction of the definition (2) and the quantity $\eta_{2200}$, yields Eq. (1).

## C. The IBM 704 Code "MTC"(Maxwellian Transmission Calculations for the Manganese Bath Eta Experiment)

### C1. Introduction

This code uses the formula for a Maxwellian flux (normalized so that $\phi_M = 1$) and computes $H_M$, $P_M$, $\eta_M^P$, and $(\eta_M^P/\eta_{2200})$.

### C2. Input

Sample input sheets are shown on pages 11 and 12. Information inserted on any one line of an input sheet will be punched on a single IBM card. The primary sheet for a given problem is devoted to information for Cards 1 through 5. The card numbers are shown in the last column of the primary input sheet; and from the sample primary input sheet it is clear that there may be two No. 4 cards. The input sheets following the primary sheet are reserved for information about cross sections and about the energy variation of $\eta$. Detailed instructions follow:

Cards 1 and 2. Lines 1 and 2 are to be filled with any identifying words you may find convenient to describe the case that is to be done. Write in one character per box. You may use boxes 2 through 72 inclusive on each of the two lines. Allowed characters are:

the 26 letters of the alphabet*;
the ten arabic numerals 0, 1, 2, ..., 9;
the ten symbols =, -, +, ., (, ), $, *, / , and the comma itself.

An empty box between words on the input sheet will correspond with a blank space between punches on the IBM card.

A typical job identification might include a case number, the date, some convenient designations for the foil thicknesses, and information identifying the particular lists of cross sections used for the calculation (since these lists may change, e.g., as better experimental information is received, or as the multiplying material is changed, or as tests are made to determine the sensitivity of the computed results to errors in the cross sections).

Card 3. $Nt_{Cd}$ is the cadmium foil thickness in units of atoms per barn of foil area. Seven boxes are reserved for this entry.

| | | |
|---|---|---|
| 2▲3 5 0 - 0 3 | means | $2.35 \times 10^{-3}$ atoms/b, |
| 0▲2 3 5 - 0 2 | means | $0.235 \times 10^{-2}$ atoms/b, |
| 0▲0 0 1 + 0 1 | means | $0.001 \times 10^{1}$ atoms/b, |
| 1▲0 0 0 + 0 0 | means | $1 \times 10^{0}$ atoms/b, |
| 2▲7 4 3 + 1 4 | means | $2.743 \times 10^{14}$ atoms/b. |

$Nt_m$ is the combined thickness of the multiplier foils (fissionable material) in units of atoms/b. $E_o$ is the most probable energy of the Maxwellian flux,

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*Print I with serifs, and slash 0 to make Ø: these devices will distinguish the letter I from the number 1, and the letter O from the number 0.

in ev. $ETA_{2200}$ is that value of $\eta$ at 2200 m/s used in the calculation of $\eta_M^P$ and $(\eta_M^P/\eta_{2200})$. $\widetilde{E}_1$, $\widetilde{E}_2$, and $\widetilde{E}_3$ are energies, in ev, which the machine will use in place of $\infty$ as upper limits to the integrals. These energies are to be written in ascending order. $\widetilde{E}_3$ should be chosen large enough to give sufficiently accurate approximations to the input integrals, but small enough to make the calculation sufficiently short and therefore inexpensive. (See later comment for time estimates.) $\widetilde{E}_1$ and $\widetilde{E}_2$ may be used to examine the convergence behavior of the integrals, or to examine the relative importance of contributions from different energy regions.

NE is the <u>number of energy intervals</u> used as the machine calculates the integrals by Simpson's rule: this will be explained more fully in the next paragraph. NE may be any number from 01 to 10 (inclusive). Leave this entry blank if the input is being written for the second or later problem in a series of problems all using the same scheme of intervals and subintervals for the Simpson's rule integration. Since information is not saved within the 704 from one run to another, the <u>first</u> problem in a machine run must have a number specified for NE.

<u>Card(s) 4</u>. These are used to indicate the <u>number of subintervals</u>, S-I, within each of the NE energy intervals, and also to indicate the energies E at INT (in units of ev) which separate the NE intervals. For example, on the first sample primary input sheet included in this report, line 4 indicates that 10 subintervals are to be used in the interval between zero ev* and 0.002 ev, then 50 subintervals

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*More accurately, $10^{-30}$ ev, since the numerical integration will start at $10^{-30}$ ev.

in the interval between 0.002 and 0.015 ev, etc. The energies $\tilde{E}_1$, $\tilde{E}_2$, and $\tilde{E}_3$ must appear as entries E at INT ; and the last E at INT must be $E_3$. Each number S-I may be any even number from 002 to 998. Note that the number of pairs S-I, E at INT must match the number NE in card 3. When the entry for NE has been left blank, then all the entries for card 4 should also be left blank. The machine calculation will take approximately $3 \times 10^{-3}$ minutes per subinterval.

Card 5. Entries on this card describe the length of the paired input lists of energy and $\sigma_m$ (total cross section of the multiplier), energy and $\sigma_{Cd}$, energy and $\eta$. (The input lists themselves are to be written on succeeding input sheets.) More detailed instructions for this card are included in the paragraphs below.

The machine will use functions of $\sigma_m$, etc., at each point of its numerical integrations, but $\sigma_m$ need not be inserted as input for each such point. Instead, the machine will use a value $\sigma_m(E)$ calculated by interpolating between values given in the input lists. The interpolation procedure assumes linearity on a log-log plot.

Each of the six lists for $E_m$, $\sigma_m$, $E_{Cd}$, $\sigma_{Cd}$, $E_\eta$, and $\eta$ may have as few as 002 or as many as 300 members. A pair of associated lists, e.g., $E_m$ and $\sigma_m$, must of course match in length.

If, within a single machine run, a given case is to use any particular list identical with the one used in the previous case, then the entry specifying the length of that list should be left blank. For example, the first case in a run must have the lengths of all six lists ($E_m$, $\sigma_m$, $E_{Cd}$,

$\sigma_{Cd}$, $E_\eta$, $\eta$) specified; but if the second case is to use identical lists except for the $\sigma_m$ list, then all entries in line 5 should be left blank except for the entry under $\sigma_m$. Naturally, the length of the new $\sigma_m$ list must match the length of the $E_m$ list which is to be re-used.

Cards 6, 7, etc. List of $E_m$, $\sigma_m$, $E_{Cd}$, $\sigma_{Cd}$, $E_\eta$, and $\eta$ are written in that order on the page(s) following the primary input page. All energies are to be given in ev, all cross sections in barns. Each list is written from left to right across the page. Use seven columns for each member of a list; and assume the same form X.XXX±XX as was used for $Nt_{Cd}$, etc. Columns 1-70 are reserved for these entries; thus ten 7-column entries are permitted per line. (Put ten entries on every line, except for the last line of a list in the case that the length of the list is not a multiple of 10. Also, lines between lists may be left blank if desired.) Columns 72-80 may be used for identifying comments.

Start each list on a new line. The lists following the primary input page of a given case must match in length and in order the specification of card 5. For example, if line 5 on the primary page is blank except for the entries 019 under $\sigma_m$, 008 under $E_\eta$, and 008 under $\eta$, then the following page must contain first a list of 19 $\sigma_m$ values, then a list of 8 $E_\eta$ values, and finally a list of 8 $\eta$ values.

The behavior of $\sigma_m$, $\sigma_{Cd}$, and $\eta$ must be specified over the entire range of integration. The numerical integration will start at $10^{-30}$ ev. Therefore the first member in each list $E_m$, $\sigma_m$, $E_{Cd}$, $\sigma_{Cd}$, $E_\eta$, and $\eta$ should correspond with $10^{-30}$ ev, while the last member should correspond with some energy greater than $\tilde{E}_3$.

MAXWELLIAN TRANSMISSION CALCULATIONS FOR ETA BATH EXPERIMENT

# 650 DATA SHEET

REQUEST 1472 JOB TITLE WRITTEN BY E. Halbert DATE 8/5/59

| 1-8 | 9-16 | 17-24 | 25-32 | 33-40 | 41-48 | 49-56 | 57-64 | 65-72 | 73-80 |
|---|---|---|---|---|---|---|---|---|---|

SAMPLE CASE A. 8/5/59. TCD=20 MILS, T23=104 MILS (NØMINAL). 1

LISTS 23-A, CD-A, ETA-A. 2

C JOB IDENTIFICATION

| $Nt_{Cd}$ | $Nt_m$ | $E_o$ | $ETA_{2200}$ | $\tilde{E}_1$ | $\tilde{E}_2$ | $\tilde{E}_3$ | | NE | |
|---|---|---|---|---|---|---|---|---|---|
| 2▲353-03 | 1▲262-02 | 0▲253-01 | 2▲297+00 | 2▲500-01 | 5▲000-01 | 1▲000+00 | | 08 | 3 |

Nt = number density x thickness.

NE = number of intervals on No. 4 card(s). If previous intervals are to be used, leave blank.

Enter in exponential form, as X▲XXXX±YZ (= X.XXXX times $10^{\pm YZ}$).

TABLE OF INTERVALS AND SUB-INTERVALS

| S-I | E at INT | S-I | E at INT | S-I | E at INT | S-I | E at INT | S-I | E at INT | S-I | E at INT | S-I | E at INT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 010 | 0▲002+00 | 050 | 0▲015+00 | 200 | 0▲050+00 | 200 | 0▲100+00 | 100 | 0▲250+00 | 100 | 0▲500+00 | 050 | 0▲750+00 | 4 |
| 050 | 1▲000+00 | | ▲ | | ▲ | | | | | | | | | 4 |

Enter energies in exponential form, as X▲XXXX±YZ. S-I's must be even integers.

| $E_m$ | $\sigma_m$ | $E_{Cd}$ | $\sigma_{Cd}$ | $E_\eta$ | $\eta$ | |
|---|---|---|---|---|---|---|
| 019 | 019 | 021 | 021 | 006 | 006 | 5 |

Enter the number of points in each table being read. Leave blank if not to be read.

Values of $\tilde{E}_1$ and $\tilde{E}_2$ must correspond to one of the interval values of energy (E at INT) in No. 4 card(s). $\tilde{E}_3$ must be equal to the last one.

SAMPLE PRIMARY INPUT PAGE FOR AN MTC PROBLEM

# 650 DATA SHEET

REQUEST 1472 JOB TITLE WRITTEN BY E. Halbert DATE 8/5/59

| 1-8 | 9-16 | 17-24 | 25-32 | 33-40 | 41-48 | 49-56 | 57-64 | 65-72 | 73-80 |
|---|---|---|---|---|---|---|---|---|---|
| 8100-318 | 100-0316 | 00-02253 | 0-024000 | -025000- | 026000-0 | 27000-02 | 1400-012 | 000-01 | E23-A 10 |
| 3000-014 | 000-0150 | 00-01600 | 0-017200 | -018000- | 019000-0 | 11000+00 | 1100+00 | | E23-A 19 |
| | | | | | | | | | |
| 1100+171 | 082+0375 | 70+02593 | 4+024665 | +024166+ | 023809+0 | 23540+02 | 2832+022 | 372+02 | X23-A 10 |
| 2053+021 | 874+0217 | 27+02160 | 2+021478 | +021511+ | 021607+0 | 21728+02 | 1870+02 | | X23-A 19 |
| | | | | | | | | | |
| 1000-311 | 000-0220 | 00-02300 | 0-024000 | -025000- | 026000-0 | 27000-02 | 8000-029 | 000-02 | ECD-A 10 |
| 1000-011 | 500-0117 | 50-01200 | 0-012200 | -013000- | 014000-0 | 15000-01 | 6000-018 | 000-01 | ECD-A 20 |
| 1100+00 | | | | | | | | | ECD-A 21 |
| | | | | | | | | | |
| 3490+033 | 490+0327 | 30+03248 | 0+032400 | +032400+ | 032500+0 | 32620+03 | 2830+033 | 012+03 | XCD-A 10 |
| 3580+036 | 800+0378 | 00+03640 | 0+035500 | +031100+ | 033100+0 | 21420+02 | 8000+013 | 700+01 | XCD-A 20 |
| 1700+01 | | | | | | | | | XCD-A 21 |
| | | | | | | | | | |
| 1000-312 | 000-0250 | 00-02200 | 0-015000 | -011001+ | 00 | | | | EETA-A 6 |
| | | | | | | | | | |
| 2300+002 | 300+0022 | 93+00227 | 0+002290 | +002270+ | 00 | | | | ETA-A 6 |

SAMPLE SECOND INPUT PAGE FOR AN MTC PROBLEM

### C3. Output

A sample output sheet is reproduced on page 15. The first line is a title which will automatically be printed at the beginning of the output for each problem. The next two lines are print-outs of lines 1 and 2 (job identification) on the primary input sheet. Below this job identification, a labeled list of input numbers from card 3 is printed. The remainder of the output consists of labeled results for the following calculated quantities:

| Quantity | Definition |
|---|---|
| HM1(E1) | $\int_{10^{-30}}^{E_1} dE\ \phi_M(E)\ e^{-\ell_{Cd}(E)}$ |
| HM2(E1) | $\text{HM1(E1)} + e^{-\ell_{Cd}(\tilde{E}_1)}\ e^{-\tilde{E}_1/E_o} \left[\frac{\tilde{E}_1}{E_o} + 1\right]$ |
| 1-PM(E1) | $\dfrac{\int_{10^{-30}}^{E_1} dE\ \phi_M(E)\ e^{-\ell_m(E)} \left[1 - e^{-\ell_{Cd}(E)}\right]}{\text{ANA(E1) FROM FORMULA} - \text{HM1(E1)}}$ |
| PM(E1) | $1 - \left[1 - \text{PM(E1)}\right]$ |
| ETAM-P(E1) | $\dfrac{\int_{10^{-30}}^{\tilde{E}_1} dE\ \phi_M(E) \left[1 - e^{-\ell_{Cd}(E)}\right] \left[1 - e^{-\ell_m(E)}\right] \eta(E)}{\text{PM(E1)} \left[\text{ANA(E1) FROM FORMULA} - \text{HM1(E1)}\right]}$ |
| ETAM-P(E1)/ETA(2200) | $\text{ETAM-P(E1)/ETA}_{2200}$ |
| ANA(E1) FROM NUMERICAL INTEGRATION | $\int_{10^{-30}}^{\tilde{E}_1} dE\ \phi_M(E)\ dE \equiv \int_{10^{-30}}^{\tilde{E}_1} \frac{E}{E_o^2}\ e^{-E/E_o}\ dE$ |
| ANA(E1) FROM FORMULA | $1 - e^{-\tilde{E}_1/E_o} \left[\frac{\tilde{E}_1}{E_o} + 1\right]$ |
| DIFFERENCE | $\left\lvert \text{ANA(E1) FROM FORMULA} - \text{ANA(E1) FROM NUMERICAL INTEGRATION} \right\rvert$ |

The functions HM1(E2), HM1(E3), etc., are defined analogously to the above, with $\widetilde{E}_2$ or $\widetilde{E}_3$ appropriately substituted for $\widetilde{E}_1$.

$\widetilde{E}_3$ is to be chosen large enough so that integration up to $\widetilde{E}_3$ approximates integration up to $\infty$ for the integral quantities appearing at the right in the above table. Since $\phi_M(E)$ is normalized so that $\phi_M = 1$, ANA(E3) should be close to 1. ANA(E3) FROM NUMERICAL INTEGRATION should, of course, also be close to 1. The size of DIFFERENCE is an indication of the accuracy of the numerical integration. HM2(E3) will usually be a better approximation to

$$\int_0^\infty dE\ \phi_M(E)\ e^{-\ell_{Cd}(E)}$$

than HM1(E3) is. HM1(Ei) should approach HM2(Ei) as Ei $\longrightarrow \infty$.

Below are listed the four Maxwellian quantities in Eq. (1) and their counterparts in the code output:

| Eq. (1) Quantity | MTC Code Name |
|---|---|
| $H_M$ | HM2(E3) |
| $P_M$ | PM(E3) |
| $\eta_M^P$ | ETAM-P(E3) |
| $\eta_M^P/\eta_{2200}$ | ETAM-P(E3)/ETA(2200) |

### C4. General Comment

The machine will sometimes not handle properly numbers greater than about $e^{+87}$ or $10^{+38}$, or less than about $e^{-87}$ or $10^{-38}$. It is best to keep this in mind when preparing the input for a problem.

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MAXWELLIAN TRANSMISSION CALCULATIONS FOR ETA BATH EXPERIMENT

SAMPLE CASE A.  8/5/59.  TCD=20 MILS, T23=104 MILS (NOMINAL).
LISTS 23-A, CD-A, ETA-A.



  NT(CD)     NT(M)        E0      ETA(2200)      E1        E2        E3)
2.353E-03  1.262E-02  2.530E-02  2.297E 00  2.500E-01  5.000E-01  1.000E 00

   HM1(E1)       HM2(E1)       1-PM(E1)       PM(E1)      ETAM-P(E1)     ETAM-P(E1)/ETA(2200)
 1.98451E-03   1.98522E-03   6.78097E-03   9.93219E-01   2.29249E 00          9.98038E-01

ANA(E1) FROM NUMERICAL INTEGRATION =  9.99441E-01  ANA(E1) FROM FORMULA =  9.99444E-01  DIFFERENCE =  2.54065E-06

   HM1(E2)       HM2(E2)       1-PM(E2)       PM(E2)      ETAM-P(E2)     ETAM-P(E2)/ETA(2200)
 2.00749E-03   2.00752E-03   6.81423E-03   9.93186E-01   2.29248E 00          9.98034E-01

ANA(E2) FROM NUMERICAL INTEGRATION =  9.99997E-01  ANA(E2) FROM FORMULA = 10.00000E-01  DIFFERENCE =  2.54810E-06

0-E3


   HM1(E3)       HM2(E3)       1-PM(E3)       PM(E3)      ETAM-P(E3)     ETAM-P(E3)/ETA(2200)
 2.00753E-03   2.00753E-03   6.81423E-03   9.93186E-01   2.29248E 00          9.98034E-01

ANA(E3) FROM NUMERICAL INTEGRATION =  9.99997E-01  ANA(E3) FROM FORMULA =  1.00000E 00  DIFFERENCE =  2.54810E-06
```

MTC OUTPUT FOR SAMPLE CASE A

## D. The IBM 704 Code "GTC" (General Transmission Calculations for the Manganese Bath Eta Experiment)

### D1. Introduction

This code uses a flux which can be specified numerically (as a function of energy) as part of the input. The code computes $H_F$, $P_F$, and $\eta_F^P$.

Since this GTC code was designed to apply not only to the $\eta_{2200}$ experiments but also to experiments investigating the epithermal behavior of $\eta$, it has features not directly connected with Eq. (1). In the present report only those features directly associated with Eq. (1) will be described in detail.

The numerical integrations in this code are carried out between energies $E_1$ and $E_3$, both to be specified as part of the input. An intermediate energy value $E_2$ is also to be specified as part of the input. The flux below $E_2$ is called $\phi_{F1}$ (E), and the flux above $E_2$ is called $\phi_{F2}$(E). This division was made to allow for the option of changing $\phi_{F1}$(E) and re-calculating the $E_1$-to-$E_2$ contributions to certain integrals, while keeping $\phi_{F2}$(E) fixed and re-using previously calculated $E_2$-to-$E_3$ contributions. Further information relevant to this division will appear in the explanatory sections to follow.

### D2. Input

Sample input sheets are reproduced on pages 22 and 23. The input format is very similar to that for MTC, the Maxwellian code. Again, information inserted on any one line of an input sheet will be punched on a single IBM card. The primary sheet for a given problem is devoted to information for cards 1-6. The sample primary input sheet shows that there may be two No. 5 cards and many No. 6 cards. Input sheets following the primary sheets are reserved for information about the energy variation of the flux, of the cross sections, and of $\eta$. Detailed instructions follow:

Cards 1 and 2. These are reserved for a description of the case to be run. All the comments on page 7 referring to input cards 1 and 2 for the Maxwellian code (MTC) apply here too. Since there are more kinds of input information for GTC than there are for MTC, a typical GTC job description will contain correspondingly more information.

Card 3. As in the Maxwellian code, the machine calculates values of $\sigma_m(E)$, etc., for its numerical integrations by interpolating between values given in paired input lists of energy and $\sigma_m$, etc. Again, the interpolation procedure is based on the assumption of linearity on a log-log plot.

The first six entries on card 3 describe the length of the paired input lists of $\hat{E}_1$ and $\phi_{F1}$, $\hat{E}_2$ and $\phi_{F2}$, $\hat{E}_3$ and $\sigma_{Cd}$. Each of these six lists may have as few as 002 or as many as 100 members. A pair of associated lists, e.g., $\hat{E}_1$ and $\phi_{F1}$, must of course match in length. The next six entries on card 3 are not directly connected with Eq. (1); they refer to the lengths of input lists for $\hat{E}_4$ and $\sigma_B$, $\hat{E}_5$ and $\sigma_{sB}$, and $\hat{E}_6$ and $\sigma_{sm}$ – which are relevant to experiments investigating the epithermal behavior of $\eta$, as described in a forthcoming report. Lists for these quantities, however, must be inserted at least for the first problem in a given run. For simplicity, each of these six lists may be kept down to two members, and therefore the number 002 may be used for each of these six entries on card 3. The seventh pair of entries on card 3 refers to the lengths of the lists $\hat{E}_7$ and $\eta$; these lists may be anywhere from 002 to 300 in length. The eighth pair of lists, for $\hat{E}_8$ and $\sigma_m$, can be anywhere from 002 to 600 in length.

If within a single machine run, a given case is to use any particular list identical with the corresponding list in the previous case, then the associated entry on card 5 should be left blank. Thus the first case in a machine run must have the lengths of all sixteen lists specified, but input for succeeding cases in the run may contain blanks on card 3. If only one partner of a paired entry is left blank, the number written for the other partner must of course match the common length of the pair as previously specified.

The final entry for card 3, labeled CC on the input sheet, is used to indicate whether the $E_2$-to-$E_3$ contributions to all numerical integrals are to be taken from the preceding problem in the run (CC = 1), read from input card 5 (CC = 2), or calculated by the machine (CC = blank). The first case in a given run must have CC = blank or CC = 2.

Card 4. $Nt_{Cd}$ is the cadmium foil thickness in units of atoms per barn of foil area. Use the form X▲XXX±XX, as explained on page 7 in the instructions for card 3 of the Maxwellian code. $Nt_m$ is the combined thickness of the multiplier foils in units of atoms per barn. $Nt_B$ is a number not directly connected with Eq. (1), but some entry must be made; the number 1▲0 0 0 + 0 0 is suggested.

$E_1$ is the energy at which the numerical integrations are to start. $E_2$ is the energy ($> E_1$) marking the division between $\phi_{F1}(E)$ and $\phi_{F2}(E)$. $E_3$ is the energy ($> E_2$) division marking the upper limit for numerical integrations involving $\phi_{F2}(E)$. All energies are to be given in ev.

NE is the <u>number of energy intervals</u> used as the machine calculates the integrals by Simpson's rule: this will be explained more fully under <u>Card(s) 6</u>. NE may be any number from 02 to 99 (inclusive). Leave this entry blank if the input is being written for the second or later problem in a series of problems all using the same scheme of intervals and subintervals for the Simpson's rule integration. Since information cannot be saved within the 704 from one run to another, the <u>first</u> problem in a machine run must have a number specified for NE.

<u>Card(s) 5</u>. When CC = 2 on card 3, the $E_2$-to-$E_3$ contributions to all numerical integrals are to be read from card 5. The $E_2$-to-$E_3$ contributions relevant to Eq. (1) are called $\phi_{F2}$, $\psi_{F2}$, $N_{F2}$, and $Z_{F2}$, where

$$\phi_{F2} = \int_{E_2}^{E_3} dE\ \phi_{F2}(E), \tag{20}$$

$$\psi_{F2} = \int_{E_2}^{E_3} dE\ \phi_{F2}(E)\ e^{-\ell_{Cd}}, \tag{21}$$

$$N_{F2} = \int_{E_2}^{E_3} dE\ \phi_{F2}(E) \left[1 - e^{-\ell_{Cd}}\right] e^{-\ell_m}, \tag{22}$$

$$Z_{F2} = \int_{E_2}^{E_3} dE \; \phi_{F2}(E) \left[1 - e^{-\ell_{Cd}}\right] \left[1 - e^{-\ell_m}\right] \eta(E). \qquad (23)$$

When CC $\neq$ 2, the input lines describing cards 5 should be left blank. When CC = 2, the entries labeled $\phi_{F2}$, $\Psi_{F2}$, $N_{F2}$, and $Z_{F2}$ should be inserted using the exponential form X‸XXXXX±XX. Note that these entries allow six significant digits, rather than four. (Any values of $\phi_{F2}$, etc., inserted on cards 5 will presumably have been read from the printed output of a previous case. Output numbers are printed to six significant digits.)

The remaining seven entries on card 5 ($\alpha_2$, etc.) refer to integrals not directly connected with Eq. (1). However, when CC = 2 these entries must not be left blank; and the number 0‸0 0 0 0 0 + 0 0 is suggested for each of these entries.

Card(s) 6. These cards are analogous to card(s) 4 for the Maxwellian code. The entries indicate the number of subintervals, S-I, within each of the NE energy intervals, and also indicate the energies E at INT (in units of ev) which separate the NE intervals. For example, on the sample primary input sheet included in this report, lines 6 indicate that 100 subintervals are to be used in the interval between E1 and 0.125 ev, then 120 subintervals in the interval between 0.125 and 0.5 ev, etc. The energies $E_2$ and $E_3$ should appear as entries E at INT, and the last E at INT should be $E_3$. Each S-I may be any even number from 002 to 998. Note that the number of pairs S-I, E at INT should match the number NE in card 4. If the entry for NE has been left blank, then all the entries for card 6 should also be blank. The machine calculation will take approximately 4 x $10^{-3}$ minutes per subinterval.

Cards 7, 8, etc. Lists of $\hat{E}_1$ $\phi_1$, etc., are written on the page(s) following the primary input page. The format to be used is exactly the same as the format of the lists for the Maxwellian code: see page 10 of this report. The lists must match in length and in order the specifications of card 3. When an entry on card 3 has been left blank, the corresponding list should be omitted from the sequence of lists.

As mentioned previously, the first case in a machine run must have all entries on card 3 filled in, even for quantities not directly connected with Eq. (1). If 002 has been inserted on card 3 for each of the entries labeled $\hat{E}_4$, $\sigma_B$, $\hat{E}_5$, $\sigma_{sB}$, $\hat{E}_6$, $\sigma_{sm}$, then satisfactory lists for the pair $\hat{E}_4$, $\sigma_B$ would be

$E_1$(in form $X_\blacktriangle XXX \pm XX$), $E_3$(in form $X_\blacktriangle XXX \pm XX$)

and

$1_\blacktriangle 0\ 0\ 0 + 0\ 0$, $1_\blacktriangle 0\ 0\ 0 + 0\ 0$

respectively. The same pair of lists is also satisfactory for the pair $\hat{E}_5$, $\sigma_{sB}$ and for the pair $\hat{E}_6$, $\sigma_{sm}$.

The behavior of the flux, the cross sections, and $\eta$ should be specified over the entire range of integration. Therefore the first member of each list should correspond with $E_1$ or some lower energy, while the last member should correspond with $E_3$ or some higher energy.

GENERAL TRANSMISSION CALCULATIONS FOR ETA BATH EXPERIMENT

## 650 DATA SHEET

REQUEST 1472 JOB TITLE ____ WRITTEN BY E. Halbert DATE 8/6/59

| 1-8 | 9-16 | 17-24 | 25-32 | 33-40 | 41-48 | 49-56 | 57-64 | 65-72 | 73-80 | |
|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLE | CASE Y. | 8/6/59. | TCD=20MI | LS, T23= | 104MILS. | LISTS C | D-2, ETA | 23-P, | | 1 |
| X23-2, | ALL ØTHE | RS-Y. E1 | =2.53-02 | , E2=5-0 | 1, E3=5+ | 06. | | | | 2 |

C JOB DESCRIPTION

| $\hat{E}_1$ | $\phi_{F1}$ | $\hat{E}_2$ | $\phi_{F2}$ | $\hat{E}_3$ | $\sigma_{Cd}$ | $\hat{E}_4$ | $\sigma_B$ | $\hat{E}_5$ | $\sigma_{sB}$ | $\hat{E}_6$ | $\sigma_{sm}$ | $\hat{E}_7$ | $\eta$ | $\hat{E}_8$ | $\sigma_m$ | CC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 014 | 014 | 002 | 002 | 059 | 059 | 002 | 002 | 002 | 002 | 002 | 002 | 053 | 053 | 328 | 328 | | 3 |

CC = 1 if $\phi_{F2}$, $\psi_{F2}$, etc., from previous problem to be used.
CC = 2 if $\phi_{F2}$, etc., to be read from cards 5.
CC = blank if $\phi_{F2}$, etc., to be calculated.

Enter the number of points in each table being read. Leave blank if not to be read.

| $Nt_{Cd}$ | $Nt_m$ | $Nt_B$ | $E_1$ | $E_2$ | $E_3$ | NE | |
|---|---|---|---|---|---|---|---|
| 2353-03 | 1262-02 | 1000+00 | 2530-02 | 5000-01 | 5000+06 | 10 | 4 |

Nt = number density x thickness.
NE = number of intervals on No. 6 card(s). If previous intervals are to be used, leave blank.

Enter in exponential form, as X.XXXX±YZ (= X.XXXX times $10^{\pm YZ}$).

| $\phi_{F2}$ | $\psi_{F2}$ | $N_{F2}$ | $Z_{F2}$ | $\alpha_2$ | | |
|---|---|---|---|---|---|---|
| | | | | | | 5 |
| $\beta_2$ | $\gamma_2$ | $\delta_2$ | $\epsilon_2$ | $\theta_2$ | 2 | |
| | | | | | | |

If column 49 of card 3 has a 2, fill in this card as X.XXXX±YZ.

TABLE OF INTERVALS AND SUB-INTERVALS

Enter energies in exponential form. S-I's must be even integers.

| S-I | E at INT | S-I | E at INT | S-I | E at INT | S-I | E at INT | S-I | E at INT | S-I | E at INT | S-I | E at INT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 0125+00 | 120 | 0500+00 | 400 | 5000+00 | 300 | 1000+01 | 100 | 1000+02 | 100 | 1000+03 | 100 | 1000+04 | 6 |
| 100 | 1000+05 | 100 | 1000+06 | 100 | 5000+06 | | | | | | | | | |

SAMPLE PRIMARY INPUT PAGE FOR A GTC PROBLEM

WCX-2628 (9-56)

# 650 DATA SHEET

REQUEST 1472 JOB TITLE WRITTEN BY E. Halbert DATE 8/6/59

```
1-8     9-16    17-24   25-32   33-40   41-48   49-56   57-64   65-72            73-80
2530-02 2783-02 3036-02 3289-02 3542-02 3795-02 5060-02 6325-02 7590-02 8855-02  EPHI1Y10
1012-01 1139-01 1265-01 5060-01                                                  EPHI1Y14
1000-03 8000-03 1600-02 2400-02 3200-02 4000-02 8000-02 1200-01 1600-01 2000-01  PHI1Y 10
2200-01 2200-01 2000-01 5000-02                                                  PHI1Y 14
5060-01 5060+06                                                                  EPHI2Y 2
5000-02 5000-09                                                                  PHI2Y  2
```

Insert the twelve appropriate cards saved from "Fast Flux Case 1."

```
                                                                                 ECD2  10
                                                                                 ECD2  20
                                                                                 ECD2  30
                                                                                 ECD2  40
                                                                                 ECD2  50
                                                                                 ECD2  59
                                                                                 XCD2  10
                                                                                 XCD2  20
                                                                                 XCD2  30
                                                                                 XCD2  40
                                                                                 XCD2  50
                                                                                 XCD2  59
2530-02 5000+06                                                                  EBY    2
1000+00 1000+00                                                                  XBY    2
2530-02 5000+06                                                                  ESBY   2
1000+00 1000+00                                                                  XSBY   2
2530-02 5000+06                                                                  ES23Y  2
1000+00 1000+00                                                                  XS23Y  2
```

Use here the appropriate cards saved from "Fast Flux Case 1."
There will be 78 cards, for the last four lists ($\hat{E}_7$, $\eta$, $\hat{E}_8$, $\tau_{m}$).
They are marked EET23P, ETA23P, E232, and X232.

SAMPLE SECOND INPUT PAGE FOR A GTC PROBLEM

WCX-2628 (9-56)

350 023

### D3. Output

A sample of the GTC output is reproduced on page 26. The first line is a title which will automatically be printed at the beginning of the output for each problem. The next two lines are print-outs of lines 1 and 2 (job description) on the primary input sheet.

Following these is a heading FROM E1 TO E2. Information relevant to Eq. (1) is contained in three places: (1) in the last block of numbers under the heading FROM E1 TO E2 (before the heading FROM E2 TO E3), (2) in the last block of numbers under the heading FROM E2 TO E3, and (3) in the two blocks of numbers under the heading FROM E1 TO E3. Below are listed general definitions for the output quantities relevant to Eq. (1) which are printed out under these headings:

FROM Ei TO Ej (i,j = 1,2; or i,j = 2,3; or i,j = 1,3)

$$\text{PHIF} = \int_{Ei}^{Ej} dE\, \phi_F(E),$$

$$\text{PSIF} = \int_{Ei}^{Ej} dE\, \phi_F(E)\, e^{-\ell_{Cd}},$$

$$\text{NF} = \int_{Ei}^{Ej} dE\, \phi_F(E) \left[1 - e^{-\ell_{Cd}}\right] e^{-\ell_m},$$

$$\text{ZF} = \int_{Ei}^{Ej} dE\, \phi_F(E) \left[1 - e^{-\ell_{Cd}}\right] \left[1 - e^{-\ell_m}\right] \eta(E).$$

FROM E1 TO E3

$$HF = PS1F/PH1F = \int_{E1}^{E3} dE\, \phi_F(E)\, e^{-\ell_{Cd}} \Big/ \int_{E1}^{E3} dE\, \phi_F(E),$$

$$PF = \left[1 - NF/(PH1F - PS1F)\right] = \int_{E1}^{E3} dE\, \phi_F(E)(1-e^{-\ell_{Cd}})(1-e^{-\ell_m}) \Big/ \int dE\, \phi_F(E)(1-e^{-\ell_{Cd}}),$$

$$ETAF = ZF/\left[PF(PH1F - PS1F)\right]$$

$$= \int_{E1}^{E3} dE\, \phi_F(E)(1-e^{-\ell_{Cd}})(1-e^{-\ell_m})\, \eta(E) \Big/ \int_{E1}^{E3} dE\, \phi_F(E)(1-e^{-\ell_{Cd}})(1-e^{-\ell_m}).$$

Below are listed the three non-Maxwellian quantities in Eq. (1) and their counterparts in the code output.

| Eq. (1) Quantity | GTC Code Name |
|---|---|
| $H_F$ | HF |
| $P_F$ | PF |
| $\eta_F^P$ | ETAF |

D4. General Comment

The comment about MTC given under C4 (page 14) is also applicable to GTC.

```
GENERAL TRANSMISSION CALCULATIONS FOR ETA BATH EXPERIMENT

SAMPLE CASE Y. 6/6/59. TCD=20MILS, T23=104MILS. LISTS CD-2, ETA23-P,
X23-2, ALL OTHERS-Y. E1=2.53-02, E2=5-01, E3=5+06.

FROM E1 TO E2

E=0.1250E-00  ALPHA=0.213837E-04  BETA=0.611541E-08  GAMMA=0.268220E-08
DELTA=0.937882E-05  EPSILON=0.947035E-05  THETA=0.947035E-05  XI=0.937882E-05

E=0.5000E-00  ALPHA=0.709513E-02  BETA=0.793053E-05  GAMMA=0.347830E-05
DELTA=0.311190E-02  EPSILON=0.344645E-02  THETA=0.344645E-02  XI=0.311190E-02

PHIF=0.491540E-01  PSIF=0.545220E-02  NF=0.194785E-02  ZF=0.951990E-01
ALPHA=0.709513E-02  BETA=0.793053E-05  GAMMA=0.347830E-05  DELTA=0.311190E-02
EPSILON=0.344645E-02  THETA=0.344645E-02  XI=0.311190E-02

FROM E2 TO E3

E=0.5000E 01  ALPHA=0.583903E 36  BETA=0.741513E 33  GAMMA=0.325225E 33
DELTA=0.256098E 36  EPSILON=0.288756E 36  THETA=0.288756E 36  XI=0.256098E 36

E=1.0000E 01  ALPHA=0.583903E 36  BETA=0.741513E 33  GAMMA=0.325225E 33
DELTA=0.256098E 36  EPSILON=0.288756E 36  THETA=0.288756E 36  XI=0.256098E 36

E=1.0000E 02  ALPHA=0.583903E 36  BETA=0.741513E 33  GAMMA=0.325225E 33
DELTA=0.256098E 36  EPSILON=0.288756E 36  THETA=0.288756E 36  XI=0.256098E 36

E=1.0000E 03  ALPHA=0.583903E 36  BETA=0.741513E 33  GAMMA=0.325225E 33
DELTA=0.256098E 36  EPSILON=0.288756E 36  THETA=0.288756E 36  XI=0.256098E 36

E=1.0000E 04  ALPHA=0.583903E 36  BETA=0.741513E 33  GAMMA=0.325225E 33
DELTA=0.256098E 36  EPSILON=0.288756E 36  THETA=0.288756E 36  XI=0.256098E 36

E=1.0000E 05  ALPHA=0.583903E 36  BETA=0.741513E 33  GAMMA=0.325225E 33
DELTA=0.256098E 36  EPSILON=0.288756E 36  THETA=0.288756E 36  XI=0.256098E 36

E=1.0000E 06  ALPHA=0.583903E 36  BETA=0.741513E 33  GAMMA=0.325225E 33
DELTA=0.256098E 36  EPSILON=0.288756E 36  THETA=0.288756E 36  XI=0.256098E 36

E=0.5000E 07  ALPHA=0.583903E 36  BETA=0.741513E 33  GAMMA=0.325225E 33
DELTA=0.256098E 36  EPSILON=0.288756E 36  THETA=0.288756E 36  XI=0.256098E 36

PHIF=0.638029E 36  PSIF=0.456806E 36  NF=0.204966E 35  ZF=0.366458E 36
ALPHA=0.583903E 36  BETA=0.741513E 33  GAMMA=0.325225E 33  DELTA=0.256098E 36
EPSILON=0.288756E 36  THETA=0.288756E 36  XI=0.256098E 36

FROM E1 TO E3

PHIF=0.638029E 36  PSIF=0.456806E 36  NF=0.204966E 35  ZF=0.366458E 36
ALPHA=0.583903E 36  BETA=0.741513E 33  GAMMA=0.325225E 33  DELTA=0.256098E 36
EPSILON=0.288756E 36  THETA=0.288756E 36  XI=0.256098E 36

HF=0.715964E 00  PF=0.886899E 00  ETAF=0.228000E 01  R(S)=0.             R(O)=0.202213E 01
ETAF(S)=0.228000E 01  ETAF(O)=0.228000E 01
ETAF(R,S)=(0.           )R + ( 0.100000E 01)
ETAF(R,O)=(0.288756E 36)R / 0.256098E 36
```

GTC OUTPUT FOR SAMPLE CASE Y

# APPENDIX

## LISTINGS OF FORTRAN SOURCE PROGRAMS FOR MTC AND GTC

# MTC FORTRAN SOURCE PROGRAM

```
C1472RLW MAXWELLIAN TRANSMISSION CALCULATIONS FOR ETA BATH EXPERIMENT   14720101
   1 DIMENSIONEIV(9),EI(9,10),TLM(3),TCM(3),TEI(9,3),ETIL(3),KP(8),
    1JP(8)
  51 DIMENSIONTBL(300,8),DELE(10),NPTS(10),TPM(3),ANAC(3),KO(4),THM2(3)14720111
    1,ETAR(3),Y(9)                                                      14720112
     WRITEOUTPUTTAPE9,3                                                 14720113
   3 FORMAT(71H1           MAXWELLIAN TRANSMISSION CALCULATIONS FOR ETA 14720115
    1BATH EXPERIMENT)                                                   14720116
   4 IF(SENSESWITCH1)20,5                                               14720122
   5 READINPUTTAPE4,6                                                   14720123
   6 FORMAT(72H                                                         14720125
    1          )                                                        14720201
     READINPUTTAPE4,7                                                   14720203
   7 FORMAT(72H                                                         14720205
    1          )                                                        14720206
     READINPUTTAPE4,8,(CDNT,TNM,E0,ETA22H,ETIL(1),ETIL(2),              14720208
    1ETIL(3),BNT,NE)                                                    14720209
   8 FORMAT(8E7.3,I2)                                                   14720211
     IF(NE-1)11,9,9                                                     14720213
   9 INTV=NE                                                            14720215
     READINPUTTAPE4,10,(NPTS(KL),DELE(KL),KL=1,NE)                      14720217
  10 FORMAT(7(I3,E7.3))                                                 14720219
  11 READINPUTTAPE4,12,(JP(I),KP(I),I=1,7,2)                            14720221
  12 FORMAT(8I3)                                                        14720223
     DO19J=1,7,2                                                        14720301
     IF(JP(J))16,16,13                                                  14720303
  13 N=JP(J)                                                            14720305
     READINPUTTAPE4,14,(TBL(KL,J),KL=1,N)                               14720307
  14 FORMAT(10E7.3)                                                     14720309
     DO15KL=1,N                                                         14720311
  15 TBL(KL,J)=LOGF(TBL(KL,J))                                          14720313
  16 IF(KP(J))19,19,17                                                  14720315
  17 M=KP(J)                                                            14720317
     READINPUTTAPE4,14,(TBL(KL,J+1),KL=1,M)                             14720319
     DO18KL=1,M                                                         14720321
  18 TBL(KL,J+1)=LOGF(TBL(KL,J+1))                                      14720323
  19 CONTINUE                                                           14720325
     GOTO29                                                             14720401
  20 READ6                                                              14720403
```

```
      READ7                                                             14720405
      READ8,(CDNT,TNM,E0,ETA22H,ETIL(1),ETIL(2),ETIL(3),BNT,NE)         14720407
      IF(NE-1)22,21,21                                                  14720409
   21 INTV=NE                                                           14720410
      READ10,(NPTS(KL),DELE(KL),KL=1,NE)                                14720411
   22 READ12,(JP(I),KP(I),I=1,7,2)                                      14720413
      DO28J=1,7,2                                                       14720415
      IF(JP(J))25,25,23                                                 14720417
   23 N=JP(J)                                                           14720419
      READ14,(TBL(KL,J),KL=1,N)                                         14720421
      DO24KL=1,N                                                        14720423
   24 TBL(KL,J)=LOGF(TBL(KL,J))                                         14720425
   25 IF(KP(J))28,28,26                                                 14720501
   26 M=KP(J)                                                           14720503
      READ14,(TBL(KL,J+1),KL=1,M)                                       14720505
      DO27KL=1,M                                                        14720507
   27 TBL(KL,J+1)=LOGF(TBL(KL,J+1))                                     14720509
   28 CONTINUE                                                          14720511
   29 ETILD=ETIL(1)                                                     14720605
      DO234KL=1,3                                                       14720607
      EX=ETIL(KL)/E0                                                    14720609
      IF(EX-87.3)33,233,233                                             14720600
  233 ANAC(KL)=1.0                                                      14720600
      GOTO234                                                           14720600
   33 ANAC(KL)=1.0-(EXPF(-EX)*(EX+1.0))                                 14720611
  234 CONTINUE                                                          14720600
      K=1                                                               14720613
      DO34I=1,4                                                         14720615
   34 KO(I)=1                                                           14720617
      BLIM=1.0E-30                                                      14720619
      TLIM=DELE(1)                                                      14720621
      MM=1                                                              14720623
      EE=1.0E-30                                                        14720625
      DO35L=1,4                                                         14720701
   35 EIV(L)=0.0                                                        14720703
      IF(SENSESWITCH2)136,138                                           14720705
  136 DO137L=5,9                                                        14720707
  137 EIV(L)=0.0                                                        14720709
  138 DO142LT=1,3                                                       14720711
```

```
      DO139L=1,4                                                        14720713
  139 TEI(L,LT)=0.0                                                     14720715
      IF(SENSESWITCH2)140,142                                           14720717
  140 DO141L=5,9                                                        14720719
  141 TEI(L,LT)=0.0                                                     14720721
  142 CONTINUE                                                          14720723
      LT=0                                                              14720600
      DO85I=1,INTV                                                      14720817
      COEFF1=2.0                                                        14721303
      COEFF2=4.0                                                        14721305
      NPT=NPTS(I)                                                       14721309
      PTS=NPT                                                           14721311
      EINC=(TLIM-BLIM)/PTS                                              14721313
      DO70M=1,NPT                                                       14721315
      IF(MM-1)110,110,400                                               14721207
  400 EE=EE+EINC                                                        14721317
      GOTO110                                                           14720819
   55 EE=EXPF(EE)                                                       14721109
      IF((EE/E0)-87.3)240,239,239                                       14720600
  239 Y(1)=0.0                                                          14720600
      GOTO241                                                           14720600
  240 Y(1)=(EE/(E0*E0))*EXPF(-EE/E0)                                    14721111
  241 PSI=V1*Y(1)                                                       14721113
   56 Y(2)=PSI                                                          14721115
      Y(3)=Y(1)*V2*V3                                                   14721117
      Y(4)=Y(1)*V2*V4*ETAE                                              14721119
      IF(SENSESWITCH2)57,58                                             14721121
   57 Y(5)=PSI*V5                                                       14721123
      Y(6)=PSI*V6*V3                                                    14721125
      Y(7)=PSI*V6*V4*ETAE                                               14721201
      Y(8)=PSI*V3                                                       14721203
      Y(9)=PSI*V4*ETAE                                                  14721205
   58 IF(MM-1)59,59,62                                                  14721207
   59 DO60L=1,4                                                         14721209
   60 EI(L,I)=Y(L)                                                      14721211
      IF(SENSESWITCH2)61,163                                            14721213
   61 DO162L=5,9                                                        14721215
  162 EI(L,I)=Y(L)                                                      14721217
  163 MM=2                                                              14721307
```

```
      EE=EE+EINC                                                        14721317
      GOTO110                                                           14721319
   62 IF(M-NPT)65,64,63                                                 14721321
   63 STOP77                                                            14721323
   64 COEFF2=1.0                                                        14721325
   65 DO66L=1,4                                                         14721401
   66 EI(L,I)=EI(L,I)+(Y(L)*COEFF2)                                     14721403
      IF(SENSESWITCH2)67,69                                             14721405
   67 DO68L=5,9                                                         14721407
   68 EI(L,I)=EI(L,I)+(Y(L)*COEFF2)                                     14721409
   69 COEFF1=-COEFF1                                                    14721411
   70 COEFF2=COEFF2+COEFF1                                              14721413
      COEFF=EINC/3.0                                                    14721415
      DO171L=1,4                                                        14721417
  171 EI(L,I)=EI(L,I)*COEFF                                             14721419
      IF(SENSESWITCH2)172,170                                           14721421
  172 DO73L=5,9                                                         14721423
   73 EI(L,I)=EI(L,I)*COEFF                                             14721425
  170 IF(EE-ETILD)273,74,71                                             14721521
   71 IF((EE-ETILD)-1.0E-6)74,74,72                                     14721523
   72 STOP7                                                             14721525
  273 IF(ABSF(EE-ETILD)-1.0E-5)74,74,80                                 14721601
   74 IF(K-3)75,86,72                                                   14721603
   75 LT=LT+1                                                           14721605
      DO182M=1,I                                                        14721607
      DO179L=1,4                                                        14721609
  179 TEI(L,LT)=TEI(L,LT)+EI(L,M)                                       14721611
      IF(SENSESWITCH2)180,182                                           14721613
  180 DO181L=5,9                                                        14721615
  181 TEI(L,LT)=TEI(L,LT)+EI(L,M)                                       14721617
  182 CONTINUE                                                          14721619
      THM2(LT)=TEI(2,LT)+(V1*(1.0-ANAC(LT)))                            14721705
      TEI(3,LT)=TEI(3,LT)/(ANAC(LT)-TEI(2,LT))                          14721707
      TPM(LT)=1.0-TEI(3,LT)                                             14721709
      TEI(4,LT)=TEI(4,LT)/(TPM(LT)*(ANAC(LT)-TEI(2,LT)))                14721711
      ETAR(LT)=TEI(4,LT)/ETA22H                                         14721713
      IF(SENSESWITCH2)78,79                                             14721715
   78 TEI(5,LT)=TEI(5,LT)/THM2(LT)                                      14721717
      TEI(6,LT)=TEI(6,LT)/(THM2(LT)*(1.0-TEI(5,LT)))                    14721719
```

```
      TEI(7,LT)=TEI(7,LT)/(THM2(LT)*(1.0-TEI(6,LT))*(1.0-TEI(5,LT)))    14721721
      TLM(LT)=1.0-TEI(6,LT)                                               14721701
      TEI(8,LT)=TEI(8,LT)/THM2(LT)                                        14721703
      TCM(LT)=1.0-TEI(8,LT)                                               14721705
      TEI(9,LT)=TEI(9,LT)/(THM2(LT)*TCM(LT)*ANAC(LT))                     14721707
   79 K=K+1                                                               14721807
      ETILD=ETIL(K)                                                       14721809
   80 IF(EE-TLIM)81,84,81                                                 14721811
   81 IF(ABSF((EE-TLIM)/EE)-1.0E-5)84,84,82                               14721813
   82 PRINT83,EE,TLIM                                                     14721815
   83 FORMAT(11H  ENERGY = E16.8,14H  TOP LIMIT = E16.8)                  14721817
      PAUSE77777                                                          14721819
   84 EE=DELE(I)                                                          14721821
      BLIM=EE                                                             14721823
      TLIM=DELE(I+1)                                                      14721825
      MM=1                                                                14721901
   85 CONTINUE                                                            14721903
   86 DO191I=1,INTV                                                       14721905
      DO88L=1,4                                                           14721907
   88 EIV(L)=EIV(L)+EI(L,I)                                               14721909
      IF(SENSESWITCH2)189,191                                             14721911
  189 DO190L=5,9                                                          14721913
  190 EIV(L)=EIV(L)+EI(L,I)                                               14721915
  191 CONTINUE                                                            14721917
      HM2E=EIV(2)+(V1*(1.0-ANAC(3)))                                      14721708
      ROV=EIV(3)/(ANAC(3)-EIV(2))                                         14721709
      PM=1.0-ROV                                                          14722007
      ETAV=EIV(4)/(PM*(ANAC(3)-EIV(2)))
      ETARV=ETAV/ETA22H                                                   14722011
      IF(SENSESWITCH2)89,90                                               14722013
   89 EKMV=EIV(5)/HM2E                                                    14721717
      DIV=HM2E*(1.0-EKMV)                                                 14722017
      RO1V=EIV(6)/DIV                                                     14721719
      VLM=1.0-RO1V                                                        14722021
      ENMV=EIV(7)/(DIV*(1.0-RO1V))                                        14721721
      RO2V=EIV(8)/HM2E                                                    14721723
      CM=1.0-RO2V                                                         14722101
      ENMCV=EIV(9)/(HM2E*CM*EIV(1))                                       14721725
   90 WRITEOUTPUTTAPE9,91                                                 14722105
```

```
   91 FORMAT(1H /1H )                                                   14722107
      LT=1                                                              14722109
      WRITEOUTPUTTAPE9,6                                                14722111
      WRITEOUTPUTTAPE9,7                                                14722113
      IF(SENSESWITCH2)92,95                                             14722115
   92 WRITEOUTPUTTAPE9,93                                               14722117
   93 FORMAT(83H0  NT(CD)     NT(M)      NT(B)       E0      ETA(2200)  14722119
     1   E1         E2         E3)                                      14722120
      WRITEOUTPUTTAPE9,94,CDNT,TNM,BNT,E0,ETA22H,ETIL(1),ETIL(2),       14722122
     1ETIL(3)                                                           14722123
   94 FORMAT(1H 1PE9.3,7E11.3)                                          14722125
      GOTO98                                                            14720600
   95 WRITEOUTPUTTAPE9,96                                               14722201
   96 FORMAT(78H0  NT(CD)     NT(M)       E0      ETA(2200)      E1     14722203
     1   E2         E3)                                                 14722204
      WRITEOUTPUTTAPE9,97,CDNT,TNM,E0,ETA22H,ETIL(1),ETIL(2),ETIL(3)    14722206
   97 FORMAT(1H 1PE9.3,6E11.3)                                          14722208
   98 WRITEOUTPUTTAPE9,91                                               14722210
      WRITEOUTPUTTAPE9,99,LT,LT,LT,LT,LT,LT                             14722212
   99 FORMAT(9H    HM1(EI1,13H)       HM2(EI1,13H)     1-PM(EI1,12H)    14722214
     1   PM(EI1,15H)      ETAM-P(EI1,15H)       ETAM-P(EI1,11H)/ETA(220014722215
     2))                                                                14722216
      WRITEOUTPUTTAPE9,100,TEI(2,LT),THM2(LT),TEI(3,LT),TPM(LT),        14722201
     1TEI(4,LT),ETAR(LT)                                                14722202
  100 FORMAT(1H 1PE12.5,4E14.5,E21.5)                                   14722220
      IF(SENSESWITCH2)101,104                                           14722222
  101 WRITEOUTPUTTAPE9,102,LT,LT,LT,LT,LT,LT,LT                         14722224
  102 FORMAT(8H0   KM(EI1,14H)       1-LM(EI1,12H)       LM(EI1,15H)    14722301
     1  ETAM-L(EI1,12H)     1-CM(EI1,12H)       CM(EI1,15H)      ETAM-C(14722302
     2EI1,1H))                                                          14722303
      WRITEOUTPUTTAPE9,103,TEI(5,LT),TEI(6,LT),TLM(LT),TEI(7,LT),       14722204
     1TEI(8,LT),TCM(LT),TEI(9,LT)                                       14722205
  103 FORMAT(1H 1PE12.5,6E14.5)                                         14722307
  104 DIF=ABSF(TEI(1,LT)-ANAC(LT))                                      14722207
      WRITEOUTPUTTAPE9,105,LT,TEI(1,LT),LT,ANAC(LT),DIF                 14722209
  105 FORMAT(6H0ANA(EI1,31H) FROM NUMERICAL INTEGRATION = 1PE12.5,      14722313
     17H  ANA(EI1,17H) FROM FORMULA = 1PE12.5,15H  DIFFERENCE = 1PE12.  14722314
     25)                                                                14722315
      LT=LT+1                                                           14722317
```

```
      IF(LT-3)98,106,109                                                14722319
  106 TEI(2,LT)=EIV(2)                                                  14722211
      THM2(LT)=HM2E                                                     14722323
      TEI(1,LT)=EIV(1)                                                  14722213
      TEI(3,LT)=ROV                                                     14722215
      TEI(4,LT)=ETAV                                                    14722217
      ETAR(LT)=ETARV                                                    14722407
      TPM(LT)=PM                                                        14722403
      IF(SENSESWITCH2)107,108                                           14722409
  107 TEI(5,LT)=EKMV                                                    14722221
      TEI(6,LT)=RO1V                                                    14722223
      TLM(LT)=VLM                                                       14722415
      TEI(7,LT)=ENMV                                                    14722225
      TEI(8,LT)=RO2V                                                    14722401
      TCM(LT)=CM                                                        14722421
      TEI(9,LT)=ENMCV                                                   14722403
  108 WRITEOUTPUTTAPE9,300                                              14722423
  300 FORMAT(5H00-E3)                                                   14722424
      GOTO98                                                            14722425
  109 WRITEOUTPUTTAPE9,3                                                14722501
      GOTO4                                                             14722503
  110 EE=LOGF(EE)                                                       14722505
      NO=0                                                              14722507
      J=-1                                                              14722509
      ASSIGN118TONN                                                     14722510
  111 NO=NO+1                                                           14722512
      J=J+2                                                             14722513
      KL=KO(NO)                                                         14722514
  112 IF(EE-TBL(KL,J))117,116,113                                       14722515
  113 KL=KL+1                                                           14722517
      GOTO112                                                           14722519
  116 KL=KL+1                                                           14722523
      SIG=EXPF(TBL(KL,J+1))                                             14720600
      GOTONN,(118,125,131,236)                                          14720600
  117 ARG=((TBL(KL,J+1)-TBL(KL-1,J+1))*(EE-TBL(KL-1,J)))/(TBL(          14722601
     1KL,J)-TBL(KL-1,J))+TBL(KL-1,J+1)                                  14722602
      SIG=EXPF(ARG)                                                     14722604
      GOTONN,(118,125,131,236)                                          14722606
  118 EXPB=TNM*SIG                                                      14722608
```

```
      IF(EXPB-87.3)120,119,119                                          14722610
119   V3=0.0                                                            14722612
      GOTO121                                                           14722614
120   V3=EXPF(-EXPB)                                                    14722616
121   V4=1.0-V3                                                         14722618
      KO(NO)=KL                                                         14722620
      ASSIGN125TONN                                                     14722622
      IF(SENSESWITCH3)122,111                                           14722624
122   PRINT123,J,KL,SIG                                                 14722701
123   FORMAT(2I3,E16.8)                                                 14722703
124   GOTO111                                                           14722705
125   EXPA=CDNT*SIG                                                     14722707
      IF(EXPA-87.3)127,126,126                                          14722709
126   V1=0.0                                                            14722711
      GOTO128                                                           14722713
127   V1=EXPF(-EXPA)                                                    14722715
128   V2=1.0-V1                                                         14722717
      KO(NO)=KL                                                         14722719
      ASSIGN131TONN                                                     14722721
      IF(SENSESWITCH2)129,135                                           14722723
129   IF(BNT)339,339,130                                                14722725
130   J=5                                                               14722801
      IF(SENSESWITCH3)122,111                                           14722803
131   EXPC=BNT*SIG                                                      14722805
      IF(EXPC-87.3)133,132,132                                          14722807
132   V5=0.0                                                            14722809
      GOTO134                                                           14722811
133   V5=EXPF(-EXPC)                                                    14722813
134   V6=1.0-V5                                                         14722815
      KO(NO)=KL                                                         14722817
135   ASSIGN236TONN                                                     14722319
      J=3                                                               14722821
      IF(SENSESWITCH3)122,111                                           14722823
236   ETAE=SIG                                                          14722825
      KO(NO)=KL                                                         14722901
      IF(V6)200,201,201                                                 14720901
200   V6=0.0                                                            14720903
201   IF(V2)202,203,203                                                 14720905
202   V2=0.0                                                            14720907
```

```
203 IF(V4)204,255,255                                           14720909
204 V4=0.0                                                      14720911
255 IF(SENSESWITCH3)237,55                                      14722903
237 PRINT123,J,KL,ETAE                                          14720000
    GOTO55                                                      14722907
339 V5=1.0                                                      14722915
    V6=0.0                                                      14722917
    GOTO135                                                     14722919
    END(0,1,0,0,0)                                              14722921
```

## GTC FORTRAN SOURCE PROGRAM

```
C1472 BFM
    1 FORMAT(58H1GENERAL TRANSMISSION CALCULATIONS FOR ETA BATH EXPERIME
     1NT/1H )
    2 FORMAT(72H                                                        147201
     1                    /72H                                          147201
     2                                                                  147201
    3 FORMAT(16I3,I1)                                                   147201
    4 FORMAT(6E7.3,I2)                                                  147201
    5 FORMAT(10E7.3)                                                    147201
   10 FORMAT(7(I3,E7.3))                                                147201
   15 FORMAT(5E9.5/6E9.5)                                               14720101
      DIMENSION JP(8),KP(8),JPP(8),E(6,100),X(6,100),IS(99),EI(99).     14720108
     1EE(300),XE(300),ES(600),XM(600)                                   14720109
      DIMENSION Q(11),LK(8),SUM(11),Y(11),SS(11),QT(11),XA(8)
  100 WRITE OUTPUT TAPE 9, 1                                            14720113
      READ INPUT TAPE 1, 2                                              14720101
      READ INPUT TAPE 1, 3, (JP(I),KP(I),I=1,8),IC                      14720102
      READ INPUT TAPE 1, 4, TNC,TNM,TNB,E1,E2,E3,NE                     14720103
      IF (IC-2) 13, 14, 13                                              14720207
   14 READ INPUT TAPE 1, 15, (Q(I),I=1,11)                              14720107
   13 IF (NE) 11, 12, 11                                                14720211
   11 READ INPUT TAPE 1, 10, (IS(I),EI(I),I=1,NE)                       14720111
      NEE=NE
   12 DO 6 I=1,6
      IF (JP(I)) 7, 8, 7                                                14720217
    7 M=JP(I)                                                           14720219
      JPP(I)=JP(I)                                                      14720220
      READ INPUT TAPE 1, 5, (E(I,J),J=1,M)                              14720113
    8 IF (KP(I)) 9, 6, 9                                                14720224
    9 M=KP(I)                                                           14720301
      READ INPUT TAPE 1, 5, (X(I,J),J=1,M)                              14720114
    6 CONTINUE                                                          14720305
      I=7                                                               14720201
      IF (JP(I)) 70, 71, 70                                             14720203
   70 M=JP(I)                                                           14720205
      JPP(I)=JP(I)
      READ INPUT TAPE 1, 5, (EE(J),J=1,M)
   71 IF (KP(I)) 72, 69, 72                                             14720209
   72 M=KP(I)                                                           14720211
```

```
      READ INPUT TAPE 1, 5, (XE(J),J=1,M)
   69 I=8                                                      14720214
      IF (JP(I)) 73, 74, 73                                    14720215
   73 M=JP(I)                                                  14720217
      JPP(I)=JP(I)                                             14720218
      READ INPUT TAPE 1, 5, (ES(J),J=1,M)
   74 IF (KP(I)) 75, 76, 75                                    14720221
   75 M=KP(I)
      READ INPUT TAPE 1, 5, (XM(J),J=1,M)
   76 WRITE OUTPUT TAPE 9, 2                                   14720119
      WRITE OUTPUT TAPE 9, 44                                  14720120
      JJJ=1                                                    14720306
      EB=E1                                                    14720307
      ET=E2                                                    14720308
      NEB=1                                                    147203
      DO 200 NY=1,11
  200 SS(NY)=0.0
      DO87N=1,8
   87 LK(N)=1                                                  14720425
   65 DO 99 JJ=NEB,NEE                                         14720301
      NP=IS(JJ)+1                                              14720311
      SI=IS(JJ)                                                14720312
      C1=2.0                                                   14720313
      C2=4.0                                                   14720314
      DO 88 NY=1,11                                            14720509
   88 SUM(NY)=0.0                                              14720511
      DE=(EI(JJ)-EB)/SI                                        14720316
      DO 24 K=1,NP                                             14720318
      EA=EB                                                    14720320
      DO 25 N=1,6                                              14720407
      NO=JPP(N)                                                14720324
      IV=LK(N)                                                 14720418
      DO26L=IV,NO                                              14720420
      IF (EA-E(N,L)) 27, 17, 26
   26 CONTINUE                                                 14720405
   27 D1=LOGF(E(N,L)/E(N,L-1))                                 14720101
      EN1=LOGF(E(N,L)/EA)                                      14720102
      EN2=LOGF(X(N,L-1))                                       14720103
      EN3=LOGF(EA/E(N,L-1))                                    14720104
```

```
      EN4=LOGF(X(N,L))                                                  14720105
      EN5=(EN1*EN2+EN3*EN4)/D1                                          14720107
      XA(N)=EXPF(EN5)                                                   14720111
      IF (SENSESWITCH 1) 59, 60                                         14720113
   59 PRINT 61, (D1,EN1,EN2,EN3,EN4,EN5,XA(N),EA)                       14720115
   61 FORMAT(4H D1=E11.5,3H 1=E11.5,3H 2=E11.5,3H 3=E11.5,             14720119
     13H 4=E11.5,3H 5=E11.5,3H X=E11.5,3H E=E11.5)                      14720121
     GO TO 60
   17 XA(N)=X(N,L)                                                      14720123
   60 LK(N)=L                                                           14720421
   25 CONTINUE                                                          14720411
      N=7                                                               14720411
      IV=LK(N)
      NO=JPP(N)
      DO 80 L=IV,NO
      IF(EA-EE(L))78,18,80
   80 CONTINUE                                                          14720418
   78 D1=LOGF(EE(L)/EE(L-1))                                            14720203
      EN1=LOGF(EE(L)/EA)                                                14720205
      EN2=LOGF(XE(L-1))                                                 14720206
      EN3=LOGF(EA/EE(L-1))                                              14720207
      EN4=LOGF(XE(L))                                                   14720208
      EN5=(EN1*EN2+EN3*EN4)/D1                                          14720210
      XA(N)=EXPF(EN5)                                                   14720212
      IF (SENSESWITCH 1) 62, 63                                         14720214
   62 PRINT 61, (D1,EN1,EN2,EN3,EN4,EN5,XA(N),EA)                       14720216
      GO TO 63
   18 XA(N)=XE(L)                                                       14720201
   63 LK(N)=L
   85 N=8                                                               14720401
      NO=JPP(N)                                                         14720402
      IV=LK(N)
      DO 81 L=IV,NO
      IF (EA-ES(L)) 82, 83, 81
   81 CONTINUE                                                          14720407
   82 D1=LOGF(ES(L)/ES(L-1))                                            14720220
      EN1=LOGF(ES(L)/EA)                                                14720222
      EN2=LOGF(XM(L-1))                                                 14720224
      EN3=LOGF(EA/ES(L-1))                                              14720301
```

```
69 SUM(NY)=SUM(NY)+Y(NY)                                          14720515
   GO TO 41                                                       14720605
66 DO90NY=1,4                                                     14720517
90 SUM(NY)=SUM(NY)+C2*Y(NY)                                       14720519
41 ASSIGN 23 TO NN                                                14720615
   PSI=SUM(2)                                                     14720523
   DEXL=DEXM                                                      14720618
   XC=XA(6)/XAM
   EL=ELM                                                         14720620
   EXL=EXM                                                        14720621
16 IF (EL-.001) 42, 42, 43
42 PL=0.0
   GO TO 20
43 IF (EL-1.0) 48, 48, 49
48 PL=-0.5*EL*(.577216+LOGF(EL)-1.5)+EL**2/
  16.-EL**3/48.+EL**4/360.                                        14720704
   GO TO 19
49 PL=1.-1./EL*(.5-EXL/(EL+2.5))
19 IF((PL*XC)-.99)21,20,20
20 S=DEXL*XC                                                      14720716
   GO TO 22                                                       14720717
21 S=DEXL*XC*(1.-PL*(1.-XC)/(1.-PL*XC))
22 IF (SENSESWITCH 2) 64, 77                                      14720311
64 PRINT 79, EL,PL,XC,S,EXL,EXM,EXC,EXB                           14720313
79 FORMAT(3H L=E11.5,4H PL=E11.5,3H X=E11.5,3H S=E11.5,           14720318
  15H EXL=E11.5,5H EXM=E11.5,5H EXC=E11.5,4H XB=E10.4)            14720319
77 GO TO NN, (23,30)
23 SM=S                                                           14720723
   EL=ELB                                                         14720724
   DEXL=1.0-EXB                                                   14720725
   IF (DEXL) 28, 29, 29                                           14720801
28 DEXL=0.0                                                       14720803
29 XC=XA(5)/XAB
   EXL=EXB                                                        14720806
   ASSIGN 30 TO NN                                                14720807
   GO TO 16                                                       14720809
30 DESI=XA(7)*SSI*DEXL
   Y(5)=DESI*DEXM                                                 14720901
   Y(6)=DESI*SM
```

```
      DP=DEXL*SSI
      Y(7)=DP*SM
      Y(8)=DEXM* S *SSI
      Y(9)=DP                                                           14720909
      Y(10)= S *SSI
      Y(11)=DEXM*DP                                                     14720913
      IF (SENSESWITCH 3) 84, 94                                         14720322
   84 PRINT95,(Y(NY),NY=1,11)                                           14720324
   95 FORMAT(3H Y=11E10.3)                                              14720326
   94 IF (K-1) 31, 32, 31
   31 IF (K-NP) 91, 32, 32                                              14720915
   32 DO 33 NY=5,11                                                     14720917
   33 SUM(NY)=SUM(NY)+Y(NY)                                             14720919
      IF (K-NP) 92, 24, 24
   91 DO 36 NY=5,11                                                     14720923
   36 SUM(NY)=SUM(NY)+C2*Y(NY)                                          14720925
      C1=-C1
      C2=C2+C1                                                          14720919
   92 EB=EA+DE                                                          14720923
   24 CONTINUE                                                          14720925
   44 FORMAT(14H0FROM E1 TO E2)                                         14721001
   45 FORMAT(14H0FROM E2 TO E3)                                         14721003
   46 FORMAT(14H0FROM E1 TO E3)                                         14721005
   47 FORMAT(6H0PHIF=E12.6,7H  PSIF=E12.6,5H  NF=E12.6,5H  ZF=E12.6/    14720005
     17H ALPHA=E12.6,7H  BETA=E12.6,8H  GAMMA=E12.6,8H  DELTA=E12.6/    14720009
     29H EPSILON=E12.6,8H  THETA=E12.6,5H  XI=E12.6)                    14720013
      DO 93 NY=1,11                                                     14721001
      SUM(NY)=SUM(NY)*DE/3.                                             14721003
   93 SS(NY)=SUM(NY)+SS(NY)                                             14721004
  102 FORMAT(3H0E=E10.4,8H  ALPHA=E12.6,7H  BETA=E12.6,8H  GAMMA=E12.6/ 14720015
     17H DELTA=E12.6,10H  EPSILON=E12.6,8H  THETA=E12.6,5H  XI=E12.6)   14720019
      WRITE OUTPUT TAPE 9, 102, EA, (SS(NY),NY=5,11)
      IF (ET-EA)199,103,199                                             14721017
  199 QO=(ET-EA)/ET                                                     14721015
      IF(ABSF(QO)-1.0E-6)103,103,99                                     147215//
   99 CONTINUE                                                          14721019
  103 WRITE OUTPUT TAPE 9, 47, (SS(NY),NY=1,11)                         14721021
      IF (SENSESWITCH 4) 96, 97                                         14720401
   96 PRINT101,K,EA,ET,QO,JJJ,NP                                        14720403
```

```
101 FORMAT(3H K=I3,3E13.6,3H J=I1,3H P=I3)                              14720405
 97 IF (JJJ-1) 118, 98, 118
 98 IF (IC-1) 106, 108, 108
106 JJJ=2                                                                14721101
    EB=E2                                                                14721102
    ET=E3                                                                14721103
    NEB=JJ+1                                                             14721104
    DO 107 NY=1,11                                                       14721105
    Q(NY)=SS(NY)
107 SS(NY)=0.0
    WRITE OUTPUT TAPE 9, 45                                              14721108
    GO TO 65                                                             14721109
108 WRITE OUTPUT TAPE 9, 45                                              14721121
    WRITEOUTPUTTAPE9,47,(Q(NY),NY=1,11)                                  1472
118 DO 110 NY=1,11                                                       14721124
110 QT(NY)=Q(NY)+SS(NY)                                                  14721125
    IF(JJJ-1)120,122,120                                                 1472
122 WRITE OUTPUT TAPE 9,46                                               14721201
    WRITE OUTPUT TAPE 9,47,(QT(NY),NY=1,11)                              14721202
    FF=QT(1)                                                             14721204
    HF=QT(2)/FF                                                          14721205
    PF=1.0-(QT(3)/(FF-QT(2)))
    ETA=QT(4)/(PF*(1.0-HF)*FF)                                           14721207
    A=QT(5)                                                              14721209
    B=QT(6)                                                              14721210
    G=QT(7)                                                              14721211
    D=QT(8)                                                              14721212
    EP=QT(9)                                                             14721213
    TSI=QT(11)
    XIG=TSI-G
    DET=(EP-QT(10))
    R1=(A-B+G-D)/DET                                                     14721216
    DET=DET/XIG
    R2=A/EP                                                              14721217
    R3=(A-B)/(TSI-G)                                                     14721218
    R4=A/TSI                                                             14721219
    DB=(D-G)/XIG
111 FORMAT(4H0HF=E12.6,5H  PF=E12.6,7H  ETAF=E12.6,7H  R(S)=E12.6,      14721222
   17H  R(O)=E12.6/9H ETAF(S)=E12.6,10H  ETAF(O)=E12.6)                  14721224
```

```
112 FORMAT(12H ETAF(R,S)=(E12.6,6H)R + (E13.6,1H)/
   112H ETAF(R,O)=(E12.6,5H)R / E12.6)
    WRITE OUTPUT TAPE 9, 111, HF,PF,ETA,R1,R2,R3,R4                     14721305
    WRITE OUTPUT TAPE 9,112,DET,D5,EP,TSI
    GO TO 100
120 DO121NY=1,11
121 Q(NY)=SS(NY)                                                        1472
    GOTO122                                                             1472
    END(0,1,0,0,0)                                                      1472
```

## ACKNOWLEDGMENT

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## DISTRIBUTION

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