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BURNUP: A FORTRAN IV CODE FOR COMPUTING U AND Pu FUEL BURNUP FROM U, Pu, AND Nd MASS SPECTROMETRIC MEASUREMENTS

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FOREWORD

The computer code BURNUP was written in 1964 and has been in use at this laboratory since that time. During this three-year period of use, it has been debugged and improved. The present form represents the sixth production version. Although a single sample can be processed, the averaging procedures for nuclear constants are most effective when five to fifty samples from the same fuel load are pooled in a single case. The code will process data obtained by the American Society for Testing and Materials (ASTM), Method E-321, for determination of atom percent fission in U and Pu fuel.

This report is one of three which summarize five years of work on accurate nuclear fuel burnup analysis. The other two reports are GEAP-5354, "Determination of Nd-148 in Irradiated U and Pu as a Measure of Burnup" and GEAP-5356, "A Survey and Evaluation of Thermal Fission Yields for U-235, Pu-239, U-233, and Pu-241."

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ABSTRACT

This code correlates heavy element isotopic analysis with fission product Nd, U, and Pu concentrations in an irradiated U fuel for calculation of burnup (atom percent fission and MWd/MT). Certain reactor parameters including effective neutron absorption cross sections for all U and Pu isotopes, capture-to-fission ratios for U-235, Pu-239 and Pu-241, a two-group description of the neutron spectrum, the average neutron temperature, the reactor fast fission factor, and the distribution of the sources of fission among the fissionable nuclides are computed from the experimental measurements. A description of the method, the equations used, and instructions for use of the code are included.

INTRODUCTION

The development of a method for calculating U and Pu fuel burnup from U, Pu, and Nd mass spectrometric measurements was first reported in GEAP-4817. Modifications to the original program were reported in GEAP-5124 and GEAP-5462. Further improvements which have been incorporated are described in this report, which revises and supersedes the earlier reports.

Among the improvements and additions are adaptations to:

1. Include uranium fuels containing initial Pu, e.g., in Pu recycle and mixed UO_2 - PuO_2 fuels, including the computation of pre-irradiation fuel composition.
2. Samples irradiated in various near-thermal neutron spectra through the introduction of Wescott formalism in which the epithermal index, the neutron temperature, and the effective neutron cross sections for heavy element and fission product nuclides are calculated from the experimental data.
3. Include recycled uranium fuel in which initial U-236 content is unknown. For this case, the U-235 fission contribution is calculated from the change in the U-235:U-238 ratio.

4. Include a Pu-242 burnout correction factor which becomes important at high exposures.
5. Increase flexibility to permit (a) computation even though several pre- or post-irradiation ratios are not known; (b) use of Am, Cm, and Np analyses where available; and (c) use of different irradiation and cooling times for each sample.
6. Improve error diagnostics to help detect errors of decimal, inversion, transposition, and key punching, which account for the most common sources of error.

PROGRAM DESCRIPTION

The hand calculation of burnup in irradiated nuclear fuel (containing no Th-232 or U-233) from the mass spectrometric determination of U, Pu, and stable fission products can be tedious. With machine computation, it is possible to obtain more accurate burnup values by applying corrections that are usually neglected. In addition, values for the capture-to-fission ratio, α , for U-235 and Pu-239 are obtained.

The required calculations have been programmed in a free style FORTRAN IV code called BURNUP which is available on request from the USAEC computer center at Argonne National Laboratory. In this code, burnup in megawatt-days per metric ton is calculated from U, Pu, and Nd mass spectrometric analyses. The calculation of burnup from heavy element isotopic composition could be based on the measured changes in U-236:U-238 and U-235:U-238 ratio changes caused by irradiation. However, these two ratios are sensitive to U-238 contamination. A more sensitive measure of burnup is the change in the U-236:U-235 ratio which is independent of U-238 but which is dependent on a knowledge of the capture-to-fission ratio in U-235, α_5 .

To make use of the change in the U-236:U-235 ratio, α_5 is first calculated from the data. On the basis of this calculation, samples are arranged in three sets: S-1, S-2 and S-3. Set S-1 includes the samples that contain a small amount of U-238 contamination. For these samples, the average α_5 of the uncontaminated samples is used with the U-236:U-235 ratio for the U-235 burnup calculations. Set S-2 includes the samples for which an acceptable α_5 cannot be calculated because of statistical scatter. For these samples,

the input α_5 is used. Set S-3 includes all normal samples from which an average α_5 is calculated for use in subsequent steps. Each set is further divided into either subset 1 for samples containing large amounts of pre-irradiation Pu or subset 2 for samples which do not. For subset 1, the capture-to-fission ratio for Pu-239, α_9 , is calculated from the data. For subset 2, the input α_9 is used.

The isotopic composition of the U and Pu in the sample is calculated from the measured isotopic ratios corrected for occasional traces of U-238 by the average α_5 , and for impurities contained in the isotopic diluent, such as U-234, in the U-233 added. An initial atom percent fission is computed for U-235, Pu-239, Pu-241, and U-238 from the change in the heavy element isotopic composition according to equations described elsewhere.¹

A correction is then made for the U-236 burnout based on an integrated exposure (nv_0t) obtained from the U-235 depletion. The U-238 burnout correction, determined from the change in the Pu content (including Pu-239 and Pu-241 fissions and Pu-241 decay correction) is made. Finally, an iteration of the initial set of calculations, with the data corrected as described, yields final values for the atom percent fission of each fissionable species. In addition, the concentrations of U and Pu (calculated from the sample volume, and spike volume and concentration) are adjusted to a pre-irradiation basis for use with the subsequent Nd data.

Stable fission product Nd-148, -146, and -145 atom concentrations in the irradiated fuel (each of which is directly proportional to burnup) are computed from measured ratios of each isotope to Nd-150 used as an isotopic diluent. Corrections are made for:

1. Burnout of each isotope,
2. Production of Nd-142 from fission product Pr-141 by neutron absorption,
3. Natural Nd contamination as indicated by the residual Nd-142 which does not occur in fission,
4. Small amounts of fission product Nd-150 in the Nd-150 spike position, and
5. Isotopic impurities in the Nd-150 isotopic diluent.

From the effective fission yields, determined from the various sources of fission as previously computed from the heavy element data, and the adjusted heavy element concentration, the total atom percent fission is calculated for each sample. The capture-to-fission ratio for Pu-239 is obtained from the heavy element data and a comparison of the results for atom percent fission obtained by both methods. Finally, the total atom percent fission is converted to burnup in megawatt-days per metric ton.

The program takes 15 to 20 seconds set-up time and 1 to 3 seconds machine time per sample in a type GE-635 digital computer. Burnup analyses calculated this way are more accurate and less expensive than hand calculations.

GUIDE TO APPENDICES

The instructions for calculating burnup as programmed appear in Appendices A, B, and C and will be useful to those who want to make a few hand calculations as well as to those who want to follow the reasoning behind the computation. The required symbols are defined in Appendix A. Where possible, a logical letter of the alphabet was selected for each variable. In some instances, the source of the symbol is indicated by underscoring in the definition of the letter selected. One, two, or three asterisks and sometimes subscripts 1, 2, and 3 are added to symbols to indicate that one, two, or three corrections have been made or one, two, or three different values are obtained for that variable.

The equations in Appendix B apply equally well to uranium fuels which contain initial plutonium as to those fuels which do not. Use is made of changes in the heavy element isotopic ratios in these computations to supplement analyses of stable fission products. Corrections are included for known nuclear reactions to make the burnup calculations valid up to very high exposures.

Constants built into the program are listed in Appendix C with instructions for preparation of sample data cards.

TESTS FOR CONSISTENCY OF INPUT DATA

Although the computer will faithfully perform the arithmetic calculations, the output will be only as reliable as the input data. Before submitting a series of samples for calculation, it is possible to observe consistency in the data by plotting $M_{8/5}$, $M_{4/5}$, $R_{0/9}$, $R_{1/9}$, and $R_{2/9}$ against $M_{6/5}$. Each of these plots will be a smooth curve for any single fuel load. Of these plots, the $M_{8/5}$ and $R_{2/9}$ versus $M_{6/5}$ are nearly straight lines over a wide range of exposures (see Fig. 1). At this stage of data analysis, errors of decimal, inversion, and transposition can be readily found and corrected.

As a further precaution, several criteria for reliability have been included in the code. In addition to low natural Nd contamination, these criteria require reasonable and consistent values for

1. α_5 and α_9 ,
2. Atom percent fission from heavy element and Nd methods.
3. Atom percent fission from Nd-148, Nd-146, and Nd-145 data, and
4. Sample-to-spike ratio, $M_{48/50}$.

Values which appear in the output are made more reliable because grossly inconsistent data are rejected. The consistency of the resultant output data can be shown by plotting R_9 , R_0 , R_1 , R_2 , $R_{9/8}$, $M_{6/8}$, and $M_{8/5}$ against $M_{6/5}^{**}$. In addition, M_4 , M_5 , M_6 , M_8 , F_5 , F_9 , F_1 , F_8 , F_T^* , F_{88} , F_{55} , F_{66} , F_{568} , P , $1-Q$, W_T^* , and MWd/MT^* are smooth functions of $M_{6/5}^{**}$ or MWd/MT . If any outlying points appear on the plots (see Fig. 2), or any data are rejected by the computer, they can be singled out for examination or re-analysis.

ESTIMATION OF PRECISION OF OUTPUT DATA

It is also of interest to know what uncertainty can be expected in burnup as calculated from Nd fission-product analysis or by heavy element isotopic analysis. Exclusive of biases in constants, e.g., fission yields, burnout cross sections, and spike calibrations, the uncertainty in a re-

FIGURE 1. INPUT DATA CONSISTENCY (Dresden 1)

FIGURE 2. OUTPUT DATA CONSISTENCY (Dresden 1)

ported burnup is the result of uncertainties in the measured mass spectrometric ratios.

To estimate the precision of burnup and other calculated quantities, a typical sample with 8625 MWd/MT burnup was selected for study. The atom percent of the U-238, U-235, and U-234 in the sample before irradiation was 98.48, 1.51, and 0.0094 at. %, respectively. The various precisions were determined theoretically² and empirically by computer simulation with the BURNUP code. The results of the study showed which mass ratios are most important in the calculations and which method can be expected to give the better precision.

Forty simulated samples were submitted to the computer. For each sample, the "observed" isotopic ratios were found by attaching a random normal deviate to each nominal value. The comparison between theoretical precisions and those observed in the simulation is:

<u>QUANTITY</u>	<u>RESULT</u>	<u>THEORETICAL</u> <u>σ, %</u>	<u>SIMULATED</u> <u>σ, %</u>
α_5	0.188	3.7	3.6
α_9	0.651	ND*	5.6
Pu-239:U-238	0.00301	ND	0.66
U-235 fission, at. %	0.610	1.15	1.15
Pu-239 fission, at. %	0.190	1.02	1.87
Pu-241 fission, at. %	0.0103	ND	1.32
U-238 fission, at. %	0.0768	ND	0.83
HE** Burnup, MWd/MT	8613	0.81	0.88
Fission/ml (by Nd,	4.74×10^{16}	0.40	0.58
Atoms U/ml	5.28×10^{18}	0.51	0.49
Nd burnup, MWd/MT	8650	0.67	0.76

*Not Determined

**Heavy Element

The agreement is good between theoretical and simulated precision values. It can be seen that the capture-to-fission ratios α_5 and α_9 are the least precisely known. The burnup as measured by heavy element and Nd methods have a standard deviation, σ , of ± 0.81 and $\pm 0.67\%$, respectively.

The average of these two burnup values (with a 40 to 60 weighting ratio) would have a standard deviation of $\pm 0.51\%$. If the primary interest is to obtain precise measurements of burnup, most attention should be directed toward obtaining precise values for certain critical ratios on the mass spectrometer. In the heavy element method, the critical ratios are U-236:U-235 and also U-235:U-238 when only a few samples are run. In the Nd method, the critical ratios are Nd-148, -146, and -145:Nd-150 and U-233:U-238.

LIMITATIONS OF THE HEAVY ELEMENT METHOD

It should be noted that the heavy element method is dependent on the Nd method to compute α_9 .

Even in fuel which is essentially free of initial U-236, the heavy element method is less precise than the neodymium method not only because of the difficulty in obtaining $R_{6/5}^0$ measurements (e.g., when U-236 and U-235 are less than 0.13 and 0.80% abundant, respectively) to an accuracy of much better than $\pm 2\%$ standard deviation.

Uranium which has recycled through a power reactor would lead to even greater difficulties in calculating burnup by the heavy element method because $R_{6/5}^0$ (if it can be obtained at all for any particular piece of fuel) then becomes a random variable whose uncertainty markedly affects the precision of F_5 . After one chemical reprocessing cycle (in which the U-236 will recycle) the heavy element method, as described here, will probably be of little value.

When only a few samples are run (especially if they are taken from different locations in the reactor) a bias is introduced in the burnup calculated by the heavy element method through the use of an over-all average α_5 value when in fact, the actual α_5 varies axially and radially over a reactor by as much as 5%. This bias can be removed, at the expense of some further loss in precision, by calculating α_5 for each sample.

On the other hand, the Nd method does not require values for either α_5 or α_9 and requires no pre-irradiation isotopic data. In addition, Nd. (in contrast to U-236) is not recycled in a volatile fluoride or conventional

aqueous fuel reprocessing plant, and the Nd-148:Nd-150 ratio of a typical fission product Nd sample spiked with Nd-150 (e.g., 6% Nd-148, 30% Nd-150) can be very accurately measured to $\pm 0.5\%$ standard deviation.

BLOCK DIAGRAM OF BURNUP

- ① Return with U-238 burnout correction factor, Q; and first estimate of α_9 .
- ② Return with Q-corrected nuclear constants and Pu-242 burnout factor.
- ③ Return with average α_9 containing all corrections including Pu-242 burnout.
- ④ Print

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1. B. F. Rider , and C. P. Ruiz, "Determination of Atom Percent Fission in Uranium Fuel," Progress in Nuclear Energy Series IX, Analytical Chemistry 3, Part 2, C. E. Crouthamel, ed. Pergamon Press (1962).
2. B. F. Rider , J. Paul Peterson, Jr., J. L. Jaech, C. P. Ruiz, and F. R. Smith, "Accurate Nuclear Fuel Burnup Analysis XV," USAEC Doc. GEAP-4950 (September, 1965).

GEAP-5355

APPENDIX A

SELECTED SYMBOLS FOR BURNUP CALCULATIONS

APPENDIX A

SELECTED SYMBOLS FOR BURNUP CALCULATIONS
IN ORDER OF APPEARANCE IN APPENDIX B

<u>Symbol</u>	<u>Meaning</u>
$M_{3/8}, M_{3/5}, M_{5/8}$	Isotopic ratios of U-233 to U-238, of U-233 to U-235, and U-235 to U-238 in the <u>mixture</u> of spike and sample.
$M_{6/5}, M_{4/5}$	Isotopic ratios of U-236 and U-234 to U-235 in the <u>mixture</u> of spike and sample.
$R_{2/9}, R_{0/9}, R_{1/9}$	Isotopic ratio of Pu-242, Pu-240, and Pu-241 to Pu-239 in the "as received" (unspiked) sample.
$M_{2/9}, M_{0/9}, M_{2/0}$	Isotopic ratios of Pu-242 to Pu-239, of Pu-240 to Pu-239, and Pu-242 to Pu-240 in the <u>mixture</u> of spike and sample.
V_{SA}, V_{SP}	<u>V</u> olume of <u>s</u> ample and <u>v</u> olume of <u>s</u> pike used in the analysis.
$M_{42/50}, M_{48/50},$ $M_{46/50}, M_{45/50}$	Isotopic ratios of Nd-142, -148, -146, and -145 to Nd-150 in the <u>mixture</u> of spike and sample.
$R_{243/239}, R_{244/239}$	Atom ratio of Am-243 and Cm-244 to Pu-239 in the "as received" (unspiked) sample.
$R_{7/8}$	Np-237 to U-238 atom ratio
S/M	Surface to mass ratio of UO_2 fuel (cm^2/g)
$S_{4/3}, S_{8/3}, S_{9/2}$	Isotopic ratio of U-234 and U-238 to U-233, and of Pu-239 to Pu-242, in the spike solution.
S_3	Atoms per milliliter of U-233 in the spike.

$C_{2/9}, C_{3/8}$	Isotopic ratio of Pu-242 to Pu-239 and U-233 to U-238 in the mixed <u>calibration</u> standard prepared from NBS Standards No. 949 and No. 950.
C_9/C_8	Ratio of Pu-239 to U-238 in the mixed <u>calibration</u> standard.
$R'_{3/8}$	Ratio of U-233 to U-238 in the "As- <u>R</u> eceived" (unspiked) samples: $R'_{3/8} \approx 0$ for non-Th-232, non-U-233 fuels.
$P_{2/9}, P_{3/8}$	Ratio of Pu-242 to Pu-239 and the ratio of U-233 to U-238 in the <u>primary</u> calibration mixture of calibration standard and spike.
$S_{50/42}, S_{50/48}, S_{50/46}, S_{50/45}$	Isotopic ratio of Nd-150 to Nd-142, -148, -146, and -145 in the spike.
$S_{1/2}$	Pu-241 to Pu-242 atom ratio in the spike
$S_{0/2}$	Pu-240 to Pu-242 atom ratio in the spike
A_{50}, A_{242}	<u>A</u> toms of Nd-150 and Pu-242 per milliliter, respectively, in the spike.
$R_{6/5}^O, R_{4/5}^O$	The <u>r</u> atio of U-236 and U-234 to U-235 in the fuel before irradiation.
$R_{5/8}^O, R_{9/8}^O$	The <u>r</u> atio of U-235 and Pu-239 to U-238 in the fuel before irradiation.
$R_{0/9}^O, R_{1/9}^O, R_{2/9}^O$	The <u>r</u> atio of Pu-240, Pu-241, and Pu-242 to Pu-239 in the fuel before irradiation.

t	The decay <u>time</u> (in seconds) from the end of irradiation until the measurement.
t^*	The irradiation <u>time</u> in seconds.
$\alpha_5, \alpha_9, \alpha_1$	Effective neutron capture-to-fission ratio for U-235, Pu-239, and Pu-241, respectively.
G	Ratio of U-238 fission to thermal fissions - more commonly known as δ_{28} .
$\sigma_4, \sigma_5, \sigma_6, \sigma_3, \sigma_9, \sigma_0, \sigma_1, \sigma_2$	Neutron absorption cross-section of U-234, U-235, U-236, U-238, Pu-239, Pu-240, Pu-241, and Pu-242, respectively, in barns.
$\sigma_{45}, \sigma_{48}, \sigma_{46}, \sigma_{42}, \sigma_{41}$	Neutron absorption cross section of Nd-145, -148, -146, -142, and Pr-141, respectively (expressed in barns).
r	Westcott epithermal index
$\nu_9/\nu_5, \nu_1/\nu_5$	Ratio of the number of neutrons per fission of Pu-239 and Pu-241 to U-235, equal to 1.185 and 1.25, respectively.
λ_1	Decay constant of Pu-241 expressed in seconds.

K	A value that has been chosen to determine when α_9 can be calculated from the data with reasonable accuracy, usually = 0.1 or 0.2.
$C_{50/42}$, $C_{50/48}$, $C_{50/46}$, $C_{50/45}$, $C_{48/42}$	Ratios of Nd-150 to Nd-142, -148, -146, and -145, and the ratio of Nd-148 to Nd-142 in natural neodymium <u>contamination</u> .
V	Maximum <u>value</u> permitted for the standard deviation of the mean for the average $\bar{\alpha}_{51}^*$.
V_1	Minimum <u>value</u> permitted for $\bar{\alpha}_{51}^*$.
V_2	Maximum <u>value</u> permitted for $\bar{\alpha}_{51}^*$.
V_3	Conversion coefficient from total atom fission fraction to megawatt-days per tonne using an effective MeV/fission.
V_4	Minimum permitted individual <u>value</u> of α_9 .
V_5	Maximum permitted individual <u>value</u> of α_9 .
V_6	Ratio of the U concentration of the diluted sample analyzed for heavy elements to that analyzed for Nd.
V_7	Minimum permitted individual <u>value</u> of α_5 .
V_8	Maximum permitted individual <u>value</u> of α_5 .
V_9	Minimum acceptable <u>value</u> for $\bar{\alpha}_{93}^*$.
V_{10}	Maximum acceptable <u>value</u> for $\bar{\alpha}_{93}^*$.

- V_{11} Maximum value permitted for the standard deviation of the mean for the average α_{93}^* .
- V_{12} Maximum fractional disagreement permitted between $M_{3/8}$ and $(M_{3/5} \times M_{5/8})$ for an average $M_{3/8}$ to be calculated.
- V_{13} Maximum fractional standard deviation permitted for T_{568}^* .
- V_{14} Maximum acceptable number of standard deviations that any individual measurement of α_5 may deviate from $\bar{\alpha}_{51}$.
- V_{15} Maximum acceptable value for K_3 .
- V_{16} Minimum acceptable value for K_3 .
- V_{17} Maximum acceptable value for $M_{48/50}$.
- V_{18} Minimum acceptable value for $M_{48/50}$.
- V_{19} Maximum allowable value for J .
- V_{20} Maximum acceptable number of standard deviations that any individual measurement of α_9 may deviate from $\bar{\alpha}_{93}$.
- V_{21} Minimum acceptable value of Q or Q^* .
- V_{22} Maximum fraction of measured U-234 which can be subtracted as spike contamination before it is more accurate to calculate the final U-234 from the initial U-234 and the measured exposure.
- V_{23} Maximum fractional discrepancy between $(M_{3/8} \div M_{3/5})$ and $M_{5/8}$ for an average value of $M_{5/8}$ to be calculated.
- V_{24} Maximum fractional discrepancy between $(M_{2/0} \times M_{0/9})$ and $M_{2/9}$ for an average $M_{2/9}$ to be calculated.

V_{25}	The maximum ratio of $R_{6/5}^0$ to fractional change in U-235 during irradiation for accurate calculation of α_5 .
V_{26}	The minimum fractional change in U-235 during irradiation for accurate calculation of α_5 .
V_{27}	The minimum permitted value for K_{19} .
V_{28}	The maximum permitted value for K_{19} .
V_{29}	Factor to adjust rate of stepping for iteration of K_{19} .
V_{30}	Maximum number of iterations for K_{19} .
V_{31}	Relative agreement required for r on iteration.
V_{32}	Relative agreement required for α_5 on iteration.
V_{33}	Maximum number of iterations for r .
V_{34}	Maximum permitted correction for U-238 contamination.
V_{35}	Minimum permitted value of K_{20} .
V_{36}	Maximum permitted value of K_{20} .
V_{37}	Factor to adjust rate of stepping for iteration of K_{20} .
V_{38}	Maximum number of iterations for K_{20} .

- V_{39} Proportionality constant between $\epsilon-1$ and $(r/R_{5/8}^0)$.
- V_{40} Number of standard deviations an individual σ_6 may differ from $\bar{\sigma}_6$ to be acceptable.
- V_{41} Number of standard deviations an individual r may differ from $\bar{r}$ to be acceptable.
- V_{42} Minimum permitted value for K_{21} .
- V_{43} Maximum permitted value for K_{21} .
- V_{44} Factor to adjust stepping rate for K_{21} .
- V_{45} Maximum number of iterations for K_{21} .
- V_{46} Maximum permitted fractional deviation from unity for K_{22} .
- V_{47} Factor to adjust stepping rate for K_{22} .
- V_{48} Maximum number of iterations for K_{23} .
- V_{49} Maximum permitted fractional deviation from unity for K_{23} .
- V_{50} Factor to adjust stepping rate for K_{23} .
- V_{51} Maximum number of iterations for K_{23} .
- V_{52} Maximum permitted fractional deviation from unity for K_{24} .

V_{53}	Factor to adjust stepping rate for K_{24} .
V_{54}	Maximum number of iterations for K_{24} .
V_{55}	Minimum fractional deviation from unity for $\frac{\sigma_2}{\sigma_1}$.
V_{56}	Maximum fractional deviation from unity for $\frac{\sigma_2}{\sigma_1}$.
V_{57}	Maximum number of passes from D-10 to I-67d.
V_{58}	Initial value of KR
V_{59}	If Pu-241 is to be reported as of the end of irradiation, then $V_{59} = 1$. If Pu-241 is to be reported as of the date of analysis, let $V_{59} = 0$.
V_{60}	Conversion factor from total atom fraction fission to megawatt days per matrix ton assuming 205 MeV/fission.
V_{61}	$V_{61} = 1$ for fast and $V_{61} = 0$ for thermal spectrum.
$\sigma_{8, 2n}$	The (n, 2n) effective neutron cross section of U-238
$\sigma_{5F}^o, \sigma_4^o, \sigma_5^o, \sigma_6^o, \sigma_7^o, \sigma_8^o, \sigma_9^o, \sigma_0^o, \sigma_{1F}^o, \sigma_2^o, \sigma_{41}^c, \sigma_{42}^o, \sigma_{45}^o, \sigma_{46}^o, \sigma_{48}^o$	The 2200 meter/sec neutron absorption cross sections for U-235 fission, U-234, U-235, U-236, Np-237, U-238, Pu-239, Pu-240, Pu-241 fission, Pu-242, Pr-141, Nd-142, Nd-145, Nd-146, and Nd-148, respectively.
$s_4^o, s_5^o, s_6^o, s_7^o, s_9^o, s_0^o, s_1^o, s_2^o, s_{5F}^o, s_{41}^o, s_{42}^o, s_{45}^o, s_{46}^o, s_{48}^o$	Westcott s values for 2200 meter/sec neutrons for U-234, U-235, U-236, Np-237, Pu-239, Pu-240, Pu-241, Pu-242, U-235 fission, Pr-141, Nd-142, Nd-145, Nd-146, and Nd-148, respectively.
T_o	Room temperature = 293° Kelvin
TEMP	Neutron Temperature
B_2	Burnout correction factor for Pu-242

K_2	Calculated quantity, ideally 0, to test agreement between Nd-148 and Nd-145 + Nd-146.
K_3	Calculated quantity, ideally 0, to test agreement in atom percent fission derived from Nd and heavy element isotopic data.
$Y_{05}, Y_{85}, Y_{65}, Y_{55}, Y_{15}$	Fission yield of Nd-150, Nd-148, Nd-146, Nd-145, and Pr-141, respectively, in thermal fission of U-235.
$Y_{09}, Y_{89}, Y_{69}, Y_{59}, Y_{19}$	Fission yield of Nd-150, -148, -146, -145, and Pr-141, respectively, in thermal fission of Pu-239.
$Y_{01}, Y_{81}, Y_{61}, Y_{51}, Y_{11}$	Fission yield of Nd-150, -148, -146, -145, and Pr-141, respectively, in thermal fission of Pu-241.
$Y'_{05}, Y'_{85}, Y'_{65}, Y'_{55}, Y'_{15}$	Fission yield of Nd-150, -148, -146, -145 and Pr-141, respectively, in epithermal fission of U-235.
$Y'_{09}, Y'_{89}, Y'_{69}, Y'_{59}, Y'_{19}$	Fission yield of Nd-150, -148, -146, -145 and Pr-141, respectively, in epithermal fission of Pu-239.
$Y'_{01}, Y'_{81}, Y'_{61}, Y'_{51}, Y'_{11}$	Fission yield of Nd-150, -148, -146, -145 and Pr-141, respectively, in epithermal fission of Pu-241.
$Y_{08}, Y_{88}, Y_{68}, Y_{58}, Y_{18}$	Fission yield of Nd-150, -148, -146, -145, and Pr-141, respectively, in fast fission of U-238.
N_4^0, N_5^0, N_8^0	Fraction of original heavy element atoms (mass > 228) which were U-234, U-235, and U-238, respectively.
$R_{2/8}^0, R_{0/8}^0, R_{1/8}^0$	The ratio of Pu-242, Pu-240, and Pu-241 to U-238 before irradiation.

α_{51}	Effective neutron capture-to-fission ratio for U-235 calculated from Equation (1) in Appendix II.
$\bar{\alpha}_{51}$	Average of all acceptable α_{51} values.
$S\alpha_{51}$	Standard deviation of a single observation of α_{51} .
H	Ratio of final U-235 enrichment to initial value.
N_6^*	Correction factor for U-236 burnout.
$M_{6/5}^*$	U-236 burnout corrected value of $M_{6/5}$.
$F_{51}, F_{52}, F_{53}, F_{54}$	Fraction of heavy element atoms that fissioned as U-235 as calculated from four different equations.
F_9, F_1, F_8	Fraction of heavy element atoms that fissioned as Pu-239, Pu-241, and U-238, respectively.
F	Total fraction of heavy element atoms fissioned.
M_8, M_4, M_5, M_6	Isotopic abundance of U-238, -234, -235, and -236 (in percent) in the irradiated sample uranium.
A, B, C, D	Intermediate constants in the calibration of the U-233 plus Pu-242 mixed spike (A and B) or in the determination of $R_{9/8}$ of the sample (C and D).
$R_{9/8}, R_{0/8}, R_{1/8}, R_{2/8}$	Ratio of Pu-239, -240, -241, and -242 to U-238 in the irradiated sample.
R_9, R_0, R_1, R_2	Isotopic abundance of Pu-239, Pu-240, Pu-241, and Pu-242 (in percent) in the irradiated sample plutonium.

W	Exposure in $nv_0 t$ divided by σ_5 .
X	Arbitrary statistic to determine whether α_9 can be calculated from the data.
$R_{1/8}^{***}$	Ratio of Pu-241 to U-238 corrected for decay during and after irradiation.
A_8	Atoms of U-238 per milliliter of sample.
P	Pu-239 captures per milliliter of sample.
α_{91}	Capture-to-fission ratio for Pu-239 (first calculation).
* , ** , ***	One, two, or three asterisks indicate that one, two, or three corrections were applied to the value.
Q	Correction factor for U-238 burnout.
$Q_{3/8}, Q_{5/8}, Q_{7/8}$	U-238 burnout corrected values for $M_{3/8}, M_{5/8}$, and $R_{7/8}$.
N_{FL}	Atoms of fuel per cm^3 .
N_{ML}	Atoms of moderator in fuel region per cm^3 .
A_M	Atom ratio of moderator to fuel in the fuel region (for UO_2 , $A_M=2$; for UC, $A_M=1$; and for U, $A_M=0$).
N_M	Molecules of moderator in moderator region per cm^3 .
MWF	Molecular weight of fuel.
MWM	Molecular weight of moderator.

D_f	Density of material in fuel region.
D_m	Density of material in moderator region.
V_R	Ratio of volume occupied by moderator to volume occupied by fuel.
RAD	Radius (cm) for cylinders or spheres or half-thickness (cm) for slabs.
JC	Integer to select the approximate column number in Table B (for slab JC=2; for cylinder JC=3; and for sphere JC=3).
$\Sigma_{SF}, \Sigma_{CF}, \Sigma_{IF}, \Sigma_{FF}, \Sigma_{TF}$	Macroscopic cross section in fuel region due to fuel for scattering, capture, inelastic scattering, fission, and total, respectively.
$\Sigma_{SM}, \Sigma_{CM}, \Sigma_{IM}, \Sigma_{TM}$	Macroscopic cross section in fuel region due to moderator for scattering, capture, inelastic scatter, and total, respectively.
$\Sigma_{SL}, \Sigma_{CL}, \Sigma_{IL}, \Sigma_{TL}$	Macroscopic cross section in lumped fuel region for scatter, capture, inelastic scatter, and total, respectively.
$\Sigma_{SM}, \Sigma_{CM}, \Sigma_{IM}, \Sigma_{TM}$	Macroscopic cross section in moderator region due to moderator for scatter, capture, inelastic scatter, and total, respectively.
$\sigma_{SFL}, \sigma_{CFL}, \sigma_{IFL}, \sigma_{FFL}, \sigma_{TFL}$	Microscopic cross section in lumped fuel region due to fuel for scatter, capture, inelastic scatter, fission, and total, respectively.

$\sigma_{\text{SML}}, \sigma_{\text{CML}}, \sigma_{\text{IML}}, \sigma_{\text{TML}}$	Microscopic cross section in lumped fuel region due to moderator for scatter, capture, inelastic scatter, and total, respectively.
$\sigma_{\text{SM}}, \sigma_{\text{CM}}, \sigma_{\text{IM}}, \sigma_{\text{TM}}$	Microscopic cross section in moderator region due to moderator for scatter capture, inelastic scatter, and total, respectively.
ν_8, ν_5	Number of neutrons per fission from U-238 and U-235, respectively.
χ	Fraction of neutrons above the U-238 fission threshold.
N_{AL}	Number of neutrons that are emitted at some $E \geq E_f$ per collision in the lumped fuel, where E_f is the U-238 fission threshold.
N_{BL}	Number of neutrons that are emitted at some $E < E_f$ per collision in the lumped fuel.
N_{AH}	Number of neutrons that are emitted at some $E \geq E_f$ per collision in the homogeneous region.
N_{BH}	Number of neutrons that are emitted at some $E < E_f$ per collision in the homogeneous region.
P_c	First collision probability with a uniform source.
$\Delta_1, \dots, \Delta_{14}$	Calculated constants for Nd equations.
$M_{\text{T58}}, \dots, F_{\text{T8}}$	Summarized terminal values for $M_{5/8}$ through F_8 from heavy element calculations required for Nd calculations.
$E_{50}, E_{48}, E_{46}, E_{45}, E_{41}$	Effective fission yields of Nd-150, -148, -146, -145, and Pr-141 in the irradiated sample.

$E_{0/8}, E_{0/6}, E_{0/5}$	Ratio of the <u>effective</u> fission yields of Nd-150 to Nd-148, -146, and -145, respectively.
A_{48}, A_{46}, A_{45}	<u>Atoms</u> of Nd-148, -146, and -145, respectively, per milliliter of sample.
T_8, T_{56}, T_{568}	Fissions per milliliter of sample determined from Nd-148, Nd-145 + Nd-146, and the average of Nd-148, Nd-145, and Nd-146, respectively.
Z	Heavy element atoms per milliliter of sample on a pre-irradiation basis.
W_T^*	Neutron exposure (nv_{ot}).
σ_f	Average effective fission cross section for all combined heavy element atoms in the fuel.
$K_1, \dots, K_{25}$	Calculated lumping constants.
A_{42}	Nd-142 <u>atoms</u> per milliliter of sample formed by [Pr-141(n, γ)Pr-142] and subsequent decay to Nd-142. This is the Nd-142 which is not natural contamination.
A_{42}^*	Nd-142 <u>atoms</u> per milliliter of sample as measured.
A_{42}^{**}	Nd-142 <u>atoms</u> per milliliter of sample from natural Nd contamination equal to $A_{42}^* \cdot A_{42}$.
$M_{50/42}^*$	Corrected ratio of Nd-150 to natural Nd-142.
$A_{48}^*, A_{46}^*, A_{45}^*$	Nd-148, -146, and -145 <u>atoms</u> per milliliter of sample corrected for influence of Nd-142 formed from Pr-141.

A_{461}, A_{462}

Nd-146 atoms per milliliter of sample formed from [Nd-145(n, γ)Nd-146] when $\sigma_{46} \neq 0$ and when $\sigma_{46} = 0$, respectively (values 1 and 2).

A_{463}, A_{464}

Nd-146 atoms per milliliter of sample formed from fission where $\sigma_{46} \neq 0$ and when $\sigma_{46} = 0$, respectively (values 3 and 4).

A_{465}

Burnout corrected Nd-146 atoms per milliliter of sample (value 5 and final).

A_{481}, A_{482}

Nd-148 atoms per milliliter of sample formed from fission when $\sigma_{48} \neq 0$ and when $\sigma_{48} = 0$, respectively (value 1 and 2).

A_{483}

Burnout corrected Nd-148 atoms per milliliter of sample (value 3 and final value).

$T_8^*, T_5^*, T_6^*, T_{568}^*, Z^*$

Burnout corrected values of T_8, T_5, T_6, T_{568} , and Z

$F_{88}, F_{55}, F_{66}, F_{568}$

Total initial heavy element atom fraction fissioned as calculated from Nd-148, Nd-145, Nd-146, and from Nd-145 + Nd-146 + Nd-148. The double subscript on the first three values is to distinguish these values from F_5 or F_8 used for the U-235 or U-238 contribution to the total fission fraction.

MWd/MT

Megawatt days per metric ton.

J

Ratio of natural Nd-148 contamination to stable fission product Nd-148.

F_{92} Atom fraction fission from fission of Pu-239 calculated from total fission fraction as determined from Nd minus F_8 , F_5 , and F_1 (value 2 and final value of F_9).

α_{92} Capture-to-fission ratio for Pu-239 (value 2).

α_{93} Experimentally measured value of α_9 (value 3 and final calculation of α_9).

$\bar{\alpha}_{93}^*$ Average of all acceptable α_{93} values.

$S_{\alpha_{93}}^*$ Standard deviation for a single observation of α_{93} .

SUM Sum of all heavy element ratios to U-238.

4, 5, 6, 8, 9, 0, 1, 2, F, T ATOM PCT Atom percent of U-234, -235, -236, -238, Pu-239, -240, -241, -242, fission, and total heavy element atom percent.

EPF9 Energy per fission of Pu-239, in MeV

EPF5 Energy per fission of U-235, in MeV

EPF8 Energy per fission of U-238, in MeV

EPF1 Energy per fission of Pu-241, in MeV

IP1, ..., IP20 Instruction to print intermediate results from 20 different groups of mathematical operations as defined below. Each IP is preset to zero to repress print out. Set any IP equal to 1, 2, or 3 to print out results only from the first, second, or third of V_{57} major iterations. Set any IP equal to 4 to print out results only from the fourth and final (if $V_{57} = 4$) major iteration. Set any IP equal to any value larger than V_{57} (e.g., 9) to print out results after every major iteration.

- IP1 HE (heavy element method) results by non-Np route of α_{51} through Q_7 .
- IP2 HE results by non-Np route of V_{30} iterations for σ_6 .
- IP3 HE results by Np route of V_{38} iterations for σ_6 .
- IP4 HE results by Np route of G through $R_{7/8}^*$.
- IP5 HE results summary for Q through MWD/MT^{**}.
- IP6 HE results of V_{45} iterations for σ_9 .
- IP7 HE results for Group S-1 individual samples for F_{53} through $M_{5/8}'$.
- IP8 HE results of V_{48} iterations for σ_0 .
- IP9 HE results of V_{51} iterations for σ_1' .
- IP10 HE results of V_{54} iterations for σ_2 .
- IP11 HE results summary of α_5 averaging process.
- IP12 HE results summary of cross sections $\sigma_8, \sigma_9, \sigma_0, \sigma_1', \sigma_2, \sigma_6, \sigma_5, \sigma_{1F}, \sigma_{5F}, \sigma_{9F}, \alpha_9', \alpha_1', \alpha_{52}, g_9$, and the Westcott epithermal index r (Symbol RR) and the absolute neutron temperature (Kelvin) (Symbol TEMP).
- IP13 Lists the Westcott Table A values for current evaluation of neutron temperatures. Please note that here Westcott lists neutron temperature in Celsius scale.
- IP14 Nd input results from initial HE iteration.

IP15	Nd input results from current HE iteration.
IP16	Summary for sources of fission and α_9 averaging process.
IP17	HE results for Group S-3 individual samples of 30 intermediate values from F_{53} through MWD/MT ^{**} .
IP18	Nd results for calculated constant values.
IP19	Nd results for K values used in error diagnostics.
IP20	Nd results for individual samples for 34 intermediate values from Z through MWD/MT.
Q ₇	Label for $(\sigma_6 - \sigma_6^0)/\sigma_6^0 s_6^0$
MPP58	Label for $M'_{5/8} - C_1 R_{5/8}$
SET A1	Label for input value of α_1
TA4, TA10, TA11	Table A values for g_{1F} , s_{5F} , and s_9 , respectively.
Q ₉	Label for σ_2/σ_2' .
EXLT	Label for $\text{EXP} (+\lambda_1 t)$
PLTS	Label for $\lambda_1 t^*$
QR	Label for $\bar{r} \sqrt{\frac{\text{TEMP}}{T_0}}$

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APPENDIX B

INSTRUCTIONS FOR CALCULATION OF NUCLEAR FUEL BURNUP

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INSTRUCTIONS FOR CALCULATION OF NUCLEAR FUEL BURNUP
FROM U, Pu, AND Nd MASS SPECTROMETRIC MEASUREMENTS

- A. Blend an aliquot of dissolved spent fuel solution with mixed U-233, Pu-242, Nd-150 spike according to Appendix A of USAEC Report GEAP-5354 (Sept. 1, 1967); and record values for $M_{3/8}$, $M_{3/5}$, $M_{5/8}$, $M_{6/5}$, $M_{4/5}$, $M_{2/9}$, $M_{0/9}$, $M_{1/9}$, $M_{2/0}$, $R_{2/9}$, $R_{0/9}$, $R_{1/9}$, V_{SA} , V_{SP} , $M_{42/50}$, $M_{48/50}$, $M_{46/50}$, $M_{45/50}$, $R_{243/239}$, $R_{244/239}$, $R_{7/8}$, S/M , t and t^* . The last six are optional. Minimum required datum is $M_{5/8}$. Other values should be included if possible. $R_{2/9}$, $R_{0/9}$, and $R_{1/9}$ are only important when using an impure Pu-242 for the spike. $M_{4/5}$ is the most difficult to obtain and is the least important ratio. Any ratio not measured should be entered as 0.
- B. Also, record a series of constants, some of which may vary from one batch of samples to the next. Spike-dependent constants are $S_{4/3}$, $S_{8/3}$, $S_{9/2}$, S_3 , $C_{2/9}$, $C_{3/8}$, C_9/C_8 , $R_{3/8}$, $P_{2/9}$, $P_{3/8}$, $S_{50/42}$, $S_{50/48}$, $S_{50/46}$, $S_{50/45}$, A_{50} , $S_{1/2}$, $S_{0/2}$, and A_{242} . Fuel-dependent constants are $R_{4/5}^0$, $R_{0/9}^0$, $R_{1/9}^0$, $R_{2/9}^0$, $R_{6/5}^0$, $R_{5/8}^0$, $R_{9/8}^0$, t , and t^* . Reactor-dependent constants are α_1 , α_5 , α_9 , G , σ_0 , σ_1 , σ_2 , σ_4 , σ_5 , σ_6 , σ_8 , σ_9 , σ_{45} , σ_{48} , σ_{41} , σ_{42} , σ_{46} , and r .
- C. Other constants are v_9/v_5 , v_1/v_5 , λ_1 , K , $C_{50/42}$, $C_{50/48}$, $C_{50/46}$, $C_{50/45}$, $C_{48/42}$, V , V_1 through V_{24} . Fission yield constants include Y_{05} , Y_{85} , Y_{65} , Y_{55} , Y_{15} , Y_{09} , Y_{89} , Y_{69} , Y_{59} , Y_{19} , Y_{01} , Y_{81} , Y_{61} , Y_{51} , Y_{11} , Y_{08} , Y_{88} , Y_{68} , Y_{58} , and Y_{18} . A base set of constants is programmed in the code, and only changes from the base set need be supplied.
- D. The following calculations will separate samples into three sets.
If $V_{61} \neq 0$, set IP-1, -4, -5, -7, -11, -16 and -17 equal to 1.
1. If V_{SP} or $V_{SA} = 0$, then set it = 1
Set α_{51} , σ_6 , and $\bar{\alpha}_{53}^{**} = 0$ and $B_2 = 1$
 - 1b. If $M_{3/8} = 0$, then $M_{3/8} = M_{3/5} M_{5/8}$
 - 2a. If $M_{3/5} \neq 0$ and $\left| \frac{M_{3/5} M_{5/8}}{M_{3/8}} - 1 \right| \leq V_{12}$, then $M_{3/8} = \frac{M_{3/5} M_{5/8} + M_{3/8}}{2}$
 - 2b. If $M_{3/5} \neq 0$ and $\left| \frac{M_{3/5} M_{5/8}}{M_{3/8}} - 1 \right| > V_{12}$ and $|M_{3/5} - 1| < |M_{3/8} - 1|$,
then $M_{3/8} = M_{3/5} M_{5/8}$

3. If $M_{3/5} \neq 0$ and $\left| \frac{M_{3/5} M_{5/8}}{M_{3/8}} - 1 \right| > V_{12}$, then print " $M_{3/5}$ is in poor agreement with $M_{3/8}$ "
4. If $M_{3/5} \neq 0$ and $\left| \frac{(M_{3/8}/M_{3/5})}{M_{5/8}} - 1 \right| \leq V_{23}$, then $M_{5/8} = \frac{(M_{3/8}/M_{3/5}) + M_{5/8}}{2}$
5. If $M_{3/5} \neq 0$ and $\left| \frac{M_{3/8}/M_{3/5}}{M_{5/8}} - 1 \right| > V_{23}$, then print " $M_{3/5}$ is in poor agreement with $M_{5/8}$ "
6. If $M_{2/9} = 0$, then $M_{2/9} = M_{2/0} M_{0/9}$
7. If $M_{2/0} \neq 0$ and $\left| \frac{M_{2/0} M_{0/9}}{M_{2/9}} - 1 \right| \leq V_{24}$, then $M_{2/9} = \frac{M_{2/0} M_{0/9} + M_{2/9}}{2}$
8. If $M_{2/0} \neq 0$ and $\left| \frac{M_{2/0} M_{0/9}}{M_{2/9}} - 1 \right| > V_{24}$, then print " $M_{2/0}$ is in poor agreement with $M_{2/9}$ "
9. Initialize $F_T = 0$ and $W_T^* = 0$
10. $M'_{5/8} = M_{5/8} / [1 - (S_{8/3})(M_{3/8})]$
- 10a. If $R_{5/8}^0 = 0$, then $R_{5/8}^0 = \frac{M_{6/5} M'_{5/8} + \alpha_5 (M'_{5/8} + M_{6/5} M'_{5/8})}{\alpha_5 + \alpha_5 R_{6/5}^0 + R_{6/5}^0}$
- 10b. If $M'_{5/8} = 0$, place the sample in S-1.
- 10c. If $R_{5/8}^0 = 0$ or if $\bar{\alpha}_{51}^{**} \neq 0$ and is not between V_1 and V_2 (TST-2); or if $\bar{\alpha}_{93}^* \neq 0$ and is not between V_9 and V_{10} (TST-3); or if $\bar{r} \neq 0$ and is $> V_8$ (TST-1); then set $V_{57} = 0$ to stop iterations and set $W_T^* = 0$ and go to D-10d. If $R_{5/8}^0 \neq 0$ and tests 1, 2, and 3 are passed (T for true); then go to D-11.
- 10d. If $M'_{5/8}$ and $M_{6/5} \neq 0$, compute D-12, E-7, E-8, E-9, and E-11 unless already done.
- 10e. Compute E-12, E-13, E-14, E-15, E-16, E-17, E-19, E-20, E-21a, E-22a, E-23a, E-23d and I-1 through I-8 unless done. Set $K_4 = 1$, $K_5 = 0$, $K_6 = 0$, $G = 0$, $M_{46/50} = 0$, $M_{45/50} = 0$; and go to I-14d.

11. $W_T^* = \frac{1}{\sigma_5} \ln \left(\frac{R_{5/8}^0}{(M'_{5/8} - C_1 R_{5/8}^0)} \right)$; if $V_{61} \neq 0$, then $W_T^* = 0$.
 If $M'_{5/8}$ or $R_{5/8}^0 = 0$, then $W_T^* = 0$
 If $W_T^* < 0$, set $W_T^* = 0$ ("error", S-1)
12. $M_{4/8}^{**} = (M_{4/5}) (M'_{5/8}) - (S_{4/3}) (M_{3/8}) \geq 0$
13. If $R_{4/5}^0 = 0$, then $R_{4/5}^0 = \frac{M_{4/8}^{**}}{R_{5/8}^0 \exp(-\sigma_4 W_T^*)}$
14. If $R_{4/5}^0$ still = 0, then $R_{4/5}^0 = 0.01$
15. $D_1 = 1 + R_{9/8}^0 (1 + R_{0/9}^0 + R_{1/9}^0 + R_{2/9}^0) + R_{5/8}^0 (1 + R_{6/5}^0 + R_{4/5}^0)$
16. $N_4^0 = \frac{(R_{5/8}^0)(R_{4/5}^0)}{D_1}$
17. $N_5^0 = \frac{R_{5/8}^0}{D_1}$
18. $N_8^0 = \frac{1}{D_1}$
19. $R_{2/8}^0 = (R_{9/8}^0)(R_{2/9}^0)$
20. $R_{0/8}^0 = (R_{9/8}^0)(R_{0/9}^0)$
21. $R_{1/8}^0 = (R_{9/8}^0)(R_{1/9}^0)$
22. If $\frac{(S_{4/3})(M_{3/8})}{(M_{4/5})(M'_{5/8})}$ is not between 0 and V_{22} , then $M_{4/8}^{**} = \frac{N_4^0}{N_8^0} \exp(-\sigma_4 W_T^*)$
23. If $R_{6/5}^0 = 0$, then $R_{6/5}^0 = \frac{M_{6/5} M'_{5/8} - \alpha_5 (R_{5/8}^0 - M'_{5/8} - M_{6/5} M'_{5/8})}{(1 + \alpha_5) R_{5/8}^0} \geq 0$
24. If $R_{6/5}^0 \leq 0$, place in S-1
25. This step is deleted.
26. If $M'_{5/8}$ and $M_{6/5} = 0$, then place in Set S-1
27. $R_{6/8}^0 = R_{6/5}^0 R_{5/8}^0$

28a. If $\bar{\sigma}_6 \neq 0$, then $\sigma_6 = \bar{\sigma}_6$

28b. $R_{6/8}^{o*} = R_{6/8}^o \exp(-\sigma_6 W_T^*)$

28c. $R_{4/8}^o = R_{4/5}^o R_{5/8}^o$

28d. $M_{4/8} = M_{4/5} M'_{5/8}$

28e. $M_{6/8} = M_{6/5} M'_{5/8}$

28f. $M_{6/8}^* = M_{6/8} - R_{6/8}^{o*}$

28g. $M_{5/8}^{***} = M_{4/8}^{**} + M'_{5/8}$

29. $R_{5/8}^{o*} = R_{5/8}^o \left(1 + \frac{N_4^o}{N_5^o} \right)$

30. If $\alpha_{51} = 0$, then $\alpha_{51} = \frac{M_{6/8}^*}{R_{5/8}^{o*} - M_{5/8}^{***} - M_{6/8}^*}$

If $\bar{\alpha}_{51}^{**} \neq 0$, then $\alpha_{51} = \bar{\alpha}_{51}^{**}$

31. If α_{51} is not between V_7 and V_8 , place that sample in S-1

32a. If $\frac{R_{5/8}^o - M'_{5/8}}{R_{5/8}^o} < v_{26}$ or $\frac{M_{6/5} - R_{6/5}^o}{M_{6/5}} < v_{26}$ or $\frac{(R_{6/5}^o)(R_{5/8}^o)}{R_{5/8}^o - M'_{5/8}} > v_{25}$,

place in S-1

32b. Westcott g and s values appear in TABLE A (KR, KC) where the K's are the row and column number.

32c. If $KR = 0$, then $KR = V_{58}$

33. $r_1 = \left\{ \frac{\sigma_5^o [\text{TABLE A (KR, 3)}] - \sigma_{5F}^o [\text{TABLE A (KR, 5)}] (1 + \alpha_{51})}{\sigma_{5F}^o [\text{TABLE A (KR, 7)}] (1 + \alpha_{51}) - \sigma_5^o [\text{TABLE A (KR, 6)}]} \right\}$

If $r_1 < 0$, then set it = 0

$$34. \quad \sigma_5 = \sigma_5^o \left\{ [\text{TABLE A (KR, 3)}] + r_1 [\text{TABLE A (KR, 6)}] \right\}$$

35. If S/M and $R_{7/8}$ are both $\neq 0$, go to D-53

$$36. \quad \text{TEMP} = \text{TABLE A (KR, 1)} + 273$$

$$37. \quad \sigma_6 = \sigma_6^o \left[1 + \left(r_1 \sqrt{\frac{\text{TEMP}}{T_o}} \right) s_6^o \right]$$

$$38. \quad C_1 R_{6/8} = \frac{\alpha_{51} \sigma_5^o R_{5/8}^o}{(1 + \alpha_{51})(\sigma_6 - \sigma_5)} \left[\exp(-\sigma_5 W_T^*) - \exp(-\sigma_6 W_T^*) \right]$$

39. If $R_{4/5}^o \neq 0.01$ and if $\frac{S_{4/3} M_{3/8}}{M_{4/5} M_{5/8}'}$ is between 0 and V_{22} ,

$$\text{then } \sigma_4 = \frac{1}{W_T^*} \ln (R_{4/8}^o / M_{4/8})$$

40. If $R_{4/5}^o = 0.01$ or if $\frac{S_{4/3} M_{3/8}}{M_{4/5} M_{5/8}'}$ is not between 0 and V_{22} ,

$$\text{then } \sigma_4 = \sigma_4^o \left[1 + \left(r_1 \sqrt{\frac{\text{TEMP}}{T_o}} \right) s_4^o \right]$$

$$41. \quad C_2 R_{6/8} = \frac{\alpha_{51} \sigma_4 \sigma_5 R_{4/8}^o}{1 + \alpha_{51}} \left[\frac{\exp(-\sigma_4 W_T^*)}{(\sigma_5 - \sigma_4)(\sigma_6 - \sigma_4)} + \frac{\exp(-\sigma_5 W_T^*)}{(\sigma_4 - \sigma_5)(\sigma_6 - \sigma_5)} \right. \\ \left. + \frac{\exp(-\sigma_6 W_T^*)}{(\sigma_4 - \sigma_6)(\sigma_5 - \sigma_6)} \right]$$

$$42. \quad C_1 R_{5/8} = \frac{\sigma_4 R_{4/8}^o}{\sigma_5 - \sigma_4} \left[\exp(-\sigma_4 W_T^*) - \exp(-\sigma_5 W_T^*) \right]$$

$$43. \quad R_{6/8}^{o*} = R_{6/8}^o \exp(-\sigma_6 W_T^*)$$

$$44. \quad K_{19} = \left[\frac{(R_{6/8}^{o*} + C_1 R_{6/8} + C_2 R_{6/8}) / M_{5/8}'}{M_{6/5}} \right] - 1$$

If $K_{19} > 0.2$, then set it = 0.2

If $K_{19} < -0.2$, then set it = -0.2

45. If K_{19} is not between V_{27} and V_{28} , then $\sigma_6 = \sigma_6^0 \left(\frac{1}{1 + V_{29} K_{19}} \right)$

and return to D-38 for V_{30} iterations maximum.

$$46. \quad r_2 \sqrt{\frac{\text{TEMP}}{T_0}} = \frac{\sigma_6 - \sigma_6^0}{\sigma_6^0 s_6^0}$$

$$47a. \quad r_2 = r_2 \sqrt{\frac{\text{TEMP}}{T_0}} \div \sqrt{\frac{\text{TEMP}}{T_0}}$$

$$47b. \quad H = (M'_{5/8} - C_1 R_{5/8}) / R_{5/8}^0 \leq 1$$

$$47c. \quad N_6^* = \frac{(\sigma_5 - \sigma_6)}{\sigma_5} \left[\frac{1-H}{H \sigma_6 / \sigma_5 - H} \right] \geq 1$$

$$48. \quad M_{6/8}^* = (M_{6/8} - R_{6/8}^{0*} - C_2 R_{6/8}) N_6^*$$

$$49. \quad \alpha_{52} = \frac{M_{6/8}^*}{R_{5/8}^0 - M'_{5/8} + C_1 R_{5/8} - M_{6/8}^*}$$

$$50. \quad r_3 = \frac{\sigma_5^0 [\text{TABLE A (KR, 3)}] - \sigma_{5F}^0 [\text{TABLE A (KR, 5)}] (1 + \alpha_{52})}{\sigma_{5F}^0 [\text{TABLE A (KR, 7)}] (1 + \alpha_{52}) - \sigma_5^0 [\text{TABLE A (KR, 6)}]}$$

$$51. \quad \text{If } \frac{r_1}{r_2} \neq 1 \pm V_{31} \text{ or if } \frac{r_1}{r_3} \neq 1 \pm V_{31} \text{ or if } \frac{\alpha_{51}}{\alpha_{52}} \neq 1 \pm V_{32},$$

then $\alpha_{51} = \alpha_{52}$, and go to D-33 for a maximum of V_{33} iterations.

Outside of loop set $\alpha_{51} = \alpha_{52}$

52a. Print out r_1 , r_2 , r_3 , σ_6 , and α_{52} for each iteration

52b. Now set $r = (r_3 + r_2)/2$

52c. If S/M or $R_{7/8} = 0$, then go to D-88

53. If S/M and $R_{7/8}$ are $\neq 0$, then $\text{TEMP} = \text{TABLE A (KR, 1)} + 273$

$$54. \quad \sigma_7 = \sigma_7^o \left[1.02 + \left(r_1 \sqrt{\frac{\text{TEMP}}{T_o}} \right) s_7^o \right]$$

$$55. \quad \sigma_{5F} = \sigma_5 \left(\frac{1}{1 + \alpha_{51}} \right)$$

$$\text{If } \bar{\alpha}_{93}^* \neq 0, \text{ then } \alpha_9 = \bar{\alpha}_{93}^*$$

$$56. \quad \sigma_{9F} = \sigma_9 \left(\frac{1}{1 + \alpha_9} \right)$$

$$57. \quad \sigma_{1F} = \sigma_1 \left(\frac{1}{1 + \alpha_1} \right)$$

$$58. \quad I_8 = 4.0 + 24.7 \sqrt{S/M}$$

$$59. \quad s_8^o = 1.1275 \left[\frac{I_8}{2.75} - 0.5 \right]$$

$$60a. \quad \text{If } \sigma_8 = 0, \text{ then}$$

$$\sigma_8 = \sigma_8^o \left[1 + \left(r_1 \sqrt{\frac{\text{TEMP}}{T_o}} \right) s_8^o \right]$$

$$60b. \quad \text{If } \bar{\sigma}_6 = 0, \text{ then go to D-73}$$

$$61. \quad W_T^* (\text{Fast}) = \frac{G W_T^* (\sigma_{5F}^{R_o/8} + \sigma_{9F}^{R_o/8} + \sigma_{1F}^{R_o/8})}{\sigma_{8F}}$$

$$62. \quad W_T^* (\text{Total}) = W_T^* (\text{Fast}) + W_T^*$$

$$63. \quad \sigma_8' = \sigma_8 \left[\frac{W_T^*}{W_T^* (\text{Total})} \right]$$

$$64. \quad \sigma_7' = \sigma_7 \left[\frac{W_T^*}{W_T^* (\text{Total})} \right]$$

$$65. \quad \sigma_{8,2n}' = \sigma_{8,2n} \left[\frac{W_T^* (\text{Fast})}{W_T^* (\text{Total})} \right]$$

66. For Np-237 formed from n,2n reaction on U-238, calculate

$$C_1 R_{7/8} = \frac{\sigma_{8,2n}'}{\sigma_7' - \sigma_8'} \{ \exp[-\sigma_8' W_T^* (\text{Total})] - \exp[-\sigma_7' W_T^* (\text{Total})] \}$$

$$67. \quad R_{7/8}^* = R_{7/8} - C_1 R_{7/8}$$

NOTE: $R_{7/8}^*$ is the amount of Np-237 formed by the capture of U-235 and U-236. Neglect formation of Np-237 from U-234 capture, since assume $U-236 \geq U-234$ and formation from U-234 is third order.

$$68. \quad C_2 R_{7/8} = \frac{\alpha_{51} \sigma_5 \sigma_6 R_{5/8}^0}{1 + \alpha_{51}} \left[\frac{\exp(-\sigma_5 W_T^*)}{(\sigma_6 - \sigma_5)(\sigma_7 - \sigma_5)} + \frac{\exp(-\sigma_6 W_T^*)}{(\sigma_5 - \sigma_6)(\sigma_7 - \sigma_6)} + \frac{\exp(-\sigma_7 W_T^*)}{(\sigma_5 - \sigma_7)(\sigma_6 - \sigma_7)} \right]$$

$$69. \quad C_3 R_{7/8} = \left(\frac{\sigma_6}{\sigma_7 - \sigma_6} \right) R_{6/8}^0 [\exp(-\sigma_6 W_T^*) - \exp(-\sigma_7 W_T^*)]$$

$$70. \quad C_4 R_{7/8} = C_2 R_{7/8} + C_3 R_{7/8}$$

$$71. \quad \frac{C_4 R_{7/8}}{R_{7/8}^*} - 1 = K_{20}$$

72. If K_{20} is not between V_{35} and V_{36} , then

$$\sigma_6 = \sigma_6 \left(\frac{1}{1 + V_{37} K_{20}} \right) \text{ and return to D-68 for } V_{38} \text{ iterations maximum.}$$

$$73. \quad r_2 \sqrt{\frac{\text{TEMP}}{T_o}} = \frac{\sigma_6^o - \sigma_6^o}{\sigma_6^o s_6^o}$$

$$74. \quad r_2 = r_2 \sqrt{\frac{\text{TEMP}}{T_o}} \div \sqrt{\frac{\text{TEMP}}{T_o}}; \text{ if } r_2 < 0, \text{ then set it } = 0$$

$$75. \quad C_5 R_{7/8} = \frac{\alpha_{51} \sigma_5 \sigma_6 R_{5/8}^o}{1 + \alpha_{51}} \left[\frac{\exp(-\sigma_5 W_T^*)}{(\sigma_6 - \sigma_5)(-\sigma_5)} + \frac{\exp(-\sigma_6 W_T^*)}{(\sigma_5 - \sigma_6)(-\sigma_6)} + \frac{1}{(\sigma_5)(\sigma_6)} \right]$$

$$76. \quad \text{If } R_{4/5}^o \neq 0.01 \text{ and if } \frac{S_{4/3} M_{3/8}}{M_{4/5} M_{5/8}'} \text{ is between 0 and } V_{22}, \text{ then}$$

$$\sigma_4 = \frac{1}{W_T^*} \ln \left(\frac{R_{4/8}^o}{M_{4/8}} \right)$$

$$77. \quad \text{If } R_{4/5}^o = 0.01 \text{ or if } \frac{S_{4/3} M_{3/8}}{M_{4/5} M_{5/8}'} \text{ is not between 0 and } V_{22}, \text{ then}$$

$$\sigma_4 = \sigma_4^o \left[1 + \left(r_1 \sqrt{\frac{\text{TEMP}}{T_o}} \right) s_4^o \right]$$

$$78. \quad C_1 R_{5/8} = \left(\frac{\sigma_4}{\sigma_5 - \sigma_4} \right) R_{4/8}^o \left[\exp(-\sigma_4 W_T^*) - \exp(-\sigma_5 W_T^*) \right]$$

$$79. \quad C_2 R_{6/8} = \frac{\alpha_{51} \sigma_4 \sigma_5 R_{4/8}^o}{1 + \alpha_{51}} \left[\frac{\exp(-\sigma_4 W_T^*)}{(\sigma_5 - \sigma_4)(\sigma_6 - \sigma_4)} + \frac{\exp(-\sigma_5 W_T^*)}{(\sigma_4 - \sigma_5)(\sigma_6 - \sigma_5)} + \frac{\exp(-\sigma_6 W_T^*)}{(\sigma_4 - \sigma_6)(\sigma_5 - \sigma_6)} \right]$$

$$80. \quad R_{6/8}^{o*} = R_{6/8}^o \exp(-\sigma_6 W_T^*)$$

$$81. \quad M_{6/8}^* = M_{6/8} + C_5 R_{7/8} - C_2 R_{6/8} - R_{6/8}^{o*}$$

82. This step is deleted.

$$83. \quad \alpha_{52} = \frac{M_{6/8}^*}{R_{5/8}^0 - M_{5/8}^1 + C_1 R_{5/8} - M_{6/8}^*}$$

$$84. \quad r_3 = \frac{\sigma_5^0 [\text{TABLE A (KR, 3)}] - \sigma_{5F}^0 [\text{TABLE A (KR, 5)}] (1 + \alpha_{52})}{\sigma_{5F}^0 [\text{TABLE A (KR, 7)}] - \sigma_5^0 [\text{TABLE A (KR, 6)}]}$$

If $r_3 < 0$, then set it = 0

$$85. \quad \text{If } \frac{r_1}{r_2} \neq 1 \pm V_{31} \text{ or if } \frac{r_1}{r_3} \neq 1 \pm V_{31} \text{ or if } \frac{\alpha_{51}}{\alpha_{52}} \neq 1 \pm V_{32}, \text{ then}$$

$\alpha_{51} = \alpha_{52}$ and go to D-33 for a maximum of V_{33} iterations.

Outside of loop set $\alpha_{51} = \alpha_{52}$

86. Print out r_1, r_2, r_3, σ_6 , and α_{52} for each iteration.

87. Set $r = (r_3 + r_2)/2 \leq 0$

$$88. \quad \text{Calculate } \bar{\sigma}_6 = \frac{\sum \sigma_6}{n} \text{ and } S_{\sigma_6} = \sqrt{\frac{\sum \sigma_6^2 - (\sum \sigma_6)^2/n}{n-1}}$$

89. For each sample, calculate $(\sigma_6 - \bar{\sigma}_6)$. For any samples for which this quantity exceeds $V_{40} S_{\sigma_6}$, delete its value of σ_6 from the σ_6 list and reduce n by one and reaverage.

$$90. \quad \bar{r} = \frac{\sum r}{n} \text{ and } S_r = \sqrt{\frac{\sum r^2 - (\sum r)^2/n}{n-1}}$$

For each sample, calculate $(r - \bar{r})$. For any samples for which this quantity exceeds $V_{41} S_r$, delete its value from the list of r and reduce n by one and reaverage. If $\bar{r} < 0.001$; then $\bar{r} = 0.001$.

$$91. \quad \text{For samples not placed in S-1, } \bar{\alpha}_{51} = \frac{\sum \alpha_{51}}{n} \text{ and } S_{\alpha_{51}} = \sqrt{\frac{\sum \alpha_{51}^2 - (\sum \alpha_{51})^2/n}{n-1}}$$

92. For each acceptable sample, calculate $(\alpha_{51} - \bar{\alpha}_{51})$. Form a set (S-1) of those samples for which this quantity exceeds $V_{14} (S_{\alpha_{51}})$.
93. For the remaining samples, calculate $\bar{\alpha}_{51}$ and $(S_{\alpha_{51}})$, call the new values $\bar{\alpha}_{51}^{**}$ and $S_{\alpha_{51}}^*$. These new values are based on m samples.
94. Test to see if $V_1 < \bar{\alpha}_{51}^{**} < V_2$ and $S_{\alpha_{51}}^* / \sqrt{m} < V$. If both conditions hold, the m samples used in calculating these quantities form Set S-3. If not, all samples are in Set S-2, and S-1 and S-3 are empty.
95. If $\epsilon - 1 = 0$, then $\epsilon - 1 \approx 0.034$
96. $I_u = 0$. If $G = 0$, then $G = 2.3 (\epsilon - 1) (N_8^0)$, and set $I_u = 1$.
97. If $\sigma_8 = 0$, then $\sigma_8 = 6.11$

- E. 1. From this point, calculations differ for each set. Start with set S-3, and calculate the following for each S-3 sample.

$$2. M_{6/5}^{**} = (M_{6/8}^* + R_{6/8}^{o*}) / (M_{5/8}' - C_1 R_{5/8})$$

$$3. R_{6/5}^{o*} = R_{6/8}^{o*} / R_{5/8}^o$$

$$4. F_{53} = N_5^o \left[\frac{M_{6/5}^{**} - R_{6/5}^{o*}}{M_{6/5}^{**} + \bar{\alpha}_{51}^{**} (1 + M_{6/5}^{**})} \right] \geq 0$$

$$5. F_{54} = N_8^o \left(\frac{R_{5/8}^o - M_{5/8}' + C_1 R_{5/8}}{1 + \bar{\alpha}_{51}^{**}} \right) \geq 0$$

$$6. \text{ If } F_{53} = 0; \text{ then } F_{53} = F_{54}$$

$$7. M_8 = 100 / [M_{4/8}^{**} + M_{5/8}' (1 + M_{6/5}) + 1]$$

$$8. M_4 = (M_8) (M_{4/8}^{**})$$

$$9. M_5 = (M_8) (M_{5/8}')$$

$$10. \text{ If } M_{6/5} = 0, \text{ then } M_{6/5} = \left[\frac{R_{5/8}^o + R_{6/5}^o R_{5/8}^o - (F_{54}/N_8^o) - M_{5/8}'}{M_{5/8}'} \right]$$

$$11. M_6 = (M_8) (M_{5/8}') (M_{6/5})$$

$$12. A = \frac{P_{2/9} - C_{2/9}}{1 - (P_{2/9}) (S_{9/2})}$$

$$13. \quad C = \frac{1 - (M_{2/9})(S_{9/2})}{M_{2/9} - R_{2/9}}$$

$$14. \quad B = \frac{P_{3/8} - C_{3/8}}{1 - (P_{3/8})(S_{8/3})}$$

$$15. \quad D = \frac{1 - (M_{3/8})(S_{8/3})}{M_{3/8} - R'_{3/8}} \quad \text{where } R'_{3/8} \approx 0$$

$$16. \quad A_8 = \frac{V_{SP}}{V_{SA}} (S_3)(D)$$

$$17. \quad R_{9/8} = (C_9/C_8) \frac{AC}{BD} \geq 10^{-5}$$

18. In cases where $R_{9/8} = 0$ and $R_{9/8}^0 = 0$, then

$$R_{9/8} = \sigma_8 \left[\frac{\exp(-\sigma_8 W_T^*)}{(\sigma_9 - \sigma_8)} + \frac{\exp(-\sigma_9 W_T^*)}{(\sigma_8 - \sigma_9)} \right] \geq 0$$

19. In cases where $R_{0/9}$ or $R_{1/9} = 0$, then

$$f_9 = A_0 R_{9/8}$$

$$s_9 = V_{SP} A_{242} S_{9/2}$$

$$s_0 = V_{SP} A_{242} S_{0/2}$$

$$f_0 = M_{0/9} (s_9 + f_9) - s_0$$

$$s_1 = V_{SP} A_{242} S_{1/2}$$

$$f_1 = M_{1/9} (s_9 + f_9) - s_1$$

20. In cases where $R_{0/9} = 0$, then $R_{0/9} = f_0/f_9$

In cases where $R_{1/9} = 0$, then $R_{1/9} = f_1/f_9$

$$21a. \quad R_{0/8} = (R_{0/9})(R_{9/8}) \geq 10^{-5}$$

21b. In cases where $R_{0/8} = 0$ and $R_{9/8}^0 = 0$, then

$$R_{0/8} = \sigma_8 \sigma_9 \left(\frac{\alpha_9}{1 + \alpha_9} \right) \left[\frac{\exp(-\sigma_8 W_T^*)}{(\sigma_9 - \sigma_8)(\sigma_0 - \sigma_8)} + \frac{\exp(-\sigma_9 W_T^*)}{(\sigma_8 - \sigma_9)(\sigma_0 - \sigma_9)} + \frac{\exp(-\sigma_0 W_T^*)}{(\sigma_8 - \sigma_0)(\sigma_9 - \sigma_0)} \right] \geq 0$$

$$22a. R_{1/8} = (R_{1/9})(R_{9/8}) \geq 10^{-5}$$

22b. In cases where $R_{1/8} = 0$ and $R_{9/8}^0 = 0$, then

$$R_{1/8} = \sigma_8 \sigma_9 \left(\frac{\alpha_9}{1 + \alpha_9} \right) \sigma_0 [\exp(-\lambda_1 t)] \left[\frac{\exp(-\sigma_8 W_T^*)}{(\sigma_9 - \sigma_8)(\sigma_0 - \sigma_8)(\sigma_1' - \sigma_8)} + \frac{\exp(-\sigma_9 W_T^*)}{(\sigma_8 - \sigma_9)(\sigma_0 - \sigma_9)(\sigma_1' - \sigma_9)} + \frac{\exp(-\sigma_0 W_T^*)}{(\sigma_8 - \sigma_0)(\sigma_9 - \sigma_0)(\sigma_1' - \sigma_0)} + \frac{\exp(-\sigma_1' W_T^*)}{(\sigma_8 - \sigma_1')(\sigma_9 - \sigma_1')(\sigma_0 - \sigma_1')} \right] \geq 0, \text{ where } \sigma_1' = \sigma_1 + (\lambda_1 t^*/W_T^*)$$

$$23a. R_{2/8} = (R_{2/9})(R_{9/8}) \geq 10^{-5}$$

23b. In cases where $R_{2/8} = 0$ and $R_{9/8}^0 = 0$, then

$$R_{2/8} = \sigma_8 \sigma_9 \left(\frac{\alpha_9}{1 + \alpha_9} \right) \sigma_0 \sigma_1 \left(\frac{\alpha_1}{1 + \alpha_1} \right) \left[\frac{\exp(-\sigma_8 W_T^*)}{(\sigma_9 - \sigma_8)(\sigma_0 - \sigma_8)(\sigma_1' - \sigma_8)(\sigma_2 - \sigma_8)} + \frac{\exp(-\sigma_9 W_T^*)}{(\sigma_8 - \sigma_9)(\sigma_0 - \sigma_9)(\sigma_1' - \sigma_9)(\sigma_2 - \sigma_9)} + \frac{\exp(-\sigma_0 W_T^*)}{(\sigma_8 - \sigma_0)(\sigma_9 - \sigma_0)(\sigma_1' - \sigma_0)(\sigma_2 - \sigma_0)} + \frac{\exp(-\sigma_1' W_T^*)}{(\sigma_8 - \sigma_1')(\sigma_9 - \sigma_1')(\sigma_0 - \sigma_1')(\sigma_2 - \sigma_1')} + \frac{\exp(-\sigma_2 W_T^*)}{(\sigma_8 - \sigma_2)(\sigma_9 - \sigma_2)(\sigma_0 - \sigma_2)(\sigma_1' - \sigma_2)} \right]$$

If $R_{2/8} < 0$, set it = 0

23c. In cases where $R_{2/9} = 0$ and $R_{9/8}^0 = 0$, then $R_{2/9} = R_{2/8}/R_{9/8}$

Return to E-13 if $M_{2/9} \neq 0$

23d. If $V_{59} = 1$, then $t_1 = t$

If $V_{59} = 0$, then $t_1 = 0$

$$\begin{aligned} R_9 &= \left[\frac{100 (R_{9/8})}{R_{9/8} + R_{0/8} + R_{1/8} \exp \lambda_1 t_1 + R_{2/8}} \right] \\ R_0 &= \left[\frac{100 (R_{0/8})}{R_{9/8} + R_{0/8} + R_{1/8} \exp \lambda_1 t_1 + R_{2/8}} \right] \\ R_1 &= \left[\frac{100 (R_{1/8} \exp \lambda_1 t_1)}{R_{9/8} + R_{0/8} + R_{1/8} \exp \lambda_1 t_1 + R_{2/8}} \right] \\ R_2 &= \left[\frac{100 (R_{2/8})}{R_{9/8} + R_{0/8} + R_{1/8} \exp \lambda_1 t_1 + R_{2/8}} \right] \end{aligned}$$

$$24. / 25. X = R_{9/8}^0 \left(\frac{1 - e^{-2W}}{W} \right)$$

$$26. X \equiv 2R_{9/8}^0 \quad \text{when } W \leq 0$$

$$27. R_{1/8}^{***} = R_{1/8} e^{\lambda_1 t} + \left(\frac{1 + \alpha_1}{\alpha_1} \right) \left(\frac{\lambda_1 t^* \sigma_5}{\sigma_1 W} \right) (B_2 R_{2/8} - R_{2/8}^0)$$

$$28. F_{51} = N_8^0 (R_{5/8}^0 - M_{5/8}' + C_1 R_{5/8} - M_{6/8}^*)$$

$$29. P = \left[(R_{0/8} - R_{0/8}^0) + (R_{1/8}^{***} - R_{1/8}^0) + (B_2 R_{2/8} - R_{2/8}^0) \left(\frac{1 + \alpha_1}{\alpha_1} \right) \right] \geq 0$$

30. If $\bar{\alpha}_1 \neq 0$, then $\alpha_1 = \bar{\alpha}_1$

31. On the last of V_{57} iterations, then $\alpha_9 = \bar{\alpha}_9$.

32.
$$\sigma_8 = \frac{1}{W_T^*} \ln \left[\frac{1}{1 - R_{9/8} - P \left(\frac{1 + \alpha_9}{\alpha_9} \right) + R_{9/8}^0} \right]$$
 If $W_T = 0$ go to E-36
If $\ln [- \text{term}]$ go to E-99.

33.
$$R_{9/8}' = \frac{\sigma_8}{\sigma_9 - \sigma_8} \left[\exp(-\sigma_8 W_T^*) - \exp(-\sigma_9 W_T^*) \right] + R_{9/8}^0 \exp(-\sigma_9 W_T^*)$$

34.
$$\frac{R_{9/8}'}{R_{9/8}} - 1 = K_{21}$$

35. If K_{21} is not between V_{42} and V_{43} , then $\sigma_9 = \sigma_9 (1 + V_{44} K_{21})$,
and go to E-33 for V_{45} iterations maximum.

36.
$$g_9 = \frac{\sigma_9 - \left[\sigma_9^0 \left(\bar{r} [\text{TABLE A (KR, 11)}] \right) \right]}{\sigma_9^0}$$
 If $g_9 \leq 0$, then $g_9 = 0$

37.
$$\sigma_0 = \sigma_0^0 \left[1 + \left(\bar{r} \sqrt{\frac{\text{TEMP}}{T_0}} \right) s_0 \right] = \sigma_0^0 \left[1 + \left(\bar{r} \sqrt{\frac{\text{TEMP}}{T_0}} \right) \left(4 + 55 \sqrt{\frac{S}{M}} \left(\frac{1}{1 + R_{0/8}(5000)} \right) \right) \right]$$

38.
$$\sigma_{9C} = \left\{ \frac{\sigma_8}{P} \left[\frac{\exp(-\sigma_8 W_T^*)}{(\sigma_9 - \sigma_8)(-\sigma_8)} + \frac{\exp(-\sigma_9 W_T^*)}{(\sigma_8 - \sigma_9)(-\sigma_9)} + \frac{1}{\sigma_8 \sigma_9} \right] \right. \\ \left. + \left[\frac{R_{9/8}^0}{P \sigma_9} [1 - \exp(-\sigma_9 W_T^*)] \right] \right\}^{-1}$$

39.
$$\alpha_9' = \frac{\sigma_{9C}}{\sigma_9 - \sigma_{9C}}$$

40. If $R_{243/239}$ and $R_{244/239}$ both $\neq 0$, then go to E-64.

$$41. R'_{0/8} = \sigma_8 \sigma_9 C \left[\frac{\exp(-\sigma_8 W_T^*)}{(\sigma_9 - \sigma_8)(\sigma_0 - \sigma_8)} + \frac{\exp(-\sigma_9 W_T^*)}{(\sigma_8 - \sigma_9)(\sigma_0 - \sigma_9)} + \frac{\exp(-\sigma_0 W_T^*)}{(\sigma_8 - \sigma_0)(\sigma_9 - \sigma_0)} \right] \\ + \frac{\sigma_9 C R_{9/8}^0}{\sigma_0 - \sigma_9} \left[\exp(-\sigma_9 W_T^*) - \exp(-\sigma_0 W_T^*) \right] + R_{0/8}^0 \exp(-\sigma_0 W_T^*)$$

$$42. K_{22} = \frac{R'_{0/8}}{R_{0/8}} - 1$$

43. If $K_{22} \neq 0 \pm V_{46}$, then $\sigma_0 = \sigma_0 (1 + V_{47} K_{22})$ go to E-41 for V_{48} iterations maximum.

$$44a. \sigma_1' = (1 + \alpha_1) \sigma_{1F}^0 \left\{ [\text{TABLE A (KR, 4)}] + \left(\bar{r} [\text{TABLE A (KR, 10)}] \right) \right\} + \frac{\lambda_1 t^*}{W_T^*}$$

44b. If $R_{9/8}^0 \neq 0$, then go to E-51

$$45. R'_{1/8} = \sigma_8 \sigma_9 C \sigma_0 \left[\frac{\exp(-\sigma_8 W_T^*)}{(\sigma_9 - \sigma_8)(\sigma_0 - \sigma_8)(\sigma_1' - \sigma_8)} + \frac{\exp(-\sigma_9 W_T^*)}{(\sigma_8 - \sigma_9)(\sigma_0 - \sigma_9)(\sigma_1' - \sigma_9)} \right. \\ \left. + \frac{\exp(-\sigma_0 W_T^*)}{(\sigma_8 - \sigma_0)(\sigma_9 - \sigma_0)(\sigma_1' - \sigma_0)} + \frac{\exp(-\sigma_1' W_T^*)}{(\sigma_8 - \sigma_1')(\sigma_9 - \sigma_1')(\sigma_0 - \sigma_1')} \right]$$

$$46. K_{23} = \frac{R'_{1/8}}{R_{1/8} (\exp \lambda_1 t)} - 1$$

47. If $K_{23} \neq 0 \pm V_{49}$, then $\sigma_1' = \sigma_1' (1 + V_{50} K_{23})$ go to E-45 for V_{51} iterations maximum.

$$48. \sigma_1 = \sigma_1' - \left(\frac{\lambda_1 t^*}{W_T^*} \right)$$

$$49. \quad \sigma_{1F} = \sigma_{1F}^o \left\{ [\text{TABLE A (KR, 4)}] + \bar{r} [\text{TABLE A (KR, 10)}] \right\}$$

$$50. \quad \alpha'_1 = \frac{\sigma_1 - \sigma_{1F}}{\sigma_{1F}}$$

51a. If $\alpha'_1 \leq V_{55} \alpha_1$; then set $\alpha'_1 = \text{set } \alpha_1$

51b. $\sigma_2 = 0.0$ Set counter; IT = 0

52. IT = IT + 1. NOTE: IT is a subscript denoting the ITth time.

$$53. \quad C_{1R_{2/8}}(IT) = \frac{\sigma_8 \sigma_9 \sigma_0 \sigma_1 \alpha'_1}{1 + \alpha'_1} \left[\frac{\exp(-\sigma_8 W_T^*)}{(\sigma_9 - \sigma_8)(\sigma_0 - \sigma_8)(\sigma'_1 - \sigma_8)(\sigma_2 - \sigma_8)} \right. \\ + \frac{\exp(-\sigma_9 W_T^*)}{(\sigma_8 - \sigma_9)(\sigma_0 - \sigma_9)(\sigma'_1 - \sigma_9)(\sigma_2 - \sigma_9)} + \frac{\exp(-\sigma_0 W_T^*)}{(\sigma_8 - \sigma_0)(\sigma_9 - \sigma_0)(\sigma'_1 - \sigma_0)(\sigma_2 - \sigma_0)} \\ \left. + \frac{\exp(-\sigma'_1 W_T^*)}{(\sigma_8 - \sigma'_1)(\sigma_9 - \sigma'_1)(\sigma_0 - \sigma'_1)(\sigma_2 - \sigma'_1)} + \frac{\exp(-\sigma_2 W_T^*)}{(\sigma_8 - \sigma_2)(\sigma_9 - \sigma_2)(\sigma_0 - \sigma_2)(\sigma'_1 - \sigma_2)} \right]$$

54. If $R_{9/8}^o \neq 0$, then go to E-80.

55. If IT ≥ 2 , then go to E-58.

$$56. \quad \sigma'_2 = \sigma_2^o \left[1 + \left(\bar{r} \sqrt{\frac{\text{TEMP}}{T_o}} \right) s_2^o \right]$$

57. $\sigma_2 = \sigma'_2$ If IT = 1, then go to E-52.

58. $K_{24} = [C_1 R_{2/8} (IT) / R_{2/8}] - 1$

59. If $K_{24} \neq 0 \pm V_{52}$, then $\sigma_2 = \sigma_2 (1 + V_{53} K_{24})$ go to E-52 for V_{54} iterations maximum.

60. If σ_2 / σ_2' is not between V_{55} and V_{56} , go to 62d.

61. If σ_2 / σ_2' is between V_{55} and V_{56} , then $K_{25} =$

$$\left[\frac{\exp(-\sigma_8 W_T^*)}{(\sigma_9 - \sigma_8)(\sigma_0 - \sigma_8)(\sigma_1' - \sigma_8)(\sigma_2 - \sigma_8)} + \frac{\exp(-\sigma_9 W_T^*)}{(\sigma_8 - \sigma_9)(\sigma_0 - \sigma_9)(\sigma_1' - \sigma_9)(\sigma_2 - \sigma_9)} \right. \\ + \frac{\exp(-\sigma_0 W_T^*)}{(\sigma_8 - \sigma_0)(\sigma_9 - \sigma_0)(\sigma_1' - \sigma_0)(\sigma_2 - \sigma_8)} + \frac{\exp(-\sigma_1' W_T^*)}{(\sigma_8 - \sigma_1')(\sigma_9 - \sigma_1')(\sigma_0 - \sigma_1')(\sigma_2 - \sigma_1')} \\ \left. + \frac{\exp(-\sigma_2 W_T^*)}{(\sigma_8 - \sigma_2)(\sigma_9 - \sigma_2)(\sigma_0 - \sigma_2)(\sigma_1' - \sigma_2)} \right]$$

62a. $\alpha_1' = R_{2/8} / [\sigma_8 \sigma_9 C_0 \sigma_1 K_{25} - R_{2/8}]$

62b. Step deleted.

62c. Step deleted.

62d. $B_2^\vee = C_1 R_{2/8} (1) / C_1 R_{2/8} (2)$ which is ≥ 1 and < 2 .

63. Go to E-90.

64. If $R_{243/239}$ and $R_{244/239}$ are $\neq 0$

65. $R_{3/8} = (R_{243/239})(R_{9/8})$

$$66. R_{4/8} = (R_{244/239}) (R_{9/8})$$

67. If $R_{9/8}^0 \neq 0$ and $R_{243/239}$ and $R_{244/239} \neq 0$, then go to E-71.

$$68. P_{1/8} = R_{2/8} + R_{3/8} + R_{4/8}$$

$$69. \sigma_{C1} = \left\{ \frac{\sigma_8 \sigma_9 \sigma_0}{P_{1/8}} \left[\frac{\exp(-\sigma_8 W_T^*)}{(\sigma_9 - \sigma_8)(\sigma_0 - \sigma_8)(\sigma_1' - \sigma_8)(-\sigma_8)} \right. \right. \\ + \frac{\exp(-\sigma_9 W_T^*)}{(\sigma_8 - \sigma_9)(\sigma_0 - \sigma_9)(\sigma_1' - \sigma_9)(-\sigma_9)} + \frac{\exp(-\sigma_0 W_T^*)}{(\sigma_8 - \sigma_0)(\sigma_9 - \sigma_0)(\sigma_1' - \sigma_0)(-\sigma_0)} \\ \left. \left. + \frac{\exp(-\sigma_1' W_T^*)}{(\sigma_8 - \sigma_1')(\sigma_9 - \sigma_1')(\sigma_0 - \sigma_1')(-\sigma_1')} + \frac{1}{\sigma_8 \sigma_9 \sigma_0 \sigma_1'} \right] \right\}^{-1}$$

$$70. \alpha_1' = \frac{\sigma_{C1}}{\sigma_1 - \sigma_{C1}}$$

$$71. B_2 = (R_{2/8} + R_{3/8} + R_{4/8})/R_{2/8} \text{ which is } \geq 1 \text{ and } < 2.$$

72. Go to E-90

73.-79. These instruction numbers have been deleted.

$$80. C_2 R_{2/8} \text{ (IT)} = R_{9/8}^0 \left(\frac{\sigma_9 \sigma_0 \sigma_1 \alpha_1}{1 + \alpha_1} \right) \left[\frac{\exp(-\sigma_9 W_T^*)}{(\sigma_0 - \sigma_9)(\sigma_1' - \sigma_9)(\sigma_2 - \sigma_9)} \right. \\ + \frac{\exp(-\sigma_0 W_T^*)}{(\sigma_9 - \sigma_0)(\sigma_1' - \sigma_0)(\sigma_2 - \sigma_0)} + \frac{\exp(-\sigma_1' W_T^*)}{(\sigma_9 - \sigma_1')(\sigma_0 - \sigma_1')(\sigma_2 - \sigma_1')} \\ \left. + \frac{\exp(-\sigma_2 W_T^*)}{(\sigma_9 - \sigma_2)(\sigma_0 - \sigma_2)(\sigma_1' - \sigma_2)} \right]$$

$$81. C_3 R_{2/8} \text{ (IT)} = R_{0/8}^0 \left(\frac{\sigma_0 \sigma_1 \alpha_1}{1 + \alpha_1} \right) \left[\frac{\exp(-\sigma_0 W_T^*)}{(\sigma_1' - \sigma_0)(\sigma_2 - \sigma_0)} + \frac{\exp(-\sigma_1' W_T^*)}{(\sigma_0 - \sigma_1')(\sigma_2 - \sigma_1')} \right. \\ \left. + \frac{\exp(-\sigma_2 W_T^*)}{(\sigma_0 - \sigma_2)(\sigma_1' - \sigma_2)} \right]$$

$$82. \quad C_4 R_{2/8} \text{ (IT)} = R_{1/8}^o \left(\frac{\alpha_1 \sigma_1}{1 + \alpha_1} \right) \left[\frac{\exp(-\sigma_1' W_T^*)}{(\sigma_2 - \sigma_1')} + \frac{\exp(-\sigma_2' W_T^*)}{(\sigma_1' - \sigma_2)} \right]$$

$$83. \quad C_5 R_{2/8} \text{ (IT)} = R_{2/8}^o \exp(-\sigma_2' W_T^*)$$

$$84. \quad R_{2/8}'' \text{ (IT)} = C_1 R_{2/8} \text{ (IT)} + C_2 R_{2/8} \text{ (IT)} + C_3 R_{2/8} \text{ (IT)} + C_4 R_{2/8} \text{ (IT)} \\ + C_5 R_{2/8} \text{ (IT)}$$

85. If IT = 1, then go to E-56.

$$86. \quad B_2 = R_{2/8}''(1)/R_{2/8}''(2), \text{ which is } \geq 1 \text{ and } < 2.$$

87/90. Calculate averages for $\sigma_8, \sigma_9, \sigma_0, \sigma_1', \sigma_2, \sigma_{5F}, \sigma_5, \sigma_{9F}, \sigma_{9C}$ together with their standard deviations. Reject all values over V_{20} standard deviations and reaverage. Set $\sigma_8, \sigma_9, \sigma_0, \sigma_1', \sigma_2, \sigma_{5F}, \sigma_5, \sigma_{9F}, \sigma_{9C}$ equal to their best average values for the entire case.

$$91. \quad \text{Calculate } \bar{\alpha}_9 = \frac{\sum \alpha_9'}{n}$$

$$92. \quad S_{\alpha_9} = \sqrt{\frac{\sum (\alpha_9')^2 - (\sum \alpha_9')^2/n}{n-1}} \quad \text{reject all } \alpha_9 > V_{20} S_{\alpha_9} \text{ and reaverage } \bar{\alpha}_9.$$

$$93. \quad \bar{\alpha}_1 = \frac{\sum \alpha_1'}{n} \quad \text{where } n \text{ is the number of non-zero values.}$$

$$94. \quad S_{\alpha_1} = \sqrt{\frac{\sum (\alpha_1')^2 - (\sum \alpha_1')^2/n}{n-1}}; \text{ reject all } \alpha_1' \text{ over } 2S_{\alpha_1} \text{ and reaverage } \bar{\alpha}_1.$$

$$95. \quad \bar{g}_9 = \frac{\sum g_9}{n}$$

$$96. \quad S_{g_9} = \sqrt{\frac{\sum g_9^2 - (\sum g_9)^2/n}{n-1}} \quad \text{reject all } g_9 \text{ over } 2S_{g_9} \text{ and reaverage } \bar{g}_9.$$

97. Determine from TABLE A a value of KR corresponding most closely to this $\bar{g}_9$ in KC = 2.

98. For this KR value, $TEMP = TABLE\ A\ (KR, 1) + 273$

For the remaining steps, divide the samples into further sub-sets, depending on the value of X in (25). If $X \geq K$, call it Sub-1; if $X < K$, call it Sub-2.

Subgroup-1

Subgroup-2

$$99a. \quad \alpha_{91} = \frac{P}{(R_{9/8}^o - R_{9/8} - P)}$$

$$99b. \quad F_9 = N_8^o P / \alpha_9 \geq 10^{-5}$$

100a. If $V_{61} = 0$ and α_{91} is not between 100b. Go to E-102.

V_9 and V_{10} , then set $\alpha_{91} = \alpha_9$.

$$101a. \quad F_9 = N_8^o P / \alpha_{91} \geq 10^{-9}$$

$$102. \quad F_1 = \frac{N_8^o}{\alpha_1} (B_2 R_{2/8} - R_{2/8}^o) \geq 10^{-9}$$

$$103. \quad F_{Th} = F_{53} + F_9 + F_1$$

$$104. \quad G' = G \left[\frac{F_{53}}{F_{Th}} + \left(\frac{V_9}{V_5} \right) \frac{F_9}{F_{Th}} + \left(\frac{V_1}{V_5} \right) \frac{F_1}{F_{Th}} \right]$$

$$105. \quad F_8 = G' F_{Th}$$

$$106. \quad F = F_{53} + F_9 + F_1 + F_8 \geq 10^{-5}$$

$$107. \quad V_3 = \left\{ \left[\frac{F_{53}}{F} (EPF5) + \frac{F_9}{F} (EPF9) + \frac{F_8}{F} (EPF8) + \frac{F_1}{F} (EPF1) \right] / 205 \right\} V_{60}$$

$$108. \quad MWD/MT^{**} = V_3 F$$

109. Compute Q as follows:

$$110. \quad Q = \left[1 + R_{9/8} + P \left(\frac{1 + \alpha_9}{\alpha_9} \right) + \frac{F_8}{N_8^o} - R_{9/8}^o \right]^{-1} \leq 1$$

If $Q < V_{21}$, set it = 1

111. Multiply input values $M_{3/8}$, $M'_{5/8}$, $R_{7/8}$ by Q (for use in next iteration). Go to H-1

- F. Compute values for S-1 as follows. This set will exist only if there is a set S-3. Otherwise, all data will form set S-2.

$$1a. F_{53} = N_5^0 \left[\frac{M_{6/5}^0 - R_{6/5}^0}{M_{6/5}^0 + \bar{\alpha}_{51}^{**} (1 + M_{6/5}^0)} \right] \geq 0 \text{ (use } \bar{\alpha}_{51}^{**} \text{ from Sec. E-5)}$$

$$1b. F_{54} = N_8^0 \left(\frac{R_{5/8}^0 - M_{5/8}'}{1 + \bar{\alpha}_{51}^{**}} \right) \text{ If } F_{53} = 0, \text{ then } F_{53} = F_{54}$$

$$1c. \text{ If } M_{5/8}' \text{ and } M_{6/5} \text{ both} = 0, \text{ then } F_{53} = 0$$

$$2a. M_{5/8}^* = R_{5/8}^0 - \frac{F_{53}}{N_8^0} (1 + \bar{\alpha}_{51}^{**})$$

$$2b. \text{ If } F_{53} = 0, \text{ then } M_{5/8}^* = M_{5/8}'$$

$$3. H = M_{5/8}^* / R_{5/8}^0 \leq 1$$

$$4. N_6^* = \frac{(\sigma_5 - \sigma_6)}{\sigma_5} \left(\frac{1-H}{H \sigma_6 / \sigma_5 - H} \right) \geq 1$$

5. Multiply each $M_{6/5}$ value by N_6^* to get a corrected $M_{6/5}^*$ value.

$$\text{Set } M_{6/5}^{**} = M_{6/5}^* \left(\frac{M_{5/8}^*}{M_{4/8}^{**} + M_{5/8}^*} \right) \text{ and } R_{6/5}^{o*} = R_{6/5}^0 \left(\frac{1}{1 + (N_4^0 / N_5^0)} \right)$$

$$6a. F_{53} = N_5^0 \left[\frac{M_{6/5}^{**} - R_{6/5}^{o*}}{M_{6/5}^{**} + \bar{\alpha}_{51}^{**} (1 + M_{6/5}^{**})} \right] \geq 0$$

$$6b. F_{54} = N_8^0 \left[\frac{R_{5/8}^0 - M_{5/8}'}{1 + \bar{\alpha}_{51}^{**}} \right] \text{ If } F_{53} = 0, \text{ then } F_{53} = F_{54}$$

$$\text{If } M_{5/8}' = 0; \text{ then } F_{54} = 0$$

$$6c. \text{ If both } M_{5/8}' \text{ and } M_{6/5} = 0, \text{ then } F_{53} = 0$$

$$7. M_{5/8}^{**} = R_{5/8}^0 - \frac{F_{53}}{N_8^0} (1 + \bar{\alpha}_{51}^{**})$$

8. If $F_{53} = 0$, then $M_{5/8}^{**} = M'_{5/8}$
9. If $M_{5/8}^{**} \leq 0$, then $M_{5/8}^{**} = M'_{5/8}$
- 9b. If $M'_{5/8} = 0$, then $M_{5/8}^{**} = M_{5/8}^{**}$
- 9c. $W_T^* = \frac{1}{\sigma_5} \ln \left(\frac{R_{5/8}^0}{M_{5/8}^{**}} \right)$ If $V_{61} \neq 0$, then $W_T^* = 0$.
If $R_{5/8}^0 < M_{5/8}^{**}$, print "error" and $W_T^* = 0$
10. $M_{8/8}^{**} = M_{5/8}^{**} / M'_{5/8} \geq 1$ If $M_{8/8}^{**} > 1 + V_{34}$, then set it = $1 + V_{34}$
11. $M_{3/8} = (M_{8/8}^{**}) (M_{3/8}) / [1 - (S_{8/3}) (M_{3/8})]$
12. $M_{4/8}^{**} = (M_{4/5}) (M_{5/8}^{**}) - (S_{4/3}) (M_{3/8})$
13. If $\frac{(S_{4/3}) (M_{3/8})}{(M_{4/5}) (M_{5/8}^{**})}$ is not between 0 and V_{22} ; then $M_{4/8}^{**} = \left(\frac{N_4^0}{N_8^0} \right) \exp (-\sigma_4 W_T^*)$
14. $M_8^* = 100 / [M_{4/8}^{**} + M_{5/8}^{**} (1 + M_{6/5}) + 1]$
15. $M_4^* = M_8^* M_{4/8}^{**}$
16. $M_5^* = M_8^* M_{5/8}^{**}$
17. If $M_{6/5} = 0$, then $M_{6/5} = \frac{R_{5/8}^0 + R_{6/5}^0 R_{5/8}^0 - F_{54} / N_8^0 - M_{5/8}^{**}}{M_{5/8}^{**}}$
18. $M_6^* = M_5^* M_{6/5}$
19. Go to E-12

G. Next, compute values for S-2 as follows.

$$1a. F_{53} = N_5^0 \left[\frac{M_{6/5} - R_{6/5}^0}{M_{6/5} + \alpha_5 (1 + M_{6/5})} \right] \geq 0$$

$$1b. F_{54} = N_8^O \left(\frac{R_{5/8}^O - M'_{5/8}}{1 + \alpha_5} \right) \text{ If } F_{53} = 0, \text{ then } F_{53} = F_{54}$$

$$1c. \text{ If both } M'_{5/8} \text{ and } M_{6/5} = 0, \text{ then } F_{53} = 0$$

$$2a. M_{5/8}^* = R_{5/8}^O - (F_{53}/N_8^O)(1 + \alpha_5)$$

$$2b. \text{ If } F_{53} = 0, \text{ then } M_{5/8}^* = M'_{5/8}$$

$$3. H = M_{5/8}^*/R_{5/8}^O$$

$$4. N_6^* = \frac{(\sigma_5 - \sigma_6)}{\sigma_5} \left(\frac{1 - H}{H\sigma_6/\sigma_5 - H} \right)$$

5. Multiply each $M_{6/5}$ value by N_6^* to get a corrected $M_{6/5}^*$ value.

$$\text{Set } M_{6/5}^{**} = M_{6/5}^* \left(\frac{M_{5/8}^*}{M_{4/8}^{**} + M_{5/8}^*} \right) \text{ and } R_{6/5}^{O*} = R_{6/5}^O \left(\frac{1}{1 + (N_4^O/N_5^O)} \right)$$

$$6a. F_{53} = N_5^O \left[\frac{M_{6/5}^{**} - R_{6/5}^{O*}}{M_{6/5}^{**} + \alpha_5 (1 + M_{6/5}^{**})} \right]$$

$$6b. F_{54} = N_8^O \left(\frac{R_{5/8}^O - M'_{5/8}}{1 + \alpha_5} \right); \text{ If } F_{53} = 0, \text{ then } F_{53} = F_{54}$$

$$\text{If } M'_{5/8} = 0; \text{ then } F_{54} = 0$$

$$6c. \text{ If both } M'_{5/8} \text{ and } M_{6/5} = 0, \text{ then } F_{53} = 0$$

$$7. M_{5/8}^{**} = R_{5/8}^O - (F_{53}^*/N_8^O)(1 + \alpha_5)$$

$$8. \text{ If } M_{5/8}^{**} = 0, \text{ then } M_{5/8}^{**} = M'_{5/8}$$

9. go to F-8.

H. 1. If no Nd data are available in the entire case, then go to D-10 for a total of V_{57} iterations maximum.

2. If $I_u = 0$ go to I-1.
3. If $I_u = 1$; then calculate G and ϵ as follows in the remainder of this Section H.
4. $N_{FL} = \left(\frac{1}{1 + V_R} \right) \left(\frac{D_f}{MWF} \right) (6.0231 \times 10^{23})$
5. $N_{ML} = A_M N_{FL}$
6. $N_M = \left(\frac{V_R}{1 + V_R} \right) \left(\frac{D_m}{MWM} \right) (6.0231 \times 10^{23})$
7. Compute macroscopic cross sections in the fuel region due to fuel

$$\Sigma_{SF} = \sigma_{SFL} N_{FL}$$

$$\Sigma_{CF} = \sigma_{CFL} N_{FL}$$

$$\Sigma_{IF} = \sigma_{IFL} N_{FL}$$

$$\Sigma_{FF} = \sigma_{FFL} N_{FL}$$

$$\Sigma_{TF} = \sigma_{TFL} N_{FL}$$

8. Compute macroscopic cross sections in the fuel region due to moderator

$$\Sigma_{SM} = \sigma_{SML} N_{ML}$$

$$\Sigma_{CM} = \sigma_{CML} N_{ML}$$

$$\Sigma_{IM} = \sigma_{TML} N_{ML}$$

$$\Sigma_{TM} = \sigma_{TML} N_{ML}$$

9. Compute macroscopic cross sections in the fuel region

$$\Sigma_{SL} = \Sigma_{SF} + \Sigma_{SM}$$

$$\Sigma_{CL} = \Sigma_{CF} + \Sigma_{CM}$$

$$\Sigma_{IL} = \Sigma_{IF} + \Sigma_{IM}$$

$$\Sigma_{TL} = \Sigma_{TF} + \Sigma_{TM}$$

10. Compute macroscopic cross sections in moderator region

$$\Sigma_{SM} = \sigma_{SM} N_M$$

$$\Sigma_{CM} = \sigma_{CM} N_M$$

$$\Sigma_{IM} = \sigma_{IM} N_M$$

$$\Sigma_{TM} = \sigma_{TM} N_M$$

11. Compute macroscopic cross sections of homogenized core

$$\Sigma_S = \Sigma_{SL} + \Sigma_{SM}$$

$$\Sigma_C = \Sigma_{CL} + \Sigma_{CM}$$

$$\Sigma_I = \Sigma_{IL} + \Sigma_{IM}$$

$$\Sigma_F = \Sigma_{FF}$$

$$\Sigma_T = \Sigma_{TL} + \Sigma_{TM}$$

12. Compute

$$N_{AL} = \left[\Sigma_{SL} + \chi \nu_8 \Sigma_F \right] / \Sigma_{TL}$$

$$N_{BL} = \left[\Sigma_{IL} + (1-\chi) \nu_8 \Sigma_F \right] / \Sigma_{TL}$$

$$N_{AH} = \left[\Sigma_S + \chi \nu_8 \Sigma_F \right] / \Sigma_T$$

$$N_{BH} = \left[\Sigma_I + (1-\chi) \nu_8 \Sigma_F \right] / \Sigma_T$$

13. $A_a = \Sigma_{TL}$ (RADIUS)

14. If fuel configuration is slab; JC = 2

If fuel configuration is cylinder; JC = 3

If fuel configuration is sphere; JC = 4.

15. In Table B determine what row most closely matches A_a in Column 1.
Set JR equal to that row number.

16. $P_c = \text{TABLE B (JR, JC)}$

$$G = \nu_5 \times N_8^0 \left\{ P_c \left(\Sigma_F / \Sigma_{TL} \right) / \left(1 - P_c N_{AL} \right) + \right. \\ \left. \left(1 - P_c \right) \left(\Sigma_F / \Sigma_T \right) / \left[\left(1 - P_c N_{AL} \right) \left(1 - N_{AH} \right) \right] \right\}$$

$$18. \epsilon = (1-\chi) + \chi P_c N_{BL} / (1 - N_{AL} P_c) +$$

$$\times (1 - P_c) N_{BH} / \left[(1 - N_{AL} P_c) (1 - N_{AH}) \right]$$

$$19. F_{Th} = F_{53} + F_9 + F_1$$

$$20. G' = G \left[\frac{F_{53}}{F_{Th}} + \left(\frac{\nu_9}{\nu_5} \right) \frac{F_9}{F_{Th}} + \left(\frac{\nu_1}{\nu_5} \right) \frac{F_1}{F_{Th}} \right]$$

21. Print out G' and ϵ for each case.

- I. If Nd mass spectrometric measurements are available, calculate for each case as follows:

$$1. \Delta_1 = \left(\frac{1}{s_{50/42}} - \frac{1}{c_{50/42}} \right)$$

$$2. \Delta_2 = \left(\frac{1}{c_{50/48}} - \frac{1}{s_{50/48}} \right)$$

$$3. \Delta_3 = \left(\frac{1}{c_{50/46}} - \frac{1}{s_{50/46}} \right)$$

$$4. \Delta_4 = \left(\frac{1}{c_{50/45}} - \frac{1}{s_{50/45}} \right)$$

$$5. \Delta_5 = \left(\frac{1}{c_{50/42}s_{50/48}} - \frac{1}{s_{50/42}c_{50/48}} \right)$$

$$6. \Delta_6 = \left(\frac{1}{c_{50/42}s_{50/46}} - \frac{1}{s_{50/42}c_{50/46}} \right)$$

$$7. \Delta_7 = \left(\frac{1}{c_{50/42}s_{50/45}} - \frac{1}{s_{50/42}c_{50/45}} \right)$$

$$8. \Delta_8 = \left(\frac{-1}{c_{50/42}} \right)$$

9. For each sample, if $V_{17} < M_{48/50} < V_{18}$ print " $M_{48/50}$ is outside limits"
For each sample, define F_T as a value from the output of the heavy element analysis. This will be the F (this iteration, Section E-99a for Sub-1), or F (this iteration, Section E-97b for Sub-2).

$$F_{T5} = F_{53}$$

$$F_{T9} = F_9$$

$$F_{T1} = F_1$$

$$F_{T8} = F_8$$

All from this iteration,
as was F_T .

$$9a. \quad R_{Cd5} = \frac{[TABLE A(KR, 5)] + \bar{r} [TABLE A(KR, 7)]}{\bar{r} \left\{ [TABLE A(KR, 7)] + 0.429 \sqrt{\frac{TEMP}{T_o}} \right\}}$$

$$9b. \quad R_{Cd9} = \frac{[TABLE A(KR, 9)] + \bar{r} [TABLE A(KR, 8)]}{\bar{r} \left\{ [TABLE A(KR, 8)] + 0.429 \sqrt{\frac{TEMP}{T_o}} \right\}}$$

$$9c. \quad R_{Cd1} = \frac{[TABLE A(KR, 4)] + \bar{r} [TABLE A(KR, 10)]}{\bar{r} \left\{ [TABLE A(KR, 10)] + 0.429 \sqrt{\frac{TEMP}{T_o}} \right\}}$$

$$10. \quad E_{50} = \left(\frac{1}{F_T} \right) \left\{ F_{T5} \left[\left(\frac{R_{Cd5} - 1}{R_{Cd5}} \right) Y_{05} + \frac{Y'_{05}}{R_{Cd5}} \right] + F_{T9} \left[\left(\frac{R_{Cd9} - 1}{R_{Cd9}} \right) Y_{09} + \frac{Y'_{09}}{R_{Cd9}} \right] \right. \\ \left. + F_{T1} \left[\left(\frac{R_{Cd1} - 1}{R_{Cd1}} \right) Y_{01} + \frac{Y'_{01}}{R_{Cd1}} \right] + F_{T8} Y_{08} \right\}$$

$$11. \quad E_{48} = \left(\frac{1}{F_T} \right) \left\{ F_{T5} \left[\left(\frac{R_{Cd5} - 1}{R_{Cd5}} \right) Y_{85} + \frac{Y'_{85}}{R_{Cd5}} \right] + F_{T9} \left[\left(\frac{R_{Cd9} - 1}{R_{Cd9}} \right) Y_{89} + \frac{Y'_{89}}{R_{Cd9}} \right] \right. \\ \left. + F_{T1} \left[\left(\frac{R_{Cd1} - 1}{R_{Cd1}} \right) Y_{81} + \frac{Y'_{81}}{R_{Cd1}} \right] + F_{T8} Y_{88} \right\}$$

$$12. \quad E_{46} = \left(\frac{1}{F_T} \right) \left\{ F_{T5} \left[\left(\frac{R_{Cd5} - 1}{R_{Cd5}} \right) Y_{65} + \frac{Y'_{65}}{R_{Cd5}} \right] + F_{T9} \left[\left(\frac{R_{Cd9} - 1}{R_{Cd9}} \right) Y_{69} + \frac{Y'_{69}}{R_{Cd9}} \right] \right. \\ \left. + F_{T1} \left[\left(\frac{R_{Cd1} - 1}{R_{Cd1}} \right) Y_{61} + \frac{Y'_{61}}{R_{Cd1}} \right] + F_{T8} Y_{68} \right\}$$

$$13. \quad E_{45} = \left(\frac{1}{F_T} \right) \left\{ F_{T5} \left[\left(\frac{R_{Cd5} - 1}{R_{Cd5}} \right) Y_{55} + \frac{Y'_{55}}{R_{Cd5}} \right] + F_{T9} \left[\left(\frac{R_{Cd9} - 1}{R_{Cd9}} \right) Y_{59} + \frac{Y'_{55}}{R_{Cd9}} \right] \right. \\ \left. + F_{T1} \left[\left(\frac{R_{Cd1} - 1}{R_{Cd1}} \right) Y_{51} + \frac{Y'_{51}}{R_{Cd1}} \right] + F_{T8} Y_{58} \right\}$$

$$14a. \quad E_{41} = \left(\frac{1}{F_T} \right) \left\{ F_{T5} \left[\left(\frac{R_{Cd5} - 1}{R_{Cd5}} \right) Y_{15} + \frac{Y'_{15}}{R_{Cd5}} \right] + F_{T9} \left[\left(\frac{R_{Cd9} - 1}{R_{Cd9}} \right) Y_{19} + \frac{Y'_{19}}{R_{Cd9}} \right] \right. \\ \left. + F_{T1} \left[\left(\frac{R_{Cd1} - 1}{R_{Cd1}} \right) Y_{11} + \frac{Y'_{11}}{R_{Cd1}} \right] + F_{T8} Y_{18} \right\}$$

$$14b. \quad \text{If } F_T \neq 0; \text{ go to I-15.}$$

$$14c. \quad \sigma_{9F}^0 = \sigma_9^0 \left[1/(1 + \alpha_9) \right]$$

$$D_2 = \sigma_{5F}^0 R_{5/8}^0 + \sigma_{9F}^0 R_{9/8}^0 + \sigma_{1F}^0 R_{1/8}^0$$

$$K_4 = \left[\frac{(1 - G) \sigma_{5F}^0 R_{5/8}^0}{D_2} \right]; \quad K_5 = \left[\frac{(1 - G) \sigma_{9F}^0 R_{9/8}^0}{D_2} \right]; \quad K_6 = \left[\frac{(1 - G) \sigma_{1F}^0 R_{1/8}^0}{D_2} \right]$$

$$14d. \quad E_{50} = K_4 Y_{05} + K_5 Y_{09} + K_6 Y_{01} + GY_{08}$$

$$14e. \quad E_{48} = K_4 Y_{85} + K_5 Y_{89} + K_6 Y_{81} + GY_{88}$$

$$14f. \quad E_{46} = K_4 Y_{65} + K_5 Y_{69} + K_6 Y_{61} + GY_{68}$$

$$14g. \quad E_{45} = K_4 Y_{55} + K_5 Y_{59} + K_6 Y_{51} + GY_{58}$$

$$14h. \quad E_{41} = K_4 Y_{15} + K_5 Y_{19} + K_6 Y_{11} + GY_{18}$$

$$15. \quad E_{0/8}^* = E_{50}/E_{48}$$

$$16. \quad E_{0/6}^* = E_{50}/E_{46}$$

$$17. E_{0/5}^* = E_{50}/E_{45}.$$

$$18. \Delta_9 = E_{0/8}^*/C_{50/42}$$

$$19. \Delta_{10} = E_{0/6}^*/C_{50/42}$$

$$20. \Delta_{11} = E_{0/5}^*/C_{50/42}$$

$$21. \Delta_{12} = 1 - \frac{E_{0/8}^*}{C_{50/48}}$$

$$22. \Delta_{13} = 1 - \frac{E_{0/6}^*}{C_{50/46}}$$

$$23. \Delta_{14} = 1 - \frac{E_{0/5}^*}{C_{50/45}}$$

$$24. A_{48} = \left(\frac{V_{SP}}{V_{SA}} \right) (A_{50}) \left(\frac{\Delta_1^M_{48/50} + \Delta_2^M_{42/50} + \Delta_5}{\Delta_9^M_{48/50} + \Delta_{12}^M_{42/50} + \Delta_8} \right) \text{ If } A_{48} < 0, \text{ set it } = 0$$

$$25. A_{46} = \left(\frac{V_{SP}}{V_{SA}} \right) (A_{50}) \left(\frac{\Delta_1^M_{46/50} + \Delta_3^M_{42/50} + \Delta_6}{\Delta_{10}^M_{46/50} + \Delta_{13}^M_{42/50} + \Delta_8} \right) \text{ If } A_{46} < 0, \text{ set it } = 0$$

$$26. A_{45} = \left(\frac{V_{SP}}{V_{SA}} \right) (A_{50}) \left(\frac{\Delta_1^M_{45/50} + \Delta_4^M_{42/50} + \Delta_7}{\Delta_{11}^M_{45/50} + \Delta_{14}^M_{42/50} + \Delta_8} \right) \text{ If } A_{45} < 0, \text{ set it } = 0$$

$$27. T_8 = A_{48}/E_{48} \quad \text{If } T_8 = 0, \text{ then } T_8 = \bar{F}_T \left(\frac{A_{T8}}{N_8} \right)$$

$$28. T_{56} = \frac{A_{46} + A_{45}}{E_{46} + E_{45}}$$

$$29. T_{568} = \frac{A_{48} + A_{46} + A_{45}}{E_{48} + E_{46} + E_{45}}$$

30. Obtain several output values from heavy element analysis. IMPORTANT:
Use values from 1st iteration, before adjustment for Q.

Define:

$$M_{T58} = M'_{5/8} \text{ for S-3 and } M^{**}_{5/8} \text{ for S-1 and S-2.}$$

$$M_{T48} = M^{**}_{4/8}$$

$$R_{T98} = R_{9/8}$$

$$R_{T08} = R_{0/8}$$

$$R_{T18} = R_{1/8}$$

$$R_{T28} = R_{2/8}$$

$$A_{T8} = A_8$$

$$R_{T18} = R^{***}_{1/0}$$

31. Calculate:

$$Z = A_{T8} (1 + M_{T58} + M_{T48} + M^{**}_{6/5} M_{T58} + R_{T98} + R_{T08} + R_{P18} + R_{T28} + T_8 / A_{T8})$$

$$\text{If } N_8^0 \neq 0 \text{ and } \left| \frac{Z}{A_{T8}/N_8^0} - 1 \right| > (1 - v_{21}), \text{ then } Z = A_{T8}/N_8^0$$

$$32. \sigma_f = \frac{\ln\left(\frac{Z}{Z - T_8}\right)}{W_T^*}$$

$$33. \quad \sigma_{41} = \sigma_{41}^o \left[1 + \left(\frac{-r}{\sqrt{\frac{\text{TEMP}}{T_o}}} \right) s_{41}^o \right]$$

$$\sigma_{42} = \sigma_{42}^o \left[1 + \left(\frac{-r}{\sqrt{\frac{\text{TEMP}}{T_o}}} \right) s_{42}^o \right]$$

$$\sigma_{45} = \sigma_{45}^o \left[1 + \left(\frac{-r}{\sqrt{\frac{\text{TEMP}}{T_o}}} \right) s_{45}^o \right]$$

$$\sigma_{46} = \sigma_{46}^o \left[1 + \left(\frac{-r}{\sqrt{\frac{\text{TEMP}}{T_o}}} \right) s_{46}^o \right]$$

$$\sigma_{48} = \sigma_{48}^o \left[1 + \left(\frac{-r}{\sqrt{\frac{\text{TEMP}}{T_o}}} \right) s_{48}^o \right]$$

$$34. \quad A_{42} = E_{41} \sigma_f \sigma_{41}^Z \left[\frac{e^{-\sigma_f W_T^*}}{(\sigma_{41} - \sigma_f)(\sigma_{42} - \sigma_f)} + \frac{e^{-\sigma_{41} W_T^*}}{(\sigma_f - \sigma_{41})(\sigma_{42} - \sigma_{41})} + \frac{e^{-\sigma_{42} W_T^*}}{(\sigma_f - \sigma_{42})(\sigma_{41} - \sigma_{42})} \right]$$

$$35. \quad K_1 = 1 - \frac{1}{E_{0/8}^* M_{48/50}}$$

$$36. \quad A_{42}^* = \left(\frac{V_{SP}}{V_{SA}} \right) (A_{50}) \left[\frac{1 - \frac{1}{S_{50/42} M_{42/50}} - \frac{1 - [1/(S_{50/48})^{(M_{48/50})}]}{K_1}}{\frac{1}{M_{42/50}} - C_{50/42} + \frac{C_{50/42} - (C_{48/42})^{(M_{48/50})}}{K_1}} \right]$$

$$37. \quad A_{42}^{**} = A_{42}^* - A_{42} \quad (\text{if } A_{42}^{**} \leq 0, \text{ set it } = 0)$$

$$38. \quad M_{42/50}^* = (M_{42/50}) (A_{42}^{**}/A_{42}^*)$$

$$39. \quad A_{48}^* = \left(\frac{V_{SP}}{V_{SA}} \right) (A_{50}) \left(\frac{\Delta_1 M_{48/50} + \Delta_2 M_{42/50}^* + \Delta_5}{\Delta_9 M_{48/50} + \Delta_{12} M_{42/50}^* + \Delta_8} \right) \text{ If } A_{48}^* < 0, \text{ set it } = 0$$

$$\text{If } A_{48} = 0, \text{ then set } A_{48}^* = 0$$

$$40. A_{46}^* = \left(\frac{V_{SP}}{V_{SA}} \right) (A_{50}) \left(\frac{\Delta_1^M_{46/50} + \Delta_3^{M*}_{42/50} + \Delta_6}{\Delta_{10}^M_{46/50} + \Delta_{13}^{M*}_{42/50} + \Delta_8} \right) \text{ If } A_{46}^* < 0, \text{ set it} = 0$$

If $A_{46} = 0$, then set $A_{46}^* = 0$

$$41. A_{45}^* = \left(\frac{V_{SP}}{V_{SA}} \right) (A_{50}) \left(\frac{\Delta_1^M_{45/50} + \Delta_4^{M*}_{42/50} + \Delta_7}{\Delta_{11}^M_{45/50} + \Delta_{14}^{M*}_{42/50} + \Delta_8} \right) \text{ If } A_{45}^* < 0, \text{ set it} = 0$$

If $A_{45} = 0$, then set $A_{45}^* = 0$

$$42. A_{461} = E_{45} \sigma_f \sigma_{45} Z \left[\frac{e^{-\sigma_f W_T^*}}{(\sigma_{45} - \sigma_f)(\sigma_{46} - \sigma_f)} + \frac{e^{-\sigma_{45} W_T^*}}{(\sigma_f - \sigma_{45})(\sigma_{46} - \sigma_{45})} + \frac{e^{-\sigma_{46} W_T^*}}{(\sigma_f - \sigma_{46})(\sigma_{45} - \sigma_{46})} \right]$$

$$43. A_{462} = E_{45} \sigma_f \sigma_{45} Z \left[\frac{-e^{-\sigma_f W_T^*}}{(\sigma_{45} - \sigma_f) \sigma_f} - \frac{e^{-\sigma_{45} W_T^*}}{(\sigma_f - \sigma_{45}) \sigma_{45}} + \frac{1}{\sigma_f \sigma_{45}} \right]$$

$$44. A_{463} = E_{46} Z \left(\frac{\sigma_f}{\sigma_{46} - \sigma_f} \right) (e^{-\sigma_f W_T^*} - e^{-\sigma_{46} W_T^*})$$

$$45. A_{464} = E_{46} Z (1 - e^{-\sigma_f W_T^*}) \quad \text{If } A_{464} < 0, \text{ set it} = 0$$

$$46. A_{465} = A_{46}^* \left(\frac{A_{464} + A_{462}}{A_{461} + A_{463}} \right)$$

$$46b. \text{ If } W_T^* = 0, \text{ then } A_{465} = A_{46}^*$$

$$47. A_{481} = E_{48} Z \left(\frac{\sigma_f}{\sigma_{48} - \sigma_f} \right) (e^{-\sigma_f W_T^*} - e^{-\sigma_{48} W_T^*})$$

$$48. A_{482} = E_{48} Z (1 - e^{-\sigma_f W_T^*}) \quad \text{If } A_{482} < 0, \text{ set it} = 0$$

$$49. A_{483} = A_{48}^* (A_{482}/A_{481})$$

$$49b. \text{ If } W_T^* = 0, \text{ then } A_{483} = A_{48}^*$$

$$49c. J = \frac{A_{42}^{**} (C_{48/42})}{A_{483}}$$

$$50. \quad T_8^* = A_{483}/E_{48} \quad \text{If } J > V_{19} \text{ print "Hi J"}$$

$$51a. \quad T_5^* = \frac{A_{45}^* + A_{462}}{E_{45}} \geq 0 \quad \text{If } A_{45}^* = 0, \text{ then } T_5^* = 0$$

$$52b. \quad T_6^* = \frac{A_{465} - A_{462}}{E_{46}} \geq 0$$

$$52c. \quad T_{568}^* = \frac{T_8^* + T_5^* + T_6^*}{n} \quad \text{where } n = \text{number of non-zero "T" terms}$$

$$52d. \quad SD = \sqrt{\frac{\sum T_x^2 - (\sum T_x)^2/n}{n-1}}$$

$$52e. \quad \text{If } \frac{SD}{T_{568}^*} \geq V_{13}, \text{ print "poor Nd precision"; then}$$

$$K_7 = |T_{568}^* - T_8^*|$$

$$K_8 = |T_{568}^* - T_6^*|$$

$$K_9 = |T_{568}^* - T_5^*|$$

$$52f. \quad \text{If } K_7 > K_8 \text{ and } K_9, \text{ then } T_{568}^* = \frac{T_5^* + T_6^*}{2}$$

$$52g. \quad \text{If } K_8 > K_7 \text{ and } K_9, \text{ then } T_{568}^* = \frac{T_8^* + T_5^*}{2}$$

$$53. \quad \text{If } K_9 > K_8 \text{ and } K_7, \text{ then } T_{568}^* = \frac{T_8^* + T_6^*}{2}$$

$$54. \quad Z^* = A_{T8} (1 + M_{T58} + M_{T48} + M_{6/5}^{**} M_{T58} + R_{T98} + R_{T08} + R_{P18} \\ + R_{T28} + T_{568}^* / A_{T8})$$

$$\text{If } N_8^0 \neq 0 \text{ and } \left| \frac{Z^*}{A_{T8}/N_8^0} - 1 \right| > (1 - V_{21}), \text{ then } Z^* = A_{T8}/N_8^0$$

$$55a. \quad F_{88} = T_8^* / Z^*$$

$$55b. \quad F_{55} = T_5^* / Z^*$$

$$55c. \quad F_{66} = T_6^* / Z^*$$

$$56a. \quad F_{568} = T_{568}^* / Z^*$$

$$56b. \quad \text{If } F_{T5} = 0, \text{ go to I-57f.}$$

$$56c. \quad \text{If } F_T = 0, \text{ go to I-58.}$$

$$57a. \quad K_3 = \frac{F_T}{F_{568}} - 1$$

$$57b. \quad \text{If } K_3 \text{ is between } V_{15} \text{ and } V_{16}; \text{ go to I-58}$$

$$57c. \quad \text{If } R_{9/8}^0 = 0, \text{ then } R_{9/8}^{**} = \sigma_8 \left[\frac{\exp(-\sigma_8 W_T^*)}{\sigma_9 - \sigma_8} + \frac{\exp(-\sigma_9 W_T^*)}{\sigma_8 - \sigma_9} \right]$$

$$57d. \quad K_{10} = \left[\frac{R_{9/8}^{**} (M_{3/8})^2}{R_{T98}} \right] - 1$$

$$K_{11} = \left[\frac{F_T}{F_{568}} \left(\frac{(0.1) F_{T5} + F_{T9}}{F_{T5} + F_{T9}} \right) \right] - 1$$

$$K_{12} = \left[\frac{F_T}{F_{568}} \left(\frac{(10) F_{T5} + F_{T9}}{F_{T5} + F_{T9}} \right) \right] - 1$$

$$K_{13} = \left[\frac{F_T}{F_{568}} \left(\frac{(1/3) F_{T5} + F_{T9}}{F_{T5} + F_{T9}} \right) \right] - 1$$

$$K_{14} = \left[\frac{F_T}{F_{568}} \left(\frac{(3) F_{T5} + F_{T9}}{F_{T5} + F_{T9}} \right) \right] - 1$$

$$K_{15} = \left\{ \frac{F_T}{F_{568}} \left[\frac{\left(\frac{238}{233} \right)^2 F_{T5} + F_{T9}}{F_{T5} + F_{T9}} \right] \right\} - 1$$

$$K_{16} = \left\{ \frac{F_T}{F_{568}} \left[\frac{\left(\frac{238}{233} \right) F_{T5} + F_{T9}}{F_{T5} + F_{T9}} \right] \right\} - 1$$

$$K_{18} = \left[\frac{1 - (S_{9/2}/M_{2/9})}{C (1/M_{2/9}) - (R_{2/9})} \right]$$

$$K_{17} = \left[\frac{K_{18} R_{T98}}{R_{9/8}^{**}} \right] - 1$$

Print "caution"

Select smallest K from K_{10} through K_{17}

If this smallest K is $> V_{15}$ in absolute value, print out this fact

If this smallest K is $< V_{15}$ in absolute value, then

If this smallest K is K_{10} , print "See if $M_{3/8}$ is inverted"

If this smallest K is K_{11} , print "See if $M_{3/8}$ is a factor of 10 low"

If this smallest K is K_{12} , print "See if $M_{3/8}$ is a factor of 10 high"

If this smallest K is K_{13} , print "See if $M_{3/8}$ is a scale factor of 3 low"

If this smallest K is K_{14} , print "See if $M_{3/8}$ is a scale factor of 3 high"

If this smallest K is K_{15} , print "See if $M_{3/8}$ has inverted bias correction"

If this smallest K is K_{16} , print "See if $M_{3/8}$ was not bias corrected"

If this smallest K is K_{17} , print "See if $M_{2/9}$ is inverted"

57e. If $F_{T5} \neq 0$; go to I-58

$$57f. \text{ If } F_{T5} = 0, \text{ then } F_{T5} = \left[\frac{F_{568} - (1 + G \frac{\nu_9}{\nu_5}) F_{T9} - (1 - G \frac{\nu_1}{\nu_5}) F_{T1}}{1 + G} \right] \geq 0$$

$$57g. F_{T8} = G \left[F_{T5} + \left(\frac{\nu_9}{\nu_5} \right) F_{T9} + \left(\frac{\nu_1}{\nu_5} \right) F_{T1} \right] \geq 0$$

$$57h. F_T = F_{T5} + F_{T9} + F_{T1} + F_{T8} \geq 0$$

$$58a. V_3 = \left\{ \left[\frac{F_{T5}}{F_T} (EPF5) + \frac{F_{T9}}{F_T} (EPF9) + \frac{F_{T8}}{F_T} (EPF8) + \frac{F_{T1}}{F_T} (EPF1) \right] / 205 \right\} V_{60}$$

$$58b. MWD/MT^* = V_3 F_T$$

$$58c. MWD/MT = V_3 F_{568}$$

$$59. F_{92} = F_{568} - F_{T5} - F_{T8} - F_{T1} \geq 0$$

For previously defined Subgroup 1,

$$60. \alpha_{92} = \alpha_{91}$$

$$61. \alpha_{93} = \left(\frac{F_{T9}}{F_{92}} \right) \alpha_{92} \quad \text{If } F_{92} = 0, \text{ set } \alpha_{93} = \alpha_{92}$$

For previously defined Subgroup 2

$$62. \alpha_{93} = (F_{T9}/F_{92}) \alpha_9 \quad \text{If } F_{92} = 0 \text{ and } V_{61} = 0, \text{ then set } \alpha_{93} = \alpha_9.$$

If α_{93} is not between V_9 and V_{10} , then $F_{T5} = F_{54}$ and go to I-59 once.

63. For all samples excluding those for which $V_4 > \alpha_{93} > V_5$

$$\bar{\alpha}_{93} = \frac{\sum \alpha_{93}}{n}, \text{ and}$$

$$64. S\alpha_{93} = \sqrt{\frac{\sum \alpha_{93}^2 - (\sum \alpha_{93})^2/n}{n-1}}$$

65. For each acceptable sample calculate $\alpha_{93} - \bar{\alpha}_{93}$. Exclude from $\bar{\alpha}_{93}$ all samples for which this quantity exceeds $V_{20}(S\alpha_{93})$, recalculate $\bar{\alpha}_{93}$ and $S\alpha_{93}$ call new values $\bar{\alpha}_{93}^*$ and $S\alpha_{93}^*$. These values are based on m samples.

66. If $\bar{\alpha}_{93}^*$ is between V_9 and V_{10} and $S\alpha_{93}^*/\sqrt{m} < V_{11}$, then $\alpha_9 = \bar{\alpha}_{93}^*$.

67a. If $V_{61} = 0$ and $\bar{\alpha}_{93}^*$ is not between V_9 and V_{10} , then $\bar{\alpha}_{93}^* = \alpha_9$.

67b. $F_{54} = N_8^0 \left(\frac{R_{5/8}^0 - M'_{5/8}}{1 + \alpha_5} \right) \geq 0$ If $M'_{5/8} = 0$; then $F_{54} = 0$

67c. If $\left| \frac{F_{54} + F_{T9} + F_{T1} + F_{T8}}{F_{568}} - 1 \right| < \left| \frac{F_{T5} + F_{T9} + F_{T1} + F_{T8}}{F_{568}} - 1 \right|$

$$\text{then } F_{T8} = G \left[F_{54} + \left(\frac{V_9}{V_5} \right) F_{T9} + \left(\frac{V_1}{V_5} \right) F_{T1} \right] \geq 0$$

$$\text{and } F_T = F_{54} + F_{T9} + F_{T1} + F_{T8} \geq 0$$

$$\text{and } F_{T5} = F_{54}$$

$$\text{and } V_3 = \left\{ \left[\frac{F_{T5}}{F_T} (\text{EPF5}) + \frac{F_{T9}}{F_T} (\text{EPF9}) + \frac{F_{T8}}{F_T} (\text{EPF8}) + \frac{F_{T1}}{F_T} (\text{EPF1}) \right] / 205 \right\} V_{60}$$

$$\text{and } \text{MWD}/\text{MT}^* = V_3 F_T \quad \text{and } \text{MWD}/\text{MT} = V_3 F_{568}$$

67d. Go to D-10 for a total of V_{57} passes maximum.

67e. Step deleted.

67f. Finally, arrange all the $M_{6/5}^{**}$ in descending order. List the corresponding, corrected values for the following quantities: R_9 , R_0 , R_1 , R_2 , $R_{9/8}$, $M_{6/8}$, $M'_{5/8}$. Graphically plot each value versus $M_{6/5}^{**}$ and visually inspect the proximity of each point to a smooth curve. Recheck or reanalyze the input data for any outlying points.

$$67g. F_{av} = (F_T + F_{568})/2$$

$$67h. \text{ If } F_T = 0; \text{ then } F_{av} = F_{568}$$

$$\text{If } F_{568} = 0; \text{ then } F_{av} = F_T$$

68. Arrange the samples in numerical order, and print out the following information:

<u>LABEL</u>	<u>OBTAINED FROM</u>	
ATM PCT U-234	M_4	Taken from the 1st iteration before Q correction
ATM PCT U-235	M_5	
ATM PCT U-236	M_6	
ATM PCT U-238	M_8	
ATM PCT Pu-239	R_9	
ATM PCT Pu-240	R_0	
ATM PCT Pu-241	R_1	
ATM PCT Pu-242	R_2	
Pu-239/U-238 AT RATIO	R_{T98}	Taken from the last iteration after Q correction
NVT EXPOSURE	W_T^*	
ATM PCT FISS (U-235)	$100 F_{T5}$	
ATM PCT FISS (Pu-239)	$100 F_{T9}$	
ATM PCT FISS (Pu-241)	$100 F_{T1}$	
ATM PCT FISS (U-238)	$100 F_{T8}$	
ATM PCT FISS (TOTAL)	$100 F_T$	
MWD/MT (By H.E.)	MWD/MT^*	
ATM PCT FISS (Nd-148)	$100 F_{88}$	
ATM PCT FISS (Nd-145)	$100 F_{55}$	
ATM PCT FISS (Nd-146)	$100 F_{66}$	
ATM PCT FISS (AVG.)	$100 F_{568}$	
MWD/MT (By Nd)	MWD/MT	

69. By use of M_4 , M_5 , M_6 , M_8 , $R_{9/8}$, $R_{0/8}$, $R_{1/8}$, and $R_{2/8}$ from the first iteration before Q correction compute the following:

$$\text{Sum} = 1 + (M_4/M_8) + (M_5/M_8) + (M_6/M_8) + R_{9/8} + R_{0/8} + R_{1/8} e^{\lambda_1 t} + R_{2/8} + F_{av} \left(\frac{1}{N_8^O Q} \right)$$

$$4 \text{ ATOM PCT} = (M_4/M_8)(100)/\text{SUM}$$

$$5 \text{ ATOM PCT} = (M_5/M_8)(100)/\text{SUM}$$

$$6 \text{ ATOM PCT} = (M_6/M_8)(100)/\text{SUM}$$

$$8 \text{ ATOM PCT} = 100/\text{SUM}$$

$$9 \text{ ATOM PCT} = (R_{9/8})(100)/\text{SUM}$$

$$0 \text{ ATOM PCT} = (R_{0/8})(100)/\text{SUM}$$

$$1 \text{ ATOM PCT} = (R_{1/8})(e^{\lambda_1 t})(100)/\text{SUM}$$

$$2 \text{ ATOM PCT} = (R_{2/8})(100)/\text{SUM}$$

$$F \text{ ATOM PCT} = F_{av} \left(\frac{100}{N_8^O Q} \right) / \text{SUM}$$

$$T \text{ ATOM PCT} = (4 + 5 + 6 + 8 + 9 + 0 + 1 + 2 + F)$$

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APPENDIX C

PROGRAMMING INFORMATION FOR USE OF COMPUTER CODE: BURNUP

APPENDIX C

PROGRAMMING INFORMATION FOR USE OF COMPUTER

CODE: BURNUP

A. PURPOSE

The calculation of burnup in irradiated nuclear fuel from the mass spectrometric determination of uranium, plutonium, and stable fission products is performed by the code.

B. INPUT DESCRIPTION

The first card must be a Serial NUMBER card obtained from operations. It is attached to request form (CE-210) which the user must fill out each time the program is run. The second card is an IDENTification card as shown below where four X's stand for the user number, the Y's are the nine required columns allotted for your initials and mail code. Both the commas and program marks are required as listed below. After Column 44, any free form message may be typed (without commas) such as "send results to C and DP Vallecitos". The third card is SELECT BURNUP. The fourth card is a LIMITS card. Do not use this card unless the run will exceed 0.06 hours. For a longer run, insert the desired time (in hundredths of an hour) in Columns 16 and 17. The fifth card is INCØDE IBMF to show the language character set as IBM fortran. These five cards left justify to Columns 1, 8, and 16; for example:

<u>Column 1</u>	<u>Column 8</u>	<u>Column 16</u>
\$	SNUMB	54321
\$	IDENT	XXXX,YYYYYYYYY,BURN-6
\$	SELECT	BURNUP
\$	LIMITS	ZZ
\$	INCØDE	IBMF

CASE Card

The CASE Card is used to identify the beginning of a set of data.

<u>Column</u>	<u>Content</u>
1-7	)BURNUP
9	*
10-14	CASE Number
28-34	Date

C. DATA INPUT

The data are read "Free Style" from cards. The data are identified by a symbol, followed by the value or values.

The recorded values for each sample are put on one or more consecutive cards. The symbolic name SAMP and the sample number i must precede the first reading.

Example

SAMP 263 0.1 5.0 . . . \$\$

All values must be separated by one or more blanks. Following the last value for each sample a double dollar sign (\$\$) must be entered.

Sample numbers (i) may be any number $1 \leq i \leq 999$.

Sample numbers do not need to be consecutive.

Samples will be processed in the order entered.

There must not be more than 50 samples per case.

The order of the elements within each sample is as follows:

(1) $M_{3/8}$	(6) $M_{2/9}$	(11) $R_{0/9}$	(16) $M_{48/50}$	(21) $R_{7/8}$
(2) $M_{3/5}$	(7) $M_{0/9}$	(12) $R_{1/9}$	(17) $M_{46/50}$	(22) S/M
(3) $M_{5/8}$	(8) $M_{1/9}$	(13) V_{SA}	(18) $M_{45/50}$	(23) t
(4) $M_{6/5}$	(9) $M_{2/0}$	(14) V_{SP}	(19) $R_{243/239}$	(24) t^*
(5) $M_{4/5}$	(10) $R_{2/9}$	(15) $M_{42/50}$	(20) $R_{244/239}$	

D. CONSTANTS

There are four classes of "constants." The value of each constant is preset within the program.

1. SPIKE DEPENDENT
2. FUEL DEPENDENT
3. REACTOR DEPENDENT
4. OTHER

To change the value of any constant, enter the appropriate symbol on a card, followed by the value desired.

1. SPIKE DEPENDENT

<u>CONSTANT</u>	<u>SYMBOL</u>	<u>PROGRAMMED VALUE</u>
$S_{4/3}$	S43	0.00016
$C_{2/9}$	C29	0.000156
$S_{9/2}$	S92	0.00274
$C_{3/8}$	C38	0.0
$S_{8/3}$	S83	0.00183
C_9/C_8	C9C8	0.010468
$R_{3/8}$	RP38	0.0
S_3	S3	5.095×10^{17}
$P_{2/9}$	P29	0.9056
$P_{3/8}$	P38	0.7966
$S_{50/42}$	S5042	127.0
$S_{50/48}$	S5048	123.9
$S_{50/46}$	S5046	90.83
$S_{50/45}$	S5045	237.30
A_{50}	A50	1.326×10^{15}
$S_{1/2}$	S12	1.36×10^{-3}
$S_{0/2}$	S02	2.00×10^{-3}
A_{242}	A242	6.063×10^{15}

2. FUEL DEPENDENT

$R_{4/5}^o$	R045	0.0
$R_{0/9}^o$	R009	0.0
$R_{1/9}^o$	R019	0.0
$R_{6/5}^o$	R065	0.0
$R_{5/8}^o$	R058	0.0
$R_{2/9}^o$	R029	0.0
$R_{9/8}^o$	R098	0.0
t	T	0.0
t*	TSTAR	0.0

3. REACTOR DEPENDENT

<u>CONSTANT</u>	<u>SYMBOL</u>	<u>PROGRAMMED VALUE</u>
α_5	ALF5	0.204
α_9	ALF9	0.570
α_1	ALF1	0.43
G	G	0.0
σ_4	SIG4	122.
σ_5	SIG5	645.6
σ_6	SIG6	50.
σ_8	SIG8	6.11
σ_9	SIG9	1700.
σ_0	SIG0	1060.
σ_1	SIG1	1880.
σ_2	SIG2	265.
σ_{45}	SIG45	100.
σ_{48}	SIG48	4.1
σ_{41}	SIG41	12.3
σ_{42}	SIG42	18.0
σ_{46}	SIG46	12.7
σ_0^o	SIG00	295.
σ_{1F}^o	SIG01F	950.
σ_2^o	SIG02	38.9
$\sigma_{8,2n}$	SIG82N	0.015
σ_{8F}	SIG8F	0.311
σ_{41}^o	SIG041	11.2
σ_{42}^o	SIG042	18.
σ_{45}^o	SIG045	60.
σ_{46}^o	SIG046	1.8
σ_{48}^o	SIG048	2.54

<u>Constant</u>	<u>Symbol</u>	<u>Programmed Value</u>
σ_{5F}^o	SIGØ5F	577.
σ_4^o	SIGØ4	95.
σ_5^o	SIGØ5	678.
σ_6^o	SIGØ6	6.
σ_7^o	SIGØ7	170.
σ_8^o	SIGØ8	2.73
σ_9^o	SIGØ9	1014.
s_{41}^o	SØ41	0.923
s_{42}^o	SØ42	0.
s_{45}^o	SØ45	1.88
s_{46}^o	SØ46	15.2
s_{48}^o	SØ48	8.
s_4^o	SØ4	7.7
s_5^o	SØ5	0.1457
s_6^o	SØ6	52.
s_7^o	SØ7	4.336
s_9^o	SØ9	2.338
s_0^o	SØ0	33.63
s_1^o	SØ1	0.8211
s_2^o	SØ2	37.58
T_o	TØ	293.
r	RR	0.06

3. REACTOR DEPENDENT (continued)

<u>CONSTANT</u>	<u>SYMBOL</u>	<u>PROGRAMMED VALUE</u>
MWF	MWF	270.07 for (UO ₂)
MWM	MWM	18.016 for (H ₂ O)
D _f	DF	10.37 for (UO ₂)
D _m	DM	0.783 for (H ₂ O 270°C)
V _R	VR	2.0 for Dresden 1
A _M	AM	2.0 for (UO ₂)
RADIUS	RAD	0.635 for Dresden 1
JC	JC	3 for Dresden 1

4. OTHER CONSTANTS

ν_9/ν_5	NU95	1.185
ν_1/ν_5	NU15	1.250
λ_1	LAMBDA1	1.671×10^{-9}
K	K	0.1000
C _{50/42}	C5042	0.2073
C _{50/48}	C5048	0.9808
C _{50/46}	C5046	0.3264
C _{50/45}	C5045	0.6771
C _{48/42}	C4842	0.2114

<u>CONSTANT</u>	<u>SYMBOL</u>	<u>PROGRAMMED VALUE</u>
Y ₀₅	Y05	0.0064
Y ₈₅	Y85	0.0166
Y ₆₅	Y65	0.0296
Y ₅₅	Y55	0.0388
Y ₁₅	Y15	0.0581
Y ₀₉	Y09	0.0096
Y ₈₉	Y89	0.0165
Y ₆₉	Y69	0.0250
Y ₅₉	Y59	0.0299
Y ₁₉	Y19	0.0575
Y ₀₁	Y01	0.0117
Y ₈₁	Y81	0.0155
Y ₆₁	Y61	0.0266
Y ₅₁	Y51	0.0313
Y ₁₁	Y11	0.0502
Y' ₀₅	YP05	0.0064†
Y' ₈₅	YP85	0.0166†
Y' ₆₅	YP65	0.0296†
Y' ₅₅	YP55	0.0388†
Y' ₁₅	YP15	0.0581†
Y' ₀₉	YP09	0.0096†
Y' ₈₉	YP89	0.0165†

†Thermal yields pending completion of epithermal measurements.

<u>CONSTANT</u>	<u>SYMBOL</u>	<u>PROGRAMMED VALUE</u>
Y'_{69}	YP69	0.0250†
Y'_{59}	YP59	0.0299†
Y'_{19}	YP19	0.0575†
Y'_{01}	YP01	0.0117†
Y'_{81}	YP81	0.0155†
Y'_{61}	YP61	0.0266†
Y'_{51}	YP51	0.0313†
Y'_{11}	YP11	0.0502†
Y_{08}	Y08	0.0087
Y_{88}	Y88	0.0197
Y_{68}	Y68	0.0320
Y_{58}	Y58	0.0360
Y_{18}	Y18	0.0546
V	V	0.015
V_1	V1	0.17
V_2	V2	0.28
V_3	V3	0.962×10^6
V_4	V4	0.0
V_5	V5	0.9
V_7	V7	0.0
V_8	V8	0.3
V_9	V9	0.4
V_{10}	V10	0.8
V_{11}	V11	0.06
V_{12}	V12	0.01
V_{13}	V13	0.1

<u>Constant</u>	<u>Symbol</u>	<u>Programmed Value</u>
V ₁₄	V14	1.0
V ₁₅	V15	0.1
V ₁₆	V16	- 0.1
V ₁₇	V17	1.5
V ₁₈	V18	0.015
V ₁₉	V19	1.5
V ₂₀	V20	1.5
V ₂₁	V21	0.96
V ₂₂	V22	0.25
V ₂₃	V23	0.02
V ₂₄	V24	0.02
V ₂₅	V25	0.06
V ₂₆	V26	+ 0.16
V ₂₇	V27	- 0.001
V ₂₈	V28	+ 0.001
V ₂₉	V29	- 4.
V ₃₀	V30	2
V ₃₁	V31	0.2
V ₃₂	V32	0.04
V ₃₃	V33	2
V ₃₄	V34	0.02
V ₃₅	V35	- 0.001
V ₃₆	V36	+ 0.001
V ₃₇	V37	1.
V ₃₈	V38	5
V ₃₉	V39	0.25

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<u>Constant</u>	<u>Symbol</u>	<u>Programmed Value</u>
V ₄₀	V40	0.7
V ₄₁	V41	0.7
V ₄₂	V42	- 0.001
V ₄₃	V43	+ 0.001
V ₄₄	V44	1.2
V ₄₅	V45	6
V ₄₆	V46	0.001
V ₄₇	V47	2.6
V ₄₈	V48	6
V ₄₉	V49	0.001
V ₅₀	V50	1.3
V ₅₁	V51	5
V ₅₂	V52	0.02
V ₅₃	V53	1.
V ₅₄	V54	5
V ₅₅	V55	0.25
V ₅₆	V56	4.0
V ₅₇	V57	4
V ₅₈	V58	17
V ₅₉	V59	1.
V ₆₀	V60	9.62×10^5
V ₆₁	V61	0.
EPF9	EPF9	210.8
EPF5	EPF5	203.3
EPF8	EPF8	200.7
EPF1	EPF1	213.0
IP1, ..., IP20	IP1, ..., IP20	4

OTHER CONSTANTS

<u>Constant</u>	<u>Symbol</u>	<u>Programmed Value</u>
σ_{SFL}	SIGSFL	5.200
σ_{CFL}	SIGCFL	0.05404
σ_{IFL}	SIGIFL	1.694
σ_{FFL}	SIGFFL	0.4124
σ_{TFL}	SIGTFL	7.3604
σ_{SML}	SIGSML	2.451
σ_{CML}	SIGCML	0.03567
σ_{IML}	SIGIML	0
σ_{TML}	SIGTML	2.4867
σ_{SM}	SIGSM	2.451
σ_{CM}	SIGCM	0.03575
σ_{IM}	SIGIM	6.120
σ_{TM}	SIGTM	8.6067
ν_8	NU8	2.671
ν_5	NU5	2.439
χ	CHI	0.816325

TABLE A

T°C	g_9	g_5	g_{1F}	g_{5F}	s_5	s_{5F}	s_{9F}	g_{9F}	s_{1F}	s_9
20	1.0723	0.9771	1.0437	0.9781	0.1354	- 0.0410	2.329	1.0487	1.0518	3.008
40	1.0909	0.9723	1.0547	0.9735	0.1501	- 0.0316	2.389	1.0623	1.0563	3.081
60	1.1117	0.9678	1.0668	0.9692	0.1640	- 0.0230	2.432	1.0777	1.0519	3.136
80	1.1350	0.9636	1.0801	0.9650	0.1771	- 0.0147	2.460	1.0952	1.0390	3.170
100	1.1611	0.9597	1.0945	0.9611	0.1893	- 0.0007	2.471	1.1150	1.0177	3.184
120	1.1903	0.9560	1.1101	0.9573	0.2008	0.0002	2.466	1.1373	0.9882	3.177
140	1.2227	0.9526	1.1269	0.9538	0.2113	0.0066	2.445	1.1623	0.9508	3.152
160	1.2582	0.9494	1.1447	0.9505	0.2208	0.0123	2.407	1.1898	0.9057	3.104
180	1.2970	0.9465	1.1635	0.9474	0.2295	0.0174	2.352	1.2200	0.8534	3.037
200	1.3388	0.9438	1.1832	0.9445	0.2373	0.0218	2.280	1.2528	0.7946	2.949
220	1.3836	0.9413	1.2038	0.9418	0.2444	0.0257	2.192	1.2880	0.7300	2.840
240	1.4313	0.9391	1.2250	0.9392	0.2508	0.0293	2.088	1.3255	0.6604	2.712
260	1.4817	0.9370	1.2469	0.9369	0.2565	0.0316	1.969	1.3653	0.5869	2.565
280	1.5354	0.9351	1.2693	0.9347	0.2614	0.0338	1.836	1.4071	0.5104	2.401
300	1.5895	0.9334	1.2920	0.9327	0.2659	0.0354	1.690	1.4507	0.4319	2.221
330	1.6758	0.9312	1.3267	0.9299	0.2716	0.0373	1.452	1.5193	0.3127	1.928
360	1.7658	0.9292	1.3616	0.9274	0.2765	0.0383	1.195	1.5910	0.1944	1.610
390	1.8588	0.9275	1.3965	0.9252	0.2807	0.0387	0.927	1.6651	0.0799	1.281
420	1.9539	0.9261	1.4311	0.9232	0.2847	0.0389	0.654	1.7410	- 0.0289	0.945
450	2.0505	0.9248	1.4652	0.9214	0.2888	0.0391	0.384	1.8182	- 0.1304	0.611
480	2.1477	0.9237	1.4984	0.9197	0.2928	0.0396	0.120	1.8959	- 0.2240	0.287
510	2.2451	0.9228	1.5308	0.9182	0.2970	0.0400	- 0.133	1.9738	- 0.3093	- 0.025
540	2.3419	0.9219	1.5620	0.9169	0.3021	0.0409	- 0.373	2.0514	- 0.3864	- 0.320

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TABLE B. Values of First Collision Probability, P_c

<u>Index, A_a</u>	<u>Slab</u>	<u>Cylinder</u>	<u>Sphere</u>
0.00	0.0000	0.0000	0.00000
0.01	0.0484	0.01320	0.00746
0.02	0.0831	0.02561	0.01484
0.03	0.1127	0.03764	0.02214
0.04	0.1390	0.04967	0.02937
0.05	0.1629	0.06108	0.03652
0.06	0.1849	0.07248	0.04360
0.07	0.2054	0.08335	0.05060
0.08	0.2246	0.09421	0.05752
0.09	0.2427	0.10459	0.06438
0.10	0.2597	0.11498	0.07116
0.12	0.2900	0.13487	0.08436
0.14	0.3200	0.15396	0.09760
0.16	0.3457	0.17231	0.10028
0.18	0.3707	0.18996	0.12296
0.20	0.3924	0.20697	0.13512
0.22	0.4142	0.22336	0.14729
0.24	0.4335	0.23918	0.15897
0.26	0.4523	0.25446	0.17065
0.28	0.4692	0.26923	0.18186
0.30	0.4859	0.28351	0.19308
0.32	0.5034	0.29733	0.2065
0.35	0.5229	0.31720	0.2199
0.38	0.5392	0.33621	0.2327
0.40	0.5554	0.34838	0.2454
0.42	0.5698	0.36019	0.2575
0.45	0.5841	0.37720	0.2696
0.48	0.5969	0.39356	0.2812
0.50	0.6097	0.40405	0.2927
0.54	0.6315	0.42414	0.3142
0.60	0.6533	0.45225	0.3357
0.64	0.6712	0.46975	0.3553

TABLE B. Values of First Collision Probability, P_c
(Continued)

<u>Index, A_a</u>	<u>Slab</u>	<u>Cylinder</u>	<u>Sphere</u>
0.70	0.6890	0.49432	0.3748
0.80	0.7187	0.5313	0.4104
0.90	0.7437	0.5639	0.4430
1.00	0.7651	0.5928	0.4728
1.20	0.8007	0.6418	0.5209
1.50	0.8363	0.6984	0.5890
2.00	0.8757	0.7636	0.6676
2.50	0.9002	0.8068	0.7230
3.00	0.9167	0.8371	0.7636
4.00	0.9375	0.8765	0.8183
5.00	0.9500	0.9008	0.8530

E. END OF DATA

To indicate to the program that all data for one Case have been given, the symbol END and the value 999 must be punched on the last card of a Case. Thus END 999 \$\$.

F. LAST CARD

A last card must follow the final case.

<u>Column</u>	<u>Contents</u>
1-5	)LAST
9	*

G. ENDJOB

The final card of an input deck must be an ENDJOB card.

<u>Column</u>	<u>Contents</u>
1	\$
8-13	ENDJOB

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