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Prediction of the Time Dependant Beta Spectrum from a Nuclear Weapon Detonation

THESIS

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PREDICTION OF THE TIME DEPENDENT BETA SPECTRUM FROM A NUCLEAR WEAPON DETONATION

THESIS

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Master of Science

By

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Preface

This thesis topic was originally suggested by Colonel I. J. Russell of the Air Force Weapons Laboratory at Kirtland AFB, New Mexico, in the spring of 1963. It was started by Lt. Robert L. Stovall, GSP/64, in October of 1963, and reported on in his thesis. Since it was not possible to completely solve the problem during the six months period available to him, he suggested that it be continued. The topic was selected by me in the spring of 1964 and the work was accomplished at the Air Force Weapons Laboratory during the period of October 1964 to March 1965.

I would like to express my sincere appreciation to Col. I. J. Russell for his guidance and encouragement. I would also like to thank Lt. Robert L. Stovall for his help in acquiring an early understanding of the complexity of the problem and also for his advice on the choosing of problem areas which could be profitable investigated.

I also want to express my thanks to Miss Gayle Mortensen for her help in compiling the data presented in Appendix B, and to Mrs. Henrietta Thomas for accomplishing the tedious task of typing the decay schemes.

The support given to me by the Air Force Weapons Laboratory, the Research Division, and Biophysics Branch in particular was excellent and materially aided in the completion of the research effort.

James E. Dieckhoner

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Abstract

This thesis develops a method by which the time dependent beta spectrum from four different types of nuclear and thermonuclear fission can be predicted. From the mass chain yield and the Equal Charge Displacement theory, the initial isotopic concentrations are predicted. The time dependent relationships within each mass chain are solved exactly. The shape of the beta decay spectra for each isotope is predicted by use of the Fermi theory. An estimation technique is used to predict the spectra from isotopes with unknown decay schemes. Attempts are made to predict the percent of the total available decay energy which is accounted for by beta decay, for those isotopes with unknown decay schemes. These procedures are combined in a set of computer programs written for the IBM 7044. The spectra predicted using the programs are compared with West's experimental results and agree within a factor of 1.4.

I. Introduction

Purpose and Scope

The purpose of the research reported in this paper is to continue development of a method by which the time dependence of the beta spectrum resulting from a nuclear or thermonuclear detonation can be predicted. This effort was started by Lt. Robert L. Stovall, AFIT GSP-64, and reported on in his thesis (Ref 17). Since Lt. Stovall's thesis is classified SECRET, in accordance with AFR 205-1, and its availability is therefore limited, enough of his work is included in this report to assure continuity of thought. Because of the complexity and number of the processes involved in these detonations, this prediction method necessitates the use of a digital computer. The problem encompasses many areas where experimental evidence is not available; in these areas the best available theoretically predicted information is used, and where no theoretical predictions are possible, the author has made approximations which he believes are logical and appropriate. In order to understand better the calculations necessary to make the predictions for any of the reactions of interest (U-235 thermal neutron fission; U-235 fission spectrum neutron fission; Pu-239 thermal neutron fission; thermonuclear neutron fission), a brief review of the typical reactions and processes which are taking place will be helpful.

When a compound nucleus fissions, it splits into two fission fragments and emits a number of neutrons, depending on the nucleus undergoing fission and the energy of the neutron causing the fission. After a large number of such fission events, a plot showing the

statistical assembly of the fission products according to their masses exhibits the familiar "double humped" shape. This curve indicates the percent of the fission product assembly characterized by each mass number. In many cases these curves have been determined experimentally. In this study the mass chains with atomic weights of 77 through 159 will be considered. In each mass chain there are several different charge values (atomic number) which can be formed. They are formed in varying amounts which can be predicted by a theoretical approach; each of the members of each of the chains then decays according to the radioactive decay law. Since the fission products are in general neutron-heavy, these decays are accomplished by the emission of beta particles. Each of the members of the mass chain may emit one or several beta particles which leave the resulting nucleus in a variety of excited states which then decay to the ground state by the subsequent emission of one or more gamma rays. In beta decay the beta particles are observed to exhibit a spectrum of energies characterized by a well defined upper limit, referred to as the end point energy. This beta spectrum for each individual beta decay is predictable by use of the Fermi theory of beta decay.

Therefore, to predict the gross beta spectrum of a mixture of fission products at any time of interest following the fission event, it is obvious that a great deal of information must be available experimentally or through theoretical means. This information consists of first, the percent of the gross mixture of fission fragments which are contained in each of the mass chains; second, the percent of the total chain yield which is accounted for immediately after fission by each member of the chain; third, the structure of each

decay chain including all branching ratios; fourth, the decay constants of each member of the chain; and fifth, the number and energy of the different betas by which each isotope decays and the end point energies of these beta decays.

Previous Work in This Area

The first effort to attempt to solve this problem took place in 1958 (Ref 14). The approach used consisted of taking the then available data from Bolles and Ballou (Ref 1) concerning the time dependent activity of the fission products from thermal neutron fission of U-235 and then using the current information concerning the decay schemes and half lives for the fission products and solving the decay equations to give the spectra. The time period over which the calculations were made was from 31.2 minutes to 119 years. No apparent effort was made to predict the spectra at shorter times. There also was no attempt made to theoretically predict or estimate any of the unknown data.

The next attempt to solve this problem occurred in 1961 (Ref 12). This effort contained a more thorough attack on the experimentally unknown data. In treating the isotopes with unknown decay schemes, however, the authors considered that all of the available energy was taken by the beta particle and none by the gamma emission from excited states of the resultant nucleus. This approach was taken in order to arrive at an upper limit for the high energy portion of the spectrum. The results of this effort were presented as graphs of total beta activity per fission versus time, the percent of total beta activity versus beta energy, and the number of beta rays per fission per

energy interval.

The most recent effort in this area is presently being conducted by the U. S. Naval Radiological Defense Laboratory (Ref 8). The main purpose of the work is to develop a means to predict the radiological properties from fractionated nuclear or thermonuclear weapon debris. In the course of developing this prediction model, it was necessary to develop a prediction method by which the abundances and activities of all of the fission product nuclides could be calculated. A great many of the assumptions made by Stovall and in this thesis are identical with those made by the researchers at the U.S.N.R.D.L., especially in the areas of chain and isomeric yield determination, partition of yield among isomeric pairs, and solution of the decay equations. It will be interesting to compare the solutions arrived at by both groups of researchers.

Results Obtained

Briefly this paper has taken the prediction method developed earlier (Ref 17) and improved its accuracy, efficiency, and versatility. Its versatility has been enhanced by the inclusion of a fourth type of fission; U-235 fission spectrum neutron fission. Its efficiency has been improved by the inclusion of the computer programs of the exact solutions to the differential equations describing the isotopic decays. The efficiency has also been improved by the development of a method by which the thermonuclear fission case can be treated in a completely unclassified manner, thereby allowing the widest dissemination of the prediction method, its results and conclusions. As a result of this wide dissemination it should be possible to more easily obtain independent critical analyses of the

method and its results. The accuracy of the method has been improved by the incorporation of new data concerning the half lives, the decay paths, and the beta decay schemes of the individual isotopes. In addition to these improvements, this paper also reports on a method which, although it has not yet yielded any useful results, should allow the determination of the percent of the total energy available in an isotopic decay which is accounted for by beta decays.

Report Presentation

The remainder of this report will discuss the topic areas in the logical sequence indicated in the preceding discussion. Chapter II will consider the experimental evidence available, and the theoretical techniques used, to predict the distribution of the fission products according to the mass chains and also the distribution of the fission products formed within each mass chain. Chapter III will discuss the characteristics of the decay chains and how their time dependence is solved. Chapter IV will present a discussion of the theory by which the individual spectrum associated with each beta decay is computed, for the isotopes with known decay schemes, and will present the estimation technique with which those isotopes with unknown decay schemes will be dealt. Chapter V will then describe the procedures by which all of these calculations are brought together by the computer codes which have been developed and how the end product, the time dependence of the beta spectrum, is obtained. Chapter VI will present the results obtained in this study and will discuss the limitations on these results. This chapter will also present a discussion of the utility of this research, and its prediction

technique, to the Air Force and to the rest of the scientific community and also suggest areas in which further effort on this problem may be fruitfully directed. The mass chain yields for the four types of fission considered in this report are contained in Appendix A. Appendix B contains all of the data pertinent to the decay schemes for mass chains numbers 77 through 159. In appendix C are found the FORTRAN listings, the definitions of all variables used, and the flow charts for the computer codes developed for this report.

II. Chain and Isotopic Yields

Mass Chain Yields

One of the basic pieces of information necessary for the solution of this problem is the percent of the total number of fission fragments which are formed with each atomic weight. This data is contained in what are commonly known as mass yield curves. The shape of the mass yield curve varies as a function of the fissioning nucleus and the energy of the neutron causing the fission. In Fig. 1 are presented the mass yield curves for (1) thermal neutron fission of U-235; (2) fission spectrum neutron fission of U-235; (3) thermal neutron fission of Pu-239; and (4) thermonuclear neutron fission. (Ref 18:17-37) (Ref 6:7-15) The values for the mass chain yields per 10,000 fissions for each of the cases are presented in Appendix A. From the shape of the mass yield curves for the four different cases, it can be seen that the trough area rises and the twin peaks widen as the energy of the fission causing neutron increases. It can also be observed that the curves are approximately symmetrical about a mass number equal to approximately one half of the mass number of the compound nucleus (the sum of the mass number of the nucleus undergoing fission plus the mass of the fission causing projectile) less the mass of the prompt neutrons emitted in the fission process.

Isotopic Yields

Once the mass chain yields are known, the next problem area is the apportionment of this yield among the various isotopes which make up this mass chain. The theory which will be used to predict the isotopic yields in this report is the one proposed by Glendenin which

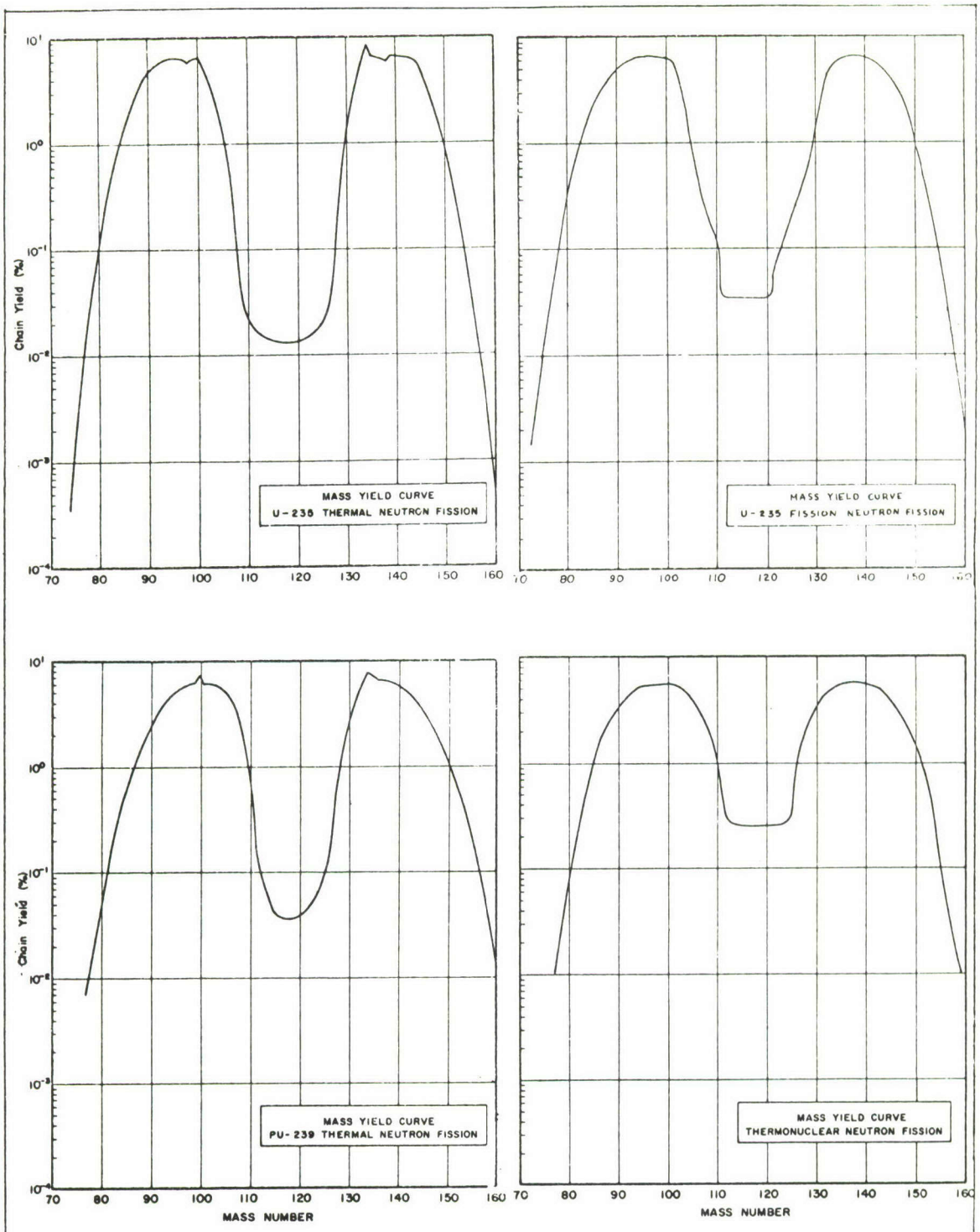

Fig. 1

Mass Yield Curves

is based on the postulate of equal charge displacement (E.C.D) (Ref 9:489-515), (Ref 4:646-63). Its initial assumption is that the most probable charge formed in fission (Z_p) for any atomic mass is equally displaced from the charge of maximum stability (Z_A) for both the light and the heavy fragments.

$$\left|(Z_A - Z_p)\right| \text{ Light fragment } = \left|(Z_A - Z_p)\right| \text{ Heavy fragment} \quad (1)$$

The particulars of this theory are described in completeness in an earlier report (Ref 17). The result of this theory, as modified by Wahl (Ref 4:649), is the prediction of the fraction of the mass chain yield which is initially formed as each member of the mass chain. This isotopic yield distribution curve as a function of the distance of the isotopic charge from the most probable charge is presented in Fig. 2. The curve is seen to be Gaussian in nature out to an absolute value of $(Z - Z_p)$ of 2.2, and exponential in form from there out to an absolute value of $(Z - Z_p)$ of 4.0.

Therefore, the problem then becomes one of calculating the value of Z_p for each of the four types of fission under investigation. Empirical values for Z_p have been calculated for U-235 thermal neutron fission using Wahl's approach. Using these U-235 thermal neutron fission values of Z_p as reference values, a means by which the Z_p values for any other type of fission could be calculated was desired A term ΔZ_p was defined:

$$\Delta Z_p \equiv Z_p \text{ (fission type of interest)} - Z_p \text{ (U-235 thermal neutron fission)} \quad (2)$$

which could be calculated by two equations:

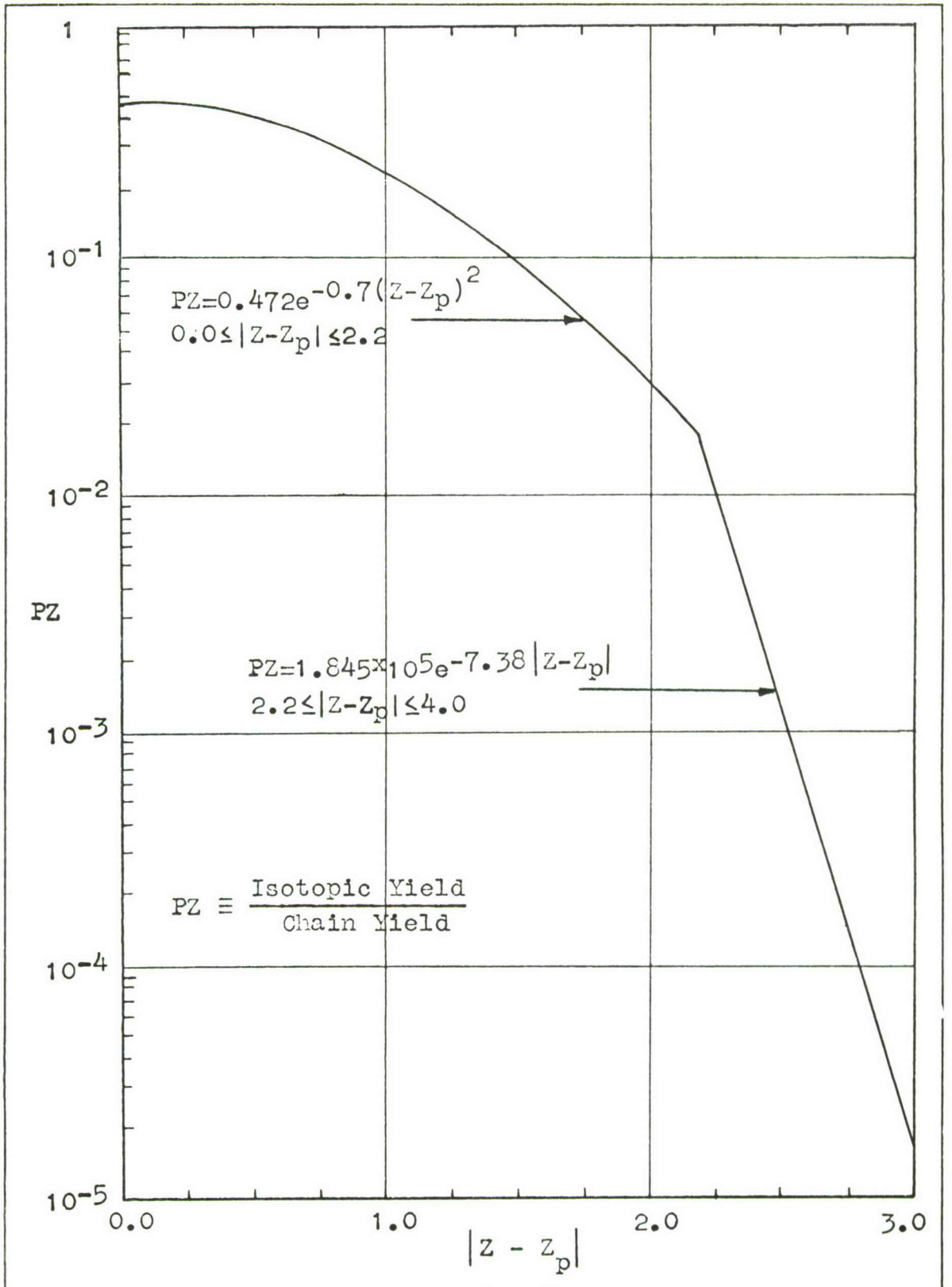

Fig. 2

Isotopic Yield Distribution Curve

$$\Delta Z_p = 1/2(Z_c-92) - 0.19(A_c-236) + 0.19(\nu_T-2.5) \quad (3)$$

$$\text{and, } \Delta Z_p = 1/2(Z_c-92) - 0.19(A_c-236) + 0.19(0.12\left[E^*-C_1\right] + C_1-2.5): \text{ where} \quad (4)$$

$Z_c \equiv$ the nuclear charge of the compound nucleus

$A_c \equiv$ the mass of the compound nucleus before the emission of prompt neutrons

$\nu_T \equiv$ the number of neutrons emitted when the compound nucleus breaks into fission fragments

$= 0.12E + C_1$

$E^* \equiv$ excitation energy of the fissioning nucleus after bombardment

$= E + C_2$

$E \equiv$ the energy of the projectile causing fission

C_1 and C_2 = constants being defined for the various fission processes as:

Nucleus	C_1	C_2
Pu-239	2.9	6.38
U-235	2.5	6.5
U-238	2.5	6.5

By use of Eqs (3) and (4), the values for ΔZ_p for the fission types of interest were determined, except for the case of thermonuclear fission. Previously, (Ref 17), this case was handled by considering the contribution to the yield from each of the two isotopic forms of

uranium which make up the thermonuclear device. The inclusion of this data caused the report to be classified. In order to allow the widest dissemination of this report, it was decided to calculate the value of ΔZ_p for the case of thermonuclear fission considering an average fissioning nucleus.

Besides its disadvantage of being classified, Stovall's method is not rigorously correct in using the experimental data (Ref:6). It assumes in calculating the U-238 thermonuclear ΔZ_p that the value of ν_T is 3.0 and likewise for the U-235 thermonuclear ΔZ_p. In both of these calculations the choice of $\nu_T = 3.0$ is taken from the symmetry in the mass yield curve of Crocker, Fig. 1. However, this value of ν_T is only expressly valid for, and was calculated from, the gross assembly of fission products from the thermonuclear fission of a mixture of U-238 and U-235. Therefore, unless the value of ν_T is independently equal to 3.0 for both the cases of U-235 and U-238 thermonuclear fission, then both of the calculated values of ΔZ_p are incorrect.

The method which was developed to determine a single value for ΔZ_p for the thermonuclear case rested on the fact that the sum of the mass numbers of the light and heavy fission fragments plus the mass of the prompt neutrons emitted in fission equals the mass of the compound nucleus. Also, knowledge that the thermonuclear fissile material is a combination of only uranium isotopes allowed the determination of the value of Z_c as being 92. A small computer program was developed which picked the mass yield corresponding to an integer mass number on one side of the mass yield curve and then searched the other side of the mass yield curve for the complementary

mass number with the identical yield. In this way all of the equal yield mass combinations were found, summed, and an average was computed. This average was therefore equal to the mass of the compound nucleus after emission of the three prompt neutrons as reported by Crocker. This yielded a value for A_c of 239. Using these values of Z_c, A_c, and ν_T in Eq (3) an unclassified value for thermonuclear ΔZ_P was determined. The values for ΔZ_P for the four cases of interest are presented in Table I.

TABLE I

Values of Z_P

Fissioning Nuclide	Neutron Energy (E)	ν_T	ΔZ_P
U-235	Thermal (0.025 ev)	2.5	0
U-235	1 Mev	2.7	0.023
Pu-239	Thermal (0.025 ev)	2.9	0.316
(Thermonuclear Mixture)	Thermonuclear	3.0	-0.475

Isomeric Pair Formation

In some instances it is possible for two isomeric states of the same isotope to be formed. At present there is no method available which will predict the relative amounts of the two isomers that are formed initially in fission. In this study, the arbitrary, simplifying assumption of a 50-50 split is made. This will be discussed further in the discussion on possible future work in the further refinement of the whole prediction method.

Since the chain and isotopic yields must be calculated only

once, for each type of fission, this data is computed and put on punched computer cards by a small computer program and used as input data in the main program. Simple linear scaling can be used to allow the use of any fission yield weapon. The present method assumes a nominal 1 MT fission yield.

III. Decay Chain Characteristics

Decay Chain Solutions

The solution of the beta spectrum as a function of time after fission requires the knowledge of the amount of each isotope of each mass chain which is present at any time after fission and also its activity. The decay chains for the mass chains of 77 through 159 are presented in Appendix I (Ref 10&15). Once the amount of each isotope initially present is known then the problem becomes one of solving the radioactive decay equations. Stovall (Ref 17:33-36) used a numerical method to solve the differential equations arising from the radioactive decay laws to determine the concentration of each isotope at the times of interest. This method had the severe practical drawbacks of: (1) taking a great deal of computer time; (2) taking progressively longer times to solve for times of interest which were very large; and (3) the answer arrived at was only approximate and the error accumulated the further the time of interest was from the time of fission. It was therefore decided that for increased flexibility and accuracy, it would be profitable to spend the necessary time to solve and program the exact solutions to the differential equations.

Once the decision was made to solve the equations exactly, it became necessary to decide which of two methods should be used. The first method considered involved the construction of a conglomerate decay chain which contained within it all of the different decay chain combinations which occur in the mass chains 77 through 159. It then

would be possible by setting certain branching ratios equal to zero, to synthesize any of the actual decay chains. This conglomerate decay chain when once constructed then would have to be solved exactly for each of its members. It was decided that this method was both too complicated to solve in the time period alloted and furthermore was too inflexible for use in case some new decay chain was encountered which was not contained in the conglomerate decay chain.

The second method considered, and the one which was actually utilized, consisted of reducing all decay chains to an arithmetic summation of straight chain decays. For example, the decay path of mass chain 77 is schematically presented in Fig. 3.

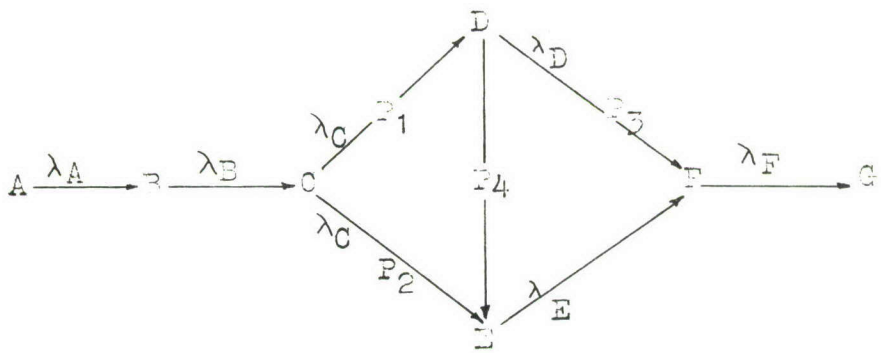

Fig. 3

Decay Scheme for Mass Chain 77

The calculation of the concentration of A, B, or C which is present at any time is a relatively simple application of the radioactive decay laws. The concentration of D is computed by considering a four member straight decay chain with P_1 percent of the contribution of

isotopes A, B, and C and 100 percent contribution from D. The concentration of E, which is a different isomeric state of D, is the sum of the contributions of the five member straight chain of A, B, C, D, and E and the four member straight chain A, B, C, E. In the five member chain the contribution from A, B, and C are multiplied by the product of P_1 and P_4; and in the four member chain, the contribution from A, B and C are multiplied by P_2. In summing these two, care must be taken to see that the decay of the isotope E is only considered once. The concentration of F is likewise a combination of three straight chains: The five member chains A, B, C, D, F and A, B, C, E, F; and the six member chain A, B, C, D, E, F. Each member's contribution is of course weighted by the appropriate branching percentages. As can be seen, this method involved the initially large task of determining all of the different paths which can lead to the formation of each of the isotopes contained in each of the 83 decay chains, and the correspondingly tedious task of putting this information on punched cards which can be accepted by a digital computer.

The maximum length straight chain which occurs in the decay chains as presented in Appendix B is ten. Fortunately, the solution for a straight chain decay of any length follows a predictable, though involved form, which increases greatly in length for each additional member in the chain. The equations to be solved are of the form:

$$\frac{dN_i}{dt} = -\lambda_i N_i + \lambda_{i-1} N_{i-1} \qquad (5)$$

where: λ_i = the decay constant of the isotope $= \frac{\ln 2}{T_{1/2}}$

$T_{\frac{1}{2}}$ = half life of the isotopes

The familiar solution for a single member decaying is:

$$N_1 = N_1^o \, e^{-\lambda t} \tag{6}$$

where: N_1 = the concentration of the isotope at time = t

N_1^o = the concentration of the isotope at time = o

λ = the decay constant of the isotope as defined above

t = the time of interest

The solution for the second member of a two member chain is:

$$N_2 = \lambda_1 N_1^o \left(\frac{e^{-\lambda_1 t}}{(\lambda_2 - \lambda_1)} + \frac{e^{-\lambda_2 t}}{(\lambda_1 - \lambda_2)}\right) + N_2^o \, e^{-\lambda_2 t} \tag{7}$$

The solution for the third member of a three member chain is:

$$N_3 = \lambda_1 \lambda_2 N_1^o \left(\frac{e^{-\lambda_1 t}}{(\lambda_2 - \lambda_1)(\lambda_3 - \lambda_1)} + \frac{e^{-\lambda_2 t}}{(\lambda_1 - \lambda_2)(\lambda_3 - \lambda_2)} + \frac{e^{-\lambda_3 t}}{(\lambda_1 - \lambda_3)(\lambda_2 - \lambda_3)}\right)$$

$$+ \lambda_2 N_2^o \left(\frac{e^{-\lambda_2 t}}{(\lambda_3 - \lambda_2)} \quad \frac{e^{-\lambda_3 t}}{(\lambda_2 - \lambda_3)}\right) + N_3^o \, e^{-\lambda_3 t} \tag{8}$$

As can be seen, the length of the solution increases very rapidly. The solution for the tenth member of a ten member chain contains ten major terms, the first term of which consists of ten members each with a denominator made up of the product of nine differences, the second term consists of nine members each with a denominator made up of the product of eight differences, and so forth. All of these solutions were written out, programmed for the computer, and the computer program cards prepared. Since the types of sources to be considered by this code are nuclear and thermonuclear explosions, the equations were solved assuming an instantaneous, non-time dependent source term. This implied that the values of N_i^o in the equations were those concentrations of the isotopes calculated as being initially formed in fission, as described in the previous chapter.

Estimation of Unknown Half-Lives

The method used to predict half-lives for those isotopes for which no measured value exists is the same one used previously. (Ref 17:23-25).

IV. Theory of Beta Decay

Description of Beta Decay

In the process of beta decay, the nucleus undergoing decay emits a beta particle and an antineutrino. This causes the resultant nucleus to increase its charge by one unit. In this decay process, the mass number of the original and final isotope is considered the same. This process is presented in equation form below:

$$ {}_{Z}^{A}A \longrightarrow {}_{Z+1}^{A}B + {}_{-1}\beta^{o} + {}_{o}\bar{\nu}^{o} \qquad (9) $$

Since the decay process involves a three body problem with the final nucleus, beta particle, and antineutrino; it is not possible to predict a monoenergetic value for the energy of the beta particle. Rather, since the atomic mass difference between the initial nucleus (${}_{Z}^{A}A$) and the mass of the final nucleus (${}_{Z+1}^{A}B$) represents the total kinetic energy available for partition between the beta particle (${}_{-1}\beta^{o}$) and the antineutrino (${}_{o}\bar{\nu}^{o}$), the process of beta decay can be characterized by the instance in which practically all of this kinetic energy is possessed by the beta particle and essentially none by the antineutrino. This maximum kinetic energy is commonly referred to as the beta end point energy (E.P.E). The observed beta particle energies therefore form a spectrum starting at zero energy and extending to a maximum value, the beta end point energy. The shape of this beta spectrum has been studied and a theory by which it can be calculated and predicted has been developed by Fermi (Ref 7:548-62).

The mathematical derivation of the Fermi theory was discussed in Stovall's report and will not be reproduced here. The spectral shapes predicted by this theory correspond to what is known as "allowed" transitions. There are other spectral shapes observed experimentally which are known as "forbidden" transitions. The terms "allowed" or "forbidden" transitions do not indicate whether or not these modes of decay are any more or less likely to occur in nature; they simply refer to those transitions whose spectral shapes are directly predicted by the Fermi theory and those whose spectral shapes are modified versions of the spectral shapes predicted by the Fermi theory.

Shape Correction Factors

In order to produce the actual spectral shapes for the forbidden transitions, a set of correction factors are used (Ref 11:557-8); these correction factors are commonly known as spectral shape factors. The determination of the degree of forbiddeness of any specific beta decay and therefore the determination of the appropriate correction factor to be applied to the results of the Fermi theory is accomplished by the calculation of a "log ft" value. The mathematical expression for the calculation of this "log ft" value (Ref 17:64) is a function of the atomic number (Z), of the nucleus undergoing decay, the maximum beta energy of the decay (E.P.E.), and the half-life ($T_{\frac{1}{2}}$) of the decay.

Table II lists the log ft values and the appropriate shape factors (C_{ft}). In the shape factors, the following definitions apply: $\varepsilon = E/m_o c^2$ where E = total energy of the beta (kinetic + rest mass), m_o = rest mass of the beta, c = speed of light; and $\varepsilon_o = E_{max}/m_o c^2$ where E max = $T_{max} + T_o$, T_{max} = maximum kinetic energy of the beta

"FORBIDDENESS"	LOG $_{10}$ ft 1/2	SHAPE FACTOR (C_{ft})
SUPERALLOWED	3.5±0.5	$C_{ft} \sim$ Unity
ALLOWED	5.0±1.0	$C_{ft} \sim$ Unity
1st FORBIDDEN	7.0±1.0	$C_{ft} \sim p^2+q^2$
UNIQUE 1st FORBIDDEN	8.5±0.5	$C_{ft} \sim 1/12(p^2+q^2)$
2nd FORBIDDEN	$\sim$ 13.0	$C_{ft} \sim p^4+10/3p^2q^2+q^4$
3rd FORBIDDEN	$\sim$ 18.0	$C_{ft} \sim p^6 +7p^2q^2(p^2+q^2) + q^6$

Transformation Relations

$p^2 \propto (\varepsilon^2-1)$ $\qquad$ $q^2 \propto (\varepsilon_0-\varepsilon)^2$

Table II

Empirical Log$_{10}$ ft Ranges and Shape Factors

(E.P.E.), and T_o = rest mass energy of the beta.

Therefore, in the calculation of the beta spectrum due to any single isotope in any of the mass chains, the following steps are taken. Consider the hypothetical decay scheme in Fig. 4.

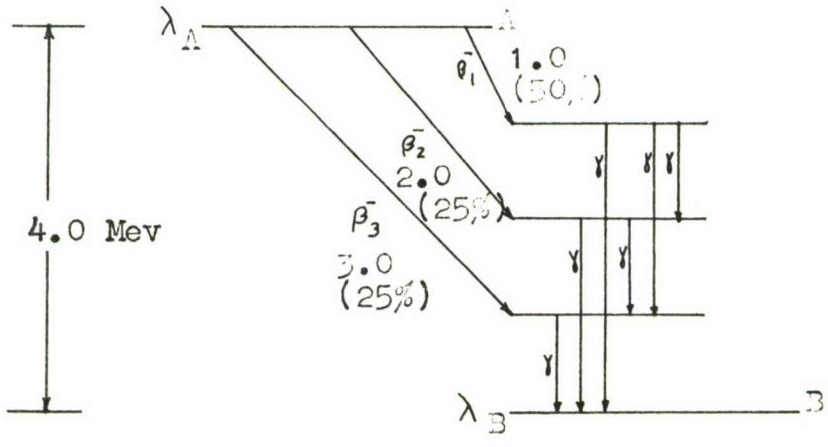

Fig. 4

Beta Decay Scheme

Consider first the beta decay characterized by an E.P.E. of 1.0 Mev. The first thing which is done is to compute the spectral shape by the Fermi theory. Then the log ft. value is computed, the appropriate shape factor determined, and the spectral shape is then modified by this shape factor. The same procedure is followed for the beta decays with E.P.E.'s of 2.0 and 3.0 Mev. When this is done, then the spectral shapes for these three betas are weighted according to the percent of the decays going by each route and summed. This sum is then normalized to give an area of one under the conglomerate spectral curve. This result is then referred to as the normalized spectral

shape for the decay of isotope A to isotope B.

Treatment of Isotopes with Unknown Decay Schemes

In the case in which only the identity of the initial and final isotopes are known, the respective half-life values are either known or estimated, and the scheme of beta decays by which isotope A decays to isotope B is not known, an approximation technique is employed. A quantity α,

$$\alpha = \frac{E_{\beta^-}}{E_T}$$

Where E_{β^-} = The total beta-antineutrino energy (E.P.E.)

E_T = The total disintegration energy

as defined above, is used in which the value of E_T is taken to be the difference in the atomic masses of isotopes A and B. Stovall (Ref 17:54) used two different empirical mass formulas, the Cameron (Ref 2:1021-32) and the Coryell (Ref 3:305-334). No attempt was made to show that one or the other of these mass formulas was superior to the other. A method to do this is presented in the section on the discussion of possible future work in the further refinement of the whole prediction technique. The Coryell mass formula was employed in the actual calculations since it yielded solutions which agreed well with the available experimental data.

For unknown decays, therefore, the value of the mass difference between the parent and daughter isotopes in the decay was multiplied by the value of α to determine the hypothetical beta E.P.E. By this method, the parent isotope is assumed to decay by one beta to an excited state of the daughter isotope. By assuming one value of α

for all isotopes with unknown decay schemes, it was illustrated that a value of $\alpha = 2/3$ matched the observed experimental data fairly well. This was the value of α used in the computer programs.

It was decided that one of the main objectives of this research would be the discovery of an alternate technique by which the value of α could be determined. The approaches investigated did not lead to any usable technique, although one showed sufficient promise of being of value to warrant further work. The approaches investigated are described below.

Alternate Approaches to the Determination of α

The first approach was to try to determine the variation of directly as a function of half life. This was accomplished by considering all of the known decays contained in the 83 decay chains of interest. For each of the known decays a value of α was determined. For example, consider the decay scheme illustrated in Fig. 4. In this case α would be determined as follows:

$$\alpha = \frac{(1.0)\ (.50) + (2.0)\ (.25) + (3.0)\ (.25)}{(4.0)} = \frac{1.75}{4}$$

$$\alpha = 0.4375 \qquad (24)$$

A total of sixty-two points were calculated and plotted on a graph of log $T_{\frac{1}{2}}$ vs. α. There was no observable correlation. It was therefore concluded that there was no simple relationship between the half-life and the value of α.

The second approach was to attempt to find a correlation between

the calculated values of α and the quantities $|Z-A_A|$ and $|Z-Z_P|$ for the known decay schemes and assume that they would be valid for the unknown decays. Plots were made in which all of the data was presented on a single sheet and also in which the data were presented on four sheets according to whether the decaying nuclide had values of Z (number of protons) and N (number of neutrons) which were odd-odd, odd-even, even-odd, or even-even. When the points were plotted, the distribution was random.

The third method used to try to determine more rigorously the value of α was suggested by a report prepared by James Griffin, of the Los Alamos Scientific Laboratory, of the delayed gammas from fission fragments (Ref 11). Although his method for theoretically synthesizing the fission process was not considered to be as rigorous as the method described in this paper and in Stovall's, the report contained plots of the total decay energy per fission per second and the gamma energy per fission per second from a time of approximately 1×10^{-3} seconds to 45 seconds after fission for the cases of several different fissioning nuclides. These theoretical plots compared well with the experimental points he used.

By computing the difference between the total decay energy and the gamma energy at the same times it was possible to determine the beta energy per fission per second at any time of interest in the time region covered by the original graphs. The desired result of this approach was to be the determination of the value of α as a function not of half-life but rather to determine values of α for a finite number of half-life groups. To do this it was necessary to divide the isotopes into six groups according to their half-life, as shown in

Table III.

TABLE III

Half-Life Grouping

Gp 1	α_1	∞ > T 1/2 $\geq$ 67 sec
Gp 2	α_2	67 > T 1/2 $\geq$ 21 sec
Gp 3	α_3	21 > T 1/2 $\geq$ 8 sec
Gp 4	α_4	8 > T 1/2 $\geq$ 4 sec
Gp 5	α_5	4 > T 1/2 $\geq$ 2 sec
Gp 6	α_6	2 > T 1/2 > 0

By summing the products of the activity (A_c), the end point energy (E.P.E.), and the appropriate value of α for all isotopes with unknown decay schemes present at several times of interest, and subtracting the contribution from those isotopes whose decay schemes are known, it should be possible to create an overdetermined set of equations with the values of the α's as the unknowns. From the graphs contained in the Griffin reports (Ref 11) the values of the beta energy, for various times, was computed and a small computer program was written to solve the overdetermined set of equations.

A set of thirteen equations, (Eqs. 12 through 24), was generated coinciding with thirteen values of the total beta energy calculated from Griffin's plots. Each equation represented the situation at one particular time. The times chosen were from 1 to 45 seconds after the instantaneous fission event. The set of equations is presented below. The values were calculated for one MT of fission and a common factor of 1×10^{-24} was applied to each term in order to reduce the size of the numbers.

$T_{(sec)}$	C_1	α_1	α_2	α_3	α_4	α_5	α_6		C_2	
1.:	3.42	+ 7.04	+ 3.28	+ 5.46	+ 26.1	+ 72.5	+ 54.4	=	136.	(12)
1.5:	3.45	+ 6.83	+ 3.43	+ 5.66	+ 25.7	+ 64.6	+ 42.5	=	103.	(13)
2.:	3.46	+ 6.60	+ 3.56	+ 5.81	+ 25.1	+ 57.4	+ 33.4	=	88.2	(14)
3.:	3.48	+ 6.11	+ 3.73	+ 6.00	+ 23.6	+ 44.8	+ 20.8	=	67.3	(15)
4.:	3.47	+ 5.61	+ 3.85	+ 6.08	+ 21.8	+ 34.7	+ 13.1	=	47.1	(16)
6.:	3.40	+ 4.65	+ 3.94	+ 5.99	+ 18.1	+ 20.6	+ 5.29	=	30.7	(17)
8.:	3.31	+ 3.79	+ 3.92	+ 5.71	+ 14.6	+ 12.1	+ 2.16	=	24.4	(18)
10.:	3.21	+ 3.07	+ 3.85	+ 5.34	+ 11.7	+ 7.12	+ .891	=	18.7	(19)
15.:	2.96	+ 1.81	+ 3.57	+ 4.33	+ 6.44	+ 1.95	+ .100	=	9.86	(20)
20.:	2.76	+ 1.08	+ 3.26	+ 3.43	+ 3.51	+ .564	+ .012	=	5.57	(21)
30.:	2.46	+ .456	+ 2.68	+ 2.11	+ 1.06	+ .061	+ ~.00	=	2.80	(22)
40.:	2.25	+ .257	+ 2.21	+ 1.30	+ .330	+ .011	+ ~.00	=	1.90	(23)
45.:	2.17	+ .213	+ 2.01	+ 1.03	+ .187	+ .007	+ ~.00	=	1.52	(24)

The term C_1 refers to the contribution resulting from the decays of the isotopes with known decay schemes. This term is computed as:

$$C_1 = \sum_{i=1}^{N} \left[Con_i \times \lambda_i \sum_{j=1}^{M} \left[Frac_{ij} \times E.P.E._{ij} \right] \right] \qquad (25)$$

Where Con_i = Concentration of isotope i at the time of interest

λ_i = Decay constant of isotope i

$Frac_{ij}$ = The fraction of isotope i which decays by a specific end point energy.

$E.P.E._{ij}$ = A beta end point energy by which isotope i decays.

N = The number of isotopes with known decay schemes

M = The number of different betas by which the isotope decays.

The term C_2 is the constant derived from Griffin's Report (Ref:11), and it is calculated as:

$$C_2 = D.E. - G.E. \tag{26}$$

Where

D.E. = Total decay energy from fission

G.E. = Total gamma energy from fission

The terms in columns α_1 through α_6 are computed as:

$$\alpha_j = \sum_{i=1}^{P} Con_{ij} \times M.D_{ij} \times \lambda_{ij} \tag{27}$$

Where α_j = The alpha value in half life group j

Con_{ij} = Concentration of isotope i in half life group j which decays in an unknown manner.

λ_{ij} = Decay constant of isotope i

$M.D._{ij}$ = The mass difference energy between isotope i and its decay product

In order to have a meaningful solution to the equations which result from condensing the two constants, in other words one in which the values of alpha range between zero and one, it is necessary that C_1 be smaller than C_2. This is the case in Eqs (12) through (22), however, in the last two equations the opposite is true. This occurrence forces the solutions to contain negative values for some of the alphas.

There are several possibilities which could account for this apparent discrepancy. The first is the data used to calculate C_2. The gamma energy data is reinforced by the experimental points with which it is compared; however, the total decay energy curve is not reinforced by experimental data. Upon trying to check on the reference given by Griffin for this curve it was discovered that the original work was presented in German and no translation was available in the time remaining for the research.

The second possible explanation for the discrepancy is based on the half-life prediction method. If this prediction method, which was originally done by Bolles and Ballou (Ref 1), predicts half-lives which are too short, it would cause the concentration of those isotopes which are included in C_1 to be higher than it should be. By increasing this concentration, the value of C_1 as calculated by Eq(25) would increase and overwhelm the value of C_2.

The lack of computer time available and the lack of time remaining in the research period precluded doing any further work in this area. In view of the difficulties encountered in this effort, it may be that the solution to this problem may have to await further experimental evidence.

V. Spectrum Calculations

Method of Solution

As explained in Chapter II, the initial concentration of the fission products from any of the types of fission considered is computed and put on punched cards. Then the normalized spectral shapes for all of the isotopic decays contained in all of the eighty-three decay chains are computed and stored on magnetic tape. These two data records are then combined by a program which puts this data on another magnetic tape which compiles the explicit data needed to solve problems involving any of the four types of fission seperately. Therefore, in order to solve a problem it is only necessary to use this data tape as input into the program, described in Chapter III, which contains the exact solutions to the differential equations resulting from the radioactive decay law. By these means it is no longer necessary to compute the isotopic yields and the spectral shapes each and every time a problem is to be solved as was necessary using Stovall's programming arrangement (Ref 17). This reduces the running time necessary on the computer from approximately an hour for a typical problem to twenty minutes to prepare the composite data tape one time only and thereafter only six minutes per problem. This time advantage becomes much greater if the time after burst at which the spectrum is desired is much longer than five or ten minutes. This is true because in the previous method using the NDA subroutine (Ref 17:34-36) the iterative solution had to start at zero time and proceed to the time of interest by small incremental steps while the present program uses the exact solutions to the differential

equations with the time of interest used as a simple variable.

A schematic presentation of the data used and the means by which the spectrum is calculated is presented in Fig. 5.

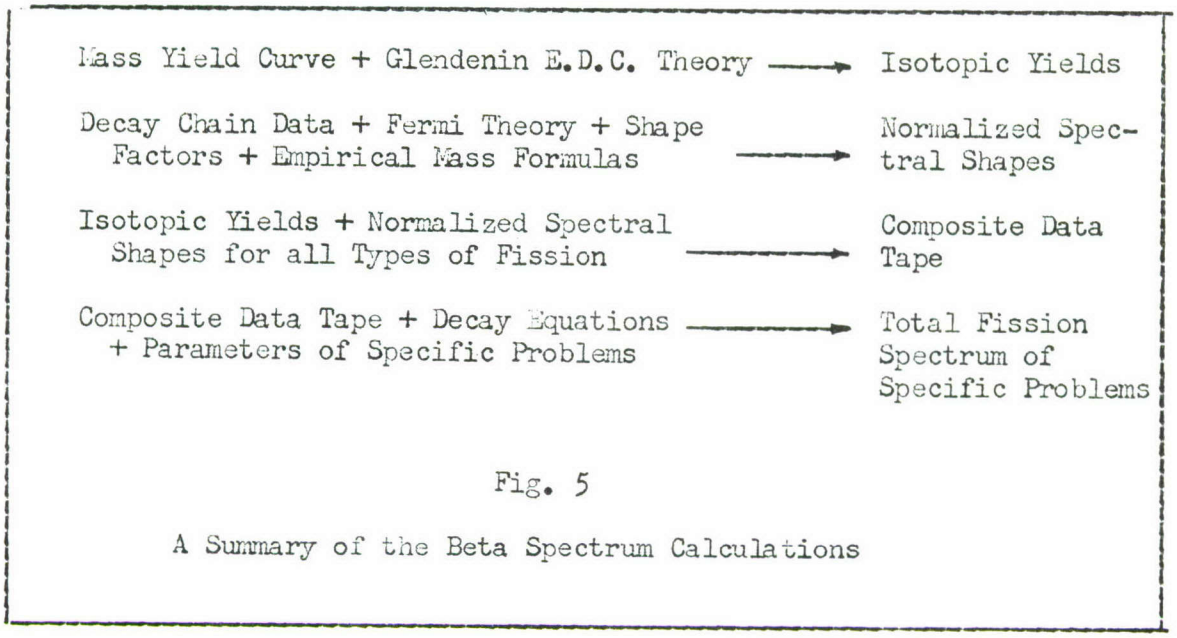

Fig. 5

A Summary of the Beta Spectrum Calculations

VI. Results and Conclusions

Results

Predictions of the time dependant beta spectrum at various times for the four cases of fission are presented in Figs. 6, 7, 8, and 9. At the present time, predictions of the spectrum resulting from high altitude detonations are based on the steady-state fission spectrum of Uranium 235 (Ref 20). The shape of this spectrum is shown on Fig 6. At the early times, it represents fairly well the high energy portion of the spectrum, but grossly overestimates the low energy portion. At late times it does a fairly accurate job of representing the low and medium energy portions of the spectrum but leads to an overestimation of the high energy portion. Therefore, depending on the time after fission when the beta particles become trapped by the magnetic field, the predicted spectrum will be in error at either the low or high end.

In order for any prediction to be useful, it is most desirable that its result should compare favorably with an independent source. In this case the independent source is the experimentally determined results of West (Ref 19). The graphic comparisons are presented in Figs. 10 through 16, and are discussed below.

Conclusions

In comparing the predictions of the model with the experimental results, it is very important to consider exactly how the two results were obtained. The method by which the experimental data was obtained is very poorly described. In a telephone conversation with West made in the Fall of 1964 by Stovall, it was discovered that the data

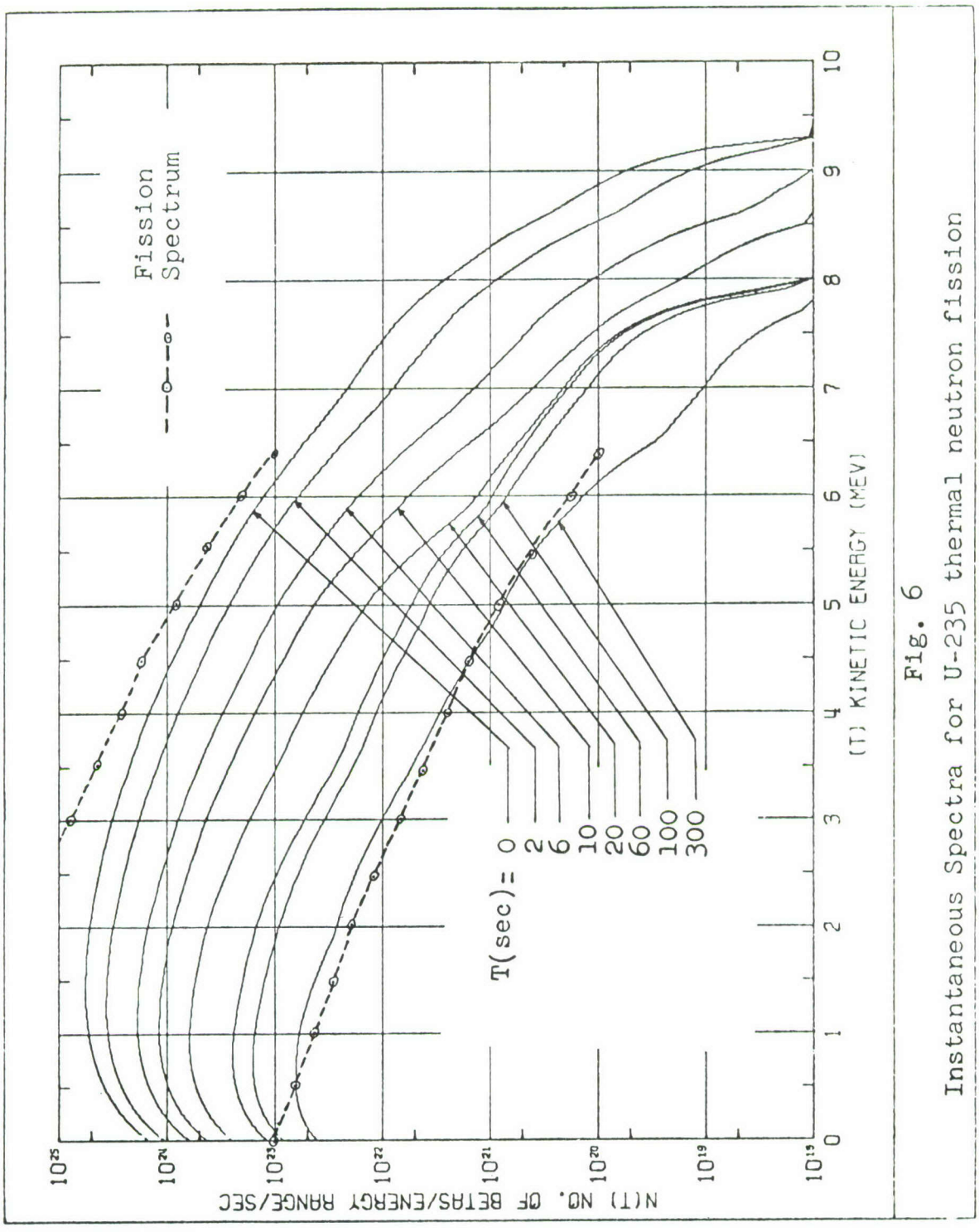

Fig. 6

Instantaneous Spectra for U-235 thermal neutron fission

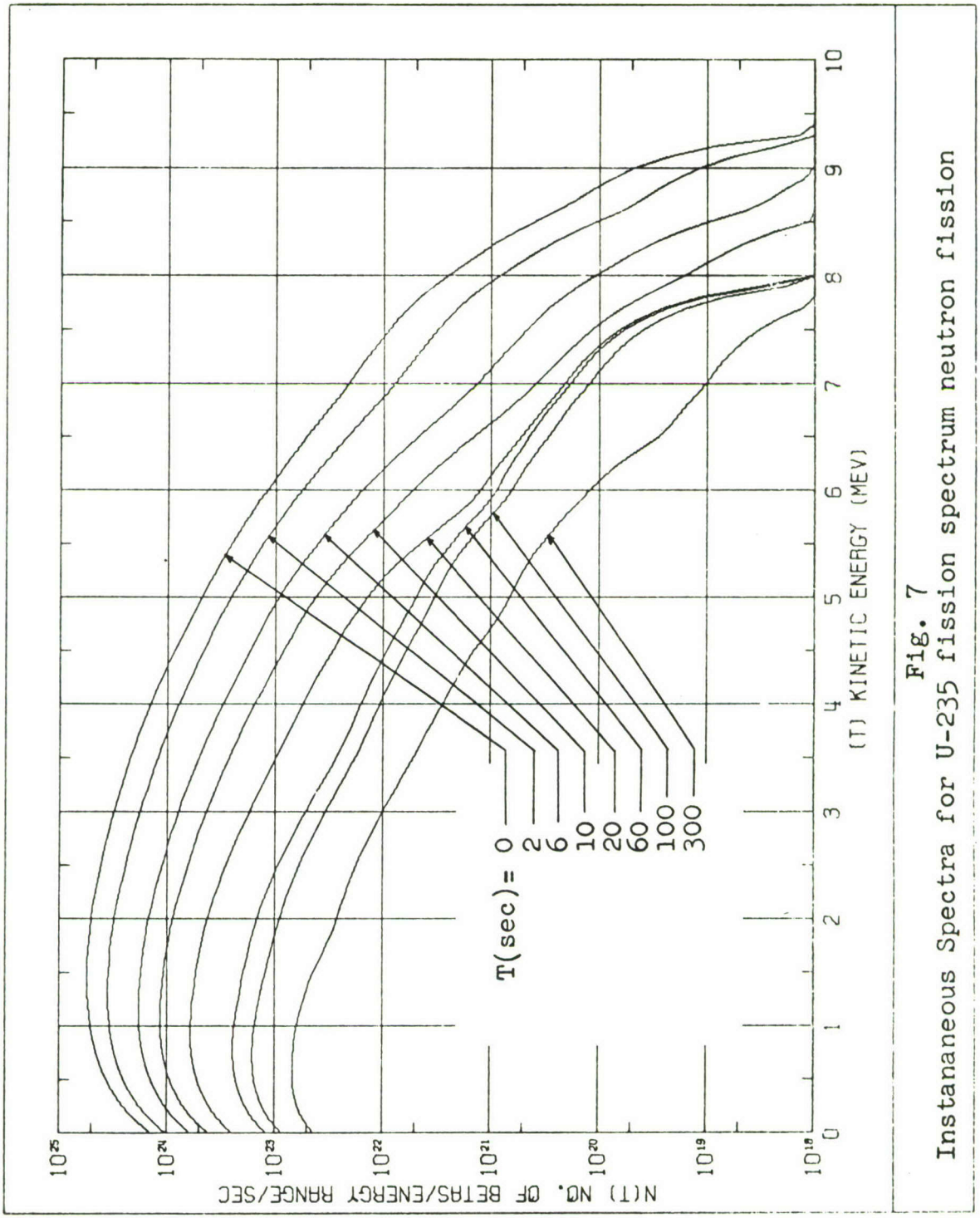

Fig. 7
Instananeous Spectra for U-235 fission spectrum neutron fission

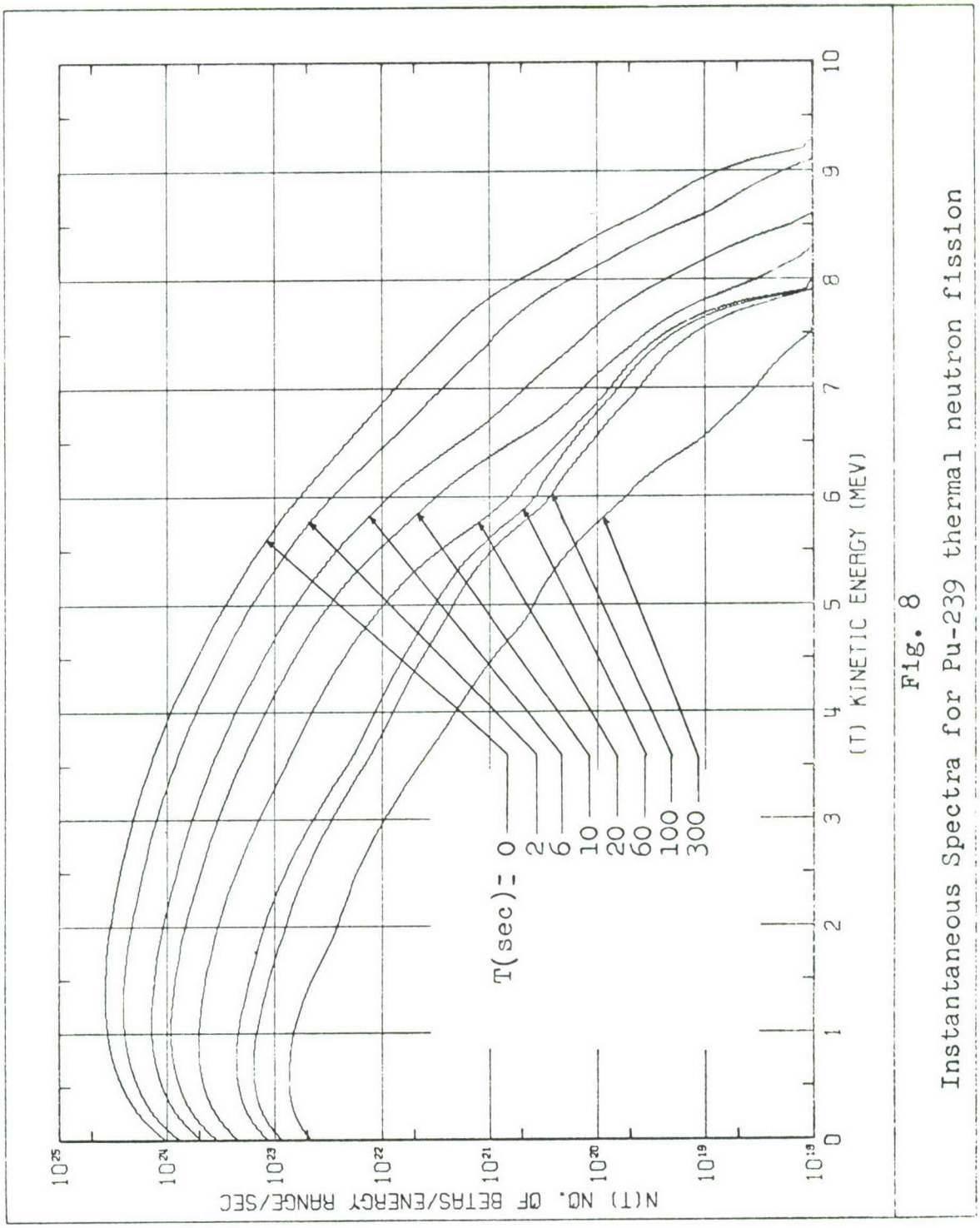

Fig. 8

Instantaneous Spectra for Pu-239 thermal neutron fission

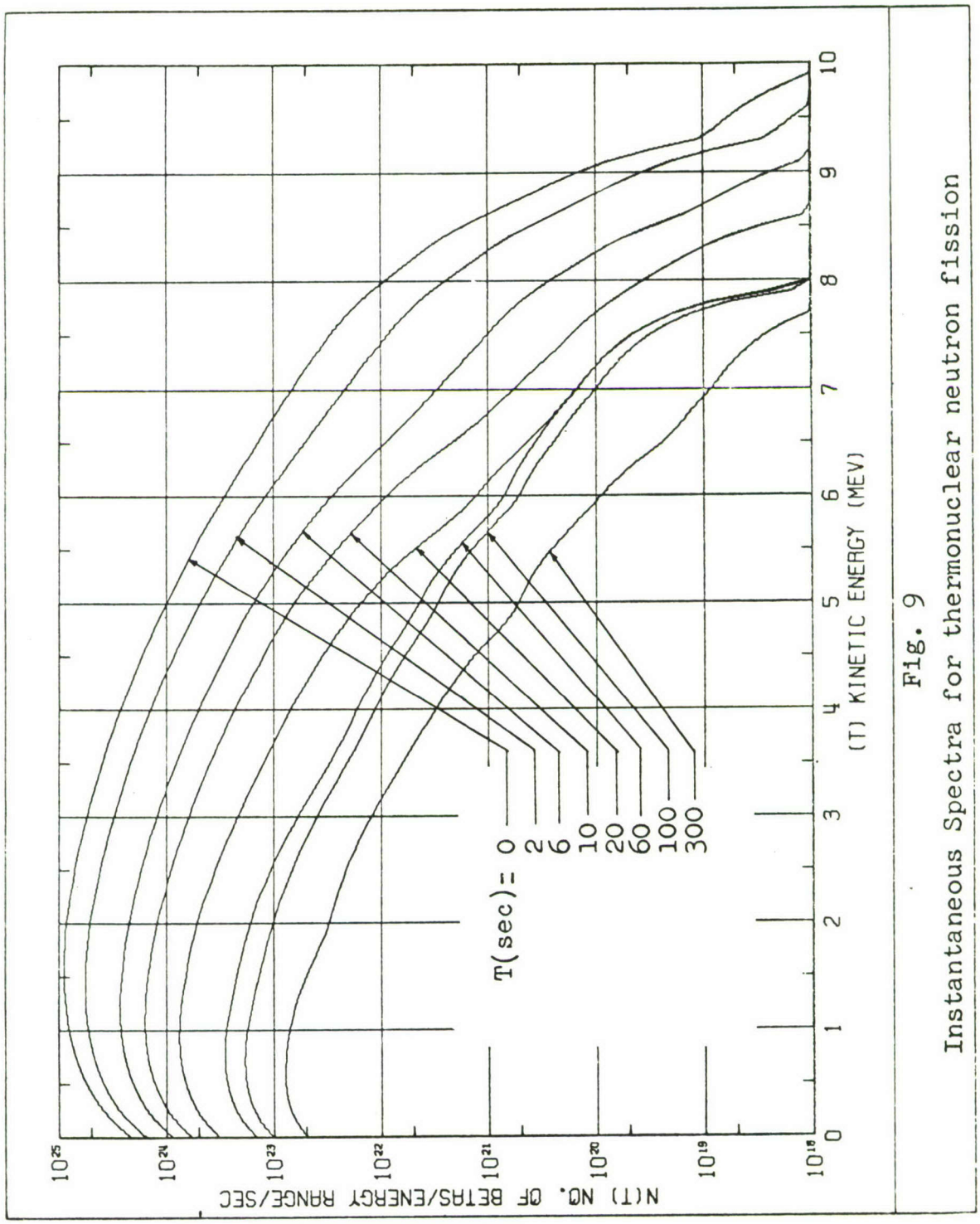

Fig. 9

Instantaneous Spectra for thermonuclear neutron fission

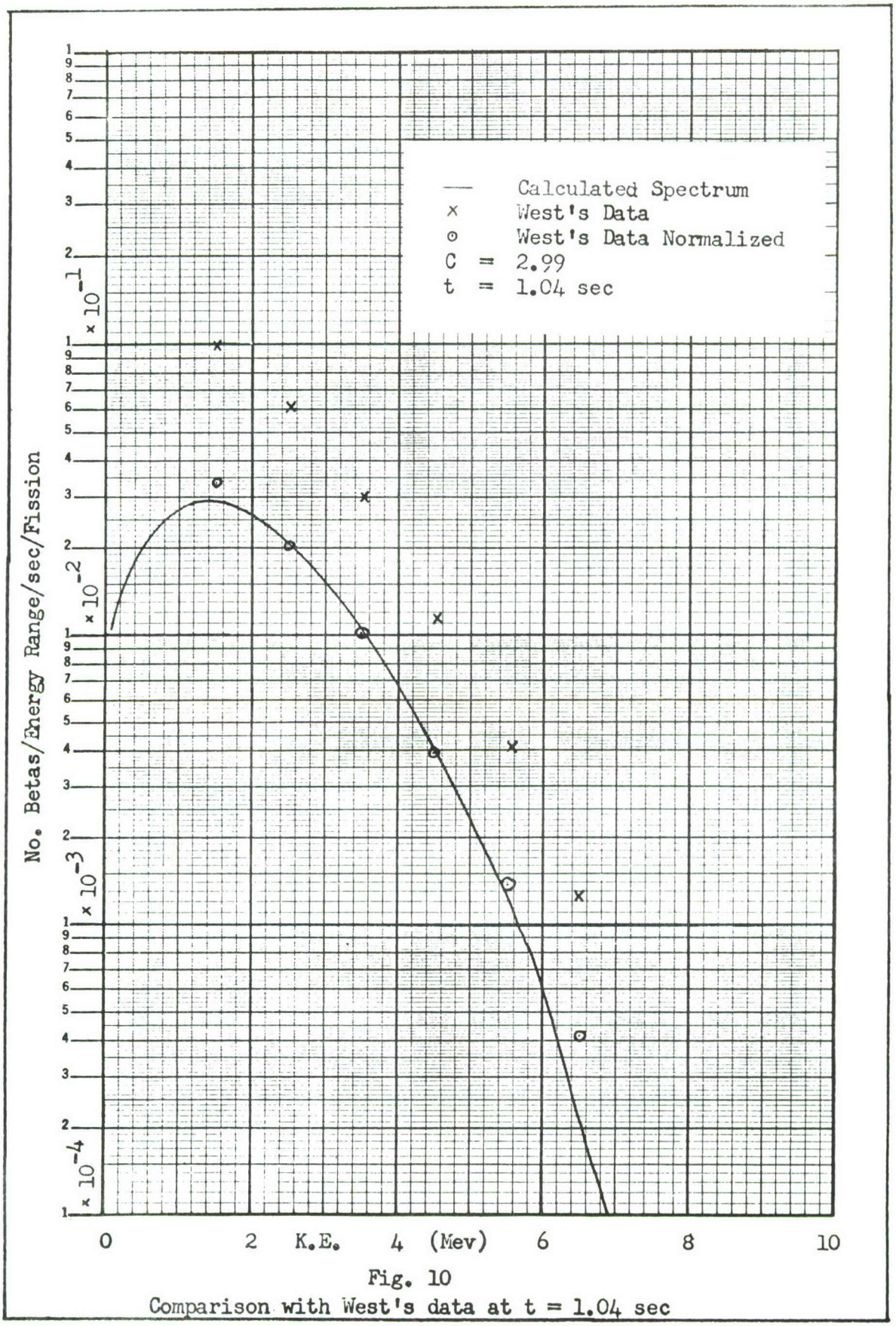

Fig. 10
Comparison with West's data at t = 1.04 sec

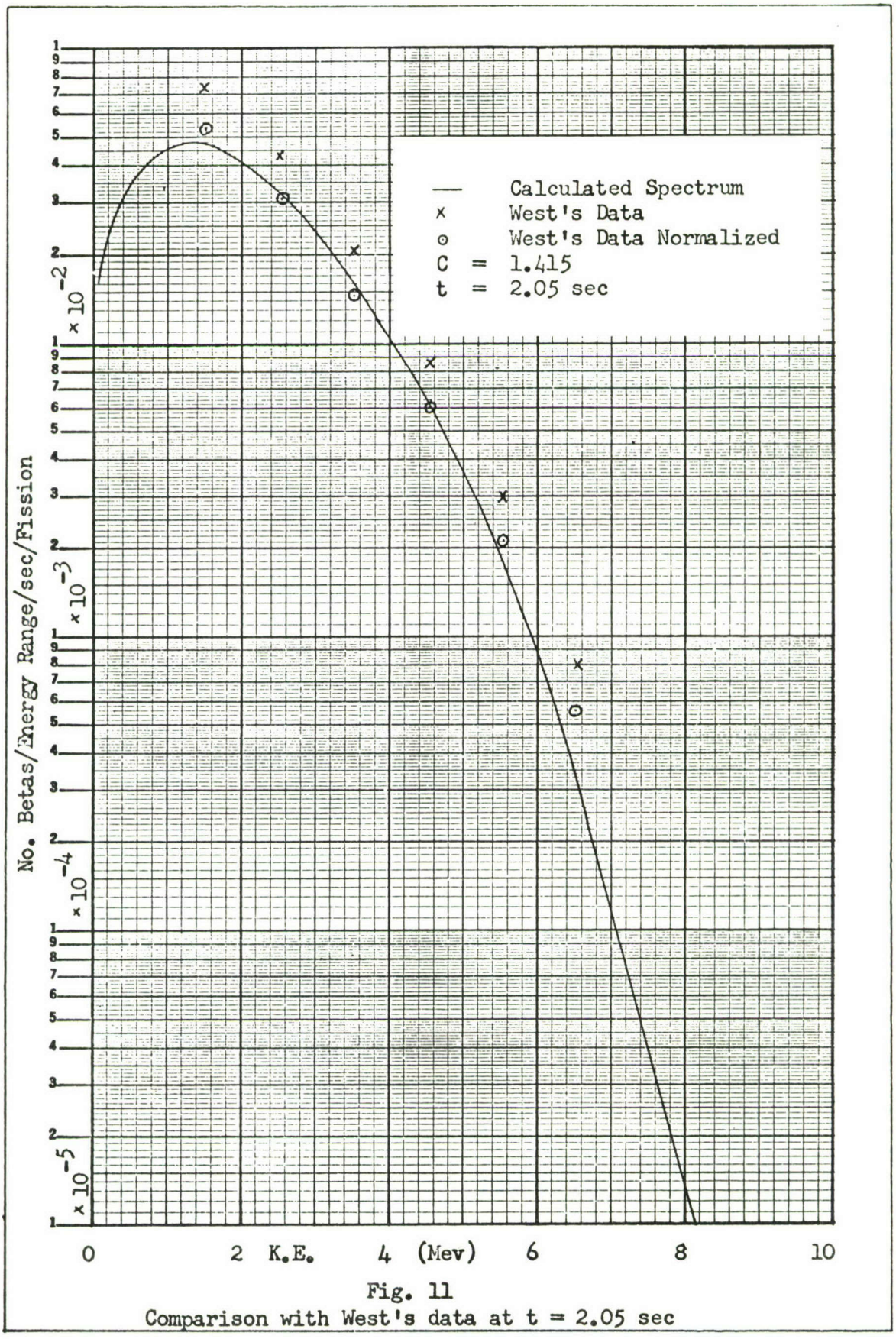

Fig. 11
Comparison with West's data at t = 2.05 sec

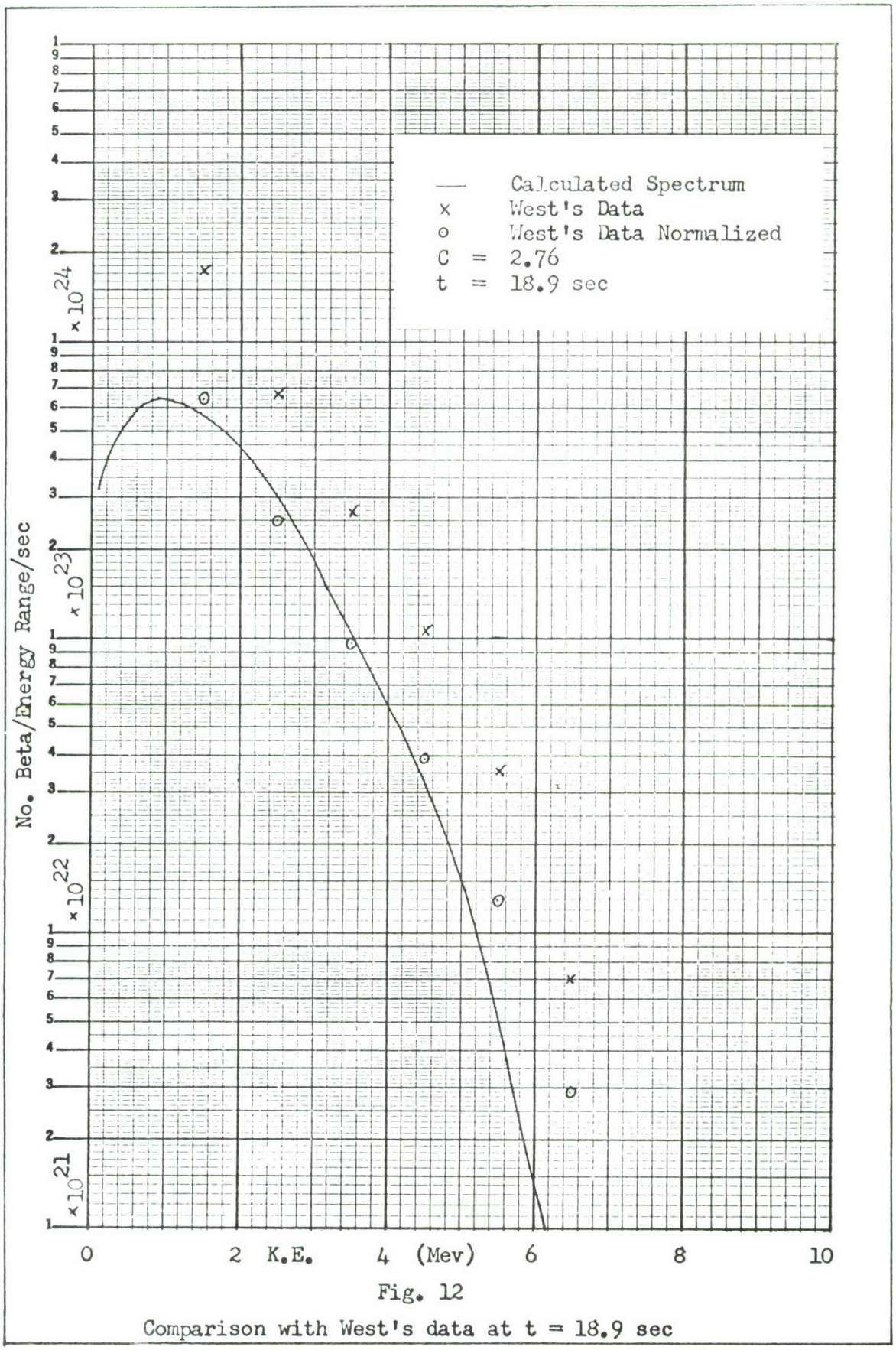

Fig. 12

Comparison with West's data at t = 18.9 sec

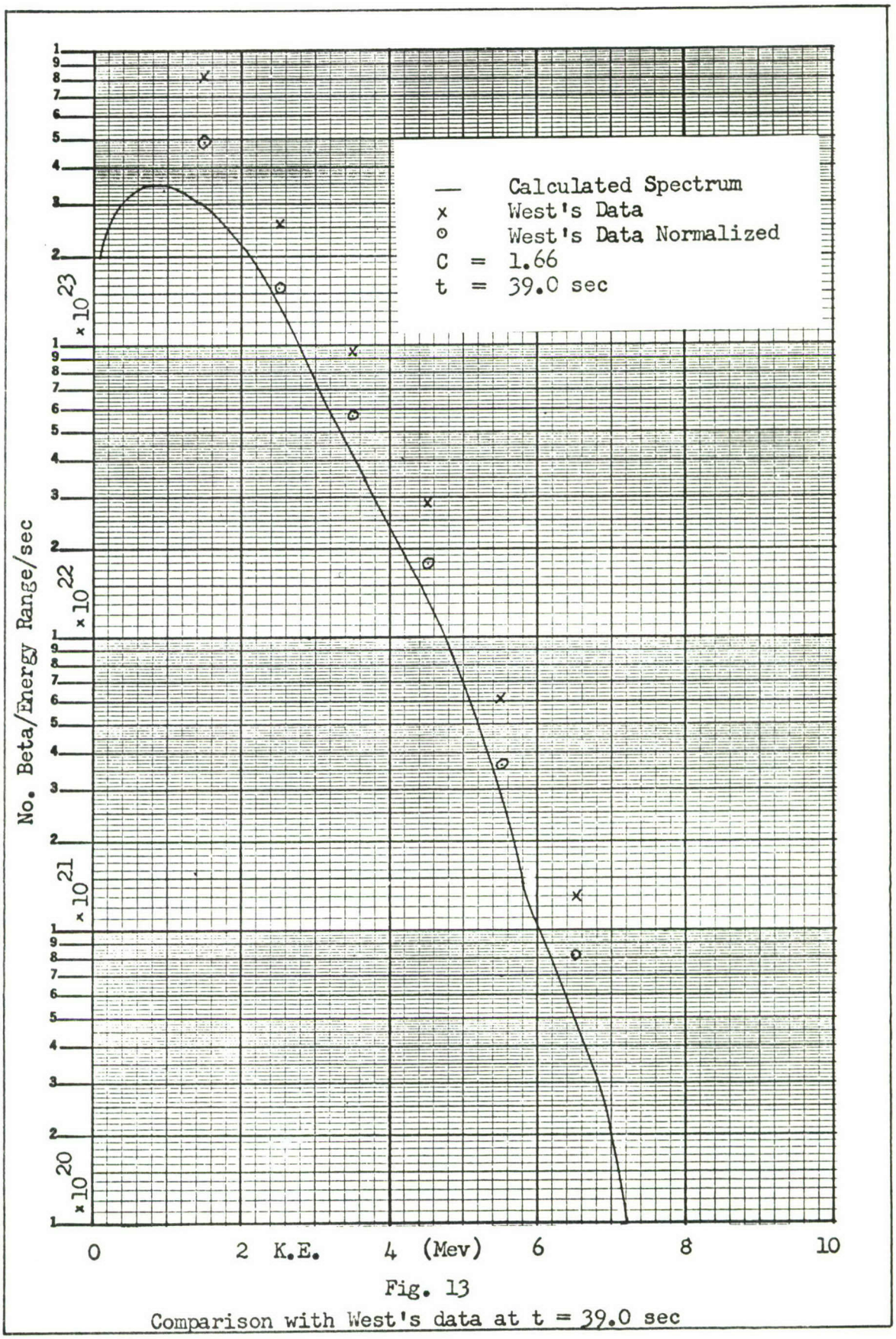

Fig. 13

Comparison with West's data at t = 39.0 sec

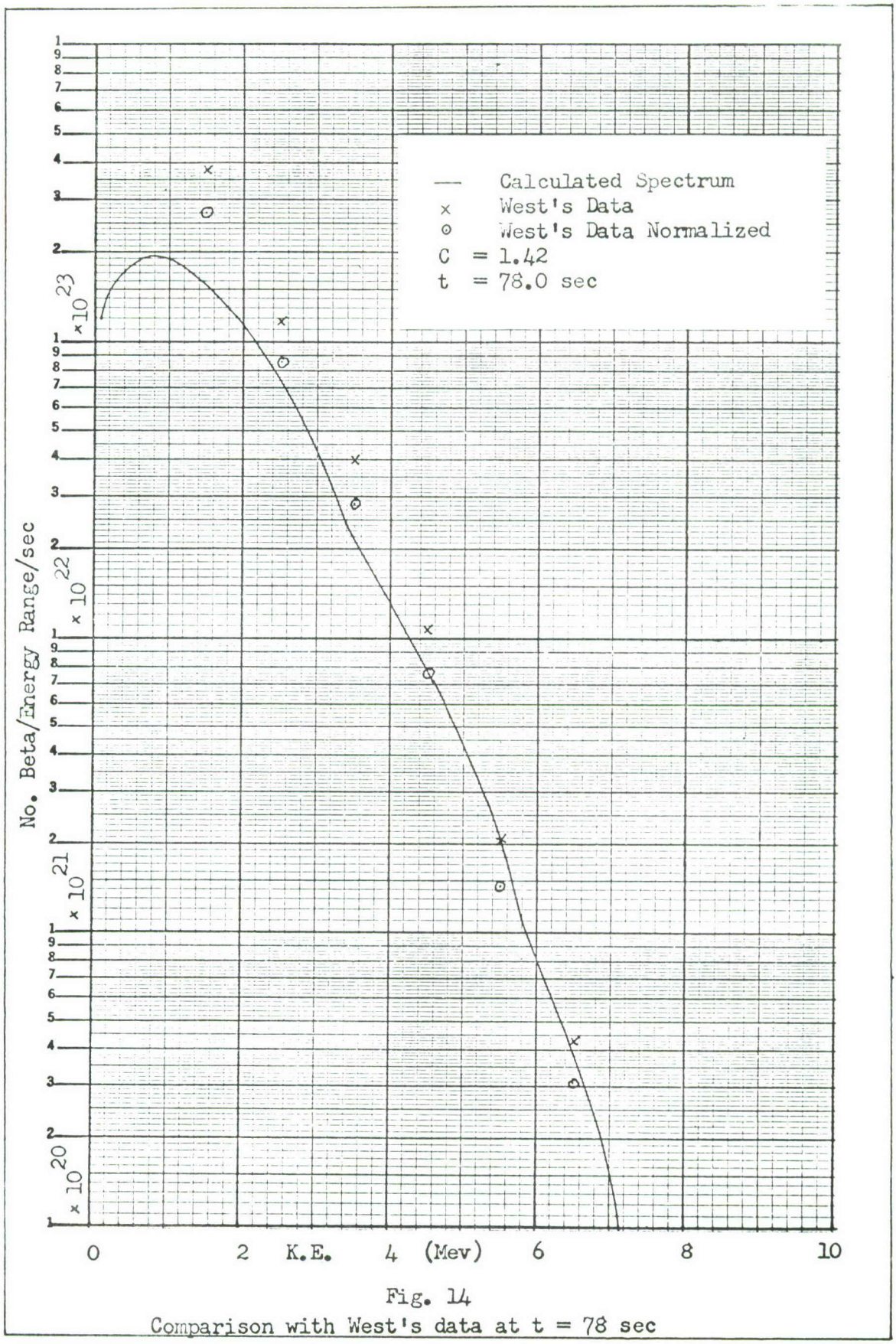

Fig. 14
Comparison with West's data at t = 78 sec

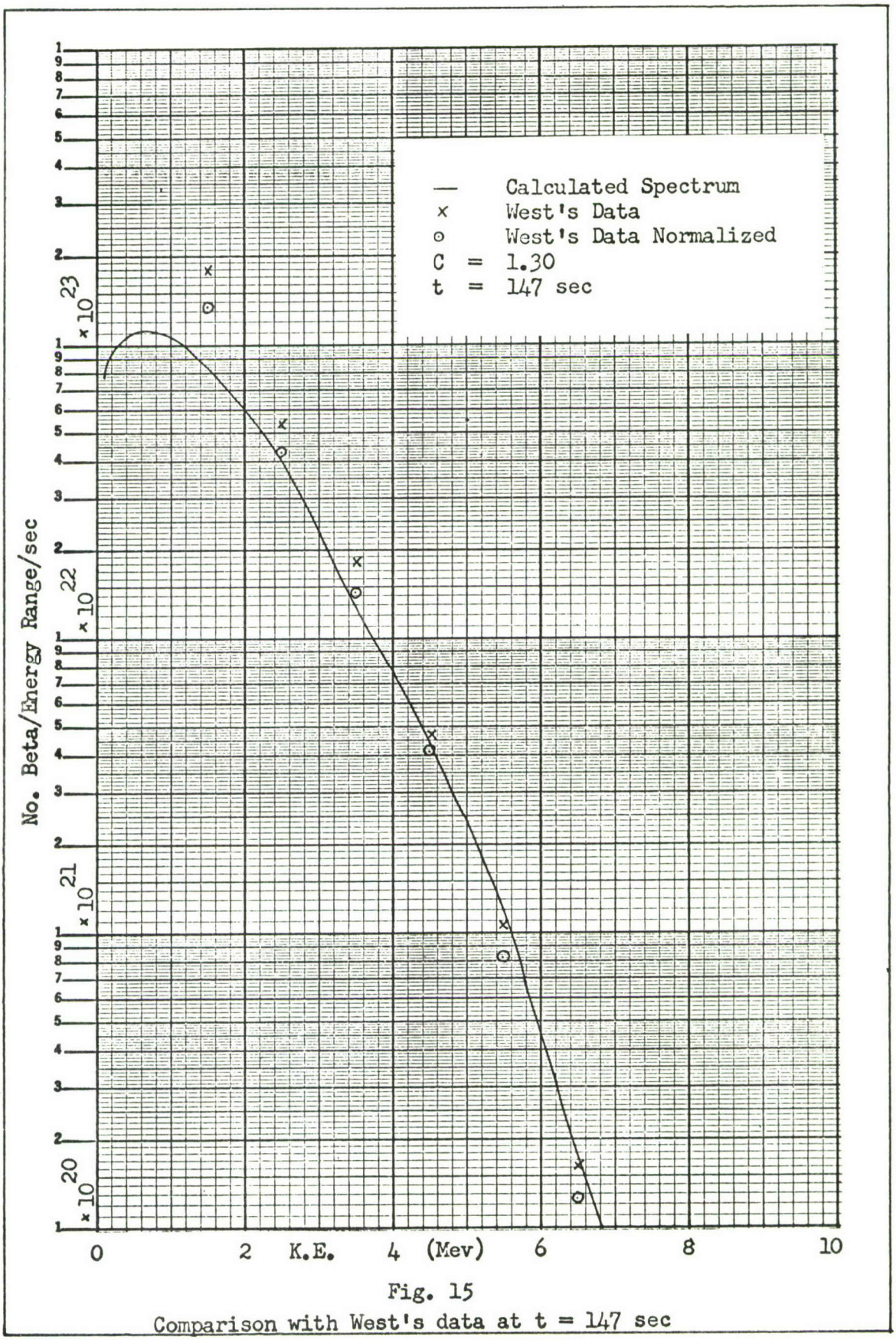

Fig. 15

Comparison with West's data at t = 147 sec

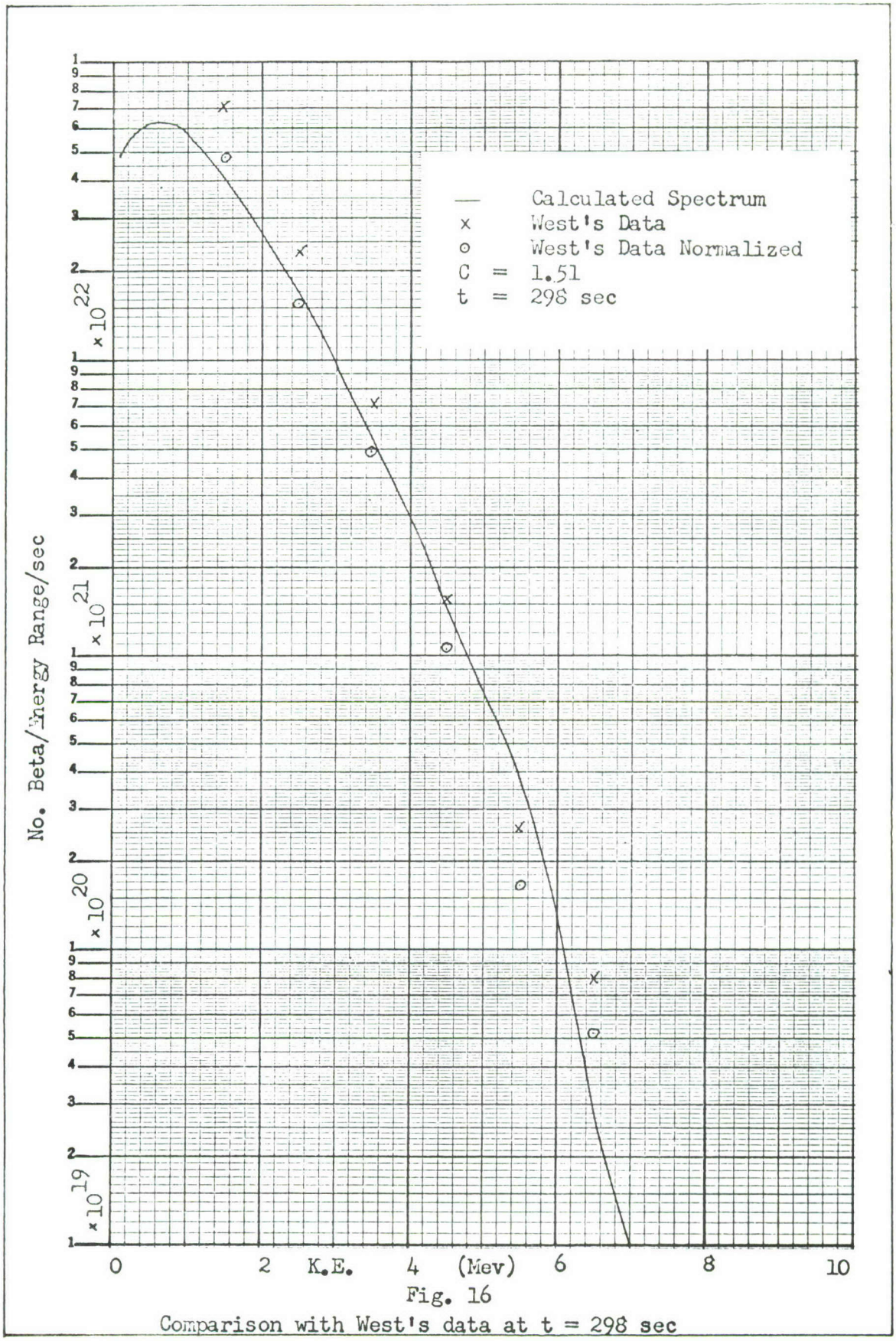

Fig. 16

Comparison with West's data at t = 298 sec

reported for 1.04 seconds was obtained by irradiating the sample for 1/2 second, waiting for 1/2 second and then counting over a 1/2 second period. Likewise the second set of data was obtained with a one second irradiation, one second wait, and a one second counting period. The exact method by which the remaining sets of data were obtained was not made clear during the conversation. In order to synthesize this experimental approach with the prediction method, it was necessary to make some assumptions. Since the prediction method assumes instantaneous formation, it was assumed that this occurred at the middle of the exposure time. A series of instantaneous spectra were calculated at times ranging from 3/4 to 1 1/4 seconds after formation. These instantaneous spectra were integrated using the trapezoidal method. The results are presented in Figure 10. The areas under the predicted points and under West's points were computed using the trapezoidal rule and West's points were adjusted to yield the same area. The factor by which West's points had to be divided was designated as C. In the first instance the value of C was 2.99. The same procedure was followed for the second data set yielding a value of C of 1.42.

When the exposure or measuring period is small compared to the waiting period, the data sets should agree well with the instantaneous spectrum. This hypothesis was tested by plotting the instantaneous spectra at times used by West against the experimental points. Once again the value of C was computed. For the times of 298, 147, and 78 seconds the values of C ranged between 1.30 and 1.51, a consistent difference between theoretical and experimental results. At 39 seconds the value of C = 1.66 which tended to suggest that the

hypothesis was not valid at this time. The comparison at 18.9 seconds supported this belief since the value of C = 2.76.

It is encouraging to note the close agreement between the predicted spectra and the adjusted experimental points. In order to make a more thorough analysis of the comparisons it is imperative that the exact method by which the data points were obtained be determined. Unfortunately West never published a full report of his work, only an abstract. Further suggested areas of work which could improve the making of comparisons are presented in the section on recommended areas for further effort.

Applications of the Results

In addition to the academic knowledge of the beta spectrum as a function of time after fission, the predictor method has an important practical usefulness as a research tool.

In recent years much has been learned about the phenomenon of trapped radiation in the area of outer space near the earth. The area in which this trapped radiation plays an important role is also an area in which many scientific and military manned and unmanned satellites are now traversing and are programmed to be using in the future. While the beta particles, which may be trapped as a result of a high altitude or near earth space nuclear or thermonuclear detonation, will not themselves constitute an appreciable direct hazard to satellites traversing this region, their interaction with the structural materials of the shell of the satellite can result in an appreciable X-ray dose as a result of bremsstrahlung reactions.

The predictor model described in this report can be used, with

minor changes in the output section, to supply data which can be used to further other research studies in the field of nuclear weapon effects. One problem to which this method can address itself concerns the study of fission fallout following a nuclear or thermonuclear detonation. In the study of this problem one of the basic items of information necessary is the composition of the nuclear debris at the time that condensation begins. By use of the predictor program, the concentrations of each of the isotopes formed directly in fission and their subsequent decay products can be determined. By a knowledge of the yield of the device, the temperature at which different elements solidify, and the time history of the temperature of the fireball, it should be possible to determine the concentration of each of the radioisotopes at the time of solidification and therefore to determine the composition of the fallout at its start.

Recommended Areas for Further Effort

Although the predictor model as presented in this report gives the beta spectrum as a function of time, there are still many areas in which it can be substantially improved in terms of accuracy and flexibility.

The first area is the continuing effort to update the input data. As more and more decay schemes and half-lives are inserted into the program to replace unknown decay schemes and predicted half-lives, less and less importance will have to be placed on the empirical mass formulas and on the assumed value of α. In conjunction with this is the incorporation of new data which may show that certain isotopes do not appear in the decay schemes shown in Appendix A. It would also

be of great assistance if some theoretical method could be developed to predict the fraction of initial yield which is accounted for by each member of the isomeric pairs. It was shown by Porile (Ref 16) that in the formation of such isomeric pairs the member with the higher spin state is usually formed in a greater amount. The determination of the ratio of formation, however, has not been refined to such a state, and complete experimental evidence has not been sufficiently obtained to justify discarding the 50-50 hypothesis. Some recent papers (Ref 5 and Ref 13) also indicate that the 50-50 split used in this paper is incorrect.

The second area concerns the choosing of a single empirical mass formula for use with those very short half-life isotopes for which no decay scheme is now known, and for which no decay scheme will probably be found. A comparison could be obtained, and a choice made between the Cameron and Coryell formulas in the following manner.

A spectrum could be obtained for a time of interest at which the activity of those isotopes with unknown decay schemes is very small. Since practically all of the isotopes which fall into this category have short half-lives, this would mean picking a time of interest of perhaps ten minutes. Next a similar spectrum could be obtained except that in this case all of the isotopes will be considered to have unknown decay schemes and the empirical mass difference determined by one of the mass formulas should be multiplied by the value of

in order to determine the E.P.E. and therefore to determine its spectrum. This procedure should be followed using each of the mass formulas and the results compared with the first spectrum obtained

using the known decay schemes. A comparison of this type could give a sound basis by which one of the mass formulas could be eliminated in future work in this field.

The third area of future work is in the area of making the predictor more flexible. As it now stands, the source is considered to be of an instantaneous nature. This is of course the correct approach to take when considering a nuclear or thermonuclear weapon detonation. However, since the validity of this model is ultimately based upon its comparison with the available experimental data, it is not unreasonable to attempt to adapt the model so that it duplicates, as closely as possible, the conditions under which the experimental evidence was obtained. In the experimental cases the fissioning material was not exposed to an instantaneous burst of neutrons but rather a steady source of neutrons. This means that the fission occurred at an approximately constant rate over a finite time interval. In the comparison which was made with West's data (Ref 19) this exposure time was one-half of a second. In this case the assumption of instantaneous formation does not appear to be gross; however, in some of the later measurements this exposure time became long enough so that an appreciable amount of decay took place, thereby making the assumption that the decay started with the isotopic concentrations typical of instantaneous formation in error. To correct this deficiency, it is recommended that the differential equations of the radioactive decay law be solved considering a constant rate production term. This will have the added advantage of allowing the predictor method to also handle the problem of fission product inventory in a nuclear reactor.

The equations which must be solved are of the form:

$$\frac{dN_i}{dt} = -\lambda_i N_i + R_i \tag{28}$$

The solution for the one and two member chains are shown in Eqs (29) and (30).

$$N_1 = \frac{R_1}{\lambda_1} (1 - e^{-\lambda_1 t}) \tag{29}$$

$$N_2 = \frac{R_1}{\lambda_2} \left(1 - \frac{\lambda_2 e^{-\lambda_1 t}}{(\lambda_2 - \lambda_1)} - \frac{\lambda_1 e^{-\lambda_2 t}}{(\lambda_1 - \lambda_2)}\right) + \frac{R_2}{\lambda_2} (1 - e^{-\lambda_2 t}) \tag{30}$$

As was the case in the solutions of the decay equations considering instantaneous formation, the solutions become very long very quickly.

The fourth area of recommended effort concerns the problem of computing the integrated beta spectrum. Solution of this problem would also add to the flexibility of the program. As in the example of the West data, the experimental evidence available as to the beta spectrum is not measured instantaneously but rather over a finite time interval. In order to simulate this for purposes of comparison, the present method calculates the instantaneous spectra at many times during this period and sums them. By integrating the exact solutions to the differential equations, an admittedly tedious but relatively simple task, it would therefore, be possible to duplicate the exact

conditions under which the experimental evidence was obtained.

After the recommended improvements discussed above are incorporated into the predictor model, the next logical step would be to attempt to combine this program with existing programs which predict the extent to which the beta particles can be expected to be trapped by the earth's magnetic field. The results of such a predictor model could then be used in other programs which compute the radiation dosage, dose rate, and physiological or physical effects of the bremsstrahlung radiation on the equipment and/or personnel in the satellite.

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Appendix A

Chain Yield

Table IV Mass Chain Yields/10^4 fissions

A	U-235th	U-235 f.sp.	Pu-239th	T. N.
77	0.8249	4.8235	0.5223	1.05
78	2.0098	7.6204	1.1745	2.02
79	5.5622	11.9882	2.4580	3.66
80	9.4156	18.7126	4.8151	6.97
81	14.1037	30.6543	9.5527	10.51
82	24.1998	42.7472	16.5159	22.42
83	54.2830	77.2805	29.0089	50.12
84	100.5002	91.5459	46.7012	78.21
85	131.0524	121.9460	54.0153	110.3
86	201.0324	172.7850	75.8235	145.3
87	249.0276	250.7498	90.8349	186.5
88	356.8627	343.5819	140.3722	226.7
89	471.7097	421.6817	171.1613	268.0
90	572.0288	507.3745	223.6839	308.8
91	582.5530	552.4071	289.3741	366.8
92	597.6441	581.9531	308.6625	411.0
93	643.5574	609.3539	395.6414	470.9
94	638.5754	619.5415	445.8155	504.0
95	625.7403	627.0754	499.3532	510.4
96	625.5302	635.8294	514.2104	521.7
97	608.0432	614.4070	558.6327	532.4
98	578.6314	613.3496	581.2419	540.2

Table IV (con't)

A	U-235th	U-235 f.sp.	Pu-239th	T. N.
99	606.6487	619.9075	609.0357	547.9
100	630.2021	609.5064	706.0404	542.5
101	502.6711	595.2214	587.1927	532.2
102	411.8747	498.5613	596.4574	511.1
103	297.8291	293.8295	559.8567	490.4
104	180.0420	170.8505	588.1182	433.2
105	90.4322	101.6695	518.0615	389.2
106	39.2247	61.0513	454.1944	335.1
107	19.0766	35.5966	343.8860	275.6
108	7.0038	24.4014	255.2732	220.8
109	3.0077	14.8411	138.3521	155.5
110	1.7777	10.9786	74.6542	79.37
111	1.8092	7.2152	22.9635	42.17
112	1.0008	4.1761	11.9365	29.99
113	1.6046	4.0181	12.0233	26.03
114	1.3736	3.9115	5.4930	26.02
115	1.0990	3.8252	4.0780	25.02
116	1.8525	3.7743	3.7349	24.90
117	1.1002	3.7600	3.5823	24.55
118	1.4236	3.7812	3.5265	24.09
119	1.4176	3.8413	3.5885	24.53
120	1.4091	3.9397	3.7287	24.83
121	1.4061	4.0615	4.3421	25.03
122	1.5075	6.2118	4.7449	25.23

Table IV (con't)

A	U-235th	U-235 f.sp.	Pu-239th	T. N.
123	1.6146	9.4494	5.6251	25.96
124	1.7807	13.1158	6.9888	30.09
125	2.1619	20.9510	9.4606	42.12
126	3.1930	34.3669	16.3245	79.04
127	13.0052	47.2269	38.4008	155.6
128	37.4850	71.1708	84.5268	220.9
129	80.2351	126.9981	169.0715	277.9
130	198.8415	213.6048	268.7451	334.2
131	293.1623	366.3871	375.8085	389.9
132	438.0352	503.8890	520.7085	434.5
133	658.0632	553.6068	684.5557	491.0
134	803.3213	590.6258	744.2233	512.3
135	646.9588	614.6103	708.4287	531.8
136	641.2265	639.7539	657.9431	542.5
137	614.9160	640.8418	659.2099	545.6
138	573.6294	629.9629	628.5799	541.6
139	652.4180	614.5107	584.1377	532.4
140	642.5670	594.2453	559.7373	522.1
141	643.8075	585.0948	530.9185	509.8
142	611.8407	562.0456	497.8704	497.8
143	602.7411	535.2041	454.2741	472.5
144	557.5730	508.7896	388.4964	410.7
145	395.3681	406.6189	309.1452	363.6
146	308.2233	322.3120	259.5084	308.8

Table IV (con't)

A	U-235th	U-235 f.sp.	Pu-239th	T.N.
147	237.1949	234.3551	205.9887	267.4
148	171.0584	181.0381	169.1711	227.3
149	112.9712	111.8032	131.3564	186.9
150	63.6805	78.8216	99.6577	145.6
151	44.2537	53.3984	79.7632	110.6
152	27.8603	35.6057	61.3763	78.06
153	17.1238	21.3461	36.8504	49.67
154	7.6331	13.4208	28.9538	22.49
155	3.2602	7.1121	22.9694	10.48
156	1.4096	2.5408	10.9796	6.98
157	0.7729	1.7284	7.5613	3.68
158	0.2015	0.8382	4.2266	2.02
159	0.1047	0.3461	2.0957	1.06

From Ref 18:17-37

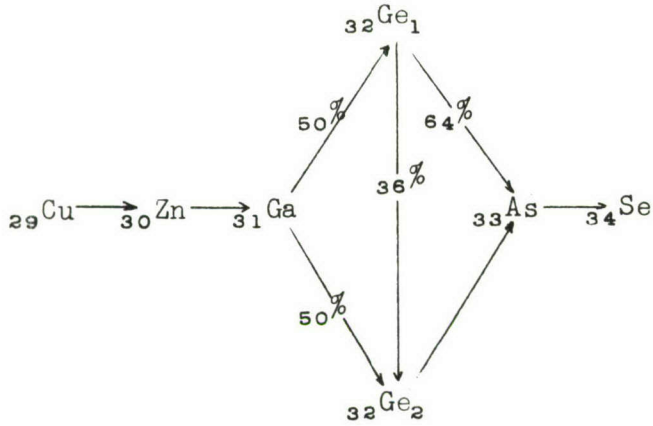
Ref 6:7-15

APPENDIX B

Nuclear Decay Schemes

This appendix contains the information necessary to describe the paths by which the isotopes formed in fission decay and the beta decay schemes for all of the known decays. The half-lives for the isotopes are given in seconds with those isotopes whose half-lives are only estimates identified by an asterisk. As described in Chapter III, the mass differences as computed by the Cameron and Coryell formulas are included for use in computing the spectral shapes for those isotopes with undetermined beta decay schemes. In the description of the beta decay schemes the first number given is the E.P.E., in Mev, of the beta particle and the number in parenthesis is the percent of the total number of isotopes which decay by emitting beta particles with this E.P.E. In the decay diagrams, the vertical arrow connecting two isotopes with the same atomic number indicates an isomeric transition and this is indicated by the letters IT in the descriptions of the decay schemes. When branching occurs in the decay diagrams, the percentage going by each route is indicated by the small number close to the decay path to which it applies. Where no percentage is given it is implied to be 100 percent.

77.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Cu	1.5 *	Cu ⟶ Zn	10.5	9.63
Zn	3.5 *	Zn ⟶ Ga	8.36	7.92
Ga	15 *	Ga ⟶ Ge	5.49	5.01
Ge_1	54	Ge ⟶ As	3.11	3.30
Ge_2	3.96×10^4	As ⟶ Se	.741	.593
As	1.4×10^5			
Se_2	stable			

Decay Schemes:

Cu ⟶ Zn	Undetermined
Zn ⟶ Ga	Undetermined
Ga ⟶ Ge_1	Undetermined (50%)
Ga ⟶ Ge_2	Undetermined (50%)
Ge_1 ⟶ As	2.7(16%), 2.9(48%), IT (36%)
Ge_2 ⟶ As	.38(3%), .76(15%), 1.2(11%), 1.3(4%), 1.56(24%), 2.12(29%), 2.27(14%)
As ⟶ Se	.16(2.8%), .438(2.7%), .684(94.4%)

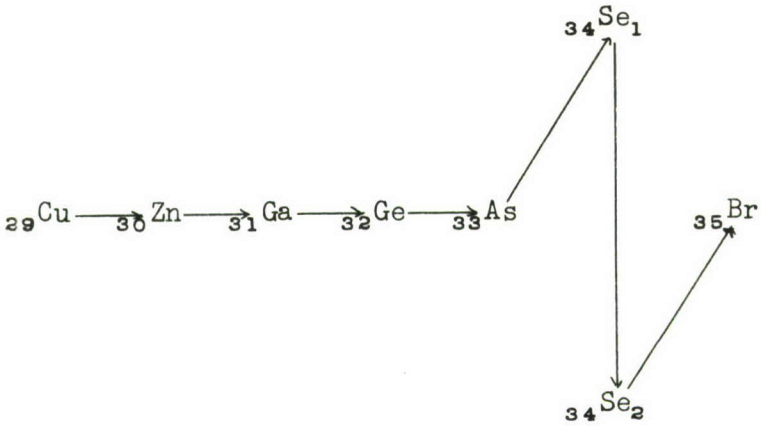
78.

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Cu	1.8 *	Cu ⟶ Zn	13.8	13.6
Zn	2.5 *	Zn ⟶ Ga	6.72	5.61
Ga	8 *	Ga ⟶ Ge	8.97	9.04
Ge	7.56×10^3	Ge ⟶ As	1.28	1.03
As	5.46×10^3	As ⟶ Se	4.50	4.46
Se	stable			

Decay Schemes:

Cu ⟶ Zn	Undetermined
Zn ⟶ Ga	Undetermined
Ga ⟶ Ge	Undetermined
Ge ⟶ As	.9 (100%)
As ⟶ Se	4.1 (50%), 1.4 (50%)

79.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Cu	1 *	Cu → Zn	12.1	11.3
Zn	1.5 *	Zn → Ga	10.0	9.61
Ga	4.5 *	Ga → Ge	7.32	6.74
Ge	25 *	Ge → As	4.77	5.07
As	540	As → Se	2.68	2.40
Se_1	234	Se → Br	.358	.327
Se_2	2.205×10^{12}			
Br	stable			

Decay Schemes:

Cu → Zn	Undetermined
Zn → Ga	Undetermined
Ga → Ge	Undetermined
Ge → As	Undetermined
As → Se_1	2.2 (100%)
Se_2 → Br	.160 (100%)

80.

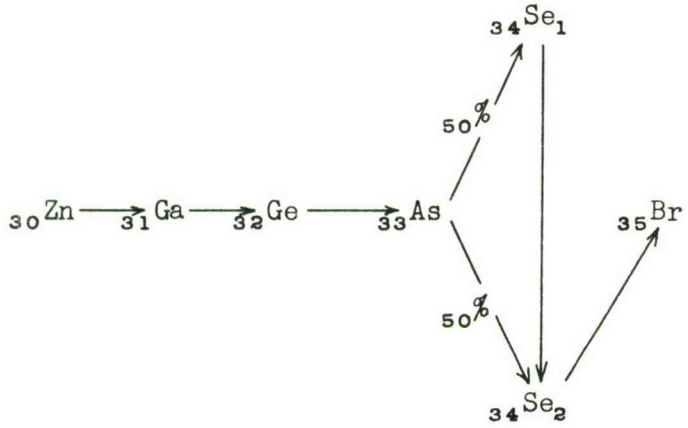
$_{29}Cu \longrightarrow_{30} Zn \longrightarrow_{31} Ga \longrightarrow_{32} Ge \longrightarrow_{33} As \longrightarrow_{34} Se$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Cu	1 *	Cu ⟶ Zn	16.7	15.2
Zn	1.5 *	Zn ⟶ Ga	8.37	7.22
Ga	3 *	Ga ⟶ Ge	10.6	10.7
Ge	25 *	Ge ⟶ As	3.13	2.74
As	15	As ⟶ Se	6.17	6.22
Se	stable			

Decay Schemes:

Cu ⟶ Zn	Undetermined
Zn ⟶ Ga	Undetermined
Ga ⟶ Ge	Undetermined
Ge ⟶ As	Undetermined
As ⟶ Se	Undetermined

81.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Zn	1.5 *	Zn ⟶ Ga	13.0	11.3
Ga	2 *	Ga ⟶ Ge	8.99	8.54
Ge	7 *	Ge ⟶ As	6.45	6.93
As	33	As ⟶ Se	4.54	4.32
Se_1	3.42×10^3	Se ⟶ Br	2.03	2.31
Se_2	1.08×10^3			
Br	stable			

Decay Schemes:

Zn ⟶ Ga	Undetermined
Ga ⟶ Ge	Undetermined
Ge ⟶ As	Undetermined
As ⟶ Se_1	Undetermined (50%)
As ⟶ Se_2	Undetermined (50%)
Se_2 ⟶ Br	1.38 (100%)

82.

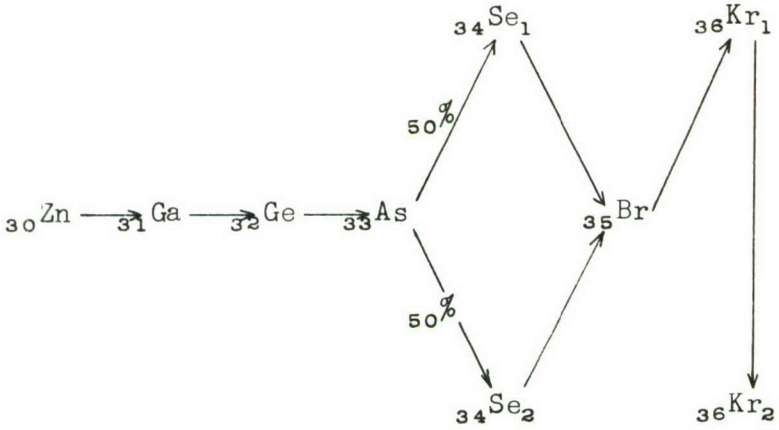
$_{30}Zn \longrightarrow {}_{31}Ga \longrightarrow {}_{32}Ge \longrightarrow {}_{33}As \longrightarrow {}_{34}Se$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Zn	1 *	Zn ⟶ Ga	12.3	9.12
Ga	1.5 *	Ca ⟶ Ge	13.6	12.7
Ge	5 *	Ge ⟶ As	4.81	4.76
As	18 *	As ⟶ Se	7.86	8.32
Se	stable			

Decay Schemes:

Zn ⟶ Ga	Undetermined
Ga ⟶ Ge	Undetermined
Ga ⟶ As	Undetermined
As ⟶ Se	Undetermined

83.

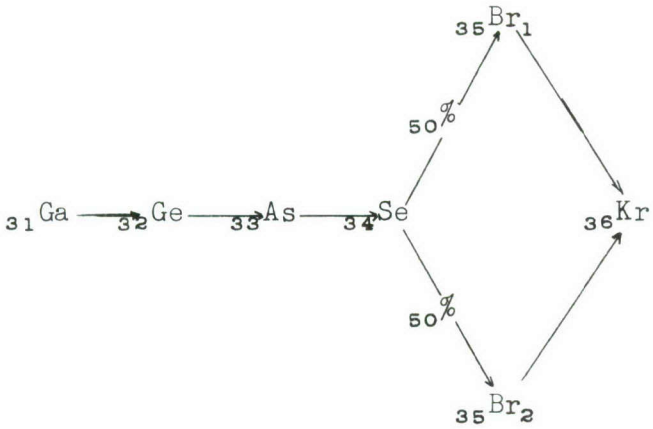


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Zn	1 *	Zn → Ga	14.5	12.6
Ga	1.5 *	Ga → Ge	12.9	9.85
Ge	2 *	Ge → As	9.44	8.29
As	7 *	As → Se	6.22	5.73
Se_1	1.5×10^3	Se → Br	3.74	3.77
Se_2	69	Br → Kr	1.77	1.41
Br	8.64×10^3			
Kr_1	6.84×10^3			
Kr_2	stable			

Decay Schemes:

Zn → Ga	Undetermined
Ga → Ge	Undetermined
Ge → As	Undetermined
As → Se_1	Undetermined (50%)
As → Se_2	Undetermined (50%)
Se_1 → Br	1.5 (100%)
Se_2 → Br	1.5 (10%), 3.4 (90%)
Br → Kr_1	.91 (20%), .96 (80%)

84.

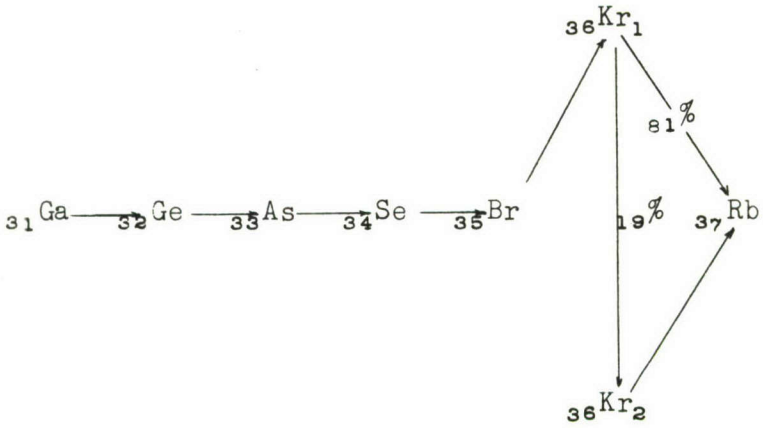


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Ga	1 *	Ga ⟶ Ge	15.1	14.0
Ge	1.5 *	Ge ⟶ As	8.72	6.11
As	4 *	As ⟶ Se	10.9	9.73
Se	180	Se ⟶ Br	2.10	1.83
Br_1	3.60×10^2	Br ⟶ Kr	5.10	5.45
Br_2	1.92×10^3			
Kr	stable			

Decay Schemes:

Ga ⟶ Ge	Undetermined
Ge ⟶ As	Undetermined
As ⟶ Se	Undetermined
Se ⟶ Br_1	Undetermined (50%)
Se ⟶ Br_2	Undetermined (50%)
Br_1 ⟶ Kr	.80 (20%), 1.9 (72%), 3.2 (8%)
Br_2 ⟶ Kr	.5 (3%), .77 (19%), .98 (2%), 1.39 (14%), 1.81 (1 5%), 2.80 (15%), 3.83 (14%), 4.68 (32%)

85.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Ga	.8 *	Ga ⟶ Ge	14.8	11.4
Ge	1 *	Ga ⟶ As	11.0	9.84
As	.43	As ⟶ Se	10.2	7.32
Se	39	Se ⟶ Br	6.74	5.40
Br	1.8×10^2	Br ⟶ Kr	3.47	3.08
Kr_1	1.584×10^4	Kr ⟶ Rb	1.03	1.16
Kr_2	3.28×10^8			
Rb	stable			

Decay Schemes:

Ga ⟶ Ge	Undetermined
Ge ⟶ As	Undetermined
As ⟶ Se	Undetermined
Se ⟶ Br	Undetermined
Br ⟶ Kr_1	2.5 (100%)
Kr_1 ⟶ Rb	.824 (81%), IT (19%)
Kr_2 ⟶ Rb	.15 (.7%), .672 (99.3%)

86.

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Ge	1.5 *	Ge ⟶ As	10.7	7.57
As	2 *	As ⟶ Se	12.4	11.2
Se	16	Se ⟶ Br	6.03	3.39
Br	54	Br ⟶ Kr	8.12	7.06
Kr	stable			

Decay Schemes:

Ge ⟶ As	Undetermined
As ⟶ Se	Undetermined
Se ⟶ Br	Undetermined
Br ⟶ Kr	3.0 (33%), 5.0 (33%), 7.1 (33%)

87.

$_{32}Ge \longrightarrow {}_{33}As \longrightarrow {}_{34}Se \longrightarrow {}_{35}Br \longrightarrow {}_{36}Kr \longrightarrow {}_{37}Rb$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Ge	1 *	Ge ⟶ As	13.2	11.4
As	1.5 *	As ⟶ Se	12.1	9.17
Se	16	Se ⟶ Br	8.28	7.31
Br	55	Br ⟶ Kr	7.41	5.05
Kr	4.68×10^3	Kr ⟶ Rb	4.05	3.19
Rb	stable			

Decay Schemes:

Ge ⟶ As	Undetermined
As ⟶ Se	Undetermined
Se ⟶ Br	Undetermined
Br ⟶ Kr	2.6 (70%), 8.0 (30%)
Kr ⟶ Rb	1.25 (25%), 3.3 (10%), 3.8 (65%)

88.

$_{32}Ge \longrightarrow {}_{33}As \longrightarrow {}_{34}Se \longrightarrow {}_{35}Br \longrightarrow {}_{36}Kr \longrightarrow {}_{37}Rb \longrightarrow {}_{38}Sr$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Ge	1 *	Ge ⟶ As	11.8	9.30
As	1.5 *	As ⟶ Se	14.6	13.0
Se	2.5 *	Se ⟶ Br	7.99	5.24
Br	16	Br ⟶ Kr	9.67	8.97
Kr	1.01×10^4	Kr ⟶ Rb	3.35	1.18
Rb	1.08×10^3	Rb ⟶ Sr	5.17	4.19
Sr	stable			

Decay Schemes:

Ge ⟶ As	Undetermined
As ⟶ Se	Undetermined
Se ⟶ Br	Undetermined
Br ⟶ Kr	Undetermined
Kr ⟶ Rb	.52 (70%), .9 (10%), 2.7 (20%)
Rb ⟶ Sr	.34 (6%), 2.5 (14%), 3.4 (4%), 5.2 (76%)

89.

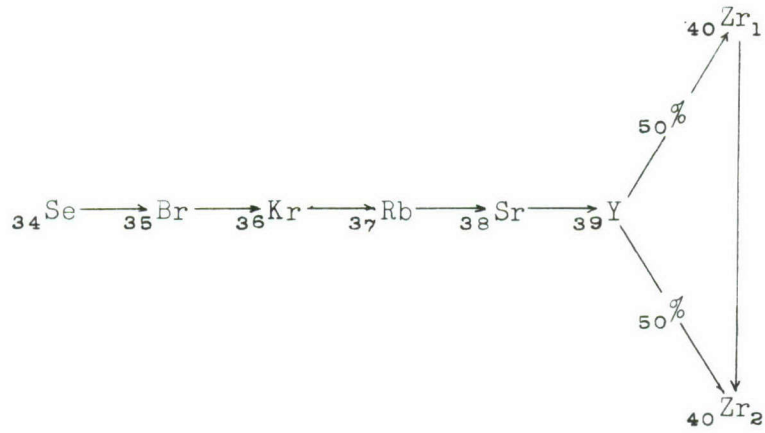
$$_{33}As \longrightarrow {}_{34}Se \longrightarrow {}_{35}Br \longrightarrow {}_{36}Kr \longrightarrow {}_{37}Rb \longrightarrow {}_{38}Sr \longrightarrow {}_{39}Y$$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
As	1.5 *	As ⟶ Se	13.2	11.0
Se	2 *	Se ⟶ Br	10.5	9.14
Br	4.5	Br ⟶ Kr	9.38	6.93
Kr	192	Kr ⟶ Rb	5.60	5.12
Rb	900	Rb ⟶ Sr	4.48	3.41
Sr	4.36×10^6	Sr ⟶ Y	1.40	1.00
Y	stable			

Decay Schemes:

As ⟶ Se	Undetermined
Se ⟶ Br	Undetermined
Br ⟶ Kr	Undetermined
Kr ⟶ Rb	2.0 (35%), 3.9 (65%)
Rb ⟶ Sr	.4 (2%), .67 (28%), 1.17 (3%), 1.33 (2%), 1.61 (53%), 2.87 (5%), 3.92 (7%)
Sr ⟶ Y	1.463 (100%)

90.

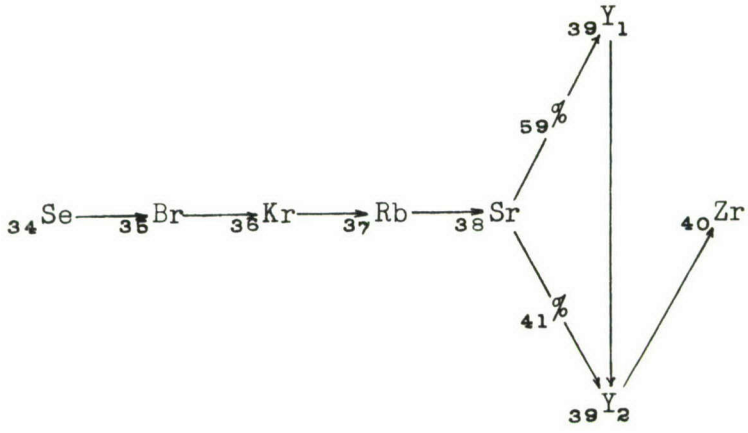


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Se	1.5 *	Se ⟶ Br	9.13	6.87
Br	1.6	Br ⟶ Kr	11.9	10.6
Kr	33	Kr ⟶ Rb	5.32	2.89
Rb	174	Rb ⟶ Sr	6.74	6.66
Sr	8.86×10^8	Sr ⟶ Y	.714	-1.09
Y	2.31×10^5	Y ⟶ Zr	2.25	2.68
Zr_1	.8			
Zr_2	stable			

Decay Schemes:

Se ⟶ Br	Undetermined
Br ⟶ Kr	Undetermined
Kr ⟶ Rb	3.2 (100%)
Rb ⟶ Sr	1.2 (15%), 2.21 (15%), 4.4 (15%), 5.81 (15%), 6.59 (39%)
Sr ⟶ Y	.544 (100%)
Y ⟶ Zr_1	2.27 (50%)
Y ⟶ Zr_2	2.27 (50%)

91.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Se	1.5 *	Se ⟶ Br	12.3	10.7
Br	2 *	Br ⟶ Kr	10.5	8.57
Kr	10	Kr ⟶ Rb	7.85	6.80
Rb	72	Rb ⟶ Sr	6.45	5.13
Sr	3.49×10^4	Sr ⟶ Y_1	2.98	2.76
Y_1	3×10^3	Y_1 ⟶ Zr	1.56	1.19
Y_2	5.10×10^6			
Zr	stable			

Decay Schemes:

Se ⟶ Br	Undetermined
Br ⟶ Kr	Undetermined
Kr ⟶ Rb	3.6 (100%)
Rb ⟶ Sr	4.6 (100%)
Sr ⟶ Y_1	1.09 (29.5%), 1.36 (29.5%)
Sr ⟶ Y_2	.61 (7%), 1.09 (3%), 2.03 (4%), 2.67 (27%)
Y_2 ⟶ Zr	.33 (.3%), 1.54 (99.7%)

92.

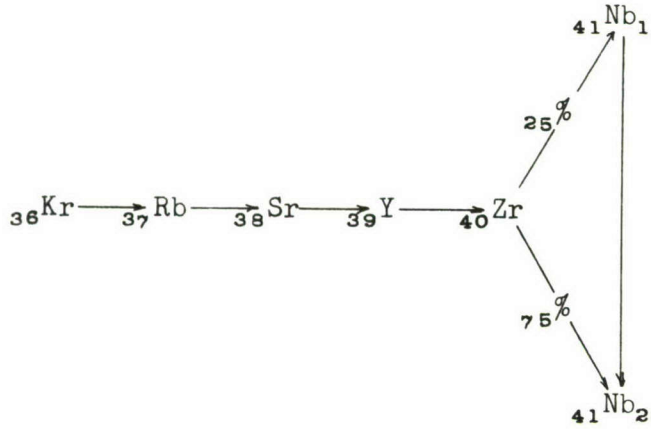
$$_{35}Br \longrightarrow {}_{36}Kr \longrightarrow {}_{37}Rb \longrightarrow {}_{38}Sr \longrightarrow {}_{39}Y \longrightarrow {}_{40}Zr$$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Br	1.5 *	Br ⟶ Kr	13.7	12.3
Kr	3	Kr ⟶ Rb	6.48	4.57
Rb	5.3	Rb ⟶ Sr	9.00	8.37
Sr	9.72×10^3	Sr ⟶ Y	2.70	.648
Y	1.27×10^4	Y ⟶ Zr	3.83	4.45
Zr	stable			

Decay Schemes:

Br ⟶ Kr	Undetermined
Kr ⟶ Rb	Undetermined
Rb ⟶ Sr	Undetermined
Sr ⟶ Y	.545 (90%), 1.5 (10%)
Y ⟶ Zr	1.26 (9%), 1.75 (3%), 3.60 (88%)

93.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Kr	2	Kr ⟶ Rb	9.67	8.25
Rb	6	Rb ⟶ Sr	7.62	6.61
Sr	498	Sr ⟶ Y	5.24	4.27
Y	3.64×10^4	Y ⟶ Zr	3.55	2.73
Zr	1.2×10^3	Zr ⟶ Nb	.499	-.120
Nb_1	1.17×10^8			
Nb_2	stable			

Decay Schemes:

Kr ⟶ Rb	Undetermined
Rb ⟶ Sr	Undetermined
Sr ⟶ Y	Undetermined
Y ⟶ Zr	.45 (.15%), .71 (1.8%), 1.47 (.9%), 1.95(3%), 2.62 (3.9%), 2.89 (90%)
Zr ⟶ Nb_1	.034 (25%)
Zr ⟶ Nb_2	.063 (75%)

94.

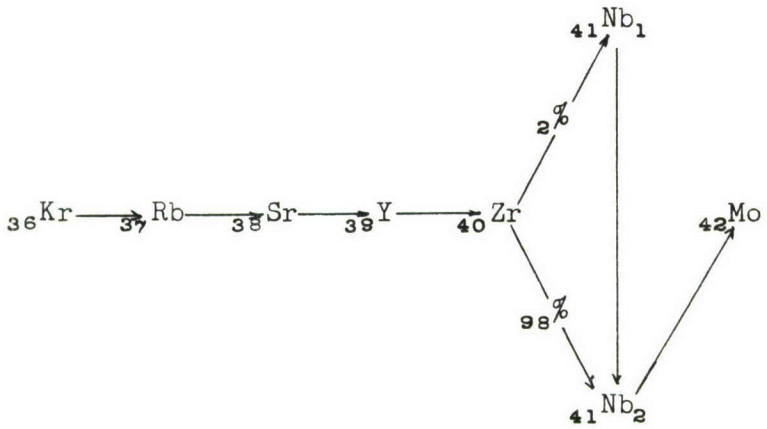
$_{36}Kr \xrightarrow{} _{37}Rb \xrightarrow{} _{38}Sr \xrightarrow{} _{39}Y \xrightarrow{} _{40}Zr$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Kr	1.5	Kr ⟶ Rb	7.95	6.34
Rb	3	Rb ⟶ Sr	10.8	10.2
Sr	78	Sr ⟶ Y	3.87	2.50
Y	1.2×10^3	Y ⟶ Zr	6.10	6.34
Zr	stable			

Decay Schemes:

Kr ⟶ Rb	Undetermined
Rb ⟶ Sr	Undetermined
Sr ⟶ Y	Undetermined
Y ⟶ Zr	5.0 (100%)

95.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Kr	1.3 *	Kr ⟶ Rb	11.1	9.79
Rb	2 *	Rb ⟶ Sr	9.10	8.19
Sr	48	Sr ⟶ Y	7.07	5.89
Y	660	Y ⟶ Zr	4.73	4.39
Zr	5.62×10^6	Zr ⟶ Nb	2.78	2.09
Nb_1	3.24×10^5	Nb ⟶ Mo	1.09	.590
Nb_2	3.02×10^6			
Mo	stable			

Decay Schemes:

Kr ⟶ Rb	Undetermined
Rb ⟶ Sr	Undetermined
Sr ⟶ Y	Undetermined
Y ⟶ Zr	Undetermined
Zr ⟶ Nb_1	.885 (2%)
Zr ⟶ Nb_2	.360 (42%), .396 (55%), 1.13 (1%)
Nb_2 ⟶ Mo	.160 (99%), .93 (1%)

96.

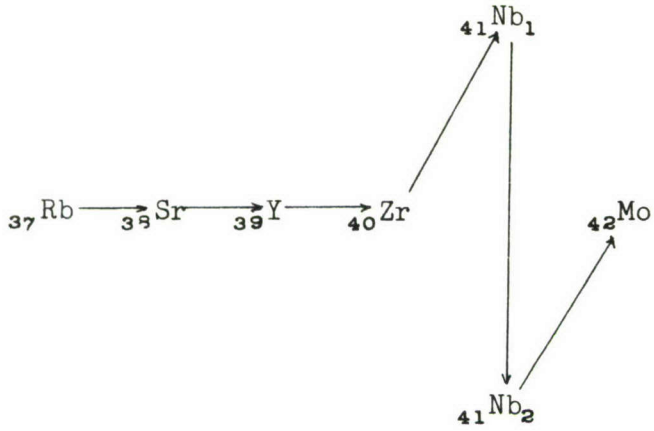
$_{36}Kr \longrightarrow {}_{37}Rb \longrightarrow {}_{38}Sr \longrightarrow {}_{39}Y \longrightarrow {}_{40}Zr \text{---} {}_{41}Nb \longrightarrow {}_{42}Mo$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Kr	.8	Kr ⟶ Rb	9.21	7.66
Rb	1 *	Rb ⟶ Sr	12.3	11.5
Sr	2.5 *	Sr ⟶ Y	5.35	3.90
Y	138	Y ⟶ Zr	7.93	7.76
Zr	stable	Zr ⟶ Nb	1.41	.138
Nb	8.28×10^4	Nb ⟶ Mo	3.63	4.00
Mo	stable			

Decay Schemes:

Kr ⟶ Rb	Undetermined
Rb ⟶ Sr	Undetermined
Sr ⟶ Y	Undetermined
Y ⟶ Zr	3.5 (100%)
Zr ⟶ Nb	No transitions - Shielded Nuclide
Nb ⟶ Mo	.37 (8%), .7 (92%)

97.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Rb	1 *	Rb ⟶ Sr	10.4	9.89
Sr	1.5 *	Sr ⟶ Y	8.53	7.63
Y	5 *	Y ⟶ Zr	6.22	6.17
Zr	6.12×10^4	Zr ⟶ Nb	4.62	3.91
Nb_1	60	Nb ⟶ Mo	2.28	2.45
Nb_2	4.32×10^3			
Mo	stable			

Decay Schemes:

Rb ⟶ Sr	Undetermined
Sr ⟶ Y	Undetermined
Y ⟶ Zr	Undetermined
Zr ⟶ Nb_1	.45 (10%), 1.91 (90%)
Nb_2 ⟶ Mo	.93 (1%), 1.267 (99%)

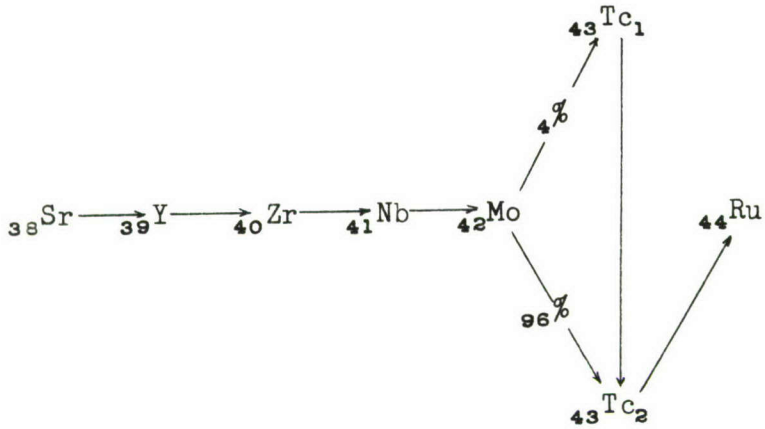
98.

$_{37}Rb \longrightarrow {}_{38}Sr \longrightarrow {}_{39}Y \longrightarrow {}_{40}Zr \longrightarrow {}_{41}Nb \longrightarrow {}_{42}Mo$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Rb	.7 *	Rb ⟶ Sr	13.9	13.2
Sr	1 *	Sr ⟶ Y	6.64	5.66
Y	2.5 *	Y ⟶ Zr	9.40	9.51
Zr	60	Zr ⟶ Nb	2.91	1.96
Nb	3.09×10^3	Nb ⟶ Mo	5.48	5.81
Mo	stable			

Decay Schemes:

Rb ⟶ Sr	Undetermined
Sr ⟶ Y	Undetermined
Y ⟶ Zr	Undetermined
Zr ⟶ Nb	Undetermined
Nb ⟶ Mo	3.1 (100%)

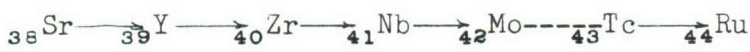


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Sr	1 *	Sr ⟶ Y	10.1	9.33
Y	1.5 *	Y ⟶ Zr	7.51	7.90
Zr	30	Zr ⟶ Nb	6.09	5.67
Nb	144	Nb ⟶ Mo	3.78	4.24
Mo	2.38×10^5	Mo ⟶ Tc	1.97	2.01
Tc_1	2.16×10^4	Tc ⟶ Ru	-.227	.583
Tc_2	6.63×10^{12}			
Ru	stable			

Decay Schemes:

Sr ⟶ Y	Undetermined
Y ⟶ Zr	Undetermined
Zr ⟶ Nb	Undetermined
Nb ⟶ Mo	3.2 (100%)
Mo ⟶ Tc_1	.45 (4%)
Mo ⟶ Tc_2	.45 (10%), .87 (1%), 1.23 (85%)
Tc_2 ⟶ Ru	.292 (100%)

100.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Sr	1 *	Sr ⟶ Y	8.11	7.11
Y	1.5 *	Y ⟶ Zr	11.0	11.0
Zr	3.5 *	Zr ⟶ Nb	4.20	3.49
Nb	180	Nb ⟶ Mo	6.97	7.36
Mo	stable	Mo ⟶ Tc	.265	-.125
Tc	16	Tc ⟶ Ru	2.99	3.74
Ru	stable			

Decay Schemes:

Sr ⟶ Y	Undetermined
Y ⟶ Zr	Undetermined
Zr ⟶ Nb	Undetermined
Nb ⟶ Mo	3.1 (45%), 3.5 (45%), 4.2 (10%)
Mo ⟶ Tc	No transition - Shielded Nuclide
Tc ⟶ Ru	2.2 (33%), 2.89 (33%), 3.37 (33%)

101.

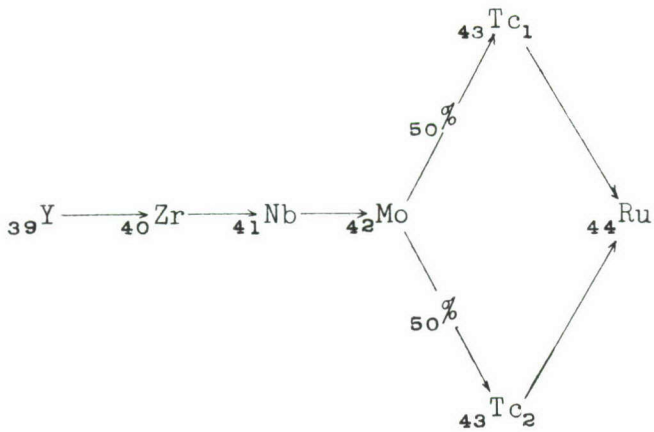
$_{38}Sr \longrightarrow {}_{39}Y \longrightarrow {}_{40}Zr \longrightarrow {}_{41}Nb \longrightarrow {}_{42}Mo \longrightarrow {}_{43}Tc \longrightarrow {}_{44}Ru$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Sr	.7 *	Sr ⟶ Y	11.5	10.6
Y	1.0 *	Y ⟶ Zr	9.00	9.17
Zr	2.5 *	Zr ⟶ Nb	7.72	6.98
Nb	60	Nb ⟶ Mo	5.08	5.59
Mo	876	Mo ⟶ Tc	3.46	3.40
Tc	840	Tc ⟶ Ru	1.28	2.01
Ru	stable			

Decay Schemes:

Sr ⟶ Y	Undetermined
Y ⟶ Zr	Undetermined
Zr ⟶ Nb	Undetermined
Nb ⟶ Mo	Undetermined
Mo ⟶ Tc	.6 (3%), .7 (38%), .8 (13%), 1.2 (11%), 1.6 (25%), 2.23 (10%)
Tc ⟶ Ru	1.07 (8%), 1.32 (92%)

102.

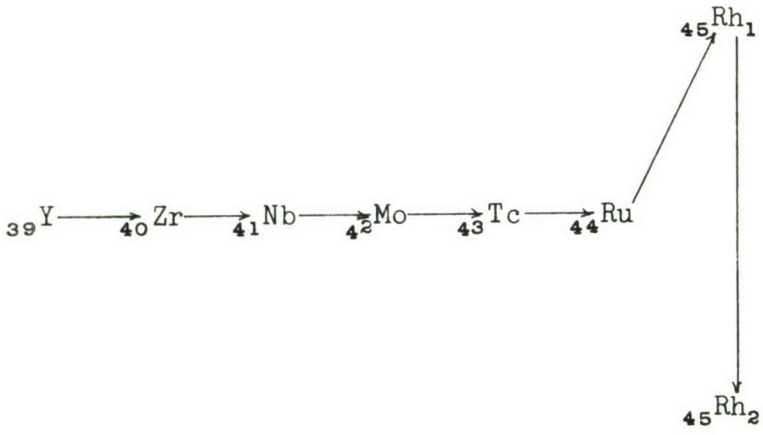


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Y	1.2 *	Y ⟶ Zr	12.4	12.3
Zr	2 *	Zr ⟶ Nb	5.70	4.83
Nb	7 *	Nb ⟶ Mo	8.60	8.69
Mo	660	Mo ⟶ Tc	1.57	1.27
Tc_1	270	Tc ⟶ Ru	4.48	5.13
Tc_2	5			
Ru	stable			

Decay Schemes:

Y ⟶ Zr	Undetermined
Zr ⟶ Nb	Undetermined
Nb ⟶ Mo	Undetermined
Mo ⟶ Tc_1	Undetermined (50%)
Mo ⟶ Tc_2	Undetermined (50%)
Tc_1 ⟶ Ru	2.0 (100%)
Tc_2 ⟶ Ru	4.1 (100%)

103.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Y	1.0 *	Y ⟶ Zr	10.3	10.4
Zr	1.5 *	Zr ⟶ Nb	9.12	8.27
Nb	4 *	Nb ⟶ Mo	6.58	6.91
Mo	25 *	Mo ⟶ Tc	5.10	4.75
Tc	72	Tc ⟶ Ru	2.60	3.39
Ru	3.46×10^6	Ru ⟶ Rb	.755	1.23
Rh_1	3.42×10^3			
Rh_2	stable			

Decay Schemes:

Y ⟶ Zr	Undetermined
Zr ⟶ Nb	Undetermined
Nb ⟶ Mo	Undetermined
Mo ⟶ Tc	Undetermined
Tc ⟶ Ru	2.5 (100%)
Ru ⟶ Rh	.10 (7%), .212 (89%), .71 (3%)

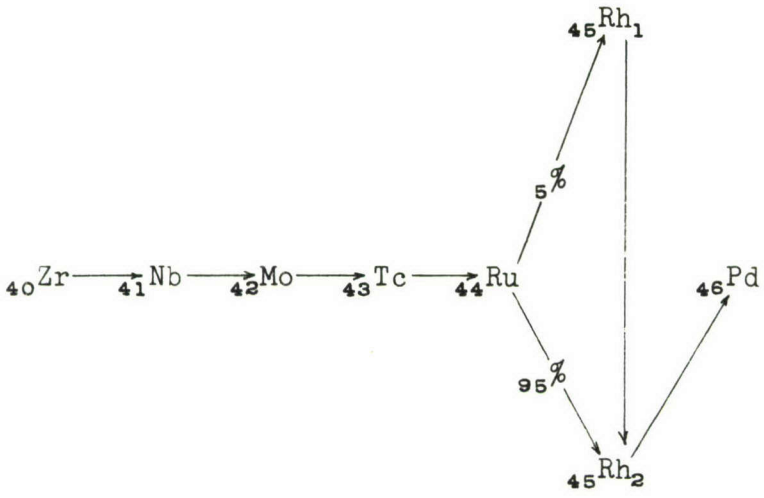
104.

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Y	1 *	Y → Zr	13.5	13.5
Zr	1.7 *	Zr → Nb	7.04	6.12
Nb	3 *	Nb → Mo	10.0	9.97
Mo	60	Mo → Tc	3.08	2.62
Tc	1.08×10^3	Tc → Ru	6.12	6.47
Ru	stable			

Decay Schemes:

Y → Zr	Undetermined
Zr → Nb	Undetermined
Nb → Mo	Undetermined
Mo → Tc	Undetermined
Tc → Ru	2.4 (100%)

105.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Zr	1.2 *	Zr ⟶ Nb	10.2	9.51
Nb	2 *	Nb ⟶ Mo	7.93	8.18
Mo	40	Mo ⟶ Tc	6.51	6.05
Tc	480	Tc ⟶ Ru	4.11	4.72
Ru	1.59×10^4	Ru ⟶ Rh	2.41	2.59
Rh_1	30	Rh ⟶ Pd	.317	1.06
Rh_2	1.296×10^5			
Pd	stable			

Decay Schemes:

Zr ⟶ Nb	Undetermined
Nb ⟶ Mo	Undetermined
Mo ⟶ Tc	Undetermined
Tc ⟶ Ru	Undetermined
Ru ⟶ Rh_1	1.08 (5%)
Ru ⟶ Rh_2	.525 (5%), .915 (10%), 1.080 (25%), 1.145 (45%), 1.870 (10%)
Rh_2 ⟶ Pd	.25 (10%), .565 (90%)

106.

$_{40}Zr \longrightarrow {}_{41}Nb \longrightarrow {}_{42}Mo \longrightarrow {}_{43}Tc \longrightarrow {}_{44}Ru \longrightarrow {}_{45}Rh \longrightarrow {}_{46}Pd$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Zr	1 *	Zr ⟶ Nb	8.29	7.38
Nb	1.5 *	Nb ⟶ Mo	11.1	11.2
Mo	4 *	Mo ⟶ Tc	4.43	3.94
Tc	9 *	Tc ⟶ Ru	7.54	7.76
Ru	3.16×10^7	Ru ⟶ Rh	.393	.498
Rh	30	Rh ⟶ Pd	3.85	4.32
Pd	stable			

Decay Schemes:

Sr ⟶ Nb	Undetermined
Nb ⟶ Mo	Undetermined
Mo ⟶ Tc	Undetermined
Tc ⟶ Ru	Undetermined
Ru ⟶ Rh	.039 (100%)
Rh ⟶ Pd	1.2 (.4%), 1.3 (.2%), 1.5 (.5%), 2.0 (2%), 2.4 (11%), 3.0 (8%), 3.54 (78%)

107.

$_{40}Zr \longrightarrow _{41}Nb \longrightarrow _{42}Mo \longrightarrow _{43}Tc \longrightarrow _{44}Ru \longrightarrow _{45}Rh \longrightarrow _{46}Pd \longrightarrow _{47}Ag$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Zr	9.6 *	Zr ⟶ Nb	11.5	10.5
Nb	1.0 *	Nb ⟶ Mo	9.19	9.24
Mo	2.5 *	Mo ⟶ Tc	7.62	7.14
Tc	270	Tc ⟶ Ru	5.47	5.84
Ru	252	Ru ⟶ Rh	3.83	3.74
Rh	1.30×10^3	Rh ⟶ Pd	1.84	2.24
Pd	2.21×10^4	Pd ⟶ Ag	-0.102	0.340
Ag	stable			

Decay Schemes:

Zr ⟶ Nb	Undetermined
Nb ⟶ Mo	Undetermined
Mo ⟶ Tc	Undetermined
Tc ⟶ Ru	Undetermined
Ru ⟶ Rh	3.0 (12%), 3.8 (9%), 4.0 (79%)
Rh ⟶ Pd	.9 (3%), 1.1 (13%), 1.2 (84%)
Pd ⟶ Ag	.035 (100%)

108.

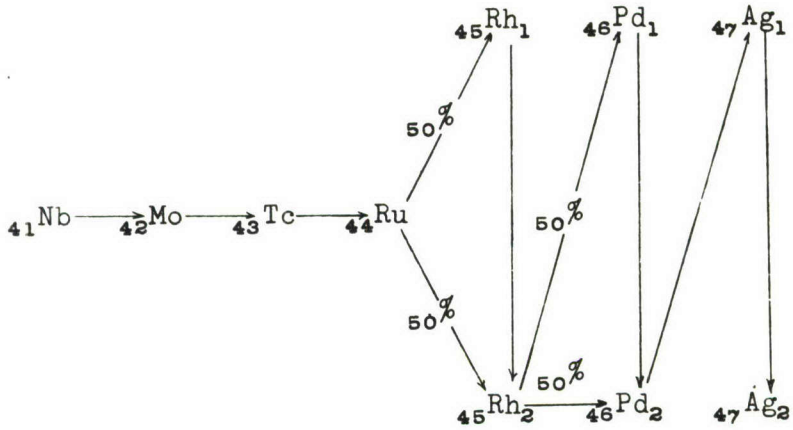
$_{41}Nb \longrightarrow _{42}Mo \longrightarrow _{43}Tc \longrightarrow _{44}Ru \longrightarrow _{45}Rh \longrightarrow _{46}Pd$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Nb	1.0 *	Nb ⟶ Mo	12.4	12.3
Mo	2.0 *	Mo ⟶ Tc	5.70	5.16
Tc	3.5	Tc ⟶ Ru	8.65	8.96
Ru	270	Ru ⟶ Rh	1.76	1.80
Rh	17	Rh ⟶ Pd	5.27	5.60
Pd	stable			

Decay Schemes:

Nb ⟶ Mo	Undetermined
Mo ⟶ Tc	Undetermined
Tc ⟶ Ru	Undetermined
Ru ⟶ Rh	1.15 (28%), 1.32 (78%)
Rh ⟶ Pd	3.5 (22%), 4.1 (17%), 4.5 (51%)

109.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Nb	1.0 *	Nb ⟶ Mo	10.4	10.4
Mo	1.5 *	Mo ⟶ Tc	8.93	8.35
Tc	2.5 *	Tc ⟶ Ru	6.74	7.08
Ru	16 *	Ru ⟶ Rh	4.95	5.01
Rh_1	50	Rh ⟶ Pd	3.21	3.54
Rh_2	30	Pd ⟶ Ag	1.33	1.67
Pd_1	288			
Pd_2	4.86×10^4			
Ag_1	40			
Ag_2	stable			

Decay Schemes:

Nb ⟶ Mo	Undetermined
Mo ⟶ Tc	Undetermined
Tc ⟶ Ru	Undetermined
Ru ⟶ Rh_1	Undetermined (50%)
Ru ⟶ Rh_2	Undetermined (50%)
Rh_2 ⟶ Pd_1	2.6 (50%)
Rh_2 ⟶ Pd_2	2.6 (50%)
Pd_2 ⟶ Ag_1	1.025 (100%)

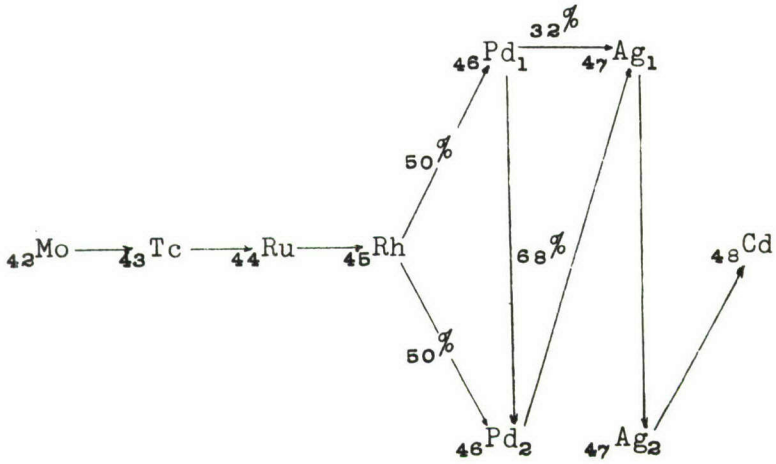
110.

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Nb	0.8 *	Nb ⟶ Mo	13.4	13.2
Mo	1.0 *	Mo ⟶ Tc	6.95	6.08
Tc	2.0 *	Tc ⟶ Ru	9.97	9.86
Ru	10 *	Ru ⟶ Rh	3.04	2.76
Rh	3.6	Rh ⟶ Pd	6.40	6.54
Pd	stable			

Decay Schemes:

Nb ⟶ Mo	Undetermined
Mo ⟶ Tc	Undetermined
Tc ⟶ Ru	Undetermined
Ru ⟶ Rh	Undetermined
Rh ⟶ Pd	Undetermined

111.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Mo	1.0 *	Mo ⟶ Tc	9.96	9.24
Tc	1.5 *	Tc ⟶ Ru	7.99	7.99
Ru	4 *	Ru ⟶ Rh	6.27	5.94
Rh	12 *	Rh ⟶ Pd	4.49	4.49
Pd_1	1.98×10^4	Pd ⟶ Ag	2.46	2.64
Pd_2	1.32×10^3	Ag ⟶ Cd	.886	.990
Ag_1	74			
Ag_2	6.48×10^5			
Cd	stable			

Decay Schemes:

Mo ⟶ Tc	Undetermined
Tc ⟶ Ru	Undetermined
Ru ⟶ Rh	Undetermined
Rh ⟶ Pd_1	Undetermined (50%)
Rh ⟶ Pd_2	Undetermined (50%)
Pd_1 ⟶ Ag_1	.61 (32%), IT (68%)
Pd_2 ⟶ Ag_1	2.13 (100%)
Ag_2 ⟶ Cd	.69 (6.2%), .79 (1.1%), 1.05 (92.7%)

112.

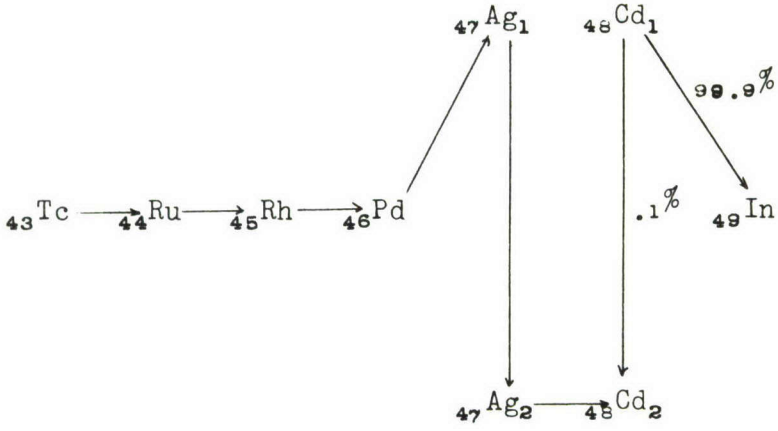
$_{42}Mo \longrightarrow {}_{43}Tc \longrightarrow {}_{44}Ru \longrightarrow {}_{45}Rh \longrightarrow {}_{46}Pd \longrightarrow {}_{47}Ag \longrightarrow {}_{48}Cd$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Mo	1 *	Mo ⟶ Tc	8.08	6.99
Tc	1.5 *	Tc ⟶ Ru	11.0	10.7
Ru	3 *	Ru ⟶ Rh	4.30	3.71
Rh	7 *	Rh ⟶ Pd	7.73	7.45
Pd	7.56×10^4	Pd ⟶ Ag	.551	.426
Ag	1.15×10^4	Ag ⟶ Cd	4.08	4.17
Cd	stable			

Decay Schemes:

Mo ⟶ Tc	Undetermined
Tc ⟶ Ru	Undetermined
Ru ⟶ Rh	Undetermined
Rh ⟶ Pd	Undetermined
Pd ⟶ Ag	.28 (100%)
Ag ⟶ Cd	.92 (.8%), 1.22 (2.6%), 1.34 (3.6%), 1.50 (1.8%), 1.61 (2%), 1.78 (4.4%), 2.01 (5.3%), 2.20 (.6%), 2.57 (1.6%), 2.63 (.9%), 2.73 (2.8%), 3.42 (18%), 4.04 (56%)

113.

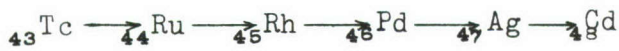


Half-lives (sec):		Mass Diff (Mev):	Cameron	Coryell
Tc	1.2 *	Tc —— Ru	9.14	5.30
Ru	2 *	Ru —— Rh	7.31	6.80
Rh	4 *	Rh —— Pd	5.76	5.38
Pd	90	Pd —— Ag	3.79	3.56
Ag_1	72	Ag —— Cd	2.18	1.94
Ag_2	1.91×10^4	Cd —— In	.253	.324
Cd_1	4.41×10^8			
Cd_2	stable			
In	stable			

Decay Schemes:

Tc —— Ru	Undetermined
Ru —— Rh	Undetermined
Rh —— Pd	Undetermined
Pd —— Ag_1	3.3 (100%)
Ag_2 —— Cd_2	2.0 (100%)
Cd_1 —— In	.575 (100%)

114.

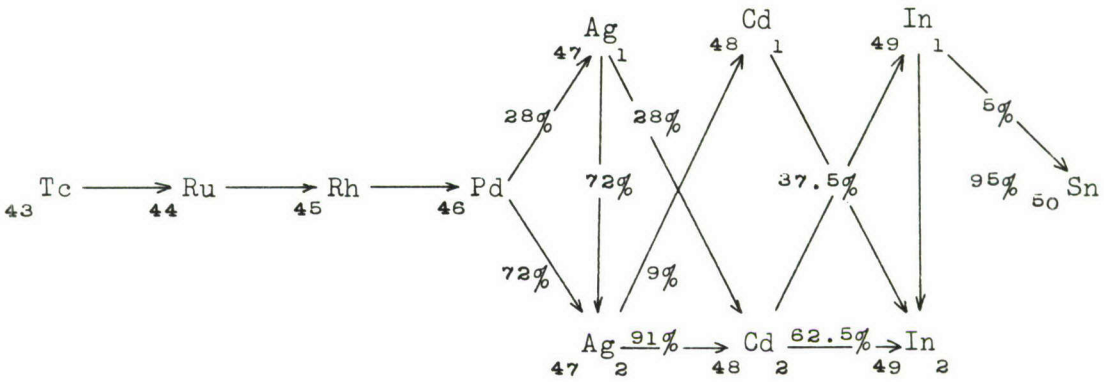


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Tc	1.0 *	Tc ⟶ Ru	12.4	11.5
Ru	1.5 *	Ru ⟶ Rh	5.45	4.58
Rh	3 *	Rh ⟶ Pd	8.77	8.29
Pd	144	Pd ⟶ Ag	1.82	1.36
Ag	5	Ag ⟶ Cd	5.42	5.07
Cd	stable			

Decay Schemes:

Tc ⟶ Ru	Undetermined
Ru ⟶ Rh	Undetermined
Rh ⟶ Pd	Undetermined
Pd ⟶ Ag	1.4 (100%)
Ag ⟶ Cd	4.6 (100%)

115.



Half-lives (sec):		Mass Diff (Mev):	Cameron	Coryell
Tc	0.8 *	Tc ⟶ Ru	10.5	9.62
Ru	1 *	Ru ⟶ Rh	8.67	7.43
Rh	2.5 *	Rh ⟶ Pd	6.91	6.04
Pd	45	Pd ⟶ Ag	4.84	4.45
Ag_1	20	Ag ⟶ Cd	3.45	2.86
Ag_2	1.26×10^3	Cd ⟶ In	1.60	1.27
Cd_1	3.72×10^6	In ⟶ Sn	.158	.182
Cd_2	1.987×10^5			
In_1	1.58×10^4			
In_2	stable			
Sn	stable			

Decay Schemes:

Tc ⟶ Ru	Undetermined
Ru ⟶ Rh	Undetermined
Rh ⟶ Pd	Undetermined
Pd ⟶ Ag_1	Undetermined (28%)
Pd ⟶ Ag_2	Undetermined (72%)
Ag_1 ⟶ Cd_2	Undetermined (28%), IT (72%)
Ag_2 ⟶ Cd_1	2.75 (9%)
Ag_2 ⟶ Cd_2	2.9 (91%)
Cd_1 ⟶ In_2	.2(.3%), .335(1%), .687(2%), 1.63(96.7%)
Cd_2 ⟶ In_1	.59(24%), .63(12.5%), .85(1%)
Cd_2 ⟶ In_2	1.11(62.5%)
In_1 ⟶ Sn	.84(5%), IT(95%)

116.

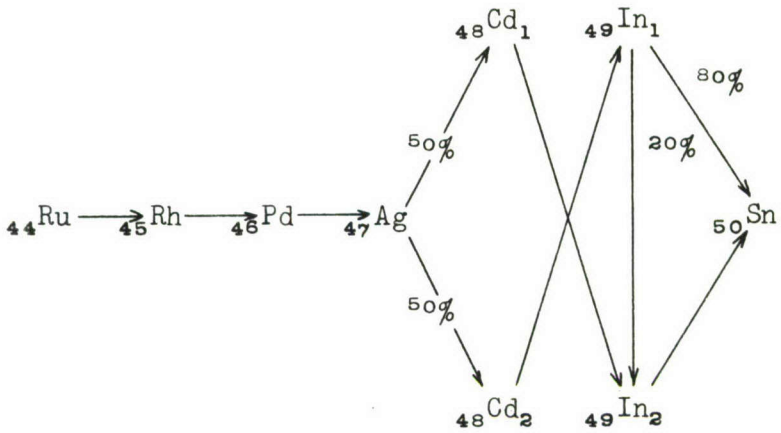
$_{44}Ru \longrightarrow {}_{45}Rh \longrightarrow {}_{46}Pd \longrightarrow {}_{47}Ag \longrightarrow {}_{48}Cd$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Ru	1.5 *	Ru ⟶ Rh	6.77	5.49
Rh	2 *	Rh ⟶ Pd	10.1	9.14
Pd	10 *	Pd ⟶ Ag	2.98	2.31
Ag	150	Ag ⟶ Cd	6.48	5.96
Cd	stable			

Decay Scheme:

Ru ⟶ Rh	Undetermined
Rh ⟶ Pd	Undetermined
Pd ⟶ Ag	Undetermined
Ag ⟶ Cd	5.0 (100%)

117.

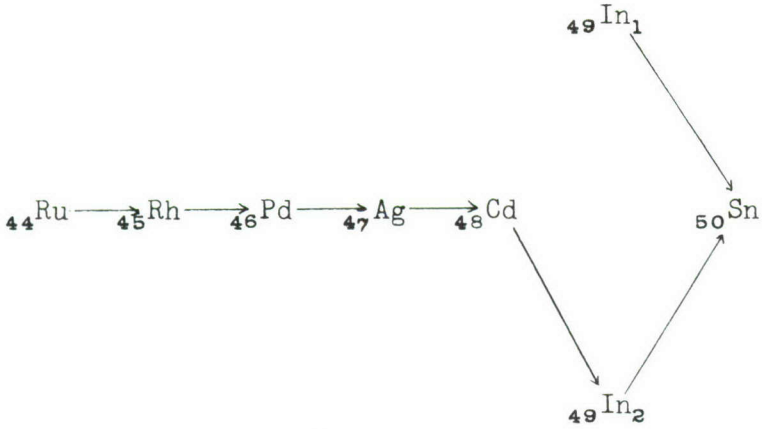


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Ru	1.0 *	Ru ⟶ Rh	9.81	8.53
Rh	1.5 *	Rh ⟶ Pd	8.24	7.15
Pd	5 *	Pd ⟶ Ag	6.21	5.37
Ag	66 *	Ag ⟶ Cd	4.62	3.79
Cd_1	1.15×10^4	Cd ⟶ In	2.66	2.21
Cd_2	1.01×10^4	In ⟶ Sn	1.44	1.13
In_1	6.84×10^3			
In_2	2.7×10^3			
Sn	stable			

Decay Schemes:

Ru ⟶ Rh	Undetermined
Rh ⟶ Pd	Undetermined
Pd ⟶ Ag	Undetermined
Ag ⟶ Cd_1	Undetermined (50%)
Ag ⟶ Cd_2	Undetermined (50%)
Cd_1 ⟶ In_2	1.0 (100%)
Cd_2 ⟶ In_1	1.8 (70%), 2.3 (30%)
In_1 ⟶ Sn	.95 (4%), 1.62 (24%), 1.77 (52%), IT (20%)
In_2 ⟶ Sn	.74 (100%)

118.

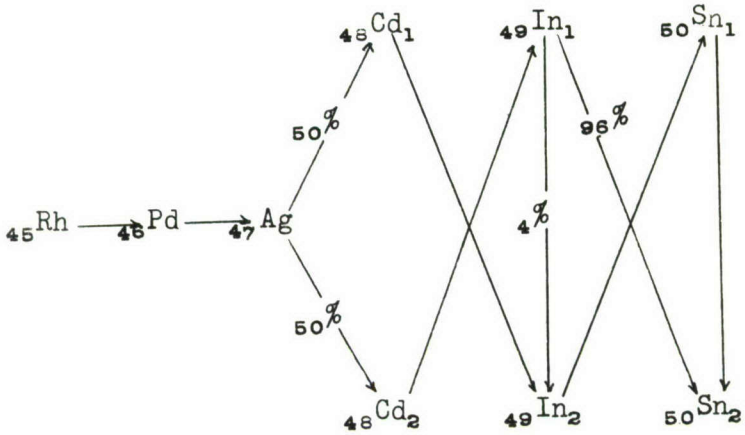


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Ru	1 *	Ru ⟶ Rh	7.80	6.37
Rh	1.5 *	Rh ⟶ Pd	11.3	9.96
Pd	4.5 *	Pd ⟶ Ag	4.32	3.23
Ag	25 *	Ag ⟶ Cd	7.85	6.82
Cd	3×10^3	Cd ⟶ In	.801	.089
In_1	270	In ⟶ Sn	4.47	3.68
In_2	5			
Sn	stable			

Decay Schemes:

Ru ⟶ Rh	Undetermined
Rh ⟶ Pd	Undetermined
Pd ⟶ Ag	Undetermined
Ag ⟶ Cd	Undetermined
Cd ⟶ In_2	.8 (100%)
In_1 ⟶ Sn	1.5 (100%)
In_2 ⟶ Sn	3.3 (20%), 4.5 (80%)

119.



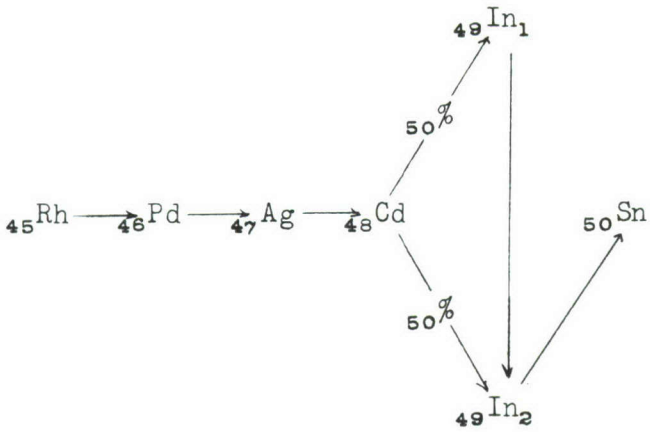
Half-lives (sec):	
Rh	1 *
Pd	3 *
Ag	17 *
Cd_1	142
Cd_2	570
In_1	1.08×10^3
In_2	120
Sn_1	2.16×10^7
Sn_2	stable

Mass Diff.(Mev):	Cameron	Coryell
Rh ⟶ Pd	9.28	8.00
Pd ⟶ Ag	7.36	6.24
Ag ⟶ Cd	5.96	4.68
Cd ⟶ In	4.04	3.12
In ⟶ Sn	2.62	2.06

Decay Schemes:

Rh ⟶ Pd	Undetermined
Pd ⟶ Ag	Undetermined
Ag ⟶ Cd_1	Undetermined (50%)
Ag ⟶ Cd_2	Undetermined (50%)
Cd_1 ⟶ In_2	Undetermined
Cd_2 ⟶ In_1	3.5 (80%), 4.0 (20%)
In_1 ⟶ Sn_2	1.8 (6%), 2.7 (90%), IT (4%)
In_2 ⟶ Sn_1	1.6 (100%)

120.

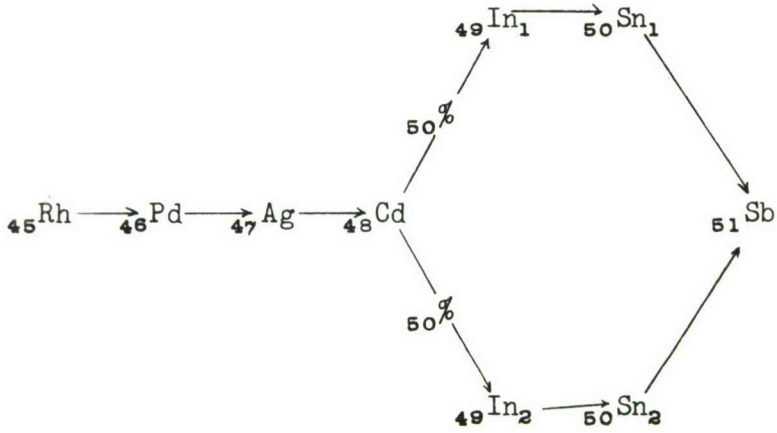


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Rh	1.5 *	Rh ⟶ Pd	12.4	10.7
Pd	2 *	Pd ⟶ Ag	5.36	4.07
Ag	6 *	Ag ⟶ Cd	9.00	7.63
Cd	60	Cd ⟶ In	2.15	.992
In_1	3	In ⟶ Sn	5.85	4.55
In_2	50			
Sn	stable			

Decay Schemes:

Rh ⟶ Pd	Undetermined
Pd ⟶ Ag	Undetermined
Ag ⟶ Cd	Undetermined
Cd ⟶ In_1	Undetermined (50%)
Cd ⟶ In_2	Undetermined (50%)
In_2 ⟶ Sn	2.2 (100%)

121.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Rh	1 *	Rh ⟶ Pd	10.8	8.77
Pd	1.5 *	Pd ⟶ Ag	8.44	7.04
Ag	4 *	Ag ⟶ Cd	7.01	5.51
Cd	210	Cd ⟶ In	5.19	3.98
In_1	186	In ⟶ Sn	3.97	2.95
In_2	30	Sn ⟶ Sb	.427	.918
Sn_1	8.88×10^8			
Sn_2	9.0×10^4			
Sb	stable			

Decay Schemes:

Rh ⟶ Pd	Undetermined
Pd ⟶ Ag	Undetermined
Ag ⟶ Cd	Undetermined
Cd ⟶ In_1	Undetermined (50%)
Cd ⟶ In_2	Undetermined (50%)
In_1 ⟶ Sn_1	3.7 (100%)
In_2 ⟶ Sn_2	2.9 (100%)
Sn_1 ⟶ Sb	.42 (100%)
Sn_2 ⟶ Sb	.383 (100%)

122.

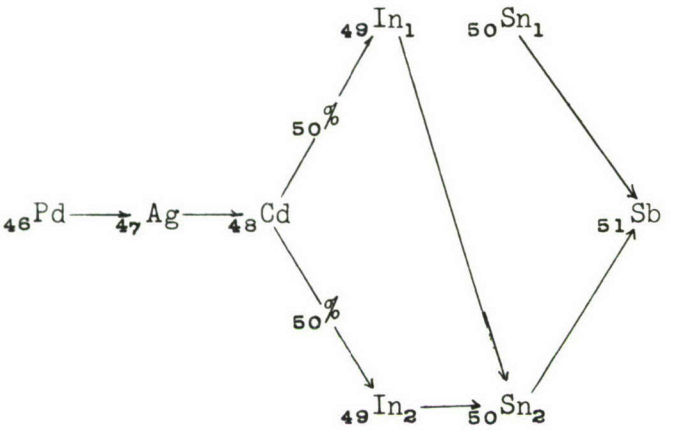
$_{46}Pd \longrightarrow_{47} Ag \longrightarrow_{48} Cd \longrightarrow_{49} In \longrightarrow_{50} Sn$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Pd	1.5 *	Pd ⟶ Ag	6.92	4.94
Ag	3 *	Ag ⟶ Cd	10.1	8.44
Cd	40 *	Cd ⟶ In	3.20	1.90
In	7.5	In ⟶ Sn	7.02	5.40
Sn	stable			

Decay Schemes:

Pd ⟶ Ag	Undetermined
Ag ⟶ Cd	Undetermined
Cd ⟶ In	Undetermined
In ⟶ Sn	Undetermined

123.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Pd	1.5 *	Pd ⟶ Ag	9.32	7.85
Ag	2.5 *	Ag ⟶ Cd	8.57	6.34
Cd	9 *	Cd ⟶ In	6.28	4.83
In_1	36	In ⟶ Sn	5.02	3.82
In_2	10	Sn ⟶ Sb	1.59	1.81
Sn_1	1.08×10^7			
Sn_2	2.40×10^3			
Sb	stable			

Decay Schemes:

Pd ⟶ Ag	Undetermined
Ag ⟶ Cd	Undetermined
Cd ⟶ In_1	Undetermined (50%)
Cd ⟶ In_2	Undetermined (50%)
In_1 ⟶ Sn_2	4.6 (100%)
In_2 ⟶ Sn_2	3.3 (100%)
Sn_1 ⟶ Sb	.34 (2%), 1.42 (98%)
Sn_2 ⟶ Sb	1.26 (100%)

124.

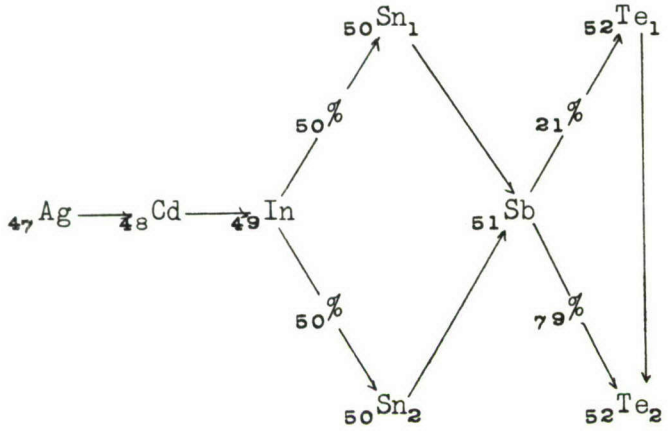
$_{46}Pd \longrightarrow {}_{47}Ag \longrightarrow {}_{48}Cd \longrightarrow {}_{49}In \longrightarrow {}_{50}Sn$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Pd	1 *	Pd ⟶ Ag	7.79	5.83
Ag	2 *	Ag ⟶ Cd	11.0	9.26
Cd	10 *	Cd ⟶ In	4.77	2.81
In	20 *	In ⟶ Sn	8.11	6.24
Sn	stable			

Decay Schemes:

Pd ⟶ Ag	Undetermined
Ag ⟶ Cd	Undetermined
Cd ⟶ In	Undetermined
In ⟶ Sn	Undetermined

125.

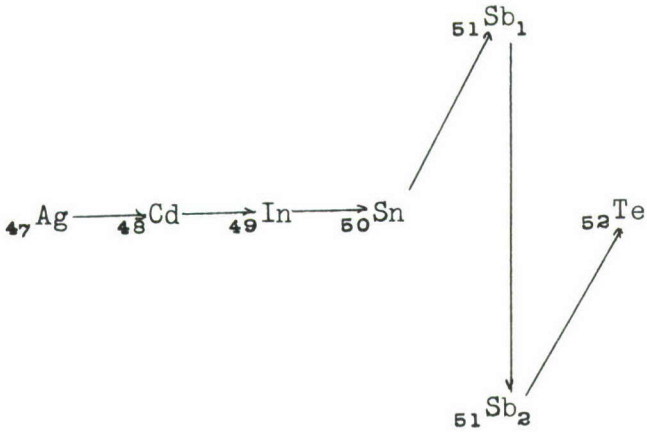


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Ag	2 *	Ag → Cd	9.45	7.20
Cd	5 *	Cd → In	7.18	5.70
In	15 *	In → Sn	6.60	4.70
Sn_1	582	Sn → Sb	2.69	2.70
Sn_2	8.12×10^5	Sb → Te	.837	.800
Sb	8.51×10^7			
Te_1	5.01×10^6			
Te_2	stable			

Decay Schemes:

Ag → Cd	Undetermined
Cd → In	Undetermined
In → Sn_1	Undetermined (50%)
In → Sn_2	Undetermined (50%)
Sn_1 → Sb	.65 (2.2%), 2.04 (97.8%)
Sn_2 → Sb	.37 (2.1%), .47(1.5%), .93 (.1%), 1.3 (1.3%), 2.33 (95%)
Sb → Te_1	.09 (.5%), .118 (1.3%), .124 (6.4%), .295 (8.6%), .437 (1.3%), .612 (2.9%)
Sb → Te_2	.09 (1.7%), .118 (4.8%), .124 (24.6%), .295 (32.5%), .437 (4.7%), .612 (10.7%)

126.

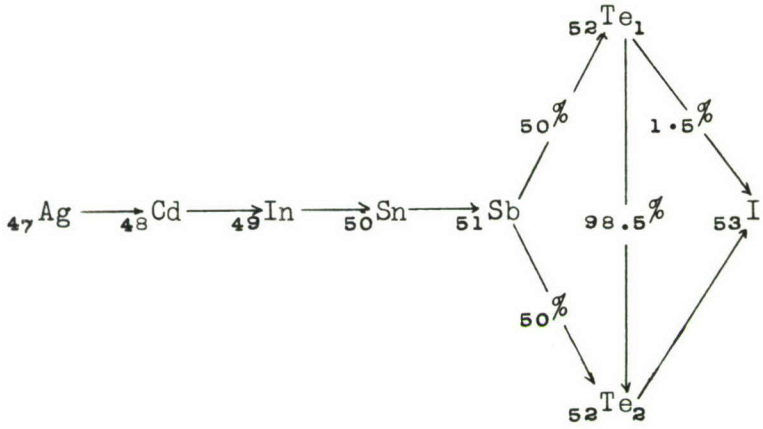


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Ag	1.5 *	Ag ⟶ Cd	11.9	10.0
Cd	3 *	Cd ⟶ In	5.65	3.71
In	7 *	In ⟶ Sn	9.01	7.02
Sn	6.30×10^{12}	Sn ⟶ Sb	1.19	.729
Sb_1	1.14×10^{3}	Sb ⟶ Te	3.93	4.04
Sb_2	1.08×10^{6}			
Te	stable			

Decay Schemes:

Ag ⟶ Cd	Undetermined
Cd ⟶ In	Undetermined
In ⟶ Sn	Undetermined
Sn ⟶ Sb_1	Undetermined
Sb_2 ⟶ Te	1.9 (100%)

127.

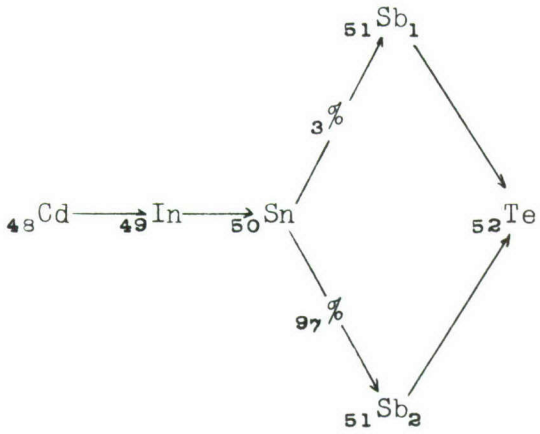


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Ag	1 *	Ag → Cd	10.3	7.99
Cd	1.5 *	Cd → In	8.10	6.51
In	3 *	In → Sn	7.48	5.53
Sn	9.36×10^3	Sn → Sb	3.60	3.55
Sb	3.2×10^5	Sb → Te	2.42	1.67
Te_1	9.07×10^6	Te → I	.738	.592
Te_2	3.35×10^4			
I	stable			

Decay Schemes:

Ag → Cd	Undetermined
Cd → In	Undetermined
In → Sn	Undetermined
Sn → Sb	Undetermined
Sb → Te_1	1.50 (50%)
Sb → Te_2	.80 (22%), .86 (6%), 1.11 (22%)
Te_1 → I	.73 (1.5%), IT (98.5%)
Te_2 → I	.27 (1%), .695 (99%)

128.

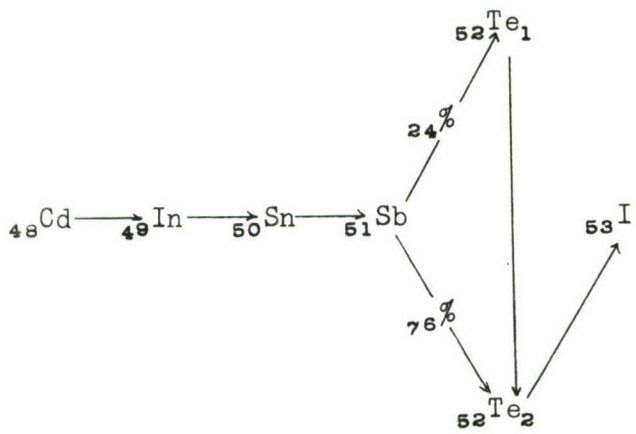


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Cd	1 *	Cd ⟶ In	6.50	4.56
In	2 *	In ⟶ Sn	9.94	7.79
Sn	3.72×10^3	Sn ⟶ Sb	2.07	1.62
Sb_1	3.46×10^4	Sb ⟶ Te	4.84	4.85
Sb_2	600			
Te	stable			

Decay Schemes:

Cd ⟶ In	Undetermined
In ⟶ Sn	Undetermined
Sn ⟶ Sb_1	Undetermined (3%)
Sn ⟶ Sb_2	Undetermined (97%)
Sb_1 ⟶ Te	1.0 (100%)
Sb_2 ⟶ Te	2.9 (100%)

129.

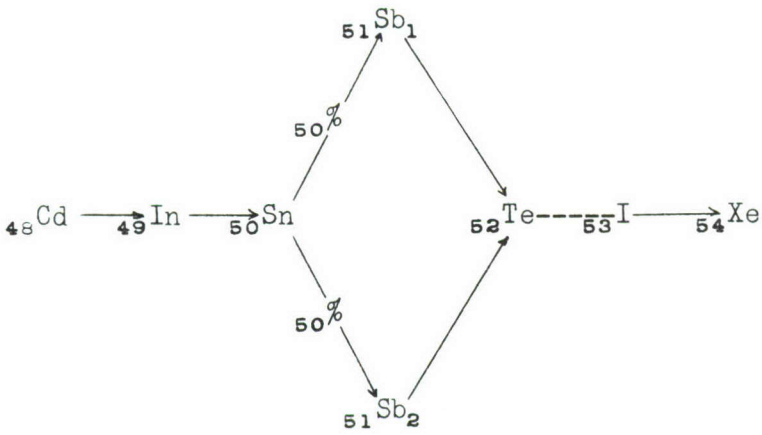


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Cd	1 *	Cd ⟶ In	8.95	7.30
In	1.5 *	In ⟶ Sn	8.34	6.34
Sn	3.60×10^3	Sn ⟶ Sb	4.53	4.38
Sb	1.55×10^4	Sb ⟶ Te	3.32	2.52
Te_1	2.85×10^6	Te ⟶ I	1.65	1.46
Te_2	4.02×10^3			
I	stable			

Decay Schemes:

Cd ⟶ In	Undetermined
In ⟶ Sn	Undetermined
Sn ⟶ Sb	Undetermined
Sb ⟶ Te_1	1.87 (4.8%), 3.32 (19.2%)
Sb ⟶ Te_2	1.87 (15%), 3.32 (61%)
Te_2 ⟶ I	.3 (1%), .7 (3%), .99 (16%), 1.453 (80%)

130.

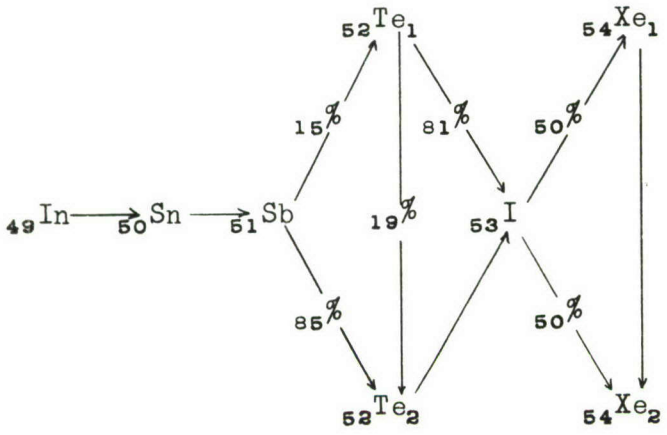


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Cd	1 *	Cd ⟶ In	8.67	12.9
In	1.5 *	In ⟶ Sn	10.8	8.71
Sn	156	Sn ⟶ Sb	2.94	2.67
Sb_1	420	Sb ⟶ Te	5.77	5.79
Sb_2	1.98×10^3	Te ⟶ I	.130	7.05
Te	stable	I ⟶ Xe	2.71	1.02
I	4.5×10^4			
Xe	stable			

Decay Schemes:

Cd ⟶ In	Undetermined
In ⟶ Sn	Undetermined
Sn ⟶ Sb_1	Undetermined (50%)
Sn ⟶ Sb_2	Undetermined (50%)
Sb_1 ⟶ Te	Undetermined
Sb_2 ⟶ Te	Undetermined
Te ⟶ I	No Transition - Shielded Nuclide
I ⟶ Xe	.6 (47%), 1.02 (53%)

131.

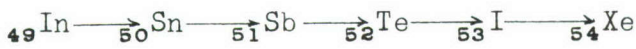


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
In	1.5 *	In → Sn	10.5	7.46
Sn	204	Sn → Sb	5.39	5.51
Sb	1380	Sb → Te	4.18	3.66
Te_1	1.04×10^5	Te → I	2.59	2.61
Te_2	1.5×10^3	I → Xe	1.19	1.16
I	6.96×10^5			
Xe_1	1.04×10^6			
Xe_2	stable			

Decay Schemes:

In → Sn	Undetermined
Sn → Sb	Undetermined
Sb → Te_1	Undetermined (15%)
Sb → Te_2	Undetermined (85%)
Te_1 → I	.215 (3.6%), .420 (43%), .570 (30%), 2.457 (4.4%), IT (19%)
Te_2 → I	1.15 (10%), 1.36 (5%), 1.68 (25%), 2.14 (60%)
I → Xe_1	.25 (1.4%), .33(4.6%), .606 (43.7%), .81(.3%)
I → Xe_2	.25 (1.4%), .33 (4.6%), .606 (43.7%), .81 (.3%)

132.

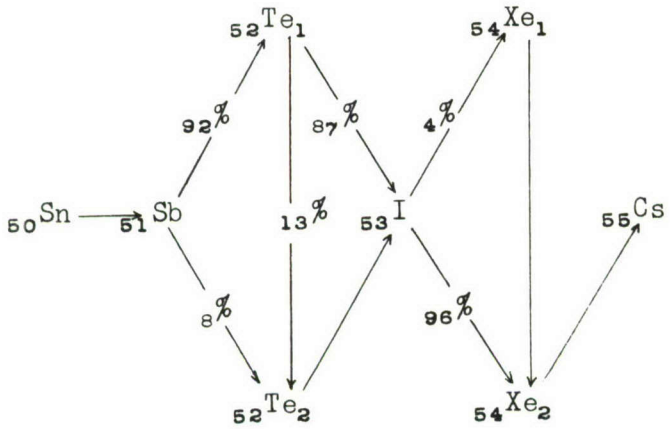


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
In	1.5 *	In → Sn	13.5	9.44
Sn	132	Sn → Sb	5.12	3.52
Sb	126	Sb → Te	6.63	6.56
Te	2.81×10^5	Te → I	1.00	.640
I	8.28×10^3	I → Xe	3.65	3.68
Xe	stable			

Decay Schemes:

In → Sn	Undetermined
Sn → Sb	Undetermined
Sb → Te	Undetermined
Te → I	.22 (100%)
I → Xe	.80 (21%), 1.04 (15%), 1.22 (12%), 1.49 (12%), 1.61 (21%), 2.14 (18%)

133.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Sn	1.8 *	Sn ⟶ Sb	8.07	6.29
Sb	246	Sb ⟶ Te	6.37	4.46
Te_1	3.0×10^3	Te ⟶ I	3.46	3.43
Te_2	120	I ⟶ Xe	2.06	2.00
I	7.56×10^4	Xe ⟶ Cs	.310	.572
Xe_1	1.99×10^5			
Xe_2	4.55×10^5			
Cs	stable			

Decay Schemes:

Sn ⟶ Sb	Undetermined
Sb ⟶ Te_1	3.67 (92%)
Sb ⟶ Te_2	4.00 (8%)
Te_1 ⟶ I	1.3 (70%), 2.4 (17%), IT (13%)
Te_2 ⟶ I	2.4 (100%)
I ⟶ Xe_1	1.54 (4%)
I ⟶ Xe_2	.5 (5.8%), 1.22 (90.2%)
Xe_2 ⟶ Cs	.268 (1%), .347 (99%)

134.

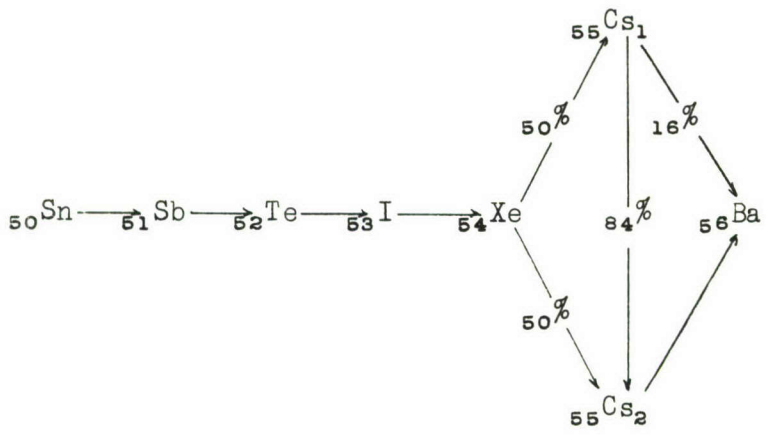
$_{50}Sn \xrightarrow{} {}_{51}Sb \xrightarrow{} {}_{52}Te \xrightarrow{} {}_{53}I \xrightarrow{} {}_{54}Xe$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Sn	1.3 *	Sn → Sb	8.04	4.63
Sb	48	Sb → Te	9.32	7.59
Te	2.52×10^3	Te → I	3.19	1.79
I	3.18×10^3	I → Xe	4.52	4.75
Xe	stable			

Decay Schemes:

Sn → Sb	Undetermined
Sb → Te	Undetermined
Te → I	Undetermined
I → Xe	.5 (6.5%), 1.05 (1%), 1.25 (23%), 1.49 (15%), 1.68 (7.5%), 1.81 (9.5%), 2.21 (12%), 2.41 (25%)

135.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Sn	1 *	Sn ⟶ Sb	9.75	7.33
Sb	24	Sb ⟶ Te	9.29	5.92
Te	60	Te ⟶ I	6.15	4.51
I	2.4×10^4	I ⟶ Xe	4.26	3.10
Xe	3.31×10^4	Xe ⟶ Cs	1.18	.282
Cs_1	3.18×10^3	Cs ⟶ Ba	-.169	-1.13
Cs_2	6.3×10^{13}			
Ba	stable			

Decay Schemes:

Sn ⟶ Sb	Undetermined
Sb ⟶ Te	Undetermined
Te ⟶ I	Undetermined
I ⟶ Xe	.47 (35%), 1.0 (40%), 1.4 (25%)
Xe ⟶ Cs_1	Undetermined (50%)
Xe ⟶ Cs_2	Undetermined (50%)
Cs_1 ⟶ Ba	Undetermined (16%), IT (84%)
Cs_2 ⟶ Ba	.21 (100%)

136.

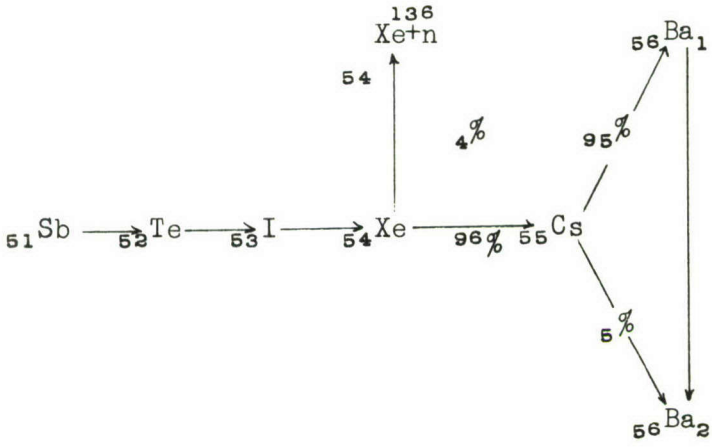
$_{51}Sb \longrightarrow _{52}Te \longrightarrow _{53}I \longrightarrow _{54}Xe \dashrightarrow _{55}Cs \longrightarrow _{56}Ba$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Sb	3 *	Sb ⟶ Te	11.0	8.58
Te	6 *	Te ⟶ I	6.12	2.90
I	83	I ⟶ Xe	7.22	5.78
Xe	stable	Xe ⟶ Cs	.924	.100
Cs	1.2×10^6	Cs ⟶ Ba	2.29	2.98
Ba	stable			

Decay Schemes:

Sb ⟶ Te	Undetermined
Te ⟶ I	Undetermined
I ⟶ Xe	2.73 (6%), 3.7 (44%), 4.16 (5%), 4.37 (24%), 5.60 (15%), 7.00 (6%)
Xe ⟶ Cs	No Transitions - Shielded Nuclide
Cs ⟶ Ba	.341 (92.6%), .657 (7.4%)

137.

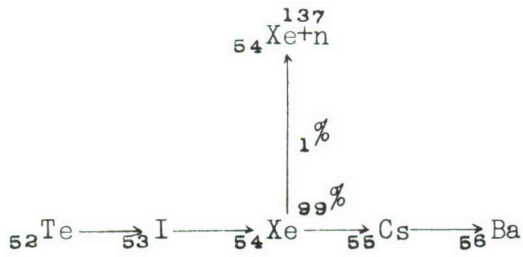


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Sb	1.5 *	Sb ⟶ Te	10.4	6.55
Te	3 *	Te ⟶ I	7.83	5.56
I	24	I ⟶ Xe	7.19	4.17
Xe	234	Xe ⟶ Cs	3.89	2.78
Cs	9.45×10^8	Cs ⟶ Ba	2.03	1.39
Ba_1	156			
Ba_2	stable			

Decay Schemes:

Sb ⟶ Te	Undetermined
Te ⟶ I	Undetermined
I ⟶ Xe	Undetermined
Xe ⟶ Cs	3.5 (96%)
Cs ⟶ Ba_1	.514 (95%)
Cs ⟶ Ba_2	1.18 (5%)

138.

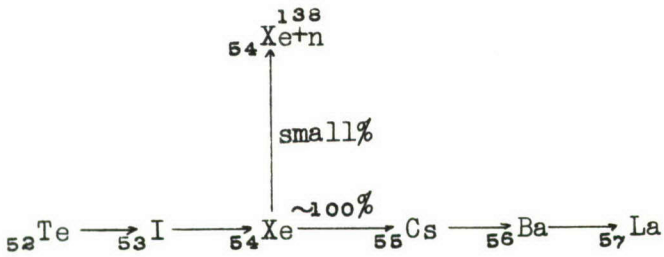


Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Te	2 *	Te ⟶ I	7.19	4.07
I	6.3	I ⟶ Xe	8.91	6.88
Xe	1.02×10^3	Xe ⟶ Cs	3.86	1.33
Cs	1.93×10^3	Cs ⟶ Ba	5.00	4.14
Ba	stable			

Decay Schemes:

Te ⟶ I	Undetermined
I ⟶ Xe	Undetermined
Xe ⟶ Cs	2.4 (99%)
Cs ⟶ Ba	2.2 (10%), 2.39 (36%), 2.53 (5%), 2.62 (16%) 2.94 (12%), 3.40 (21%)

139.



Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Te	1.3 *	Te ⟶ I	8.97	6.80
I	2	I ⟶ Xe	8.26	5.44
Xe	41	Xe ⟶ Cs	5.58	4.08
Cs	570	Cs ⟶ Ba	4.97	2.72
Ba	4.98×10^3	Ba ⟶ La	1.77	1.36
La	stable			

Decay Schemes:

Te ⟶ I	Undetermined
I ⟶ Xe	Undetermined
Xe ⟶ Cs	3.5 (50%), 4.6 (50%)
Cs ⟶ Ba	2.7 (16%), 3.4 (4%), 4.0 (80%)
Ba ⟶ La	2.17 (28%), 2.34 (72%)

140.

$_{52}Te \longrightarrow _{53}I \longrightarrow _{54}Xe \longrightarrow _{55}Cs \longrightarrow _{56}Ba \longrightarrow _{57}La \longrightarrow _{58}Ce$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Te	1 *	Te ⟶ I	7.80	5.37
I	1.8 *	I ⟶ Xe	10.0	8.12
Xe	16	Xe ⟶ Cs	4.94	2.67
Cs	66	Cs ⟶ Ba	6.69	5.42
Ba	1.11×10^6	Ba ⟶ La	1.75	-.025
La	1.45×10^5	La ⟶ Ce	3.17	2.72
Ce	stable			

Decay Schemes:

Te ⟶ I	Undetermined
I ⟶ Xe	Undetermined
Xe ⟶ Cs	Undetermined
Cs ⟶ Ba	6.0 (100%)
Ba ⟶ La	.48 (25%), .6 (10%), .9 (5%), 1.01 (60%)
La ⟶ Ce	.83 (12%), 1.10 (26%), 1.38 (45%), 1.71 (10%) 2.20 (7%)

141.

$_{53}I \longrightarrow {}_{54}Xe \longrightarrow {}_{55}Cs \longrightarrow {}_{56}Ba \longrightarrow {}_{57}La \longrightarrow {}_{58}Ce \longrightarrow {}_{59}Pr$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
I	1.5 *	I ⟶ Xe	8.88	6.70
Xe	2	Xe ⟶ Cs	6.72	5.36
Cs	24	Cs ⟶ Ba	6.06	4.02
Ba	1.08×10^3	Ba ⟶ La	3.47	2.68
La	1.40×10^4	La ⟶ Ce	3.15	1.69
Ce	2.81×10^6	Ce ⟶ Pr	-.163	.0
Pr	stable			

Decay Schemes:

I ⟶ Xe	Undetermined
Xe ⟶ Cs	Undetermined
Cs ⟶ Ba	Undetermined
Ba ⟶ La	2.8 (100%)
La ⟶ Ce	1.06 (2%), 2.43 (98%)
Ce ⟶ Pr	.435 (70%), .580 (30%)

142.

$_{53}I \longrightarrow {}_{54}Xe \longrightarrow {}_{55}Cs \longrightarrow {}_{56}Ba \longrightarrow {}_{57}La \longrightarrow {}_{58}Ce$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
I	1 *	I ⟶ Xe	10.6	9.31
Xe	1.5 *	Xe ⟶ Cs	5.56	3.98
Cs	2.3	Cs ⟶ Ba	7.84	6.65
Ba	660	Ba ⟶ La	2.83	1.32
La	5.04×10^3	La ⟶ Ce	4.88	3.99
Ce	stable			

Decay Schemes:

I ⟶ Xe	Undetermined
Xe ⟶ Cs	Undetermined
Cs ⟶ Ba	Undetermined
Ba ⟶ La	4.0 (100%)
La ⟶ Ce	2.5 (30%), 4.0 (30%), 4.5 (40%)

143.

$_{54}Xe \longrightarrow {}_{55}Cs \longrightarrow {}_{56}Ba \longrightarrow {}_{57}La \longrightarrow {}_{58}Ce \longrightarrow {}_{59}Pr \longrightarrow {}_{60}Nd$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Xe	1	Xe ⟶ Cs	7.33	6.60
Cs	2	Cs ⟶ Ba	6.68	5.28
Ba	12	Ba ⟶ La	4.62	3.96
La	840	La ⟶ Ce	4.24	2.99
Ce	1.18×10^5	Ce ⟶ Pr	1.54	1.32
Pr	1.18×10^6	Pr ⟶ Nd	1.57	.350
Nd	stable			

Decay Schemes:

Xe ⟶ Cs	Undetermined
Cs ⟶ Ba	Undetermined
Ba ⟶ La	Undetermined
La ⟶ Ce	3.3 (100%)
Cr ⟶ Pr	.22 (6%), .52 (12%), .72 (5%), 1.09 (40%), 1.38 (37%)
Pr ⟶ Nd	.933 (100%)

144.

$_{54}Xe \longrightarrow {}_{55}Cs \longrightarrow {}_{56}Ba \longrightarrow {}_{57}La \longrightarrow {}_{58}Ce \longrightarrow {}_{59}Pr \longrightarrow {}_{60}Nd$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Xe	1	Xe ⟶ Cs	6.08	5.10
Cs	1.5 *	Cs ⟶ Ba	8.45	7.73
Ba	3.5 *	Ba ⟶ La	3.46	2.48
La	15 *	La ⟶ Ce	6.03	5.11
Ce	2.46×10^7	Ce ⟶ Pr	.912	-.136
Pr	1.04×10^3	Pr ⟶ Nd	3.29	2.49
Nd	stable			

Decay Schemes:

Xe ⟶ Cs	Undetermined
Cs ⟶ Ba	Undetermined
Ba ⟶ La	Undetermined
La ⟶ Ce	Undetermined
Cr ⟶ Pr	.186 (20%), .320 (72%), 2.40 (8%)
Pr ⟶ Nd	.80 (1%), 2.29 (1.3%), 2.98 (97.7%)

145.

$_{55}Cs \longrightarrow {}_{56}Ba \longrightarrow {}_{57}La \longrightarrow {}_{58}Ce \longrightarrow {}_{59}Pr \longrightarrow {}_{60}Nd$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Cs	1 *	Cs ⟶ Ba	7.21	6.37
Ba	2 *	Ba ⟶ La	5.24	5.07
La	9 *	La ⟶ Ce	4.87	4.12
Ce	180	Ce ⟶ Pr	2.70	2.47
Pr	2.12×10^4	Pr ⟶ Nd	2.66	1.52
Nd	stable			

Decay Schemes:

Cs ⟶ Ba	Undetermined
Ba ⟶ La	Undetermined
La ⟶ Ce	Undetermined
Ce ⟶ Pr	2.0 (100%)
Pr ⟶ Nd	1.8 (100%)

146.

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Cs	1 *	Cs ⟶ Ba	9.28	8.84
Ba	1.5 *	Ba ⟶ La	3.99	3.70
La	4 *	La ⟶ Ce	6.65	6.28
Ce	840	Ce ⟶ Pr	1.55	1.14
Pr	1.44×10^3	Pr ⟶ Nd	4.45	3.72
Nd	stable			

Decay Schemes:

Cs ⟶ Ba	Undetermined
Ba ⟶ La	Undetermined
La ⟶ Ce	Undetermined
Ce ⟶ Pr	.7 (100%)
Pr ⟶ Nd	2.3 (44%), 3.7 (56%)

147.

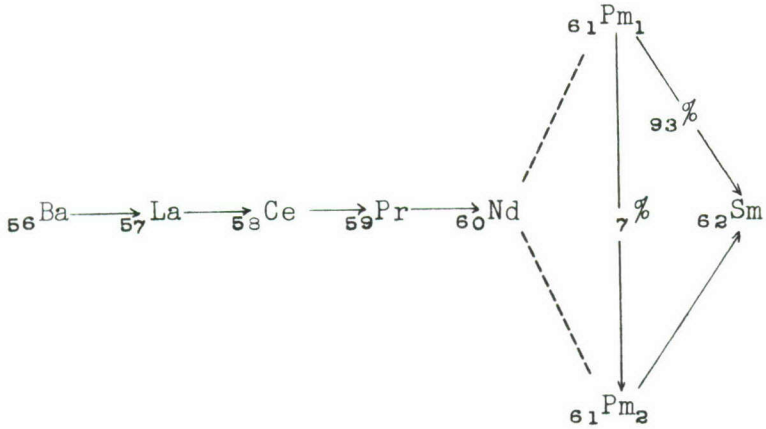
$_{56}Ba \longrightarrow _{57}La \longrightarrow _{58}Ce \longrightarrow _{59}Pr \longrightarrow _{60}Nd \longrightarrow _{61}Pm \longrightarrow _{62}Sm$

Half-lives (sec):		Mass Diff.(Mev):	Cameron	Coryell
Ba	1 *	Ba → La	6.06	6.22
La	2 *	La → Ce	5.41	5.30
Ce	72	Ce → Pr	3.33	3.68
Pr	720	Pr → Nd	3.30	2.76
Nd	9.59×10^5	Nd → Pm	.986	1.14
Pm	7.88×10^7	Pm → Sm	.941	.223
Sm	stable			

Decay Schemes:

Ba → La	Undetermined
La → Ce	Undetermined
Ce → Pr	Undetermined
Pr → Nd	Undetermined
Nd → Pm	.212 (3%), .368 (20%), .810 (77%)
Pm → Sm	.225 (100%)

148.



Half-lives (sec):		Mass Diff (Mev):	Cameron	Coryell
Ba	1 *	Ba ⟶ La	4.69	4.91
La	2 *	La ⟶ Ce	7.48	7.43
Ce	42	Ce ⟶ Pr	2.09	2.39
Pr	120	Pr ⟶ Nd	5.08	4.91
Nd	stable	Nd ⟶ Pm	-.167	-.126
Pm_1	3.72×10^6	Pm ⟶ Sm	2.74	2.39
Pm_2	4.67×10^5			
Sm	stable			

Decay Schemes:

Ba ⟶ La	Undetermined
La ⟶ Ce	Undetermined
Ce ⟶ Pr	Undetermined
Pr ⟶ Nd	Undetermined
Nd ⟶ Pm_1	No Transitions - Shielded Nuclide
Nd ⟶ Pm_2	No Transitions - Sheilded Nuclide
Pm_1 ⟶ Sm	.39 (42%), .49 (22%), .56 (7%), 68 (22%), IT (7%)
Pm_2 ⟶ Sm	.99 (41%), 1.9 (14%), 2.45 (45%)

149.

$_{57}La \longrightarrow {}_{58}Ce \longrightarrow {}_{59}Pr \longrightarrow {}_{60}Nd \longrightarrow {}_{61}Pm \longrightarrow {}_{62}Sm$

Half-lives (sec):		Mass Diff (Mev):	Cameron	Coryell
La	1.5 *	La ⟶ Ce	6.11	6.35
Ce	3.5 *	Ce ⟶ Pr	4.16	4.75
Pr	30 *	Pr ⟶ Nd	3.84	3.85
Nd	6.48×10^3	Nd ⟶ Pm	1.61	2.25
Pm	1.91×10^6	Pm ⟶ Sm	1.59	1.35
Sm	stable			

Decay Schemes:

La ⟶ Ce	Undetermined
Ce ⟶ Pr	Undetermined
Pr ⟶ Nd	Undetermined
Nd ⟶ Pm	.95 (16%), 1.1 (43%), 1.5 (31%)
Pm ⟶ Sm	.784 (3%), 1.071 (97%)

150.

$_{57}La \longrightarrow {}_{58}Ce \longrightarrow {}_{59}Pr \longrightarrow {}_{60}Nd \cdots {}_{61}Pm \longrightarrow {}_{62}Sm$

Half-lives (sec):		Mass Diff (Mev):	Cameron	Coryell
La	1.5 *	La ⟶ Ce	8.52	8.23
Ce	2.5 *	Ce ⟶ Pr	2.79	3.26
Pr	15 *	Pr ⟶ Nd	5.92	5.73
Nd	stable	Nd ⟶ Pm	.378	.765
Pm	9.72×10^3	Pm ⟶ Sm	3.37	3.23
Sm	stable			

Decay Schemes:

La ⟶ Ce	Undetermined
Ce ⟶ Pr	Undetermined
Pr ⟶ Nd	Undetermined
Nd ⟶ Pm	No Transition - Shielded Nuclide
Pm ⟶ Sm	.35 (.4%), .52 (.4%), .9 (1%), 1.02 (1.4%), 1.36 (22%), 1.46 (8.5%), 1.8 (22%), 2.28 (29.3%) 2.77 (2.5%), 3.10 (12.5%)

151.

$_{57}La \longrightarrow {}_{58}Ce \longrightarrow {}_{59}Pr \longrightarrow {}_{60}Nd \longrightarrow {}_{61}Pm \longrightarrow {}_{62}Sm \longrightarrow {}_{63}Eu$

Half-lives (sec):		Mass Diff (Mev):	Cameron	Coryell
La	1 *	La ⟶ Ce	6.99	7.05
Ce	2 *	Ce ⟶ Pr	5.20	5.46
Pr	7 *	Pr ⟶ Nd	4.55	4.57
Nd	720	Nd ⟶ Pm	2.46	2.98
Pm	1.02×10^5	Pm ⟶ Sm	2.13	2.09
Sm	2.84×10^9	Sm ⟶ Eu	.182	.496
Eu	stable			

Decay Schemes:

La ⟶ Ce	Undetermined
Ce ⟶ Pr	Undetermined
Pr ⟶ Nd	Undetermined
Nd ⟶ Pm	.24 (1%), .54 (3%), 1.19 (30%), 1.65 (7%), 1.82 (15%), 2.06 (45%)
Pm ⟶ Sm	.374 (5%), .454 (3%), .75 (6%), .85 (39%), .871 (2%), .968 (1%), 1.03 (10%), 1.09 (6%), 1.125 (8%), 1.129 (5%), 1.20 (11%)
Sm ⟶ Eu	.0543 (1.6%), .0759 (98.4%)

152.

$_{58}Ce \longrightarrow {}_{59}Pr \longrightarrow {}_{60}Nd \longrightarrow {}_{61}Pm \longrightarrow {}_{62}Sm$

Half-lives (sec):		Mass Diff (Mev):	Cameron	Coryell
Ce	1.5 *	Ce ⟶ Pr	3.68	3.99
Pr	5 *	Pr ⟶ Nd	6.96	6.43
Nd	180 *	Nd ⟶ Pm	1.09	1.51
Pm	360	Pm ⟶ Sm	4.21	3.95
Sm	stable			

Decay Schemes:

Ce ⟶ Pr	Undetermined
Pr ⟶ Nd	Undetermined
Nd ⟶ Pm	Undetermined
Pm ⟶ Sm	2.2 (100%)

153.

$$_{58}Ce \longrightarrow {}_{59}Pr \longrightarrow {}_{60}Nd \longrightarrow {}_{61}Pm \longrightarrow {}_{62}Sm \longrightarrow {}_{63}Eu$$

Half-lives (sec):		Mass Diff (Mev):	Cameron	Coryell
Ce	1.5 *	Ce ⟶ Pr	6.22	6.15
Pr	3 *	Pr ⟶ Nd	5.44	5.27
Nd	18 *	Nd ⟶ Pm	3.50	3.69
Pm	330	Pm ⟶ Sm	2.85	2.81
Sm	1.68×10^5	Sm ⟶ Eu	1.03	1.23
Eu	stable			

Decay Schemes:

Ce ⟶ Pr	Undetermined
Pr ⟶ Nd	Undetermined
Nd ⟶ Pm	Undetermined
Pm ⟶ Sm	1.65 (100%)
Sm ⟶ Eu	.641 (33.4%), .696 (45.6%), .707 (.5%) .721 (.3%), .803 (20%)

154.

$_{58}Ce \longrightarrow {}_{59}Pr \longrightarrow {}_{60}Nd \longrightarrow {}_{61}Pm \longrightarrow {}_{62}Sm$

Half-lives (sec):			Mass Diff (Mev):	Cameron	Coryell
Ce	1	*	Ce ⟶ Pr	4.66	4.79
Pr	2	*	Pr ⟶ Nd	7.98	7.17
Nd	12	*	Nd ⟶ Pm	1.98	2.35
Pm	150		Pm ⟶ Sm	5.26	4.73
Sm	stable				

Decay Schemes:

Ce ⟶ Pr	Undetermined
Pr ⟶ Nd	Undetermined
Nd ⟶ Pm	Undetermined
Pm ⟶ Sm	2.5 (100%)

155.

$$_{59}Pr \xrightarrow{} {}_{60}Nd \xrightarrow{} {}_{61}Pm \xrightarrow{} {}_{62}Sm \xrightarrow{} {}_{63}Eu \xrightarrow{} {}_{64}Gd$$

Half-lives (sec):		Mass Diff (Mev):	Cameron	Coryell
Pr	2 *	Pr ⟶ Nd	6.43	6.16
Nd	5 *	Nd ⟶ Pm	4.53	4.60
Pm	60 *	Pm ⟶ Sm	3.74	3.74
Sm	1.32×10^3	Sm ⟶ Eu	2.08	2.18
Eu	5.36×10^7	Eu ⟶ Gd	.882	1.17
Gd	stable			

Decay Schemes:

Pr ⟶ Nd	Undetermined
Nd ⟶ Pm	Undetermined
Pm ⟶ Sm	Undetermined
Sm ⟶ Eu	1.39 (5%), 1.53 (95%)
Eu ⟶ Ge	.140 (43%), .160 (37%), .185 (10%) .247 (15%)

156.

$_{59}Pr \xrightarrow{} {}_{60}Nd \xrightarrow{} {}_{61}Pm \xrightarrow{} {}_{62}Sm \xrightarrow{} {}_{63}Eu \xrightarrow{} {}_{64}Gd$

Half-lives (sec):		Mass Diff (Mev):	Cameron	Coryell
Pr	1.5 *	Pr ⟶ Nd	9.07	7.94
Nd	4.5 *	Nd ⟶ Pm	2.97	3.19
Pm	25 *	Pm ⟶ Sm	6.29	5.52
Sm	3.24×10^4	Sm ⟶ Eu	.566	.771
Eu	1.3×10^6	Eu ⟶ Gd	3.30	3.10
Gd	stable			

Decay Schemes:

Pr ⟶ Nd	Undetermined
Nd ⟶ Pm	Undetermined
Pm ⟶ Sm	Undetermined
Sm ⟶ Eu	.43 (55%), .715 (45%)
Eu ⟶ Gd	.3 (23%), .48 (34%), 1.21 (11%), 2.447 (32%)

157.

$$_{59}Pr \longrightarrow_{60} Nd \longrightarrow_{61} Pm \longrightarrow_{62} Sm \longrightarrow_{63} Eu \longrightarrow_{64} Gd$$

Half-lives (sec):		Mass Diff (Mev):	Cameron	Coryell
Pr	1.5 *	Pr ⟶ Nd	7.48	6.71
Nd	3 *	Nd ⟶ Pm	5.61	5.16
Pm	13 *	Pm ⟶ Sm	4.74	4.31
Sm	30	Sm ⟶ Eu	3.11	2.76
Eu	5.40×10^4	Eu ⟶ Ge	1.79	1.76
Gd	stable			

Decay Schemes:

Pr ⟶ Nd	Undetermined
Nd ⟶ Pm	Undetermined
Pm ⟶ Sm	Undetermined
Sm ⟶ Eu	Undetermined
Eu ⟶ Gd	1.27 (100%)

158.

$_{60}Nd \longrightarrow {}_{61}Pm \longrightarrow {}_{62}Sm \longrightarrow {}_{63}Eu \longrightarrow {}_{64}Gd$

Half-lives (sec):		Mass Diff (Mev):	Cameron	Coryell
Nd	2 *	Nd ⟶ Pm	4.03	3.78
Pm	6 *	Pm ⟶ Sm	7.38	6.06
Sm	900 *	Sm ⟶ Eu	1.56	1.38
Eu	3.6×10^3	Eu ⟶ Gd	4.33	3.66
Gd	stable			

Decay Schemes:

Nd ⟶ Pm	Undetermined
Pm ⟶ Sm	Undetermined
Sm ⟶ Eu	Undetermined
Eu ⟶ Gd	2.65 (100%)

159.

$_{60}Nd \xrightarrow{6_1} Pm \xrightarrow{6_2} Sm \xrightarrow{6_3} Eu \xrightarrow{6_4} Gd \xrightarrow{6_5} Tb$

Half-lives (sec):		Mass Diff (Mev):	Cameron	Coryell
Nd	1.8 *	Nd ⟶ Pm	6.68	5.76
Pm	3.5 *	Pm ⟶ Sm	5.80	4.91
Sm	40 *	Sm ⟶ Eu	4.21	3.36
Eu	1.14×10^3	Eu ⟶ Gd	2.79	2.36
Gd	6.48×10^4	Gd ⟶ Tb	1.46	.960
Tb	stable			

Decay Schemes:

Nd ⟶ Pm	Undetermined
Pm ⟶ Sm	Undetermined
Sm ⟶ Eu	Undetermined
Eu ⟶ Gd	2.2 (100%)
Gd ⟶ Tb	.59 (13%), .89 (24%), .947 (63%)

Appendix C

Computer Programs

This appendix contains the information necessary to understand the operations of the four computer programs referred to in the body of the thesis. This information consists of a listing of the program's Fortran statements, a list of the definitions of all terms used, and a flow chart. The information for each of the four programs is presented in this order. In programs two and four, the omission of the definition of a variable in a function or subroutine implies that the definition found earlier still applies and has been omitted for brevity.

```
C                                   PROGRAM I
C       PROGRAM TO COMPUTE AND CHECK PZ VALUES
        DIMENSION CHAIN(85),A(11),NOK(11),ANO(85),Y(85),P(85)
        READ 16,ITF,YM
        N=1
1       GO TO(2,3,4,20),ITF
2       READ 17,ANO(N),NI,ZMIN,ZP,W,CHAIN(N),WW,(11)
        READ 18,WWW
        ZP=ZP+.316
        GO TO 5
20      READ 17,ANO(N),NI,ZMIN,ZP,W,WW,WWW,(11)
        READ 18,CHAIN(N)
        ZP=ZP+.023
        GO TO 5
3       READ 17,ANO(N),NI,ZMIN,ZP,CHAIN(N),W,WW,(11)
        READ 18,WWW
        GO TO 5
4       READ 17,ANO(N),NI,ZMIN,ZP,W,WW,CHAIN(N),(11)
        READ 18,WWW
        ZP=ZP-.475
5       READ 52,(NOK(I),I=1,NI)
        Z=ZMIN
        X=CHAIN(N)
        DO 9 I=1,NI
        Z=Z+1.
        IF(1-NOK(I))6,7,8
6       Z=Z-1.
7       C=ABS(Z-ZP)
        IF(2.2-C)22,23,23
23      YIELD=6.8444E21*X*EXP(-.7*C*C)*YM
        GO TO 24
22      YIELD=2.675E27*X*EXP(-7.38*C)*YM
24      A(I)=YIELD/2.
        GO TO 9
8       C=ABS(Z-ZP)
        IF(2.2-C)27,28,28
28      YIELD=6.8444E21*X*EXP(-.7*C*C)*YM
        GO TO 29
27      YIELD=2.675E27*X*EXP(-7.38*C)*YM
29      A(I)=YIELD
9       CONTINUE
        PUNCH 100,ANO(N),ZMIN,NI
        PUNCH 101,(A(I),I=1,NI)
        Y(N)=0.0
        DO 10 I=1,NI
10      Y(N)=Y(N)+A(I)/1.45E22
        N=N+1
        GO TO 1
11      DO 12 N=1,83
12      P(N)=(CHAIN(N)-Y(N))*100./CHAIN(N)
        PRINT 103
```

```
      PRINT 104
      DO 13 N=1,41
      M=N+42
13    PRINT 105,ANO(N),CHAIN(N),Y(N),P(N),ANO(M),CHAIN(M),Y(M),P(M)
      PRINT 106,ANO(42),CHAIN(42),Y(42),P(42)
      STOP
16    FORMAT(I2,F8.4)
17    FORMAT(E10.0,I10,5E10.4)
18    FORMAT(E10.4)
52    FORMAT(11I2)
100   FORMAT(2F10.0,I10)
101   FORMAT(1P6E12.4)
103   FORMAT(1H1,39X,52HCOMPARISON OF CHAIN YIELD AND SUM OF ISOTOPIC YI
     1ELDS)
104   FORMAT(1H0,2(8X,5HA NO.,4X,11HCHAIN YIELD,3X,14HISOTOPIC YIELD,2X,
     18HPCT DIFF,5X),1H )
105   FORMAT(2(5X,F10.0,2F15.4,F10.2,5X))
106   FORMAT(5X,F10.0,2F15.4,F10.2)
      END
```

PROGRAM I

A, ANO	=	Atomic weight of mass chain
C	=	Absolute value of Z - Zp
CHAIN	=	Chain yield
ITF	=	Indicator of the type of fission: 1 indicates Pu-239 thermal neutron fission; 2 indicates U-235 thermal neutron fission; 3 indicates thermonuclear neutron fission; 4 indicates U-235 fission spectrum neutron fission
NI	=	Number of isotopes in mass chain
NOK	=	Indicator of isomeric split: 0 indicates no isomeric pair; 1 indicates first member of isomeric pair; 2 indicates second member of isomeric pair
P	=	Percent difference between chain yield and sum of isotopic yield
Y	=	Sum of isotopic yields
YIELD	=	Isotopic yield
YM	=	Number of megatons of fission
Z	=	Atomic number of isotope
ZMIN	=	One unit less than the atomic number of the first isotope in the chain
ZP	=	Most probable charge formed in fission
X, W, WW, WWW	=	Dummy variables
M, N, I	=	Indicies of "DO" loops

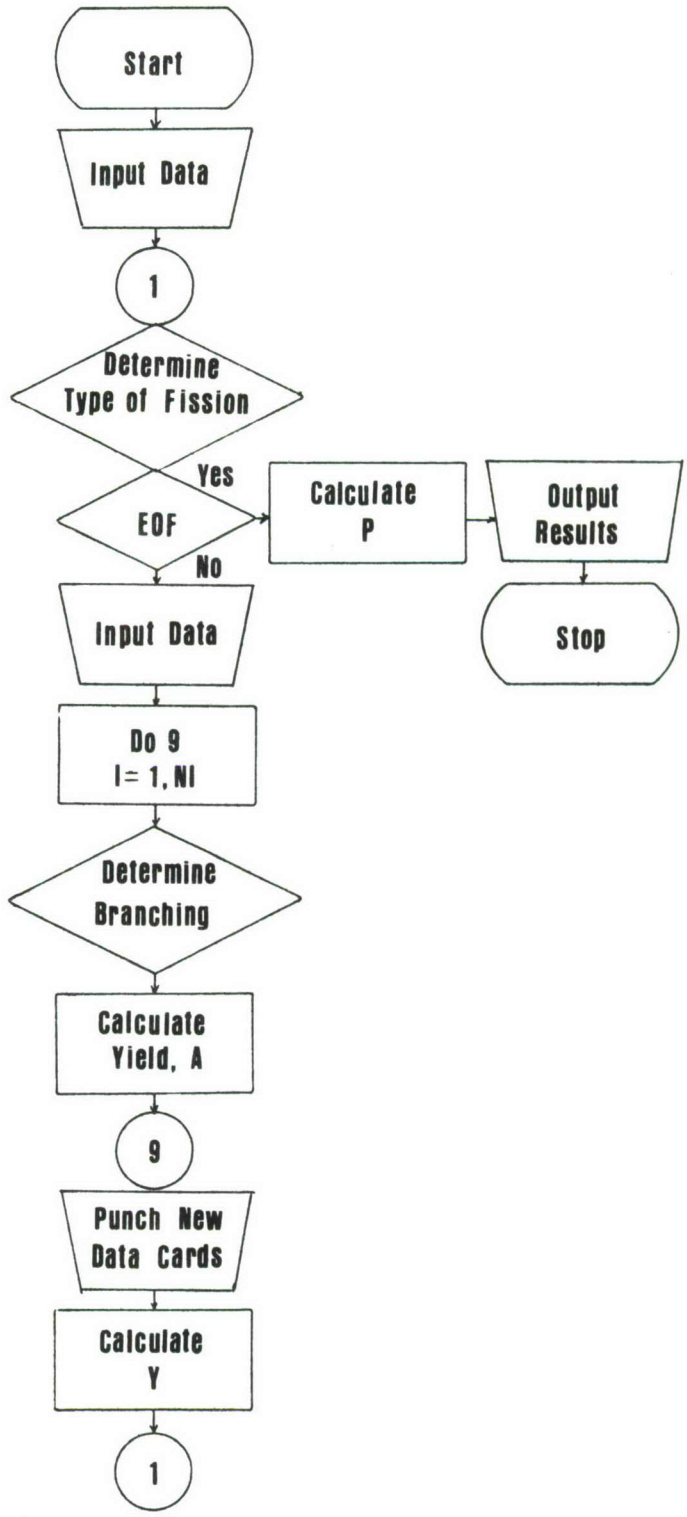


Fig. 17
Flow Chart for Program I

```
C                                PROGRAM II
C       THIS PROGRAM COMPUTES AND WRITES ON TAPE THE NORMALIZED SPECTRAL
C       SHAPES
C
        COMMON A,Z,S,SO,L,THALF,GIRLY,FRAC,EOP,FOG
        READ 91,MF,ALPHA
1       READ 17,ANO,NI,ZMIN,(16)
        WRITE TAPE 3,ANO,NI
        KA=0
        A=ANO
        Z=ZMIN
        DO 15 L=1,NI
        READ 18,IO,THALF,JO
        IF (KA) 5,4,5
4       Z=Z+1.
5       IF (JO) 6,7,6
6       KA=1
        GO TO 8
7       KA=0
8       IF(THALF)9,30,9
30      MI=1
        FUNN=0.0
        WRITE TAPE 3,MI,THALF
        WRITE TAPE 3,FUNN
        GO TO 15
9       SO=(Z/137.0371)**2
        S=SQRTF(1.0-SO)-1.0
        II=IABS(IO)
        DO 15 LOLA=1,II
        IF(IO)20,20,21
20      IF(MF)22,22,23
22      READ 90,DIFF,W
        GO TO 24
23      READ 90,W,DIFF
24      EOP=DIFF*ALPHA
        FRAC = 1.000
        GO TO 14
21      READ 19,EOP,FRAC
14      GIRLY=SHAPE(2)
        CALL BINER(LOLA,II)
15      CONTINUE
        GO TO 1
16      END FILE 3
        REWIND 3
        STOP
17      FORMAT(F10.0,I5,F10.0)
18      FORMAT(I5,1PE10.2,I5)
19      FORMAT(2F10.3)
90      FORMAT(2E10.3)
91      FORMAT(I5,E10.4)
        END
```

```
      FUNCTION SHAPE (R)
C
C     * THIS SUBROUTINE COMPUTES LOG 10 FT VALUES FOR THE FISSION PRO- *
C     *DUCTS.  THESE LOG 10 FT VALUES ARE IN TURN USED IN DETERMINING  *
C     *THE FORBIDENESS SHAPE FACTORS TO BE USED WITH THE FERMI BETA DE-*
C     *CAY THEORY IN FORMULATING SPECTRAL SHAPES.                      *
C
      COMMON A,Z,S,SQ,L,THALF,GIRLY,FRAC,EOP,FOG
      FP=GORT(1)
      FP1=ALOG(FP*THALF)/2.30258
      PSQ=5.464E03/(FP*THALF)
      IF (6.-FP1) 2,1,1
1     SHAPE=20.
      RETURN
2     IF (8.-FP1) 4,3,3
3     SHAPE=-1.
      RETURN
4     IF (10.-FP1) 6,5,5
5     SHAPE=0.0
      RETURN
6     IF (15.5-FP1) 8,7,7
7     SHAPE=1.0
      RETURN
8     SHAPE=2.0
      RETURN
      END
```

```
      FUNCTION GORT (BO)
C
C     * THIS SUBROUTINE COMPUTES THE FERMI INTEGRAL FUNCTION USING THE *
C     *TRAPEZOIDAL RULE.  THE INTEGRATION IS CALCULATED IN TWO PARTS.  *
C     *FOR T LESS THAN OR EQUAL TO 1.0 MEV EACH 0.1 MEV INTERVAL IS    *
C     *SEPERATED INTO TEN INCREMENTS.  FOR T GREATER THAN 1.0 MEV EACH *
C     *1.0 MEV INTERVAL IS SEPERATED INTO TEN INCREMENTS.              *
C
      COMMON A,Z,S,SO,L,THALF,GIRLY,FRAC,EOP,FOG
      GORT=0.
      E=0.
      CLAMY=.01957
      EO=((EOP/.511)+1.)
      NOT=101
      FOG=PHI(1)
      IF (1.-EOP) 2,2,1
1     NOT=(EOP/.01+1.)
2     DO 6 K=1,NOT
      E=E+CLAMY
      IF (K-1) 3,3,4
3     E=1.0
4     X=SQRTF(E*E-1.0)
      Y=.04585*Z*E/X
      ZAM=EO-E
      F=Y*X*FOG*ZAM*ZAM*E*CLAMY*((SO*E*E+X*X/4.)**S)/ABS(1.-EXPF(-Y))
      IF (NOT-K) 5,5,6
5     F=F/2.
6     GORT=GORT+F
      IF (1.-EOP) 8,7,7
7     RETURN
8     NOT=(EOP-1.)/.1
      CLAMY=.195/
      DO 13 K=1,NOT
      IF (K-1) 9,9,10
9     E=2.957
      GO TO 11
10    E=E+CLAMY
11    X=SQRTF(E*E-1.0)
      Y=.04585*Z*E/X
      ZAM=EO-E
      F=Y*X*FOG*ZAM*ZAM*E*CLAMY*((SO*E*E+X*X/4.)**S)/ABS(1.-EXPF(-Y))
      IF (K-1) 12,12,13
12    F=F/2.
13    GORT=GORT+F
      RETURN
      END
```

```
      FUNCTION PHI (BB)
C
C     *THIS SUBROUTINE COMPUTES PHI(Z), A FUNCTION OF ATOMIC CHARGE AND*
C     *MASS NUMBER ONLY.  NOTE THAT PHI(Z) IS UNITLESS.                *
C
      COMMON A,Z,S,SO,L,THALF,GIRLY,FRAC,EOP,FOG
      C=5.1794E12
      D=A**0.33333333
      R=1.112E-15*(D-.62025/D)
      RS=2.*S
      PHI=((C*R)**RS)*((2./GAMMA(3.+RS))**2)*(1.+S/2.)
      RETURN
      END
```

```
      FUNCTION GAMMA (X)
C
C     *THIS FUNCTION COMPUTES THE GAMMA FUNCTION OF X FOR POSITIVE AND*
C     *NEGATIVE VALUES OF X.                                          *
C
      COMMON A,Z,S,SO,L,THALF,GIRLY,FRAC,EOP,FOG
1     IF (X) 8,2,3
2     PRINT 10,X
      GAMMA=1.70141179E38
      RETURN
3     Y=X
4     GLN=0.918938568+(Y-0.5)*ALOG(Y)-Y+(1.0/(12.0*Y))-(1.0/(360.0*Y**3)
     1)+(1.0/(1260.0*Y**5))-(1.0/(1680.0*Y**7))+(1.0/(1188.0*Y**9))
      IF (GLN-88.0) 5,2,2
5     G=EXPF(GLN)
      IF (X) 7,1,6
6     GAMMA=G
      RETURN
7     GAMMA=3.1415927/(SINF(3.1415927*Y)*G)
      RETURN
8     K=-X
      Y=K
      IF (Y+X) 9,2,9
9     Y=1.0-X
      GO TO 4
10    FORMAT (18H GAMMA FUNCTION OF,1PE15.7,27H EXCEEDS +/-1.70141179E+3
     18.)
      END
```

```
      SUBROUTINE BINER(LCLA,II)
C
C     * THIS SUBROUTINE CALCULATES AND SUMS ALL OF THE INDIVIDUAL IN-   *
C     *STANTANEOUS AND INTEGRATED SPECTRA FROM THE FISSION PRODUCTS.    *
C     *IT COMBINES ALL OF THE ACTIVITY, HALF-LIFE, EPE, AND FORBIDE-    *
C     *NESS INFORMATION IN CALCULATING THE EFFECTIVE BETA SPECTRUM OF   *
C     *THE FISSION PRODUCTS.                                           *
C
      COMMON A,Z,S,SO,L,THALF,GIRLY,FRAC,EOP,FOG
      DIMENSION FUN(210),FUN1(210,11)
4     SUM=0.0
      E=0.0
      NOT=101
      CLAMY=.01957
      EO=((EOP/.511)+1.)
      IF (1.-EOP) 6,6,5
5     NOT=EOP/.01+1.
6     DO 18 K=1,NOT
      E=E+CLAMY
      IF (K-1) 7,7,8
7     E=1.0
8     X=SQRTF(E*E-1.0)
      Y=.04585*Z*E/X
      ZAM=EO-E
      F=Y*X*FOG*ZAM*ZAM*E*CLAMY*((SO*E*E+X*X/4.)**S)/ABS(1.-EXPF(-Y))
      IF (GIRLY) 10,11,9
9     IF (GIRLY-2.0) 12,13,14
10    FUN(K)=F*(X**2+ZAM**2)
      GO TO 15
11    FUN(K)=F*(X**2+ZAM**2)/12.
      GO TO 15
12    FUN(K)=F*(X**4+10.*(X**2)*(ZAM**2)/3.+ZAM**4)
      GO TO 15
13    FUN(K)=F*(X**6+7.*X*X*ZAM*ZAM*(X*X+ZAM*ZAM)+ZAM**6)
      GO TO 15
14    FUN(K)=F
15    IF (NOT-K) 16,16,17
16    SUM=SUM+FUN(K)/2.
      GO TO 18
17    SUM=SUM+FUN(K)
18    FUN(K)=FUN(K)/CLAMY
      IF (1.-EOP) 19,33,33
19    MOT=(EOP-1.)/.1+1.
      CLAMY=.1957
      DO 32 K=1,MOT
      MOTO=K+100
      IF (K-1) 20,20,21
20    E=2.957
      GO TO 22
21    E=E+CLAMY
22    X=SQRTF(E*E-1.0)
```

```
      Y=.04585*Z*E/X
      ZAM=EO-E
      F=Y*X*FOG*ZAM*ZAM*E*CLAMY*((SO*E*E+X*X/4.)**S)/ABS(1.-EXPF(-Y))
      IF (GIRLY) 24,25,23
23    IF (GIRLY-2.0) 26,27,28
24    FUN(MOTO)=F*(X**2+ZAM**2)
      GO TO 29
25    FUN(MOTO)=F*(X**2+ZAM**2)/12.
      GO TO 29
26    FUN(MOTO)=F*(X**4+10.*(X**2)*(ZAM**2)/3.+ZAM**4)
      GO TO 29
27    FUN(MOTO)=F*(X**6+7.*(X**2)*(ZAM**2)*(X**2+ZAM**2)+ZAM**6)
      GO TO 29
28    FUN(MOTO)=F
29    IF (K-1) 30,30,31
30    SUM=SUM+FUN(MOTO)/2.
      GO TO 32
31    SUM=SUM+FUN(MOTO)
32    FUN(MOTO)=FUN(MOTO)/CLAMY
      MI=MOTO
      GO TO 34
33    MI=NOT
34    IF(LOLA-1)90,77,90
77    DO 79 KO=1,210
79    FUN1(KO,L)=0.0
90    DO 83 KO=1,MI
83    FUN1(KO,L)=FUN1(KO,L)+FUN(KO)*FRAC/SUM
84    IF(LOLA-II)75,78,75
78    WRITE TAPE 3,MI,THALF
      WRITE TAPE 3,(FUN1(KO,L),KO=1,MI)
75    RETURN
      END
```

PROGRAM II

Main Program

A,ANO = Atomic weight of mass chain

ALPHA = Fraction of transition energy going by beta decay

DIFF = Mass difference between two isotopes

EOP = End point energy

FRAC = Fraction of decays with specific end point energy

FUNN = Normalized spectral value

IO, II = Number of different betas

JO = Branching indicator: 0 indicates no branching;
1 indicates branching

MI = Number of energy increments

MF = Mass Formula indicator: 0 indicates Coryell's formula;
1 indicates Cameron's formula

NI = Number of isotopes in mass chain

SHAPE = See Function SHAPE

THALF = Half-life of isotope

W = Dummy variable

Z = Atomic number of isotope

ZMIN = One unit less than the atomic number of the first isotope in the chain

FOG, GIRLY,

S, SO, = Interim Calculation Variables

KA, L = Indicies of "DO" loops

Function SHAPE

SHAPE = A function which calculates the "log ft" values

FP = Fermi Integral Function

GORT = See Function GORT

FPI, PSQ = Interim Calculation Variables

R = Dummy variable

Function GORT

GORT = A function which calculates the Fermi Integral Function

BO = Dummy variable

CLAMY = Energy Interval

E, EO, F, X,

Y, ZAM = Interim Calculation Variables

K, NOT = Indicies of "DO" loops

Function PHI

PHI = A function which computes a term used in GORT

BB = Dummy variable

C,D,R,RS = Interim Calculation Variables

Function GAMMA

GAMMA = A function which computes the value of the gamma function

X = Dummy variable

G,GLN,K,Y = Interim Calculation Variables

Subroutine BINER

BINER = A subroutine which computes and stores the values of the normalized spectral shapes

FUN = Value of the spectral shape

FUN ⊥ = Normalized value of the spectral shape

SUM = Integral value of the spectral shape

NOT, MOT,

MOTO = Interim Calculation Variables

LOLA, K,

KO = Indicies of "DO" loops

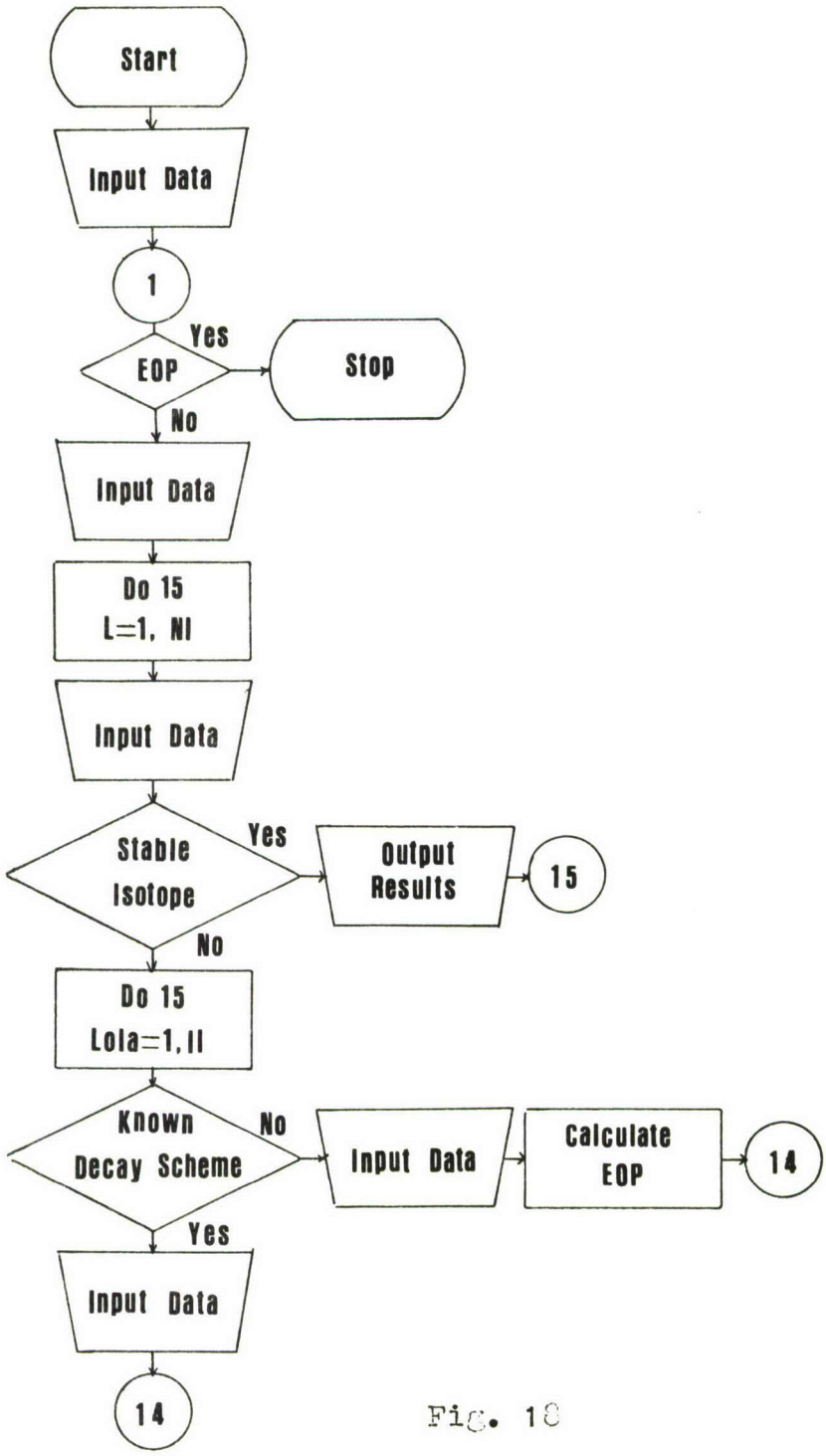


Fig. 18

Flow Chart for Program II

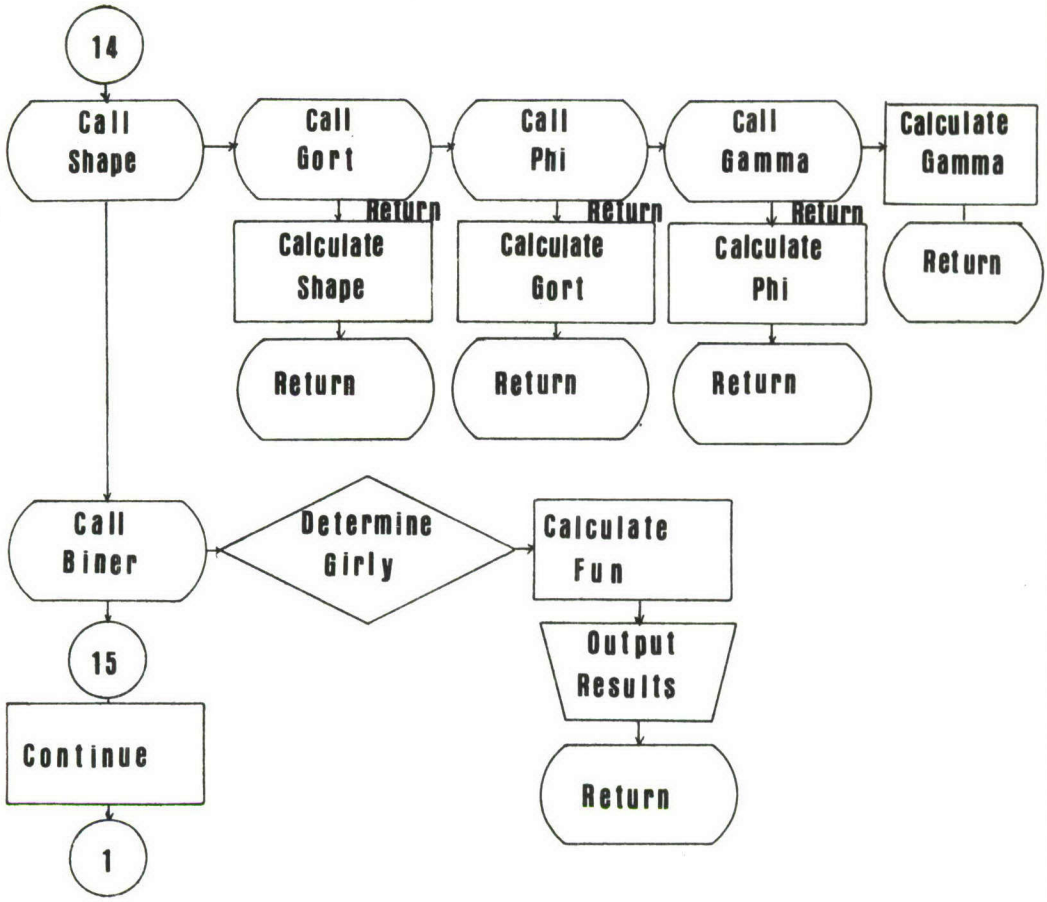


Fig. 18 (Continued)

```
C                                PROGRAM III
C      PROGRAM TO GENERATE NEW INPUT DATA TAPE
       DIMENSION A(11),THALF(11),B(11),FUN1(210,11),MI(11)
       NX=0
1      READ 101,ANO,ZMIN,NI,(8)
       READ 102,(A(I),I=1,NI)
       READ TAPE 1,ANO,NI
       DO 7 I=1,NI
       READ TAPE 1,MI(I),THALF(I)
       MM=MI(I)
7      READ TAPE 1,(FUN1(K,I),K=1,MM)
       DO 4 I=1,NI
       IF(THALF(I))2,3,2
2      B(I)=0.693/THALF(I)
       GO TO 4
3      B(I)=0.0
4      CONTINUE
       WRITE TAPE 3,ANO,NI,(A(I),I=1,NI),(B(I),I=1,NI)
       DO 5 L=1,NI
       WRITE TAPE 3,MI(L)
       MM=MI(L)
5      WRITE TAPE 3,(FUN1(K,L),K=1,MM)
       GO TO 1
8      END FILE 3
       NX=NX+1
       PRINT 103,NX
       REWIND 1
       IF(NX-4)1,6,6
6      REWIND 3
       STOP
101    FORMAT(2F10.0,I10)
102    FORMAT(1P6E12.4)
103    FORMAT(I5)
       END
```

PROGRAM III

A	=	Concentration of isotope immediately after fission
ANO	=	Atomic weight of mass chain
B	=	Decay constant of isotope
FUN 1	=	Normalized spectral shape value
MI	=	Number of energy increments
NI	=	Number of isotopes in mass chain
THALF	=	Half-life of isotope
ZMIN	=	One unit less than the atomic number of the first isotope in the chain
MM, NX	=	Interim Calculation Variables
I, K, L	=	Indicies of "DO" loops

PROGRAM III

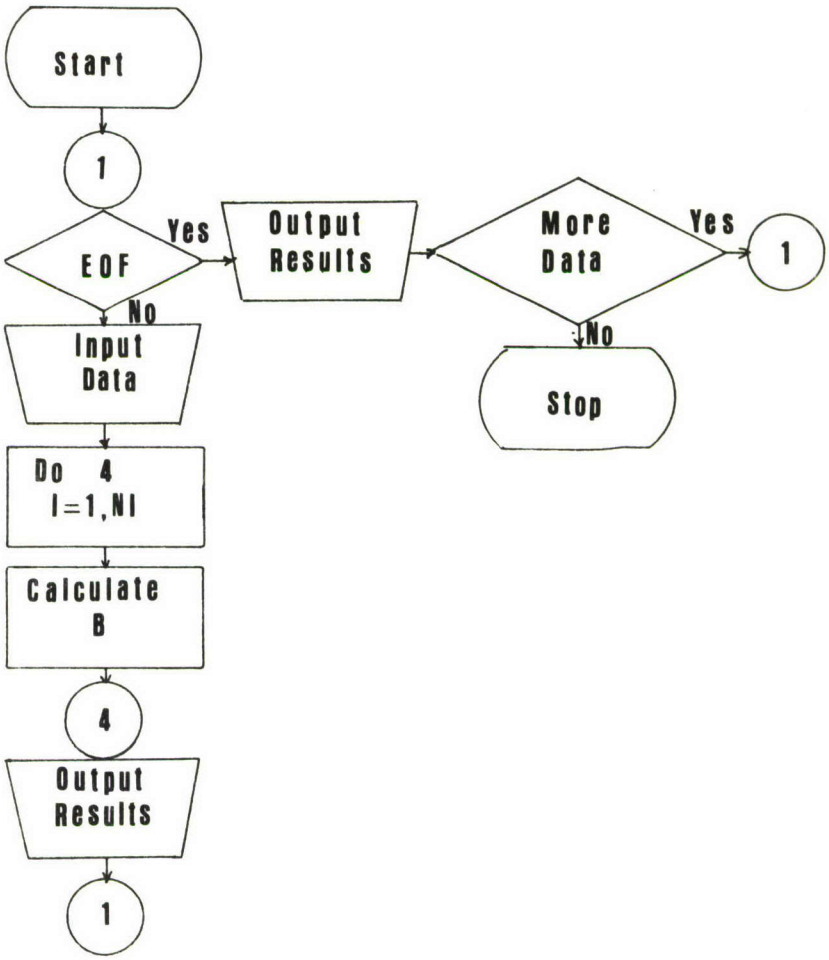


Fig. 19

Flow Chart for Program III

```
C                                PROGRAM IV
C      THIS PROGRAM SOLVES THE DECAY EQUATIONS EXACTLY
C
       DIMENSION A(11),AA(11),B(11),BB(11),FUN1(210,11),MM(11),BC(11),L(1
      111),AB(11,20),DC(10,10),E(10)
       COMMON EVE(20),SUN(20,210),ITF,SUM(210)
       READ 990,ITF,YM
       ITT=ITF-1
       IF(ITT)12,13,12
12     DO 14 NX=1,ITT
14     CALL WINDER
13     READ 990,NT
       READ 991,(EVE(K),K=1,NT)
       DO 97 KK=1,83
       READ TAPE 1,ANO,NI,(AA(I),I=1,NI),(BB(I),I=1,NI),(2000)
       DO 98 LX=1,NI
       AA(LX)=AA(LX)*YM
       READ TAPE 1,MI
       MM(LX)=MI
98     READ TAPE 1,(FUN1(KO,LX),KO=1,MI)
       DO 99 IX=1,NI
       READ 992,ANO,NP,(2000)
       DO 99 JJ=1,NP
       READ 993,NC,(BC(K),L(K),K=1,NC)
       DO 99 II=1,NT
       T=EVE(II)
       AB(IX,II)=0.0
       GO TO (10,20,30,40,50,60,70,80,90,110),NC
10     DO 11 K=1,NC
       LL=L(K)
       B(K)=BB(LL)
11     A(K)=AA(LL)
       P1=BC(1)
     1 XN1 = P1*A(1)*EXP(-B(1)*T)
       AB(IX,II)=AB(IX,II)+XN1
       GO TO 99
20     DO 21 K=1,NC
       LL=L(K)
       B(K)=BB(LL)
21     A(K)=AA(LL)
       P1=BC(1)
       P2=BC(2)
     2 DO 201 I = 1,2
       DO 201 J = 1,2
   201 DC(I,J) = B(I)-B(J)
       DO 202 I = 1,2
   202 E(I) = EXP(-B(I)*T)
       T1 = E(1)/DC(2,1)
       T2 = E(2)/DC(1,2)
       XN2 = P1*B(1)*A(1)*(T1+T2)+P2*A(2)*E(2)
       AB(IX,II)=AB(IX,II)+XN2
```

```
      GO TO 99
30    DO 31 K=1,NC
      LL=L(K)
      B(K)=BB(LL)
31    A(K)=AA(LL)
      P1=BC(1)
      P2=BC(2)
      P3=BC(3)
    3 DO 301 I = 1,3
      DO 301 J = 1,3
  301 DC(I,J) = B(I)-B(J)
      DO 302 I = 1,3
  302 E(I) = EXP(-B(I)*T)
      T1 = E(1)/(DC(2,1)*DC(3,1))
      T2 = E(2)/(DC(1,2)*DC(3,2))
      T3 = E(3)/(DC(1,3)*DC(2,3))
      XN3 = P1*B(1)*B(2)*A(1)*(T1+T2+T3)
      T1 = E(2)/DC(3,2)
      T2 = E(3)/DC(2,3)
      XN3 = XN3+P2*B(2)*A(2)*(T1+T2)+P3*A(3)*E(3)
      AB(IX,II)=AB(IX,II)+XN3
      GO TO 99
40    DO 41 K=1,NC
      LL=L(K)
      B(K)=BB(LL)
41    A(K)=AA(LL)
      P1=BC(1)
      P2=BC(2)
      P3=BC(3)
      P4=BC(4)
    4 DO 401 I = 1,4
      DO 401 J = 1,4
  401 DC(I,J) = B(I)-B(J)
      DO 402 I = 1,4
  402 E(I) = EXP(-B(I)*T)
      T1 = E(1)/(DC(2,1)*DC(3,1)*DC(4,1))
      T2 = E(2)/(DC(1,2)*DC(3,2)*DC(4,2))
      T3 = E(3)/(DC(1,3)*DC(2,3)*DC(4,3))
      T4 = E(4)/(DC(1,4)*DC(2,4)*DC(3,4))
      XN4 = P1*B(1)*B(2)*B(3)*A(1)*(T1+T2+T3+T4)
      T1 = E(2)/(DC(3,2)*DC(4,2))
      T2 = E(3)/(DC(2,3)*DC(4,3))
      T3 = E(4)/(DC(2,4)*DC(3,4))
      XN4 = XN4+P2*B(2)*B(3)*A(2)*(T1+T2+T3)
      T1 = E(3)/DC(4,3)
      T2 = E(4)/DC(3,4)
      XN4 = XN4+P3*B(3)*A(3)*(T1+T2)+P4*A(4)*E(4)
      AB(IX,II)=AB(IX,II)+XN4
      GO TO 99
50    DO 51 K=1,NC
      LL=L(K)
```

```
      B(K)=BB(LL)
51    A(K)=AA(LL)
      P1=BC(1)
      P2=BC(2)
      P3=BC(3)
      P4=BC(4)
      P5=BC(5)
    5 DO 501 I = 1,5
      DO 501 J = 1,5
  501 DC(I,J) = B(I)-B(J)
      DO 502 I = 1,5
  502 E(I) = EXP(-B(I)*T)
      T1 = E(1)/(DC(2,1)*DC(3,1)*DC(4,1)*DC(5,1))
      T2 = E(2)/(DC(1,2)*DC(3,2)*DC(4,2)*DC(5,2))
      T3 = E(3)/(DC(1,3)*DC(2,3)*DC(4,3)*DC(5,3))
      T4 = E(4)/(DC(1,4)*DC(2,4)*DC(3,4)*DC(5,4))
      T5 = E(5)/(DC(1,5)*DC(2,5)*DC(3,5)*DC(4,5))
      XN5 = P1*B(1)*B(2)*B(3)*B(4)*A(1)*(T1+T2+T3+T4+T5)
      T1 = E(2)/(DC(3,2)*DC(4,2)*DC(5,2))
      T2 = E(3)/(DC(2,3)*DC(4,3)*DC(5,3))
      T3 = E(4)/(DC(2,4)*DC(3,4)*DC(5,4))
      T4 = E(5)/(DC(2,5)*DC(3,5)*DC(4,5))
      XN5 = XN5+P2*B(2)*B(3)*B(4)*A(2)*(T1+T2+T3+T4)
      T1 = E(3)/(DC(4,3)*DC(5,3))
      T2 = E(4)/(DC(3,4)*DC(5,4))
      T3 = E(5)/(DC(3,5)*DC(4,5))
      XN5 = XN5+P3*B(3)*B(4)*A(4)
      T1 = E(4)/DC(5,4)
      T2 = E(5)/DC(4,5)
      XN5 = XN5+P4*B(4)*A(4)*(T1+T2)+P5*A(5)*E(5)
      AB(IX,II)=AB(IX,II)+XN5
      GO TO 99
60    DO 61 K=1,NC
      LL=L(K)
      B(K)=BB(LL)
61    A(K)=AA(LL)
      P1=BC(1)
      P2=BC(2)
      P3=BC(3)
      P4=BC(4)
      P5=BC(5)
      P6=BC(6)
    6 DO 601 I = 1,6
      DO 601 J = 1,6
  601 DC(I,J) = B(I)-B(J)
      DO 602 I = 1,6
  602 E(I) = EXP(-B(I)*T)
      T1 = E(1)/(DC(2,1)*DC(3,1)*DC(4,1)*DC(5,1)*DC(6,1))
      T2 = E(2)/(DC(1,2)*DC(3,2)*DC(4,2)*DC(5,2)*DC(6,2))
      T3 = E(3)/(DC(1,3)*DC(2,3)*DC(4,3)*DC(5,3)*DC(6,3))
      T4 = E(4)/(DC(1,4)*DC(2,4)*DC(3,4)*DC(5,4)*DC(6,4))
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```
      T5 = E(5)/(DC(1,5)*DC(2,5)*DC(3,5)*DC(4,5)*DC(6,5))
      T6 = E(6)/(DC(1,6)*DC(2,6)*DC(3,6)*DC(4,6)*DC(5,6))
      XN6 = P1*B(1)*B(2)*B(3)*B(4)*B(5)*A(5)*(T1+T2+T3+T4+T5+T6)
      T1 = E(2)/(DC(3,2)*DC(4,2)*DC(5,2)*DC(6,2))
      T2 = E(3)/(DC(2,3)*DC(4,3)*DC(5,3)*DC(6,3))
      T3 = E(4)/(DC(2,4)*DC(3,4)*DC(5,4)*DC(6,4))
      T4 = E(5)/(DC(2,5)*DC(3,5)*DC(4,5)*DC(6,5))
      T5 = E(6)/(DC(2,6)*DC(3,6)*DC(4,6)*DC(5,6))
      XN6 = XN6+P2*B(2)*B(3)*B(4)*B(5)*A(2)*(T1+T2+T3+T4+T5)
      T1 = E(3)/(DC(4,3)*DC(5,3)*DC(6,3))
      T2 = E(4)/(DC(3,4)*DC(5,4)*DC(6,4))
      T3 = E(5)/(DC(3,5)*DC(4,5)*DC(6,5))
      T4 = E(6)/(DC(3,6)*DC(4,6)*DC(5,6))
      XN6 = XN6+P3*B(3)*B(4)*B(5)*A(3)*(T1+T2+T3+T4)
      T1 = E(4)/(DC(5,4)*DC(6,4))
      T2 = E(5)/(DC(4,5)*DC(6,5))
      T3 = E(6)/(DC(4,6)*DC(5,6))
      XN6 = XN6+P4*B(4)*B(5)*A(4)*(T1+T2+T3)
      T1 = E(5)/DC(6,5)
      T2 = E(6)/DC(5,6)
      XN6 = XN6+P5*B(5)*A(5)*(T1+T2)+P6*A(6)*E(6)
      AB(IX,II)=AB(IX,II)+XN6
      GO TO 99
70    DO 71 K=1,NC
      LL=L(K)
      B(K)=BB(LL)
71    A(K)=AA(LL)
      P1=BC(1)
      P2=BC(2)
      P3=BC(3)
      P4=BC(4)
      P5=BC(5)
      P6=BC(6)
      P7=BC(7)
    7 DO 701 I = 1,7
      DO 701 J = 1,7
  701 DC(I,J) = B(I)-B(J)
      DO 702 I = 1,7
  702 E(I) = EXP(-B(I)*T)
      T1 = E(1)/(DC(2,1)*DC(3,1)*DC(4,1)*DC(5,1)*DC(6,1)*DC(7,1))
      T2 = E(2)/(DC(1,2)*DC(3,2)*DC(4,2)*DC(5,2)*DC(6,2)*DC(7,2))
      T3 = E(3)/(DC(1,3)*DC(2,3)*DC(4,3)*DC(5,3)*DC(6,3)*DC(7,3))
      T4 = E(4)/(DC(1,4)*DC(2,4)*DC(3,4)*DC(5,4)*DC(6,4)*DC(7,4))
      T5 = E(5)/(DC(1,5)*DC(2,5)*DC(3,5)*DC(4,5)*DC(6,5)*DC(7,5))
      T6 = E(6)/(DC(1,6)*DC(2,6)*DC(3,6)*DC(4,6)*DC(5,6)*DC(7,6))
      T7 = E(7)/(DC(1,7)*DC(2,7)*DC(3,7)*DC(4,7)*DC(5,7)*DC(6,7))
      XN7 = P1*B(1)*B(2)*B(3)*B(4)*B(5)*B(5)*A(1)*(T1+T2+T3+T4+T5+T6+T7)
      T1 = E(2)/(DC(3,2)*DC(4,2)*DC(5,2)*DC(6,2)*DC(7,2))
      T2 = E(3)/(DC(2,3)*DC(4,3)*DC(5,3)*DC(6,3)*DC(7,3))
      T3 = E(4)/(DC(2,4)*DC(3,4)*DC(5,4)*DC(6,4)*DC(7,4))
      T4 = E(5)/(DC(2,5)*DC(3,5)*DC(4,5)*DC(6,5)*DC(7,5))
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      T5 = E(6)/(DC(2,6)*DC(3,6)*DC(4,6)*DC(5,6)*DC(7,6))
      T6 = E(7)/(DC(2,7)*DC(3,7)*DC(4,7)*DC(5,7)*DC(6,7))
      XN7 = XN7+P2*B(2)*B(3)*B(4)*B(5)*B(6)*A(2)*(T1+T2+T3+T4+T5+T6)
      T1 = E(3)/(DC(4,3)*DC(5,3)*DC(6,3)*DC(7,3))
      T2 = E(4)/(DC(3,4)*DC(5,4)*DC(6,4)*DC(7,4))
      T3 = E(5)/(DC(3,5)*DC(4,5)*DC(6,5)*DC(7,5))
      T4 = E(6)/(DC(3,6)*DC(4,6)*DC(5,6)*DC(7,6))
      T5 = E(7)/(DC(3,7)*DC(4,7)*DC(5,7)*DC(6,7))
      XN7 = XN7+P3*B(3)*B(4)*B(5)*B(6)*A(3)*(T1+T2+T3+T4+T5)
      T1 = E(4)/(DC(5,4)*DC(6,4)*DC(7,4))
      T2 = E(5)/(DC(4,5)*DC(6,5)*DC(7,5))
      T3 = E(6)/(DC(4,6)*DC(5,6)*DC(7,6))
      T4 = E(7)/(DC(4,7)*DC(5,7)*DC(6,7))
      XN7 = XN7+P4*B(4)*B(5)*B(6)*A(4)*(T1+T2+T3+T4)
      T1 = E(5)/(DC(6,5)*DC(7,5))
      T2 = E(6)/(DC(5,6)*DC(7,6))
      T3 = E(7)/(DC(5,7)*DC(6,7))
      XN7=XN7+P5*B(5)*B(6)*A(5)*(T1+T2+T3)
      T1 = E(6)/DC(7,6)
      T2 = E(7)/DC(6,7)
      XN7 = XN7+P6*B(6)*A(6)*(T1+T2)+P7*A(7)*E(7)
      AB(IX,II)=AB(IX,II)+XN7
      GO TO 99
80    DO 81 K=1,NC
      LL=L(K)
      B(K)=BB(LL)
81    A(K)=AA(LL)
      P1=BC(1)
      P2=BC(2)
      P3=BC(3)
      P4=BC(4)
      P5=BC(5)
      P6=BC(6)
      P7=BC(7)
      P8=BC(8)
    8 DO 801 I = 1,8
      DO 801 J = 1,8
  801 DC(I,J) = B(I)-B(J)
      DO 802 I = 1,8
  802 E(I) = EXP(-B(I)*T)
      T1 = E(1)/(DC(2,1)*DC(3,1)*DC(4,1)*DC(5,1)*DC(6,1)*DC(7,1)*DC(8,1)
     1)
      T2 = E(2)/(DC(1,2)*DC(3,2)*DC(4,2)*DC(5,2)*DC(6,2)*DC(7,2)*DC(8,2)
     1)
      T3 = E(3)/(DC(1,3)*DC(2,3)*DC(4,3)*DC(5,3)*DC(6,3)*DC(7,3)*DC(8,3)
     1)
      T4 = E(4)/(DC(1,4)*DC(2,4)*DC(3,4)*DC(5,4)*DC(6,4)*DC(7,4)*DC(8,4)
     1)
      T5 = E(5)/(DC(1,5)*DC(2,5)*DC(3,5)*DC(4,5)*DC(6,5)*DC(7,5)*DC(8,5)
     1)
      T6 = E(6)/(DC(1,6)*DC(2,6)*DC(3,6)*DC(4,6)*DC(5,6)*DC(7,6)*DC(8,6)
```

```
     1)
      T7 = E(7)/(DC(1,7)*DC(2,7)*DC(3,7)*DC(4,7)*DC(5,7)*DC(6,7)*DC(8,7)
     1)
      T8 = E(8)/(DC(1,8)*DC(2,8)*DC(3,8)*DC(4,8)*DC(5,8)*DC(6,8)*DC(7,8)
     1)
      XN8 = P1*B(1)*B(2)*B(3)*B(4)*B(5)*B(6)*B(7)*A(1)*(T1+T2+T3+T4+T5+T
     1G+T7+T8)
      T1 = E(2)/(DC(3,2)*DC(4,2)*DC(5,2)*DC(6,2)*DC(7,2)*DC(8,2))
      T2 = E(3)/(DC(2,3)*DC(4,3)*DC(5,3)*DC(6,3)*DC(7,3)*DC(8,3))
      T3 = E(4)/(DC(2,4)*DC(3,4)*DC(5,4)*DC(6,4)*DC(7,4)*DC(8,4))
      T4 = E(5)/(DC(2,5)*DC(3,5)*DC(4,5)*DC(6,5)*DC(7,5)*DC(8,5))
      T5 = E(6)/(DC(2,6)*DC(3,6)*DC(4,6)*DC(5,6)*DC(7,6)*DC(8,6))
      T6 = E(7)/(DC(2,7)*DC(3,7)*DC(4,7)*DC(5,7)*DC(6,7)*DC(8,7))
      T7 = E(8)/(DC(2,8)*DC(3,8)*DC(4,8)*DC(5,8)*DC(6,8)*DC(7,8))
      XN8 = XN8+P2*B(2)*B(3)*B(4)*B(5)*B(6)*B(7)*A(2)*(T1+T2+T3+T4+T5+T6
     1+T7)
      T1 = E(3)/(DC(4,3)*DC(5,3)*DC(6,3)*DC(7,3)*DC(8,3))
      T2 = E(4)/(DC(3,4)*DC(5,4)*DC(6,4)*DC(7,4)*DC(8,4))
      T3 = E(5)/(DC(3,5)*DC(4,5)*DC(6,5)*DC(7,5)*DC(8,5))
      T4 = E(6)/(DC(3,6)*DC(4,6)*DC(5,6)*DC(7,6)*DC(8,6))
      T5 = E(7)/(DC(3,7)*DC(4,7)*DC(5,7)*DC(6,7)*DC(8,7))
      T6 = E(8)/(DC(3,8)*DC(4,8)*DC(5,8)*DC(6,8)*DC(7,8))
      XN8 = XN8+P3*B(3)*B(4)*B(5)*B(6)*B(7)*A(3)*(T1+T2+T3+T4+T5+T6)
      T1 = E(4)/(DC(5,4)*DC(6,4)*DC(7,4)*DC(8,4))
      T2 = E(5)/(DC(4,5)*DC(6,5)*DC(7,5)*DC(8,5))
      T3 = E(6)/(DC(4,6)*DC(5,6)*DC(7,6)*DC(8,6))
      T4 = E(7)/(DC(4,7)*DC(5,7)*DC(6,7)*DC(8,7))
      T5 = E(8)/(DC(4,8)*DC(5,8)*DC(6,8)*DC(7,8))
      XN8 = XN8+P4*B(4)*B(5)*B(6)*B(7)*A(4)*(T1+T2+T3+T4+T5)
      T1 = E(5)/(DC(6,5)*DC(7,5)*DC(8,5))
      T2 = E(6)/(DC(5,6)*DC(7,6)*DC(8,6))
      T3 = E(7)/(DC(5,7)*DC(6,7)*DC(8,7))
      T4 = E(8)/(DC(5,8)*DC(6,8)*DC(7,8))
      XN8 = XN8+P5*B(5)*B(6)*B(7)*A(5)*(T1+T2+T3+T4)
      T1 = E(6)/(DC(7,6)*DC(8,6))
      T2 = E(7)/(DC(6,7)*DC(8,7))
      T3 = E(8)/(DC(6,8)*DC(7,8))
      XN8 = XN8+P6*B(6)*B(7)*A(6)*(T1+T2+T3)
      T1 = E(7)/DC(8,7)
      T2 = E(8)/DC(7,8)
      XN8 = XN8+P7*B(7)*A(7)*(T1+T2)+P8*A(8)*E(8)
      AA(IX,II)=AA(IX,II)+XN8
      GO TO 99
90    DO 91 K=1,NC
      LL=L(K)
      B(K)=BB(LL)
91    A(K)=AA(LL)
      P1=PC(1)
      P2=PC(2)
      P3=PC(3)
      P4=PC(4)
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      P5=BC(5)
      P6=BC(6)
      P7=BC(7)
      P8=BC(8)
      P9=BC(9)
    9 DO 901 I = 1,9
      DO 901 J = 1,9
  901 DC(I,J) = B(I)-B(J)
      DO 902 I = 1,9
  902 E(I) = EXP(-B(I)*T)
      T1 = E(1)/(DC(2,1)*DC(3,1)*DC(4,1)*DC(5,1)*DC(6,1)*DC(7,1)*DC(8,1)
     1*DC(9,1))
      T2 = E(2)/(DC(1,2)*DC(3,2)*DC(4,2)*DC(5,2)*DC(6,2)*DC(7,2)*DC(8,2)
     1*DC(9,2))
      T3 = E(3)/(DC(1,3)*DC(2,3)*DC(4,3)*DC(5,3)*DC(6,3)*DC(7,3)*DC(8,3)
     1*DC(9,3))
      T4 = E(4)/(DC(1,4)*DC(2,4)*DC(3,4)*DC(5,4)*DC(6,4)*DC(7,4)*DC(8,4)
     1*DC(9,4))
      T5 = E(5)/(DC(1,5)*DC(2,5)*DC(3,5)*DC(4,5)*DC(6,5)*DC(7,5)*DC(8,5)
     1*DC(9,5))
      T6 = E(6)/(DC(1,6)*DC(2,6)*DC(3,6)*DC(4,6)*DC(5,6)*DC(7,6)*DC(8,6)
     1*DC(9,6))
      T7 = E(7)/(DC(1,7)*DC(2,7)*DC(3,7)*DC(4,7)*DC(5,7)*DC(6,7)*DC(8,7)
     1*DC(9,7))
      T8 = E(8)/(DC(1,8)*DC(2,8)*DC(3,8)*DC(4,8)*DC(5,8)*DC(6,8)*DC(7,8)
     1*DC(9,8))
      T9 = E(9)/(DC(1,9)*DC(2,9)*DC(3,9)*DC(4,9)*DC(5,9)*DC(6,9)*DC(7,8)
     1*DC(9,9))
      XN9 = P1*B(1)*B(2)*B(3)*B(4)*B(5)*B(6)*B(7)*B(8)*A(1)*(T1+T2+T3+T4
     1+T5+T6+T7+T8+T9)
      T1 = E(2)/(DC(3,2)*DC(4,2)*DC(5,2)*DC(6,2)*DC(7,2)*DC(8,2)*DC(9,2)
     1)
      T2 = E(3)/(DC(2,3)*DC(4,3)*DC(5,3)*DC(6,3)*DC(7,3)*DC(8,3)*DC(9,3)
     1)
      T3 = E(4)/(DC(2,4)*DC(3,4)*DC(5,4)*DC(6,4)*DC(7,4)*DC(8,4)*DC(9,4)
     1)
      T4 = E(5)/(DC(2,5)*DC(3,5)*DC(4,5)*DC(6,5)*DC(7,5)*DC(8,5)*DC(9,5)
     1)
      T5 = E(6)/(DC(2,6)*DC(3,6)*DC(4,6)*DC(5,6)*DC(7,6)*DC(8,6)*DC(9,6)
     1)
      T6 = E(7)/(DC(2,7)*DC(3,7)*DC(4,7)*DC(5,7)*DC(6,7)*DC(8,7)*DC(9,7)
     1)
      T7 = E(8)/(DC(2,8)*DC(3,8)*DC(4,8)*DC(5,8)*DC(6,8)*DC(7,8)*DC(9,8)
     1)
      T8 = E(9)/(DC(2,9)*DC(3,9)*DC(4,9)*DC(5,9)*DC(6,9)*DC(7,9)*DC(8,9)
     1)
      XN9 = XN9+P2*B(2)*B(3)*B(4)*B(5)*B(6)*B(7)*B(8)*A(2)*(T1+T2+T3+T4+
     1T5+T6+T7+T8)
      T1 = E(3)/(DC(4,3)*DC(5,3)*DC(6,3)*DC(7,3)*DC(8,3)*DC(9,3))
      T2 = E(4)/(DC(3,4)*DC(5,4)*DC(6,4)*DC(7,4)*DC(8,4)*DC(9,4))
      T3 = E(5)/(DC(3,5)*DC(4,5)*DC(6,5)*DC(7,5)*DC(8,5)*DC(9,5))
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      T4 = E(6)/(DC(3,6)*DC(4,6)*DC(5,6)*DC(7,6)*DC(8,6)*DC(9,6))
      T5 = E(7)/(DC(3,7)*DC(4,7)*DC(5,7)*DC(6,7)*DC(8,7)*DC(9,7))
      T6 = E(8)/(DC(3,8)*DC(4,8)*DC(5,8)*DC(6,8)*DC(7,8)*DC(9,8))
      T7 = E(9)/(DC(3,9)*DC(4,9)*DC(5,9)*DC(6,9)*DC(7,9)*DC(8,9))
      XN9 = XN9+P3*B(3)*B(4)*B(5)*B(6)*B(7)*B(8)*A(3)*(T1+T2+T3+T4+T5+T6
     1+T7)
      T1 = E(4)/(DC(5,4)*DC(6,4)*DC(7,4)*DC(8,4)*DC(9,4))
      T2 = E(5)/(DC(4,5)*DC(6,5)*DC(7,5)*DC(8,5)*DC(9,5))
      T3 = E(6)/(DC(4,6)*DC(5,6)*DC(7,6)*DC(8,6)*DC(9,6))
      T4 = E(7)/(DC(4,7)*DC(5,7)*DC(6,7)*DC(8,7)*DC(9,7))
      T5 = E(8)/(DC(4,8)*DC(5,8)*DC(6,8)*DC(7,8)*DC(9,8))
      T6 = E(9)/(DC(4,9)*DC(5,9)*DC(6,9)*DC(7,9)*DC(8,9))
      XN9 = XN9+P4*B(4)*B(5)*B(6)*B(7)*B(8)*A(4)*(T1+T2+T3+T4+T5+T6)
      T1 = E(5)/(DC(6,5)*DC(7,5)*DC(8,5)*DC(9,5))
      T2 = E(6)/(DC(5,6)*DC(7,6)*DC(8,6)*DC(9,6))
      T3 = E(7)/(DC(5,7)*DC(6,7)*DC(8,7)*DC(9,7))
      T4 = E(8)/(DC(5,8)*DC(6,8)*DC(7,8)*DC(9,8))
      T5 = E(9)/(DC(5,9)*DC(6,9)*DC(7,9)*DC(8,9))
      XN9 = XN9+P5*B(5)*B(6)*B(7)*B(8)*A(5)*(T1+T2+T3+T4+T5)
      T1 = E(6)/(DC(7,6)*DC(8,6)*DC(9,6))
      T2 = E(7)/(DC(6,7)*DC(8,7)*DC(9,7))
      T3 = E(8)/(DC(6,8)*DC(7,8)*DC(9,8))
      T4 = E(9)/(DC(6,9)*DC(7,9)*DC(8,9))
      XN9 = XN9+P6*B(6)*B(7)*B(8)*A(6)*(T1+T2+T3+T4)
      T1 = E(7)/(DC(8,7)*DC(9,7))
      T2 = E(8)/(DC(7,8)*DC(9,8))
      T3 = E(9)/(DC(7,9)*DC(8,9))
      XN9 = XN9+P7*B(7)*B(8)*A(7)*(T1+T2+T3)
      T1 = E(8)/DC(9,8)
      T2 = E(9)/DC(8,9)
      XN9 = XN9+P8*B(8)*A(8)*(T1+T2)+P9*A(9)*E(9)
      AB(IX,II)=AB(IX,II)+XN9
      GO TO 99
110   DO 111 K=1,NC
      LL=L(K)
      B(K)=BB(LL)
111   A(K)=AA(LL)
      P1=BC(1)
      P2=BC(2)
      P3=BC(3)
      P4=BC(4)
      P5=BC(5)
      P6=BC(6)
      P7=BC(7)
      P8=BC(8)
      P9=BC(9)
      P10=BC(10)
1000  DO 1001 I = 1,10
      DO 1001 J = 1,10
 1001 DC(I,J) = B(I)-B(J)
      DO 1002 I = 1,10
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1002 E(I) = EXP(-B(I)*T)
     T1 = E(1)/(DC(2,1)*DC(3,1)*DC(4,1)*DC(5,1)*DC(6,1)*DC(7,1)*DC(8,1)
    1*DC(9,1)*DC(10,1))
     T2 = E(2)/(DC(1,2)*DC(3,2)*DC(4,2)*DC(5,2)*DC(6,2)*DC(7,2)*DC(8,2)
    1*DC(9,2)*DC(10,2))
     T3 = E(3)/(DC(1,3)*DC(2,3)*DC(4,3)*DC(5,3)*DC(6,3)*DC(7,3)*DC(8,3)
    1*DC(9,3)*DC(10,3))
     T4 = E(4)/(DC(1,4)*DC(2,4)*DC(3,4)*DC(5,4)*DC(6,4)*DC(7,4)*DC(8,4)
    1*DC(9,4)*DC(10,4))
     T5 = E(5)/(DC(1,5)*DC(2,5)*DC(3,5)*DC(4,5)*DC(6,5)*DC(7,5)*DC(8,5)
    1*DC(9,5)*DC(10,5))
     T6 = E(6)/(DC(1,6)*DC(2,6)*DC(3,6)*DC(4,6)*DC(5,6)*DC(7,6)*DC(8,6)
    1*DC(9,6)*DC(10,6))
     T7 = E(7)/(DC(1,7)*DC(2,7)*DC(3,7)*DC(4,7)*DC(5,7)*DC(6,7)*DC(8,7)
    1*DC(9,7)*DC(10,7))
     T8 = E(8)/(DC(1,8)*DC(2,8)*DC(3,8)*DC(4,8)*DC(5,8)*DC(6,8)*DC(7,8)
    1*DC(9,8)*DC(10,8))
     T9 = E(9)/(DC(1,9)*DC(2,9)*DC(3,9)*DC(4,9)*DC(5,9)*DC(6,9)*DC(7,9)
    1*DC(9,9)*DC(10,9))
     T10 = E(10)/(DC(1,10)*DC(2,10)*DC(3,10)*DC(4,10)*DC(5,10)*DC(6,10)
    1*DC(7,10)*DC(8,10)*DC(9,10))
     XN10 = P1*B(1)*B(2)*B(3)*B(4)*B(5)*B(6)*B(7)*B(8)*B(9)*A(1)*(T1+T2
    1+T3+T4+T5+T6+T7+T8+T9+T10)
     T1 = E(2)/(DC(3,2)*DC(4,2)*DC(5,2)*DC(6,2)*DC(7,2)*DC(8,2)*DC(9,2)
    1*DC(10,2))
     T2 = E(3)/(DC(2,3)*DC(4,3)*DC(5,3)*DC(6,3)*DC(7,3)*DC(8,3)*DC(9,3)
    1*DC(10,3))
     T3 = E(4)/(DC(2,4)*DC(3,4)*DC(5,4)*DC(6,4)*DC(7,4)*DC(8,4)*DC(9,4)
    1*DC(10,4))
     T4 = E(5)/(DC(2,5)*DC(3,5)*DC(4,5)*DC(6,5)*DC(7,5)*DC(8,5)*DC(9,5)
    1*DC(10,5))
     T5 = E(6)/(DC(2,6)*DC(3,6)*DC(4,6)*DC(5,6)*DC(7,6)*DC(8,6)*DC(9,6)
    1*DC(10,6))
     T6 = E(7)/(DC(2,7)*DC(3,7)*DC(4,7)*DC(5,7)*DC(6,7)*DC(8,7)*DC(9,7)
    1*DC(10,7))
     T7 = E(8)/(DC(2,8)*DC(3,8)*DC(4,8)*DC(5,8)*DC(6,8)*DC(7,8)*DC(9,8)
    1*DC(10,8))
     T8 = E(9)/(DC(2,9)*DC(3,9)*DC(4,9)*DC(5,9)*DC(6,9)*DC(7,9)*DC(8,9)
    1*DC(10,9))
     T9 = E(10)/(DC(2,10)*DC(3,10)*DC(4,10)*DC(5,10)*DC(6,10)*DC(7,10)*
    1DC(8,10)*DC(9,10))
     XN10 = XN10+P2*B(2)*B(3)*B(4)*B(5)*B(6)*B(7)*B(8)*B(9)*A(2)*(T1+T2
    1+T3+T4+T5+T6+T7+T8+T9)
     T1 = E(3)/(DC(4,3)*DC(5,3)*DC(6,3)*DC(7,3)*DC(8,3)*DC(9,3)*DC(10,3
    1))
     T2 = E(4)/(DC(3,4)*DC(5,4)*DC(6,4)*DC(7,4)*DC(8,4)*DC(9,4)*DC(10,4
    1))
     T3 = E(5)/(DC(3,5)*DC(4,5)*DC(6,5)*DC(7,5)*DC(8,5)*DC(9,5)*DC(10,5
    1))
     T4 = E(6)/(DC(3,6)*DC(4,6)*DC(5,6)*DC(7,6)*DC(8,6)*DC(9,6)*DC(10,6
    1))
```

```
      T5 = E(7)/(DC(3,7)*DC(4,7)*DC(5,7)*DC(6,7)*DC(8,7)*DC(9,7)*DC(10,7
     1))
      T6 = E(8)/(DC(3,8)*DC(4,8)*DC(5,8)*DC(6,8)*DC(7,8)*DC(9,8)*DC(10,8
     1))
      T7 = E(9)/(DC(3,9)*DC(4,9)*DC(5,9)*DC(6,9)*DC(7,9)*DC(8,9)*DC(10,9
     1))
      T8 = E(10)/(DC(3,10)*DC(4,10)*DC(5,10)*DC(6,10)*DC(7,10)*DC(8,10)*
     1DC(9,10))
      XN10 = XN10+P3*B(3)*B(4)*B(5)*B(6)*B(7)*B(8)*B(9)*A(3)*(T1+T2+T3+T
     14+T5+T6+T7+T8)
      T1 = E(4)/(DC(5,4)*DC(6,4)*DC(7,4)*DC(8,4)*DC(9,4)*DC(10,4))
      T2 = E(5)/(DC(4,5)*DC(6,5)*DC(7,5)*DC(8,5)*DC(9,5)*DC(10,5))
      T3 = E(6)/(DC(4,6)*DC(5,6)*DC(7,6)*DC(8,6)*DC(9,6)*DC(10,6))
      T4 = E(7)/(DC(4,7)*DC(5,7)*DC(6,7)*DC(8,7)*DC(9,7)*DC(10,7))
      T5 = E(8)/(DC(4,8)*DC(5,8)*DC(6,8)*DC(7,8)*DC(9,8)*DC(10,8))
      T6 = E(9)/(DC(4,9)*DC(5,9)*DC(6,9)*DC(7,9)*DC(8,9)*DC(10,9))
      T7 = E(10)/(DC(4,10)*DC(5,10)*DC(6,10)*DC(7,10)*DC(8,10)*DC(9,10))
      XN10 = XN10+P4*B(4)*B(5)*B(6)*B(7)*B(8)*B(9)*A(4)*(T1+T2+T3+T4+T5+
     1T6+T7)
      T1 = E(5)/(DC(6,5)*DC(7,5)*DC(8,5)*DC(9,5)*DC(10,5))
      T2 = E(6)/(DC(5,6)*DC(7,6)*DC(8,6)*DC(9,6)*DC(10,6))
      T3 = E(7)/(DC(5,7)*DC(6,7)*DC(8,7)*DC(9,7)*DC(10,7))
      T4 = E(8)/(DC(5,8)*DC(6,8)*DC(7,8)*DC(9,8)*DC(10,8))
      T5 = E(9)/(DC(5,9)*DC(6,9)*DC(7,9)*DC(8,9)*DC(10,9))
      T6 = E(10)/(DC(5,10)*DC(6,10)*DC(7,10)*DC(8,10)*DC(9,10))
      XN10 = XN10+P5*B(5)*B(6)*B(7)*B(8)*B(9)*A(5)*(T1+T2+T3+T4+T5+T6)
      T1 = E(6)/(DC(7,6)*DC(8,6)*DC(9,6)*DC(10,6))
      T2 = E(7)/(DC(6,7)*DC(8,7)*DC(9,7)*DC(10,7))
      T3 = E(8)/(DC(6,8)*DC(7,8)*DC(9,8)*DC(10,8))
      T4 = E(9)/(DC(6,9)*DC(7,9)*DC(8,9)*DC(10,9))
      T5 = E(10)/(DC(6,10)*DC(7,10)*DC(8,10)*DC(9,10))
      XN10 = XN10+P6*B(6)*B(7)*B(8)*B(9)*A(6)*(T1+T2+T3+T4+T5)
      T1 = E(7)/(DC(8,7)*DC(9,7)*DC(10,7))
      T2 = E(8)/(DC(7,8)*DC(9,8)*DC(10,8))
      T3 = E(9)/(DC(7,9)*DC(8,9)*DC(10,9))
      T4 = E(10)/(DC(7,10)*DC(8,10)*DC(9,10))
      XN10 = XN10+P7*B(7)*B(8)*B(9)*A(7)*(T1+T2+T3+T4)
      T1 = E(8)/(DC(9,8)*DC(10,8))
      T2 = E(9)/(DC(8,9)*DC(10,9))
      T3 = E(10)/(DC(8,10)*DC(9,10))
      XN10 = XN10+P8*B(8)*B(9)*A(8)*(T1+T2+T3)
      T1 = E(9)/DC(10,9)
      T2 = E(10)/DC(9,10)
      XN10 = XN10+P9*B(9)*A(9)*(T1+T2)+P10*A(10)*E(10)
      AB(IX,II)=AB(IX,II)+XN10
99    CONTINUE
      DO 96 M=1,NI
      MMM=MM(M)
      DO 96 N=1,NT
      DO 96 I=1,MMM
96    SUN(N,I)=SUN(N,I)+FUN1(I,M)*AB(M,N)*B(M)
```

```
97    CONTINUE
2000  CALL PRINT
      STOP
990   FORMAT(I2,E8.3)
991   FORMAT(8E10.4)
992   FORMAT(F5.0,15)
993   FORMAT(I3,10(F4.3,I3))
      END
```

```
      SUBROUTINE PRINT
      COMMON EVE(20),SUN(20,210),ITF,SUM(210)
      DIMENSION ENERGY(210)
      DO 43 MO=1,200
      IF(MO-1)40,39,40
39    ENERGY(MO)=0.0
      GO TO 43
40    IF(MO-101)41,41,42
41    ENERGY(MO)=ENERGY(MO-1)+.01
      GO TO 43
42    ENERGY(MO)=ENERGY(MO-1)+.1
43    CONTINUE
      KAR = 0
44    GO TO (144,244,344,444),ITF
144   PRINT 155
      GO TO 145
244   PRINT 255
      GO TO 145
344   PRINT 355
      GO TO 145
444   PRINT 455
145   PRINT 57,(EVE(KO),KO=1,7)
      PRINT 58
      PRINT 65
      MOST=0
      IF(KAR)37,36,37
36    DO 37 KAR=1,200
      PRINT 61,(SUN(MO,KAR),MO=1,7),ENERGY(KAR)
      MOST=MOST+1
      IF(KAR-200)35,47,35
35    IF(MOST-50)37,44,44
37    CONTINUE
47    GO TO (147,247,347,447),ITF
147   PRINT 155
      GO TO 148
247   PRINT 255
      GO TO 148
347   PRINT 355
      GO TO 148
447   PRINT 455
148   PRINT 59,(EVE(KO),KO=8,13)
      PRINT 60
      PRINT 65
      MOST=0
      IF(KAR-200)46,45,46
45    DO 46 KAR=1,200
      PRINT 62,(SUN(MO,KAR),MO=8,13),ENERGY(KAR)
      MOST=MOST+1
      IF(KAR-200)49,54,49
49    IF(MOST-50)46,47,47
46    CONTINUE
```

```
54      WRITE TAPE 3,(ENERGY(MO),MO=1,195)
        DO 70 MO=1,13
70      WRITE TAPE 3,(SUN(MO,NIT),NIT=1,195)
        END FILE 3
        REWIND 3
        REWIND 1
        RETURN
57      FORMAT (/,1X,5HTIME=,F5.1,6F15.1)
58      FORMAT (/,6X,7HBIN (1),8X,7HBIN (2),8X,7HBIN (3),8X,7HBIN (4),8X,7
       1HBIN (5),8X,7HBIN (6),8X,7HBIN (7),8X,1HE)
59      FORMAT (/,1X,5HTIME=,F6.1,5F15.1)
60      FORMAT (/,6X,7HBIN (8),8X,7HBIN (9),8X,8HBIN (10),7X,8HBIN (11),7X
       1,8HBIN (12),7X,8HBIN (13),7X,1HE)
61      FORMAT (1P7E15.5,0PF9.2)
62      FORMAT (1P6E15.5,0PF9.2)
65      FORMAT (/)
155     FORMAT(1H1,24X,67HINSTANTANEOUS BETA RAY SPECTRA FROM THERMAL PU-2
       139 FISSION PRODUCTS,/,29X,58HAT VARIOUS TIMES AFTER DETONATION (BE
       2TAS/ENERGY RANGE/SEC))
255     FORMAT (1H1,24X,66HINSTANTANEOUS BETA RAY SPECTRA FROM THERMAL U-2
       135 FISSION PRODUCTS,/,29X,58HAT VARIOUS TIMES AFTER DETONATION (BE
       2TAS/ENERGY RANGE/SEC))
355     FORMAT (1H1,24X,66HINSTANTANEOUS BETA RAY SPECTRA FROM THERMONUCLE
       1R FISSION PRODUCTS,/,14X,58HAT VARIOUS TIMES AFTER DETONATION (BET
       2AS/ENERGY RANGE/SEC))
455     FORMAT(1H1,20X,75HINSTANTANEOUS BETA RAY SPECTRA FROM U-235 FISSIO
       1N SPECTRUM FISSION PRODUCTS,/,29X,58HAT VARIOUS TIMES AFTER DETONA
       2TION (BETAS/ENERGY RANGE/SEC))
        END
```

```
      SUBROUTINE WINDER
1     READ TAPE 1,ANO,(2)
      GO TO 1
2     RETURN
      END
```

PROGRAM IV

Main Program

A,AA = Concentration of isotope immediately after fission

AB = Concentration of isotope at the time of interest

ANO = Atomic weight of mass chain

B, BB = Decay constant of isotope

BC = Branching indicator which shows the fraction of the isotope which contributes to the decay

EVE, T = The time of interest

FUN 1 = Value of the normalized spectral shape

ITF = Indicator of the type of fission: 1 indicates Pu-239 thermal neutron fission; 2 indicates U-235 thermal neutron fission; 3 indicates thermonuclear neutron fission; 4 indicates U-235 fission spectrum neutron fission

L, LL = Indicators which show which isotopes in the chain contribute to the production of another isotope

MI, MM = Number of energy increments

NC = Number of isotopes in the decay path

NI = Number of isotopes in the mass chain

NT = Number of times of interest

SUN = Value of the spectrum at the time of interest

YM = Number of megatons of fission

SUM = Dummy variable

DC,E,P1,P2,
P3,P4,P5,P6,
P7,P8,P9,

P10,T1,T2,

T3,T4,T5,T6,

T7,T8,T9,

T10,XN1,XN2,

XN3,XN4,XN5,

Xn6,XN7,XN8,

XN9,XN10 = Interim Calculation Variables

I,II,IX,

ITT,J,JJ,

K,KK,KO,LX,

M,MMM,N,NX = Indicies of "DO" loops

Subroutine PRINT

PRINT = Subroutine to print results

ENERGY = Value of energy

MOST = Interim Calculation Variable

KO,KAR,

MO,NIT = Indicies of "DO" loops

Subroutine WINDER

WINDER = Subroutine to advance tape to read the next record

ANO = Dummy variable

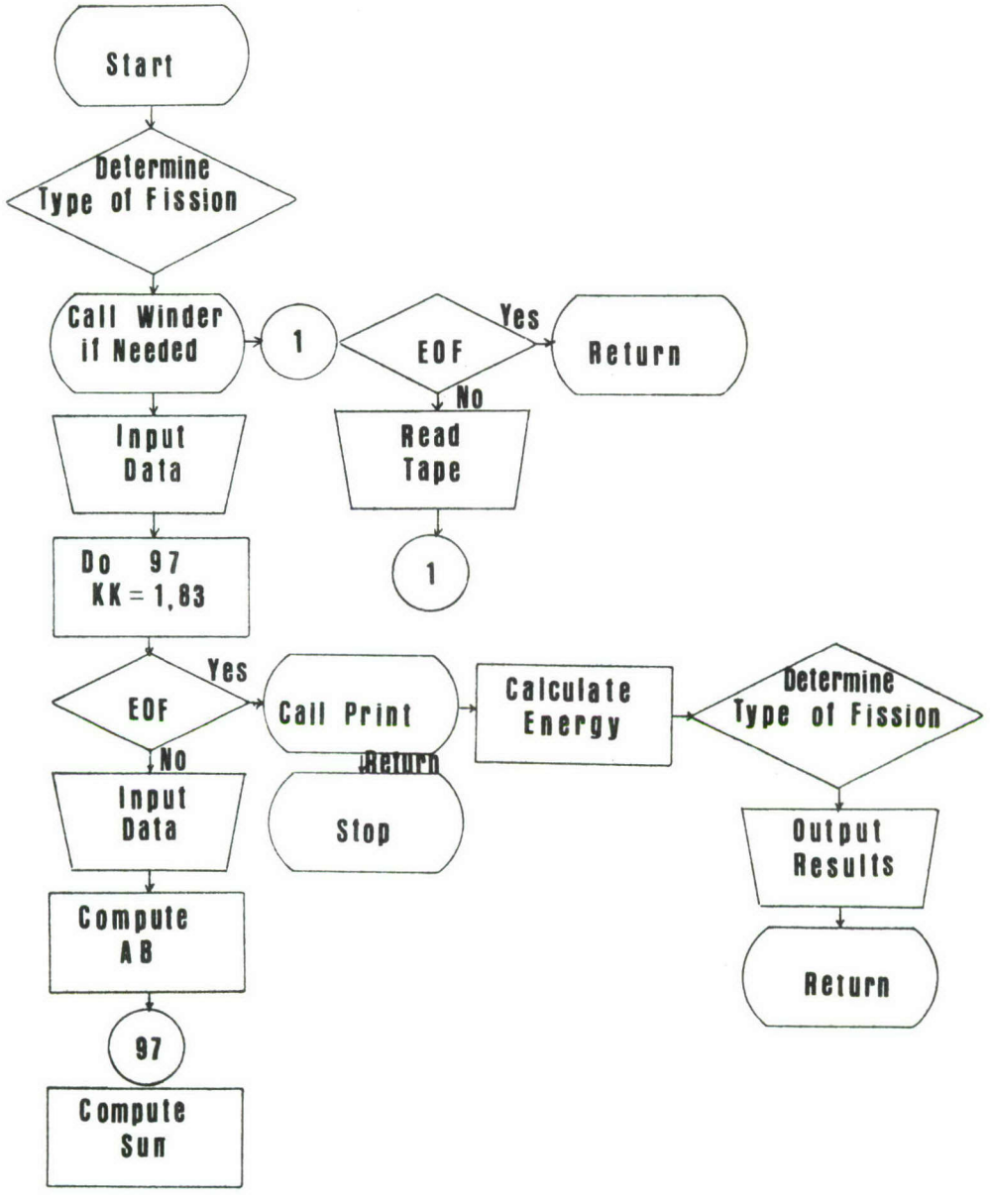

Fig. 20

Flow Chart for Program IV

Vita

James E. Dieckhoner was born on February 5, 1937 in Cleveland, Ohio, the son of William A. Dieckhoner and Elsie B. Dieckhoner. He received his B.S. degree in Chemistry from Ohio University, Athens, Ohio, in June 1959. He received his commission as Lieutenant in the USAF Reserve at that time and entered active duty in July 1959. His military assignments prior to his coming to the Air Force Institute of Technology were as Chemist, Rome Air Development Center, and Nuclear Research Officer, Air Force Weapons Laboratory, formerly the Air Force Special Weapons Center.

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