

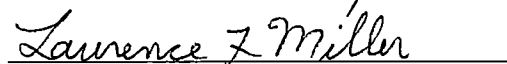
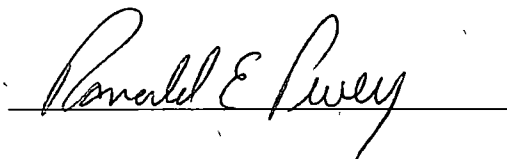
To the Graduate Council:

I am submitting herewith a thesis written by Roger Andrew Gard entitled "SPALLDKZ: A Nuclear Decay Model." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Nuclear Engineering.



Dr. Lawrence Townsend, Major Professor

We have read this thesis and
recommend its acceptance:



Accepted for the Council:



Associate Vice Chancellor and
Dean of The Graduate School

SPALDKZ: A NUCLEAR DECAY MODEL

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Roger Andrew Gard

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ABSTRACT

Currently research is being conducted at accelerator facilities, such as the Holifield Radioactive Ion Beam Facility at the Oak Ridge National Laboratory, that is key in efforts to understand nuclear structure. Targets bombarded with high-energy particles fragment into a wide assortment of radioactive nuclides. These radioactive nuclides are then collected and used in further experimentation as Radioactive Ion Beams (RIBs). To optimize current research, accurate predictions of the products of spallation reactions are needed as well as an understanding of the longevity of these radionuclides.

This work describes a numerically based nuclear decay model for predicting the time-development of spallation yields for accelerator applications (in particular RIB applications). No other loss terms (i.e. diffusion from target) accompany the time-decay in the model. The model is implemented in the computer code Spallation Decays (SPALLDKZ) which is used to predict time-dependent radionuclide amounts in accelerator targets for a feasibility study for RIB applications. SPALLDKZ uses a numerical process which solves first order differential equations over many time steps, and is not limited by the number of nuclides for which the calculations are to be made. Estimates of decay constants for exotic nuclides extending toward the neutron and proton drip lines are made to include all predicted spallation yields in the decay calculations.

Results from SPALLDKZ are compared to those from another decay code, ORIHET, to help determine the effectiveness of SPALLDKZ. This is done using spallation yields from aluminum and uranium (U-238) targets. The overall results show a good correlation between the output of the two codes.

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I. Introduction

Currently, in the field of astrophysics, there is interest in knowing how the universe was created and has progressed to its present state¹. In the field of nuclear physics, there is great interest in understanding the makeup of the atom down to the quark level¹, and whether or not it is possible to create new stable atomic structures at or near the island of stability^{1,2} ($Z=114$, $N=184$). The particle accelerator is the major tool used in this current research. The advent of next generation facilities (such as the Spallation Neutron Source to be built at the Oak Ridge National Laboratory) will make it possible to perform experiments that were previously not feasible. High-energy protons strike a stationary target and a spallation process occurs. Spallation is the terminology for the process by which a particle breaks up into smaller fragments as a result of particles colliding at high energies. Due to the spallation of the target, exotic non-terrestrial nuclides are formed. These radioactive nuclides diffuse out of the target and are separated through the use of a mass spectrometer. They are then sent as a second beam², through the use of a tandem accelerator, towards a second target. Studies of the nuclear structure can then be made.

At these experimental facilities, it is planned that targets undergo two weeks of irradiation. After the two-week period, new targets replace the old, while the old targets go through a cooling down process since they are very radioactive. It is very important to have a prior knowledge of how active a target will be, what the major contributing nuclides are, and how long it will take for the activity to decrease to acceptable levels. This information is needed because creating threshold amounts of certain undesired radionuclides will necessitate that the facility operate as a nuclear facility³ and not as a

radiological facility. Target studies are very important in helping to design targets that will optimize the production of the desired exotic spallation products while minimizing the production of problematic radionuclides.

Many of the exotic nuclides of interest have very short half-lives. It is necessary to know if these nuclides are produced in ample amounts so that they will not decay before they can diffuse from the target and be used in RIB applications. The Los Alamos High Energy Transport (LAHET⁴) code is capable of calculating spallation yields. However, the yields are only incident particle dependent and not time-dependent. By applying a conversion factor, the yields are converted to a production rate,

$$Rate = \frac{\left(\frac{yield}{proton} \right) (\# \text{ of } protons)}{1.602 \cdot 10^{-13} \mu A \cdot sec} \quad (1)$$

where yield/proton is the output generated by LAHET. The normalization of interest for this work is particles produced per micro-Amp per second. For the comparison of SPALLDKZ to that of ORIHET (discussed later), it is necessary to normalize the yields to units of gram atoms per second in Eq. (2).

$$Rate = \frac{\left(\frac{yield}{proton} \right) (6.2519 \cdot 10^{15})}{6.023 \cdot 10^{23}} \quad (2)$$

A time-dependent decay model is then coupled with the production rates to calculate a simulated beam time of two weeks and subsequent decay through 1.00×10^8 seconds (3.17 years).

SPALLDKZ is designed to follow decays without limits on the number of nuclide types for which a calculation is being performed. In order to achieve this, a nuclide

decay constant database is constructed from resources of measured half-life values.

Estimates are used for exotic nuclei that do not have measured half-life data.

When modeling the time decay of radioactive nuclides, there are generally two methods used to achieve working models⁵: numerical solutions and use of analytical solutions, such as the Bateman Equations⁶. The Bateman Equations are of the following form:

$$N_i(t) = \lambda_1 \lambda_2 \dots \lambda_{i-1} N_{1_0} \sum_{j=1}^i \frac{e^{-\lambda_j t}}{\prod_{k \neq j} (\lambda_k - \lambda_j)} \quad (3)$$

where $N_i(t)$ is the time-dependent amount of the i^{th} nuclide in a decay chain. N_{1_0} is the initial amount of the first member of the decay chain, and λ_1, λ_2 , etc. are the decay constants for the decay chain members where λ_1 corresponds to the first member of the decay chain. Note that this is the simplest form of the Bateman equation and that only the first member of the decay chain has an initial amount. The calculation for $N_i(t)$ requires that the decay constants for all of the preceding decay chain members be known. The Bateman Equations become more complicated when allowances for additional decay chain members to have initial amounts are made. The following equation includes initial amounts for the first and second members:

$$N_i(t) = \lambda_1 \lambda_2 \dots \lambda_{i-1} N_{1_0} \sum_{j=1}^i \frac{e^{-\lambda_j t}}{\prod_{k \neq j} (\lambda_k - \lambda_j)} + \lambda_2 \lambda_3 \dots \lambda_{i-1} N_{2_0} \sum_{j=2}^i \frac{e^{-\lambda_j t}}{\prod_{k \neq j, 1} (\lambda_k - \lambda_j)}. \quad (4)$$

Use of the Bateman Equations requires that approximations be made before they can be implemented. Also each nuclide's position in each decay chain is explicitly important. However, the analytical Bateman solutions allow for a user-friendly model where output times may be adjusted for each set of calculations. Algorithms involving numerical solutions are not so easily adjusted. Because of their rigid structure of loops, they require an adjustment to the source code and a recompilation to obtain different output times. Numerical solutions may use a lot of computer processor time and may also suffer from round-off errors because of the numerous iterations involved in the solution process. For this work, the decay model involves a numerical solution. This decision was arrived at for two reasons: ease of coding and creating a code that is independent of nuclide position in the decay chain. The latter facilitates the addition of any new exotic nuclides to the databases.

Several other computer codes are currently in existence, but were either not available for use at the time this project was started or were not capable of performing calculations on the large number of nuclide types for which SPALLDKZ is specifically designed. Among these codes are ORIGEN⁷, CINDER, and ORIHET. All of these use the analytical Bateman solution method. ORIHET is specifically designed for use with the charged particle codes HETC and LAHET and became available for use during the development of this project. ORIHET is used in this work to help determine the functionality of the SPALLDKZ code. Results from simultaneous runs will be covered in later sections of this thesis.

The following sections of this paper will discuss the steps involved in preparing the SPALLDKZ code, its verification, and its use. This involves the research work done

to prepare the libraries of decay constants used. It also involves the development of a decay model and implementing it in a computer code. Then SPALLDKZ is verified using another decay code for comparison. Once SPALLDKZ is verified, it is then run using Uranium yields and the results are displayed. A section is included with instruction on how to use the SPALLDKZ code.

II. Decay Constants Database

The first step in developing SPALLDKZ is to generate the nuclear decay constant database. Because of the large number of possible spallation product nuclides (nearly 3000), this is a labor-intensive enterprise. Measured values of nuclide decay half-lives are obtained from compilations published by the National Nuclear Data Center⁸ and by the Japanese Nuclear Data Committee⁹. Some of the nuclides predicted by nuclear reaction codes, such as LAHET, do not possess measured decay half lives. Most of these are either very proton or neutron rich and have mass numbers near the proton and neutron drip lines. The proton and neutron drip lines mark the limit of nuclear binding energy. A nuclide species that is proton rich beyond the proton drip line has too many nuclear particles (protons in this case) for all of them to be bound in the nucleus. Such a proton rich nucleus will instantly evaporate protons and decay into a more stable species. Likewise, a neutron rich nuclide beyond the neutron drip line will instantly evaporate neutrons and decay into a more stable species. Because it is important to include these exotic nuclides near the drip lines in research for RIB applications, a numerical extrapolation of the measured half-life data is performed to obtain reasonable estimates for the unmeasured values.

The measured half-lives are entered into Mathcad© worksheets where all half-lives are converted into seconds. Next, the half-lives are converted into decay constants using,

$$\lambda = \frac{\ln(2)}{T_{\frac{1}{2}}} \quad (5)$$

where λ is the decay constant for a nuclide and $T_{1/2}$ is the half-life. Finally a numerical spline is performed using the Mathcad© program to generate estimates for exotic nuclides that do not have measured values. An alternative solution for decay constants from the nuclides with unmeasured values is to use a uniform decay constants. However, the nuclides having measured values adjacent to those that do not have measured values have half-lives that vary widely from several seconds down to nanoseconds. Hence, it was decided that decay constants generated with a numerical spline would produce estimates that should give more realistic predictions.

Figure 1 and Figure 2 display extrapolated decay constant values for Cs (Z=55) and Ce (Z=58) respectively.

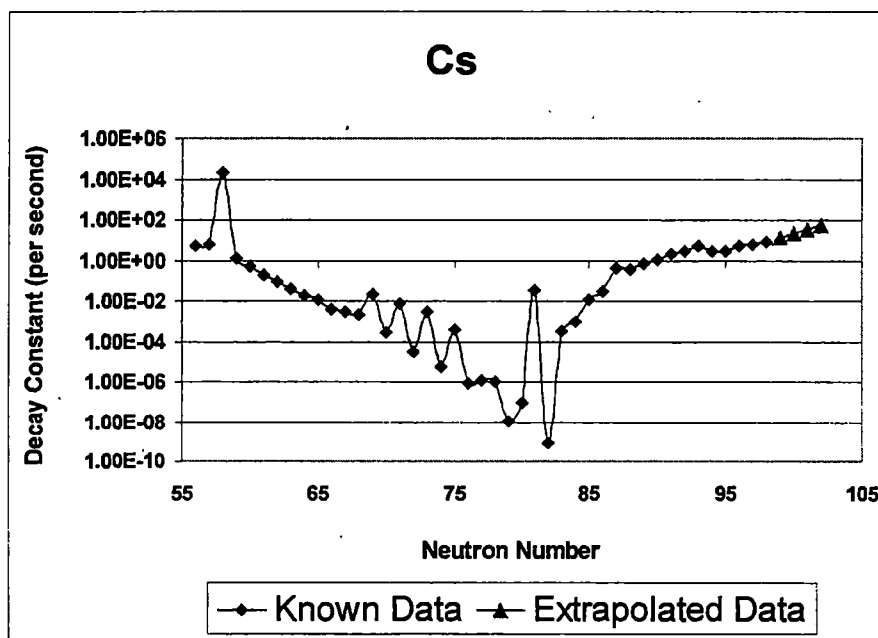


Figure 1. Extrapolated Decay Constant Values for Cs

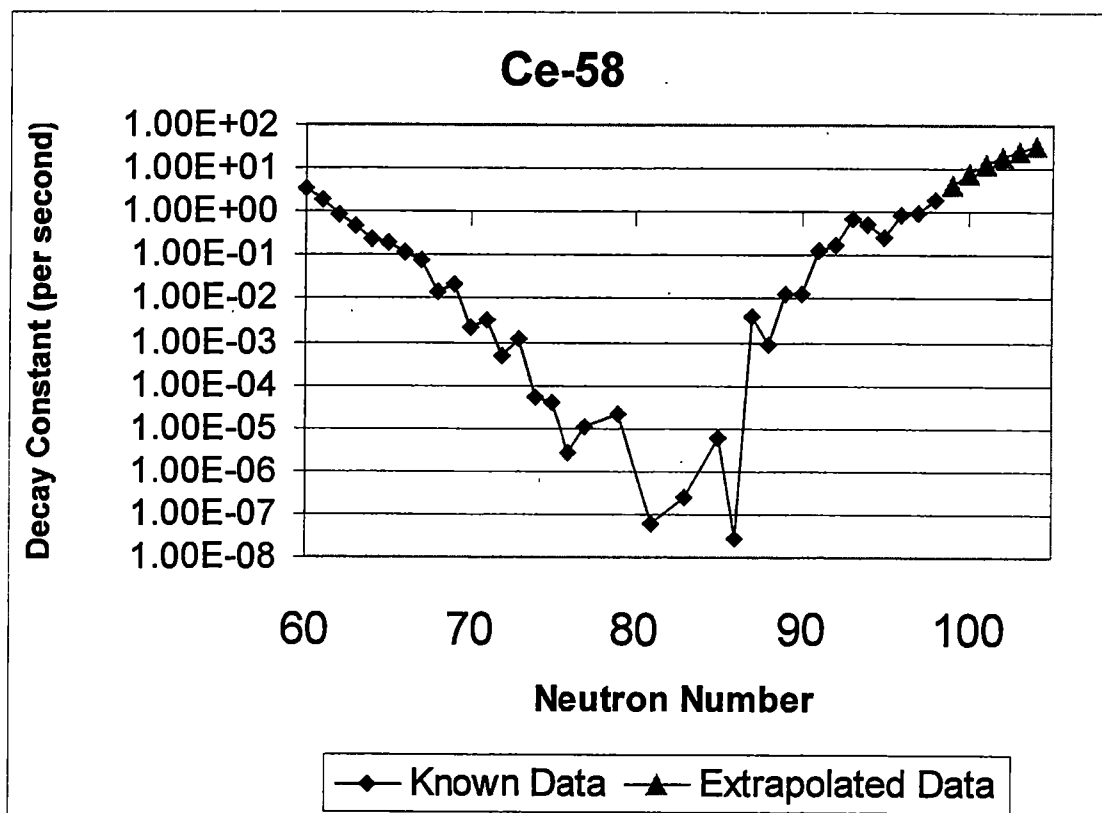


Figure 2. Extrapolated Decay Constant Values for Ce

The decay constants are stored in six data files: alpha2.dat, beta2.dat, betaneut.dat, epsilon2.dat, eprot.dat, and proton.dat. The name of the data file corresponds to the decay mode by which a particular nuclide decays: alpha decay (α), beta decay (β^-), beta decay followed by a neutron emission (β^-n), electron capture or beta plus emission (β^+), electron capture or beta plus emission followed by a proton emission (β^+p), and proton decay (p). For nuclides that have multiple decay branches, the decay constants for each decay mode are the fractional part of the total decay constant. Therefore the branching ratios are implicitly stored in the data files. Each file indexes entries by Z and N numbers. For simplicity these are also used as array location identifiers in the code. The data files reside in the same directory as the executable SPALLDKZ file, and upon execution of the code, the decay constants are read and stored into arrays.

Table 1 shows the data from proton.dat, the smallest of the data files. The other five data files are included in Appendix A as well as the extrapolated decay constants.

Table 1. Decay Constants for Proton Decay Mode

Z	N	λ (sec ⁻¹)
27	26	3.968E-02
53	56	6.359E+03
55	58	2.100E+04
65	75	7.509E-04
69	77	1.931E+00
69	78	1.238E-01
71	79	2.801E+00
71	80	5.708E+00
71	82	7.702E-01
73	83	1.733E+00
75	85	7.711E+02
79	93	3.466E+00

The existence of isomeric states creates a very valid question about their consideration in the decay model. In this work, all nuclides are assumed to be created in the ground state. This is reasonable because the LAHET output used herein does not differentiate between stable and isomeric states. It also simplifies the coding for the decay model. Another assumption that is made concerning the data files pertains to the decay processes for exotic nuclides with no values or measurements available for reference. Proton rich nuclides are assumed to decay by the β^+ process while neutron rich nuclides are assumed to decay by the β^- process. In the future, improved methods for handling isomeric states need to be developed.

III. SPALLDKZ Computer Code Development

After creating the data files containing the decay constants and fractional data, the next task is to create a FORTRAN computer code that accurately models the simultaneous buildup and decay of radionuclides produced in the spallation process during accelerator beam operation. Pure analytical solutions of the rate equations for radioactive nuclide buildup and decay are attractive because computational problems with round-off errors are reduced. However, the complexity of these solutions increases significantly as the number of decay generations being modeled is increased. Analytical methods using the Bateman equations exist and are implemented in several codes in common use such as ORIGEN. A major drawback to this method of analysis is the need to formulate decay chain solutions specifically for each decaying species.

In this work, a numerical procedure is used to model the buildup and decay of each radionuclide. Because a numerical process involves many steps through time, it is important to give careful consideration to the time step used in the calculations as well as modeling the decay correctly with appropriate mathematical solutions.

The Mathematical Model

In this work, the analytical approach is abandoned and a numerical procedure is used to model the buildup and decay of each radionuclide. SPALLDKZ models simultaneous build-up and decay differently than a decay-only process. For the build-up and decay, the starting point is a rate equation for the time rate of change in the number of nuclei $AMT(Z,N,t)$ at time t which involves a production term $P(Z,N)$. Z and N are the proton number and neutron number respectively for each particular isotope.

$$\frac{dAMT(Z, N, t)}{dt} = P(Z, N) - \lambda_T(Z, N)AMT(Z, N, t) \quad (6)$$

In Eq.(6) $\lambda_T(Z, N)$ is the total decay constant for the isotopic species. The calculations are performed through several iterations of a time step, Δt , thus the amount of a nuclide type at the end of a time step (where t = total time) is

$$AMT(Z, N, t) = P(Z, N) \frac{(1 - e^{-\lambda_T(Z, N)t})}{\lambda_T(Z, N)} + AMT(Z, N, t = 0)e^{-\lambda_T(Z, N)t} \quad (7)$$

Eq. (7) gives the amount of a nuclide at time $t + \Delta t$, which includes the amount of any new particles produced minus the amount of particles lost due to decay. The total amount of decay product, or daughter product, is

$$DTR = P(Z, N)\Delta t + AMT(Z, N, t = 0) - AMT(Z, N, t + \Delta t) \quad (8)$$

and DTR is divided up amongst the appropriate decay branches according to

$$DTR(Z, N) = DTR \cdot f \quad (9)$$

where,

$$f = \lambda_i(Z, N) / \lambda_T(Z, N) \quad (10)$$

$\lambda_i(Z, N)$ is the decay constant for the i^{th} process (beta decay, alpha decay, etc.), while $\lambda_T(Z, N)$ is the total decay constant including all processes. If there is only one decay mode (as is normally the case), then $\lambda_i(Z, N) = \lambda_T(Z, N)$ for that mode and $f=1$. Likewise, if $\lambda_i(Z, N)=0$ indicating that the i^{th} decay channel does not exist for that species, then $f=0$.

All daughter amounts $DTR(Z, N)$ calculated are stored in a dummy array until all calculations have been completed for all of the radionuclides in the current time step. Then, the dummy array values are added to $AMT(Z, N)$ to update the quantity of each radionuclide present at the end of the time step and a new time step is initiated.

The decay-only portion of the code is very similar, but the production term is omitted.

$$\frac{dAMT(Z, N, t)}{dt} = -\lambda_r(Z, N)AMT(Z, N, t) \quad (11)$$

$$AMT(Z, N, t) = AMT(Z, N, t = 0)e^{-\lambda_r(Z, N)t} \quad (12)$$

$$DTR = AMT(Z, N, t = 0)(1 - e^{-\lambda_r(Z, N)t}) \quad (13)$$

The Time Step

Once the numerical algorithm is developed, it is important to implement it with appropriate time steps that allow the algorithm to accurately calculate the time-dependent decay while minimizing computer processor time. No single time step achieves both objectives. A large time step reduces the number of iterations and therefore cuts down on processing time, but does not model the decay very accurately.

In reality, as the radionuclides are decaying in the accelerator targets, there is a wide spectrum of rates by which the nuclides decay. Some nuclides decay so rapidly that yields due to spallation last less than a second, while other nuclides are decaying so slowly that they are effectively stable for time periods less than thousands of years.

There are truly stable nuclides and the broad spectrum of nuclides that fill in the void between the very short-lived and very long-lived nuclides. It would be unwise to choose a lengthy time interval with very short-lived nuclides present, especially since many of these are the exotic nuclei that are of particular interest for RIB applications.

Many of these short-lived nuclides have half-lives on the order of milliseconds. This means that in order to accurately implement the numerical algorithm, time steps on the order of milliseconds need to be used. However, using such a short time step creates

large numbers of numerical calculations, and such calculations will require extremely lengthy computer processing time.

A clever technique used in this work is to use a varying time step. After the very short-lived nuclides decay away a very small time step is unnecessary. A larger time step is then used that will be most effective for efficiently handling the remaining short-lived nuclides. As those nuclides decay away, the time step again becomes inefficient and the new time step needs to be increased. This technique of increasing the time step works very well at reducing much of the computer processing time, but when very large time steps are used, the accuracy of the decay model is reduced. Long-lived nuclides decaying into short-lived daughters do not fit well into this scheme. This is because the output files are created at a point where the newly formed daughters are present, but their decay is not accounted for. A remedy to this problem is to use large time steps for the bulk of the time between time frames and then methodically decrease the time step back down to very small time steps as each time frame nears completion. This increases the number of times that daughter products are allowed to decay and improves the accuracy of the model.

Implementing the variable time step is easy for a base ten number system. An initial time step of 0.0001 seconds is used for ten numerical calculations. This means that a total of 0.001 seconds of decay has elapsed. Now, increasing the time step by a factor of ten and then stepping through the numerical calculation nine times will account for 0.01 seconds of decay from time zero. When the time step is increased to 0.01 seconds, the numerical process is iterated through only eight times and the time step is decreased by a factor of ten and iterated nine times. The time step is decreased and the numerical

process is iterated through nine times repeatedly until the time step reaches the value of 0.000001. Now the amount of time for which decay is accounted for is approximately 0.1 seconds. Again, the time step is increased by a factor of ten, eight numerical calculations are performed using the time step, and then the time step is decreased systematically until the elapsed time is approximately 1.0 second. This process of increasing the time step, performing the bulk of the calculation between time frames, and then stepping the time step back down to finish the rest of the calculation is repeated until the total time of decay accounted for is 1.00×10^8 seconds.

The build-up and decay portion of the code simulating the two-week beam time is done in a similar fashion, but the time step starts off at its maximum to step through the bulk of the two-week period. Then the time step is decreased systematically to finish off the simulated beam time. At the end of the build-up and decay and before any decay-only calculations are done, the first output file is written and is named 0E+00.OUT. The filename signifies the amount of time decay has occurred following the beam time, and in this case it is 0.0 seconds. The next output file is written at 0.1 seconds and is named 1E-01.OUT. Output files are written as the output times increase by a factor of ten stopping when 1.00×10^8 seconds is reached. Typical results are displayed in the next section.

IV. Comparison of SPALDKZ to ORIHET

Once SPALDKZ is coded, debugged, and put through some preliminary testing, it is ready to be fully tested. Because of its availability, ORIHET is used to check the validity of the SPALDKZ code by comparing outputs for the same input. Output from the same LAHET run is normalized to a gram atom basis and then used as input into both the SPALDKZ and ORIHET codes. This is done first with aluminum target data and then with uranium target (U-238) data. The aluminum target is light and fragments into a small number of nuclides compared to the uranium target (over 2300).

Aluminum Target

Looking first at the aluminum target output from SPALDKZ and ORIHET, the output is analyzed to check for agreement between the two calculations. Four decay chains (for $A=24-27$) are illustrated in Figures 3-6. Figure 3 shows members of the $A=25$ decay chain. F-25, Ne-25, Na-25, and Mg-25 compose the chain, but F-25 is followed only by the SPALDKZ code because of its extensive data libraries. Notice that there is very good agreement between the codes for Ne-25, Na-25, and Mg-25. Figure 3 illustrates that SPALDKZ is capable of performing decay calculations with comparable accuracy of that of the ORIHET code.

Figure 4 displays members of the $A=24$ decay chain, which includes F-24, Ne-24, Na-24, Mg-24, and O-24. For this chain, there are three nuclides present in the SPALDKZ calculations that are not present in the ORIHET calculations. They are F-24, Ne-24, and O-24. The exclusion of these nuclides from the ORIHET calculations affects the calculated amounts of Na-24 and Mg-24, both of which are calculated to have

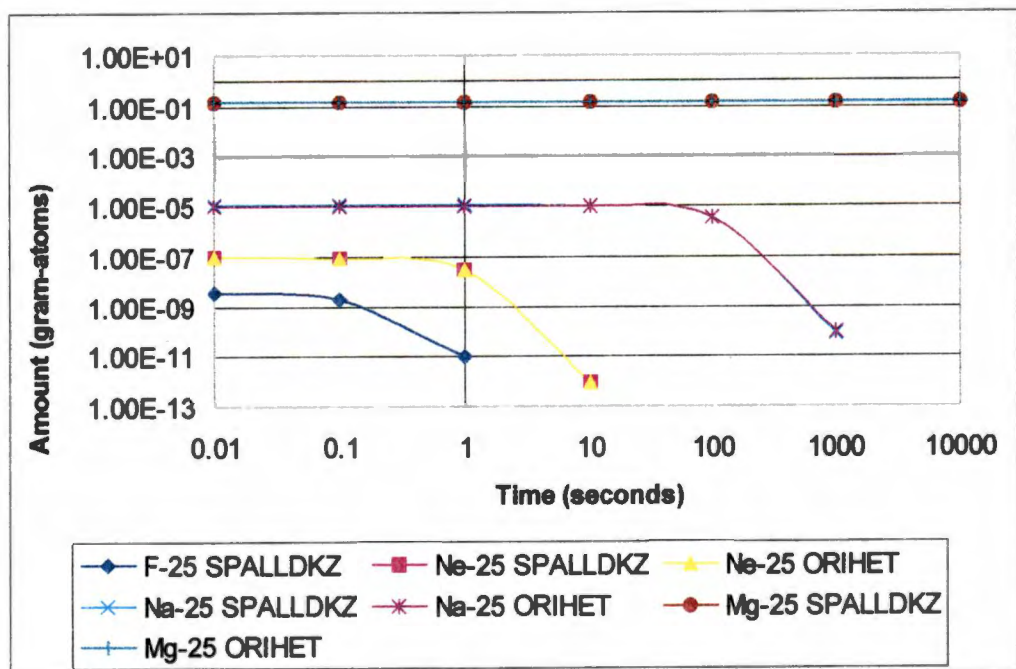


Figure 3. A=25 Decay Chain for Aluminum Target

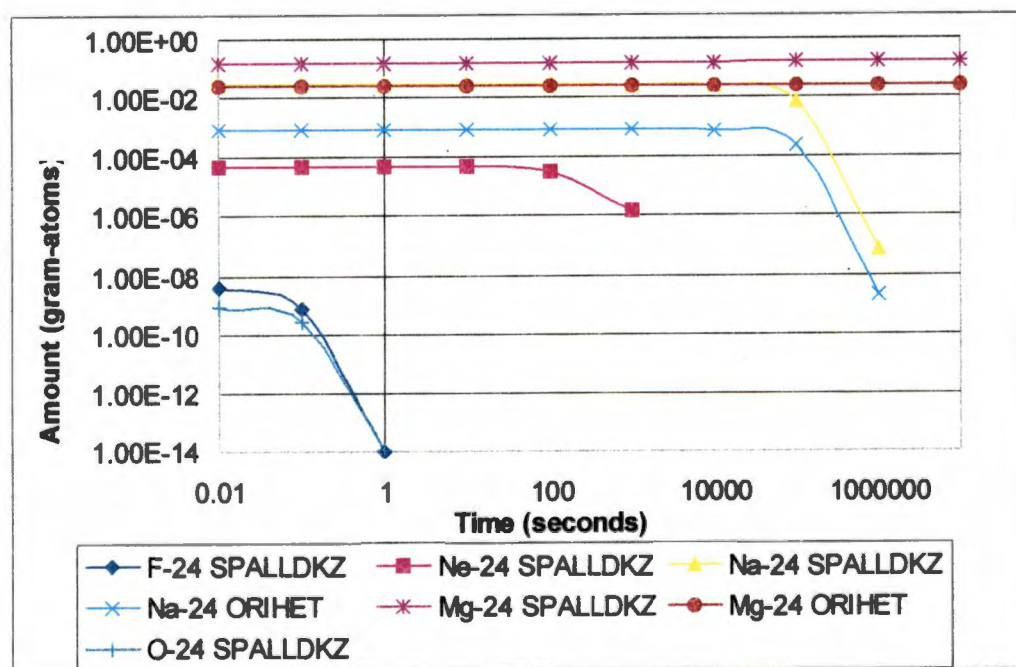


Figure 4. A=24 Decay Chain for Aluminum Target

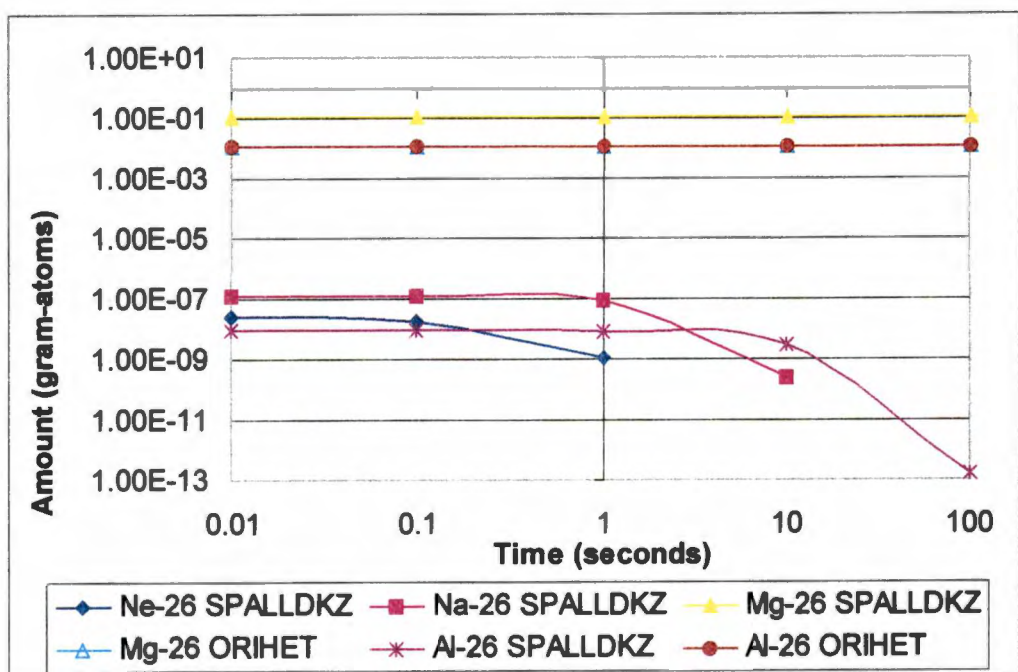


Figure 5. A=26 Decay Chain for Aluminum Target

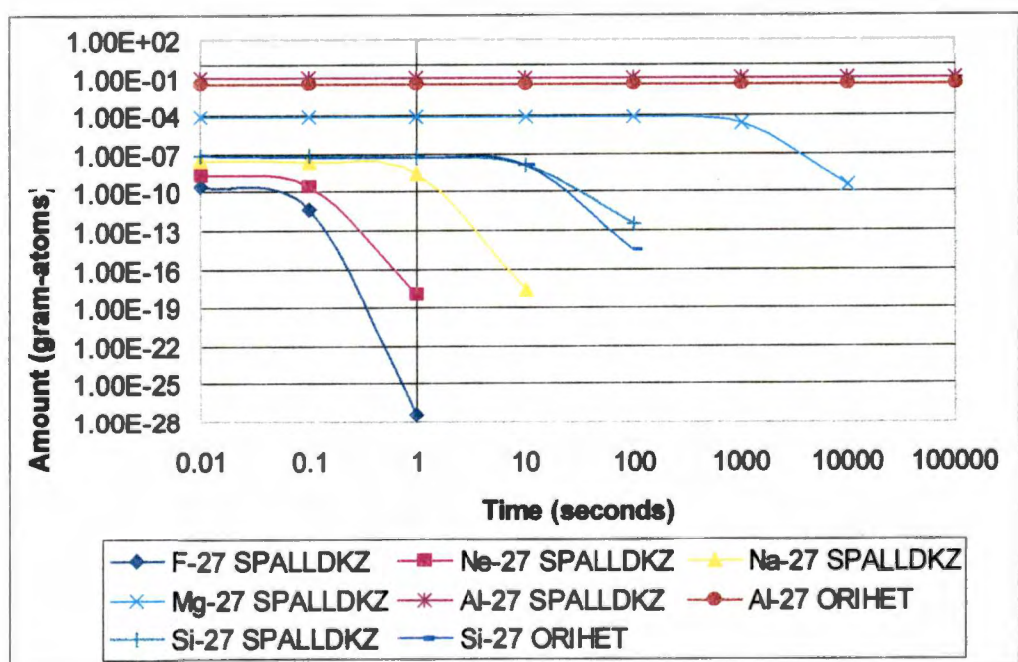


Figure 6. A=27 Decay Chain for Aluminum Target

higher amounts by the SPALLDKZ code. Figure 4 illustrates the ability of SPALLDKZ to handle exotic nuclides in its calculations.

Figure 5 displays the A=26 decay chain which includes Ne-26, Na-26, Mg-26, and Al-26. For this chain, Ne-26 and Na-26 are included only in the SPALLDKZ calculation. This is evidenced by the increased amount of Mg-26 calculated by SPALLDKZ. Notice that the calculations for Al-26 differ greatly. This is because Al-26 has a metastable state, which has a half-life of 6.3452 seconds. This is very short-lived compared to the 7.4×10^5 year half-life of the ground state. It is very evident that ORIHET is using the half-life corresponding to the ground state, while SPALLDKZ is using the half-life corresponding to the metastable state. In general, SPALLDKZ typically uses the ground state half-life, but the stark contrast between the half-life of the ground state and the metastable for Al-26 gives consideration for use of the shorter half-life.

The occurrence of calculational differences due to metastable states is not uncommon in this research. This will become more evident as the uranium results are discussed later. Because of its structure, SPALLDKZ is currently limited to using either the ground state or the metastable state for a nuclide. ORIHET is capable of using both the metastable and the ground state.

Figure 6 displays the A=27 decay chain, which includes F-27, Ne-27, Na-27, Mg-27, Al-27, and Si-27. Notice again how contributions from F-27, Ne-27, Na-27, and Mg-27, nuclides included in only the SPALLDKZ calculation, contribute to an increased amount of stable product.

Uranium Target

The calculations with the Aluminum target data show that SPALLDKZ has the ability to calculate decay effectively for the β^+ and β^- processes through short decay chains. The Uranium target is chosen because of its large array of spallation and fission products. At high energies, both processes occur. For this work, two decay chains are studied. They are the chains that decay down to the stable products Pb-207 and Pb-208. These chains are chosen because their members decay by α , β^+ , and β^- processes, have multiple decay branches, and compose lengthy chains.

Figure 7 displays the decay chain that includes the stable Pb-208 as its final product. There are 29 nuclides involved in the decay chain.

Figure 8 displays the decay of U-232. U-232 has a 69.8 year half-life and is far removed from Pb-208 in the decay chain. Thus its contributions to the stable Pb-208 are negligible for the relatively short time periods of these calculations. Knowing this allows for a careful look at the nuclides with $A \geq 232$. The comparisons between SPALLDKZ and ORIHET are very good for Np-232, U-232, and Pa-232. Np-232 and Pa-232 (displayed in Figure 9 and Figure 10 respectively) have identical results, while the U-232 results differ slightly, with the SPALLDKZ amount being approximately 10% less than the ORIHET calculation. Contributions from $\text{Np-236} \rightarrow \text{Pu-236} \rightarrow \text{U-232}$ may be responsible for this difference. It is evident that ORIHET is using Np-236 (Figure 11) in its metastable state, which has a 22.5 hour half-life, whereas SPALLDKZ handles Np-232 in its ground state, which is effectively stable.

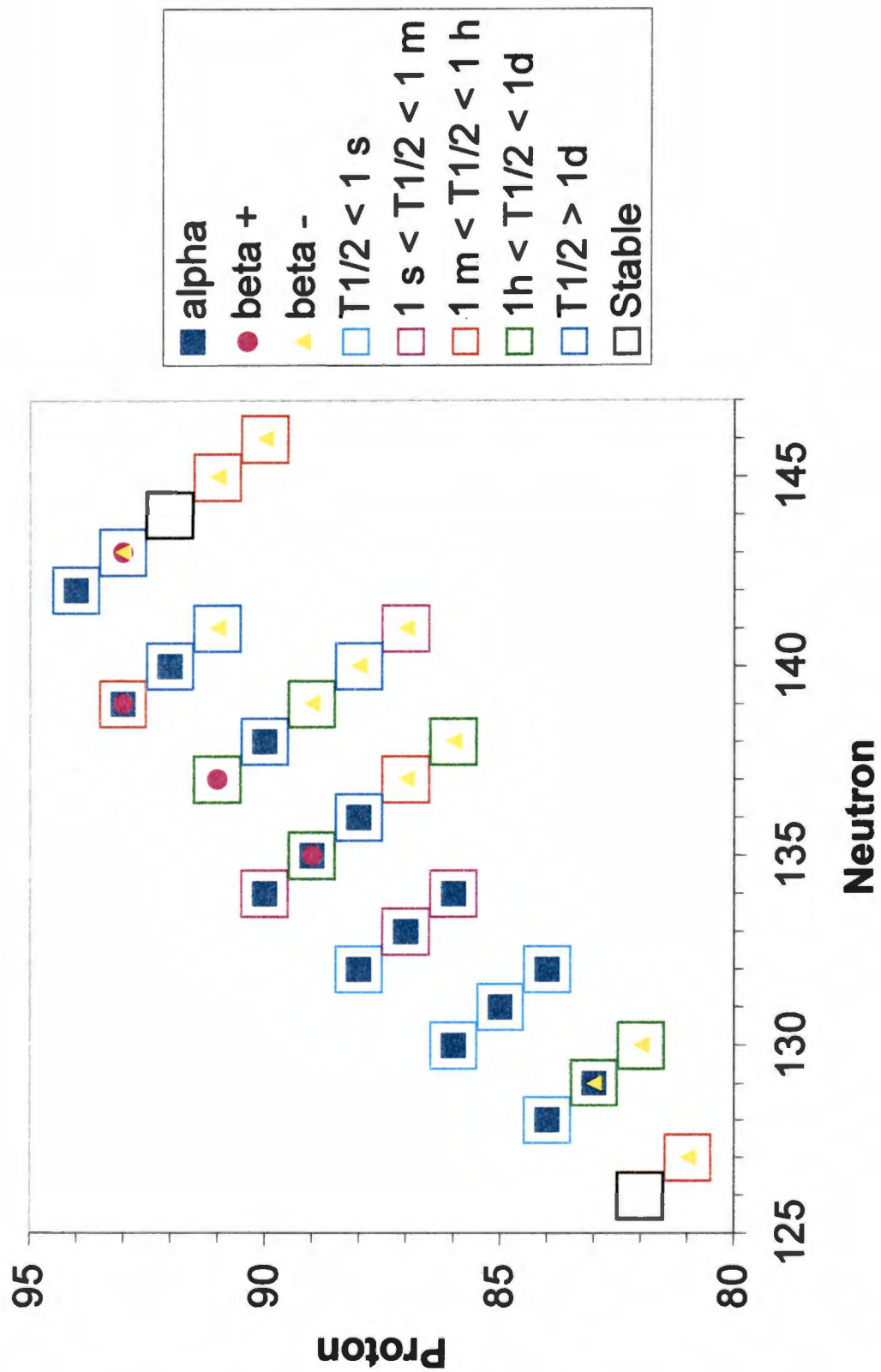


Figure 7. Decay Chain Including Pb-208 From Uranium Target

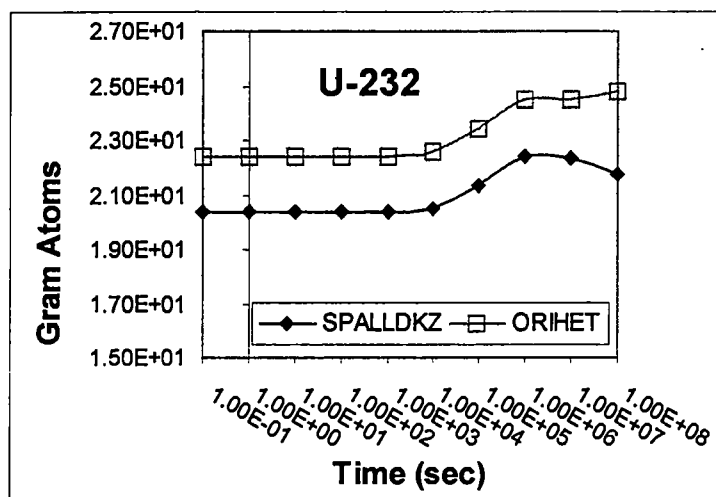


Figure 8. Decay of U-232 From Uranium Target

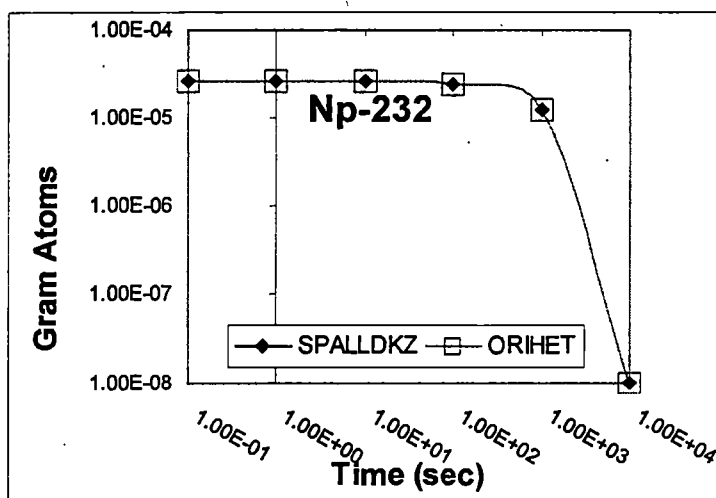


Figure 9. Decay of Np-232 From Uranium Target

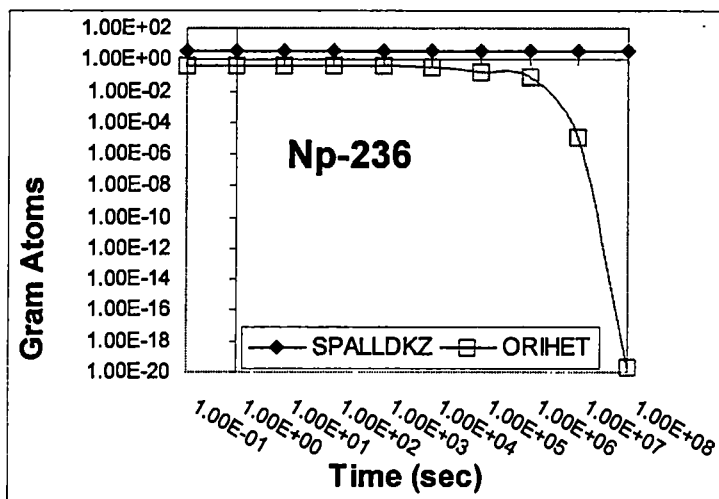


Figure 10. Decay of Pa-232 From Uranium Target

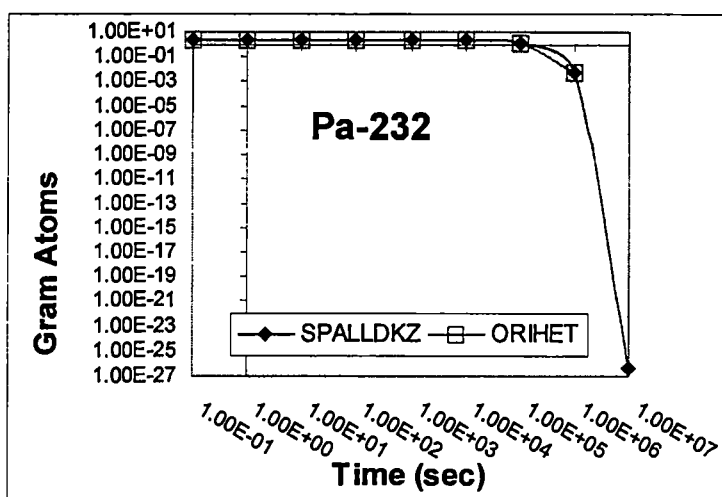


Figure 11. Decay of Np-236 From Uranium Target

The production rates of U-232, Np-232, and Pa-232 require that the total amount of these three nuclides produced in a two-week period is 22.42 gram atoms. ORIHET calculates 22.42 gram atoms of U-232 alone. (The amounts given are from the 0.00 second decay following the two-week beam time.) SPALLDKZ calculates 20.39 gram atoms for U-232. Given that both codes calculate 2.03 gram atoms for Pa-232 and 2.64×10^{-5} gram atoms for Np-232, this difference in the amount of U-232 either results from contributions from Pu-236 or it suggests that ORIHET is incorrect.

The production rates of Pu-236 (Figure 12), Np-236, and U-236 (Figure 13) require that the total amount of these nuclides produced in the two-week period is 157.89 gram atoms. Both SPALLDKZ and ORIHET differ from this amount having totals of 197.2 gram atoms from each of the codes. This implies that there are contributions from other nuclides namely Pa-236 and Th-236, which contribute to U-236 through β^- decay. Now, Pa-236 (Figure 14) and Th-236 (Figure 15) produce 34.537 gram atoms and 4.796 gram atoms respectively for the two-week period. This brings the total amount of gram atoms produced by Pu-236, Np-236, U-236, Pa-236, and Th-236 to 197.22 gram atoms. Both SPALLDKZ and ORIHET calculate amounts of Pa-236 and Th-236 on the order of magnitude of 10^{-2} gram atoms therefore not making any significant additions to the previous total of 197.2 gram atoms. Hence, the calculated difference in U-232 between SPALLDKZ and ORIHET does not originate from any of the A=236 nuclides.

It is noteworthy to examine the differences between SPALLDKZ and ORIHET calculations for Pu-236, Np-236, and U-236. These differences originate due to the metastable state of Np-236. The ground state of Np-236 has a half-life of 1.55×10^5 years rendering it effectively stable. Actually SPALLDKZ considers Np-236 to be stable.

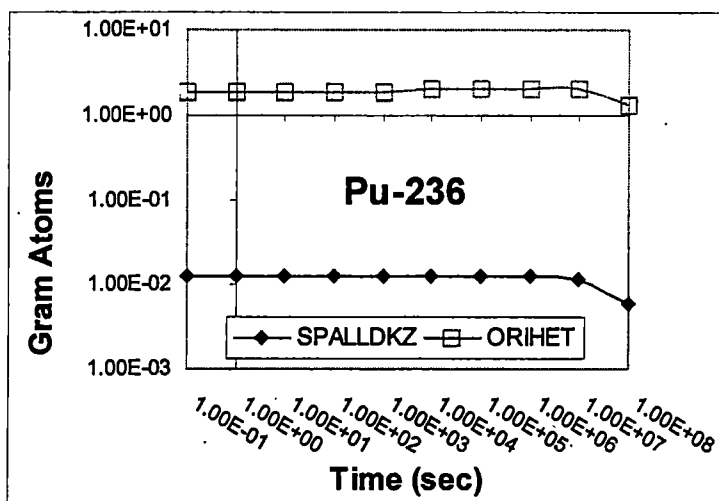


Figure 12. Decay of Pu-236 From Uranium Target

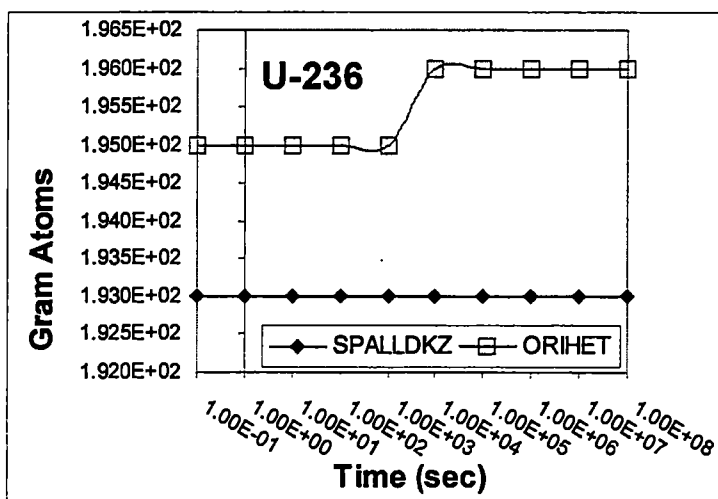


Figure 13. Decay of U-236 From Uranium Target

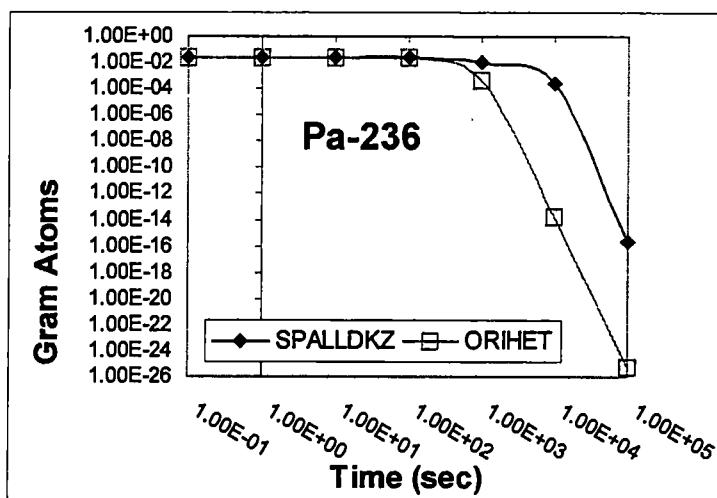


Figure 14. Decay of Pa-236 From Uranium Target

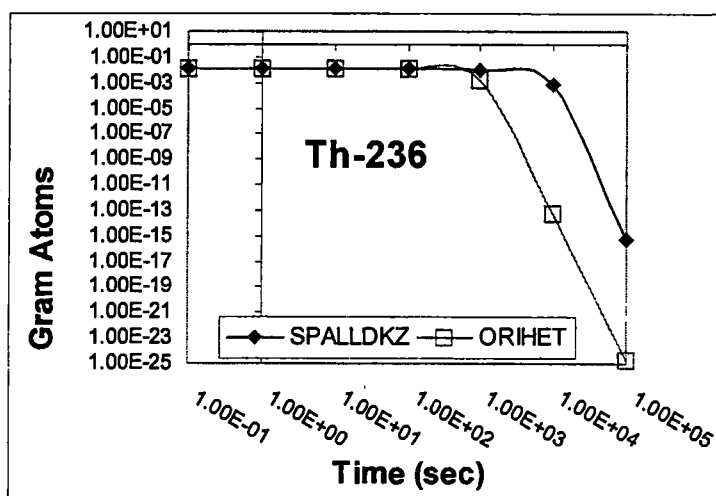


Figure 15. Decay of Th-236 From Uranium Target

The metastable state has a 22.5 hour half-life which does not decay into the ground state but rather decays by both β^+ (52%) and β^- (48%) processes. This explains why ORIHET has calculated greater amounts of Pu-236 and U-236 while SPALLDKZ calculates a greater amount of Np-236. Also, because of ORIHET's consideration of Np-236 as a metastable and its subsequent decay $\text{Np-236} \rightarrow \text{Pu-236} \rightarrow \text{U-232}$, there is a continued rise in U-232 for ORIHET versus evidence of decay for SPALLDKZ for the last two time frames (1.00×10^7 sec and 1.00×10^8 sec).

Because of U-232's long half-life, analysis of the $A \geq 232$ decay chain members is facilitated compared to that of the $A < 232$ nuclides. Focusing on the stable end-product of the decay chain, Pb-208 (Figure 16) exists almost entirely as a decay product. The production rate (Pb-208 is 1.038×10^{-8} gram atoms per second) yields a total of 1.255×10^{-2} gram atoms, which differs vastly from the amounts calculated by SPALLDKZ and ORIHET. Calculated Pb-208 amounts are on the scale of 8-10 gram atoms.

Po-212 (Figure 17) and Tl-208 (Figure 18) are the two most immediate contributors to Pb-208. Tl-208 is not a spallation product calculated by LAHET and therefore exists only as a decay product. The amount of Po-212 created during the two-week beam time is 7.533×10^{-2} gram atoms. Thus neither Po-212 nor Tl-208 make any significant contributions to the Pb-208 amount on their own account. However, any amount of radionuclide product that eventually decays to Pb-208 must first decay to either of these two nuclides.

Bi-212 (Figure 19) decays into both Tl-208 and Po-212, but like Tl-208, it does not have a production rate and exists only as a decay product. Pb-212 feeds Bi-212, but does not have a production rate either. Po-216 feeds Pb-212, and it, too, does not have a

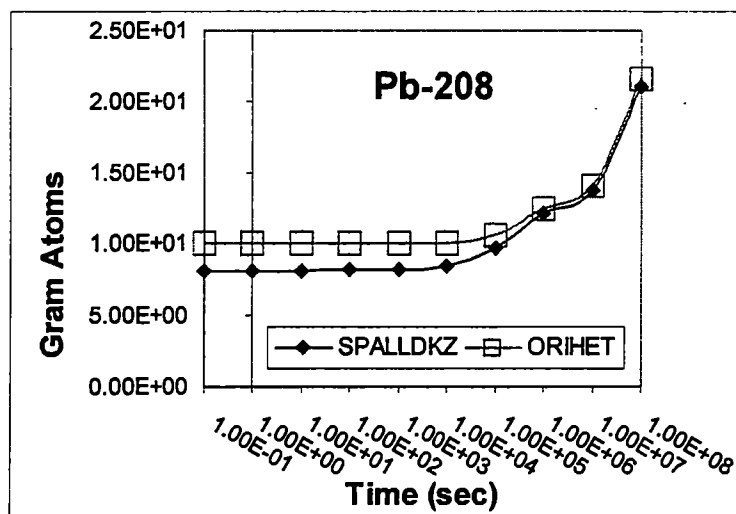


Figure 16. Decay of Pb-208 From Uranium Target

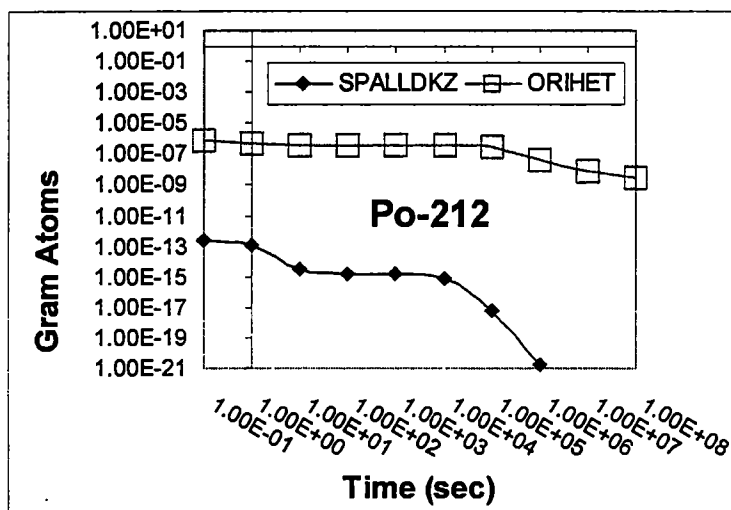


Figure 17. Decay of Po-212 From Uranium Target

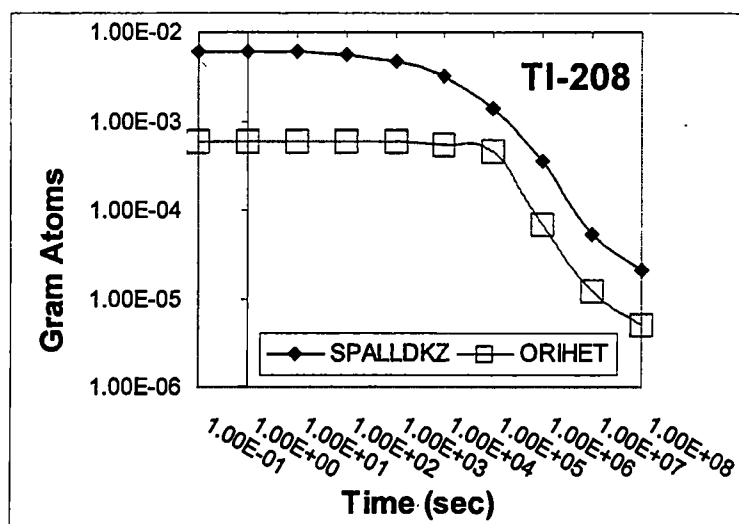


Figure 18. Decay of Tl-208 From Uranium Target

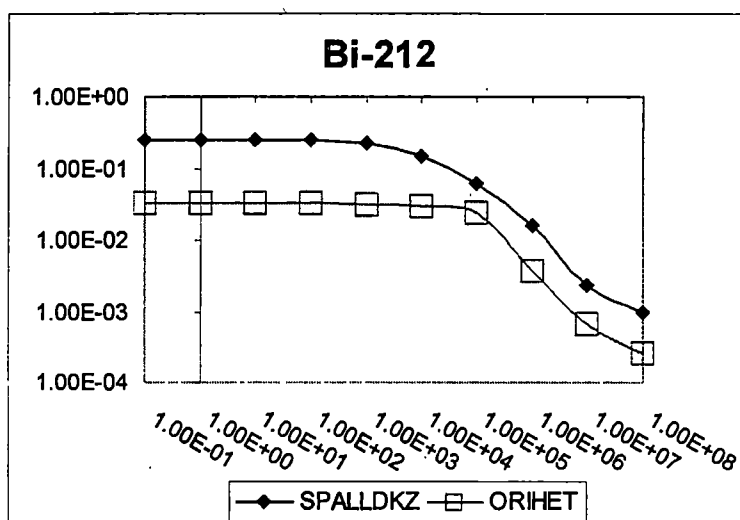


Figure 19. Decay of Bi-212 From Uranium Target

production rate. At-216 (Figure 20) is the lightest nuclide that makes any contribution to Tl-208, and the lightest nuclide to yield more than a gram atom of material is Ra-220 (Figure 21). It quickly becomes evident how complicated the decay scheme is and how difficult it is to determine its process, which is why computer codes are written to do the calculations in the first place.

Observe Bi-212, which has two metastable states. The ground state has a half-life of 60.55 minutes and decays by both β^- (64%) and α (36%) processes. The first metastable state has a half-life of 25.0 minutes and also decays by β^- (33%) and α (67%) processes, and the second metastable has a half-life of 7.0 minutes and decays by the β^- process. The manner that the computer codes handle the metastable states of nuclides becomes important in instances such as these where branching ratios and decay type are determined by the different isomeric states. The vast majority of differences between the SPALLDKZ and ORIHET calculations are a result of treating metastable states differently. Besides Bi-212 and the previously mentioned Np-236, Po-212 is the only other metastable nuclide in this decay chain. It is very easy to see the differences in the computer code calculations for Po-212, which has a long-lived metastable state in comparison to its ground state. Also, the metastable decays by alpha emission and does not decay to the ground state. Other decay chain members not displayed here are included in Appendix C.

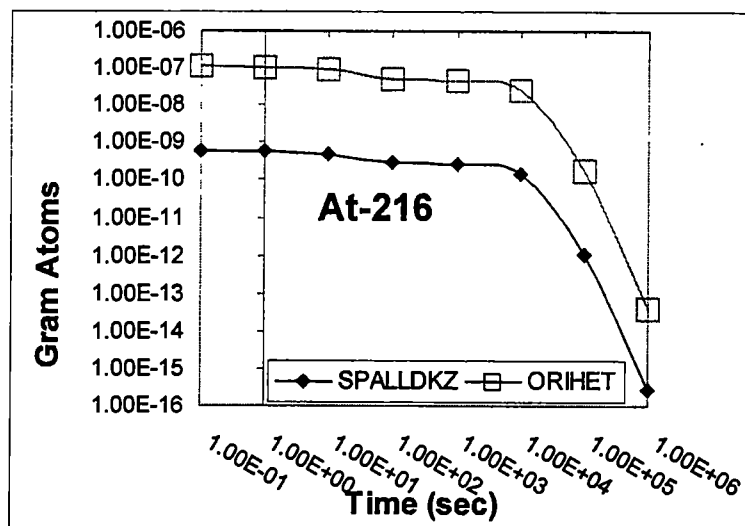


Figure 20. Decay of At-216 From Uranium Target

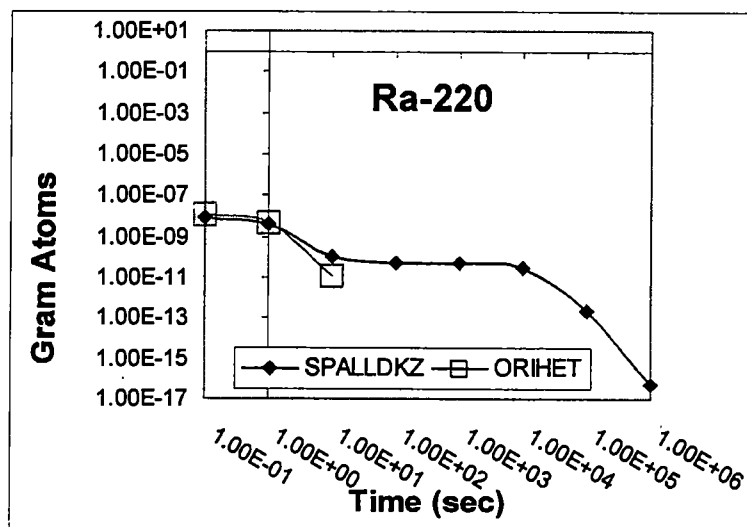


Figure 21. Decay of Ra-220 From Uranium Target

Analysis of the second decay scheme involves 51 total nuclides and has as its stable products Pb-207, Tl-203, Hg-199, and Pt-194. This decay chain is illustrated in Figure 22. Counting Pb-207 (displayed in Figure 23), there are 34 nuclides that contribute to Pb-207. This decay chain is much more complex than the previous one ending in Pb-208 and will not be discussed with the same in-depth detail. However, Figures 24-26 illustrate the decay chain members that are most adjacent to Pb-207. There is generally good comparison between the calculations of the two computer codes. Even though some nuclide amounts do not match identically (again a product of metastable states) notice that the slopes of the curves match very well. Other decay chain members not displayed here appear in Appendix C.

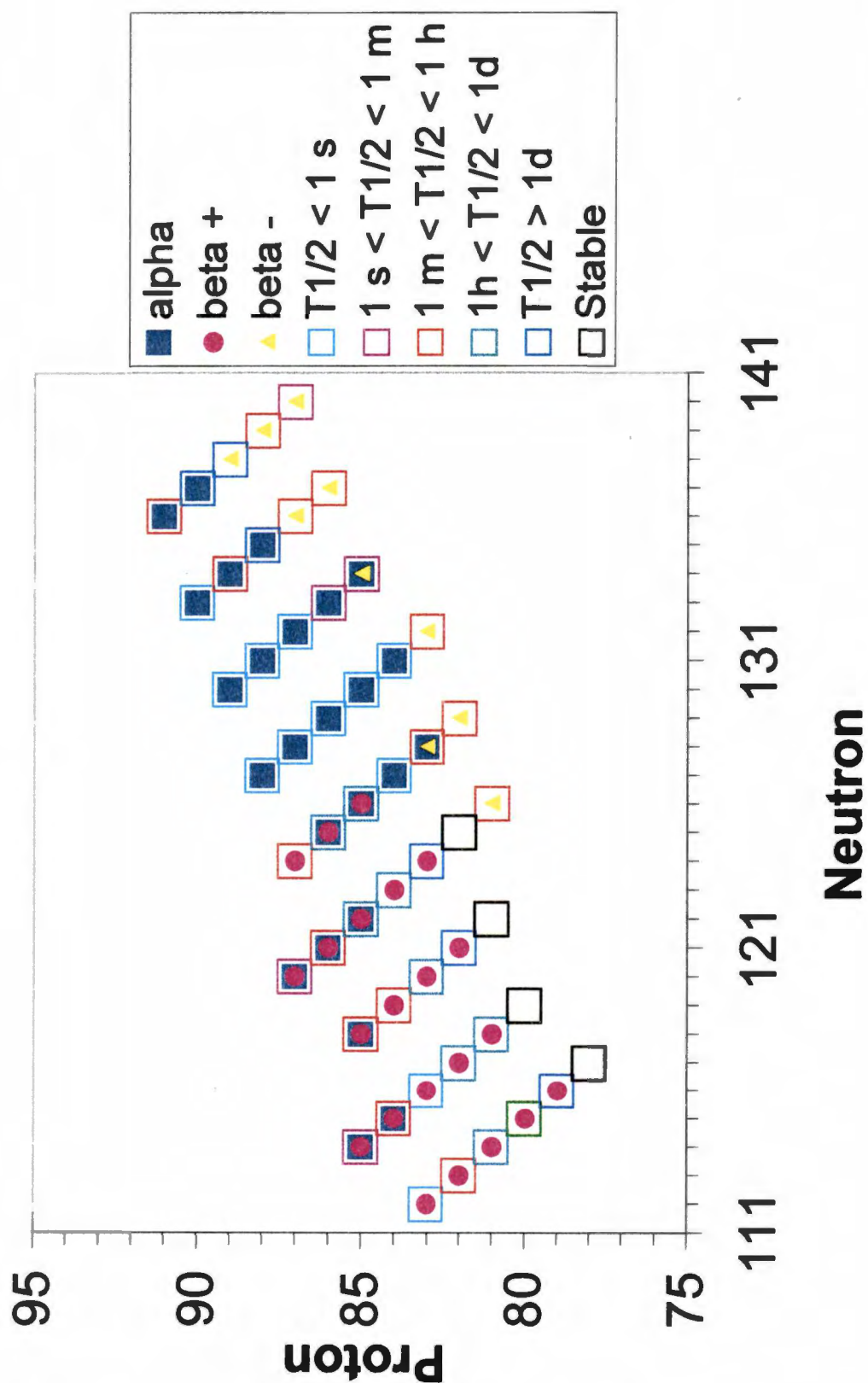


Figure 22. Decay Chain Including Pb-207 From Uranium Target

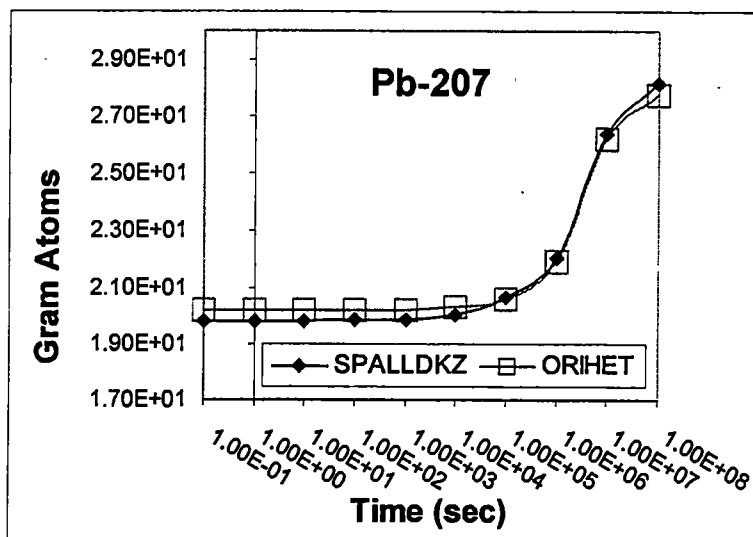


Figure 23. Decay of Pb-207 From Uranium Target

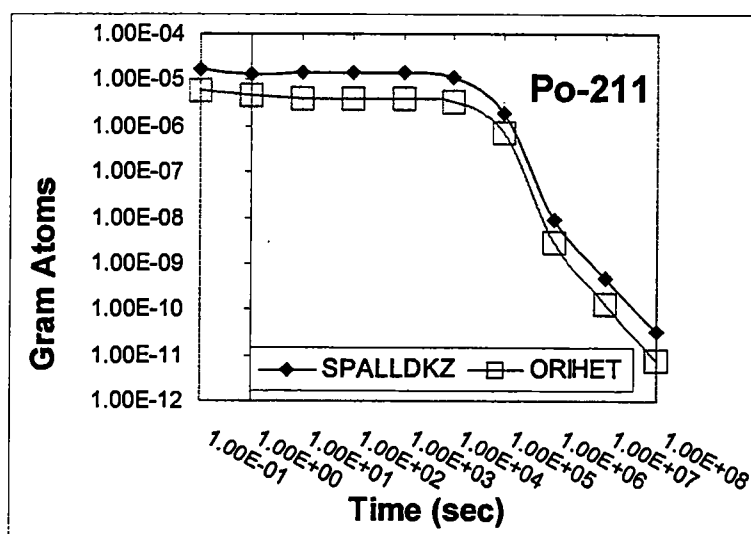


Figure 24. Decay of Po-211 From Uranium Target

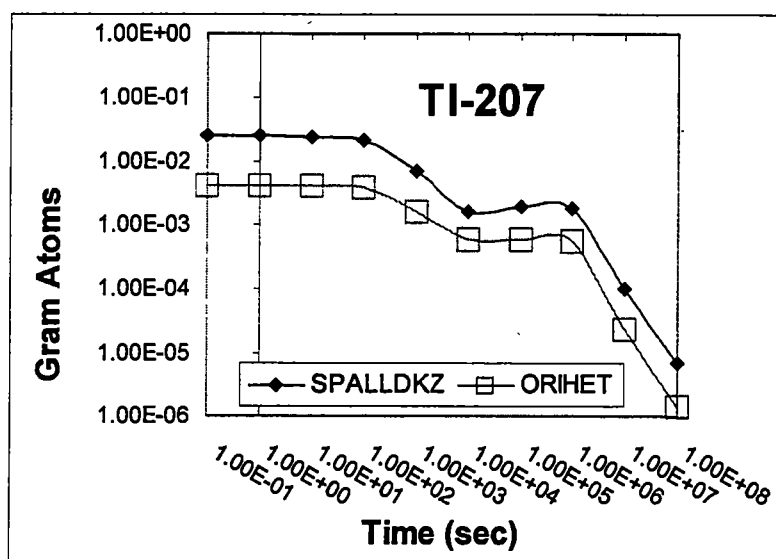


Figure 25. Decay of Tl-207 From Uranium Target

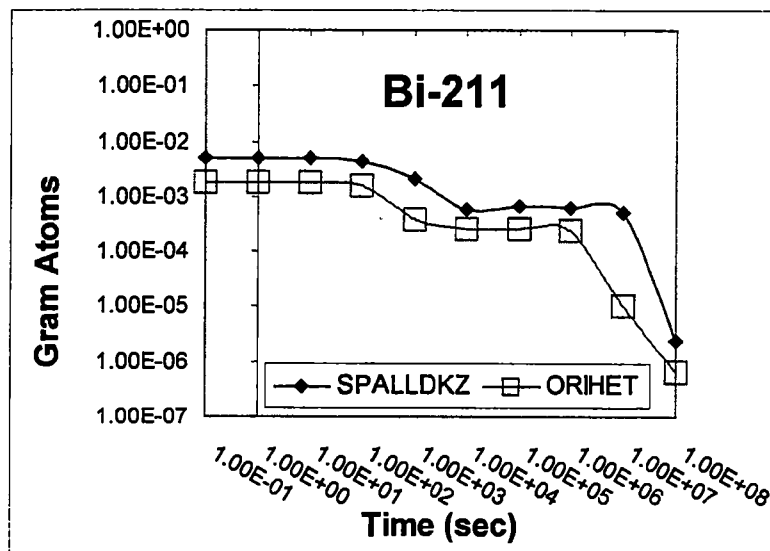


Figure 26. Decay of Bi-211 From Uranium Target

V. Results

Once the effectiveness of SPALLDKZ is determined, some calculations are performed on the Uranium data using the preferred normalization of particles produced per micro-Amp per second rather than using the gram atom basis. Results from the calculations are plotted in Figures 27-37. These figures illustrate the rapid decay of the short-lived nuclides, which can be seen by noting the thinning width of the yield curves as time increases. At 1.0×10^8 seconds, the curve is basically displaying the nuclear stability curve. Note also that the spallation/fission processes induced by high-energy protons striking Uranium produces nuclides from the very light ($A \approx 10-20$) to the very heavy ($A \approx 230$).

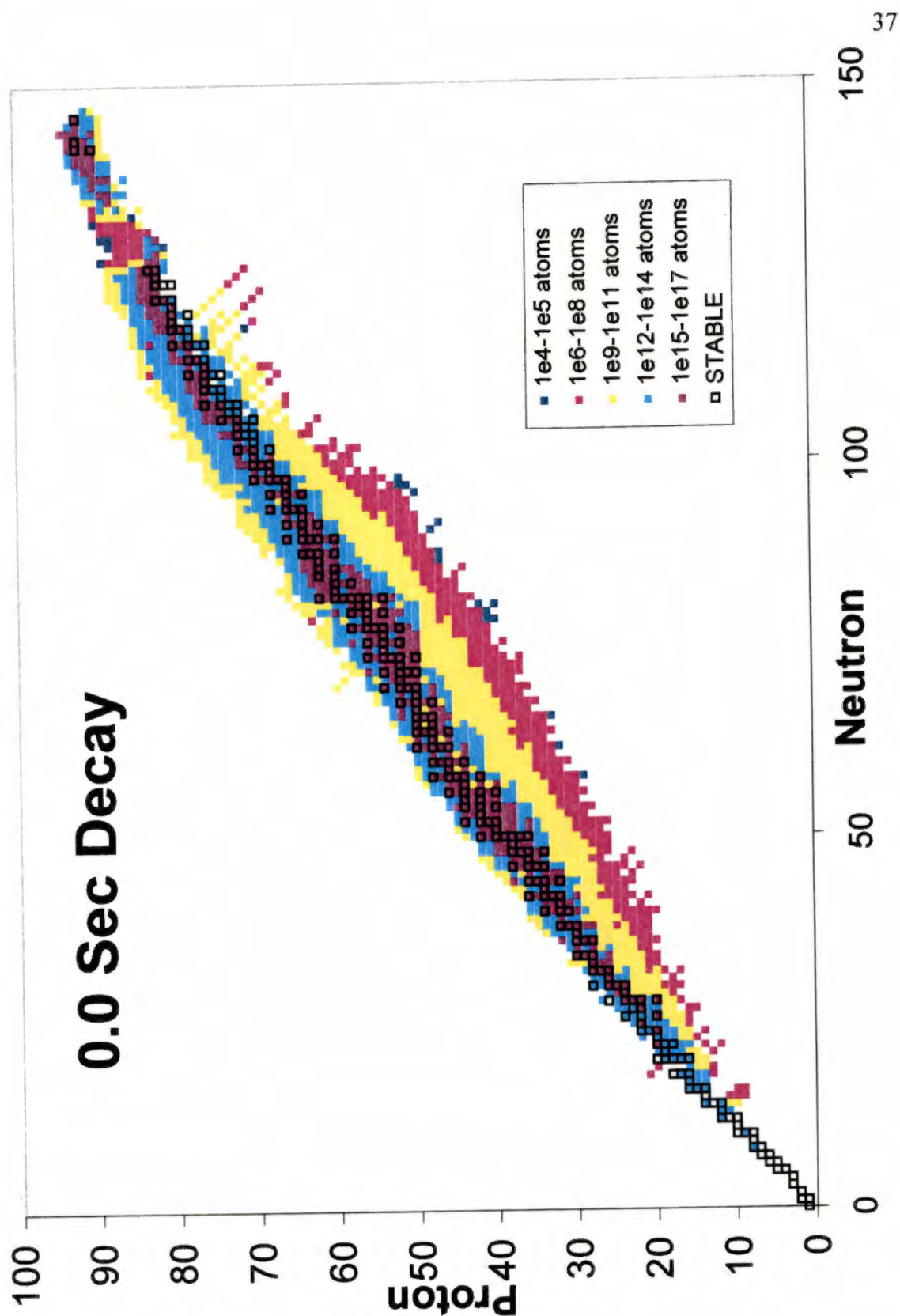


Figure 27. Decay of Uranium Yields: 0.0 sec

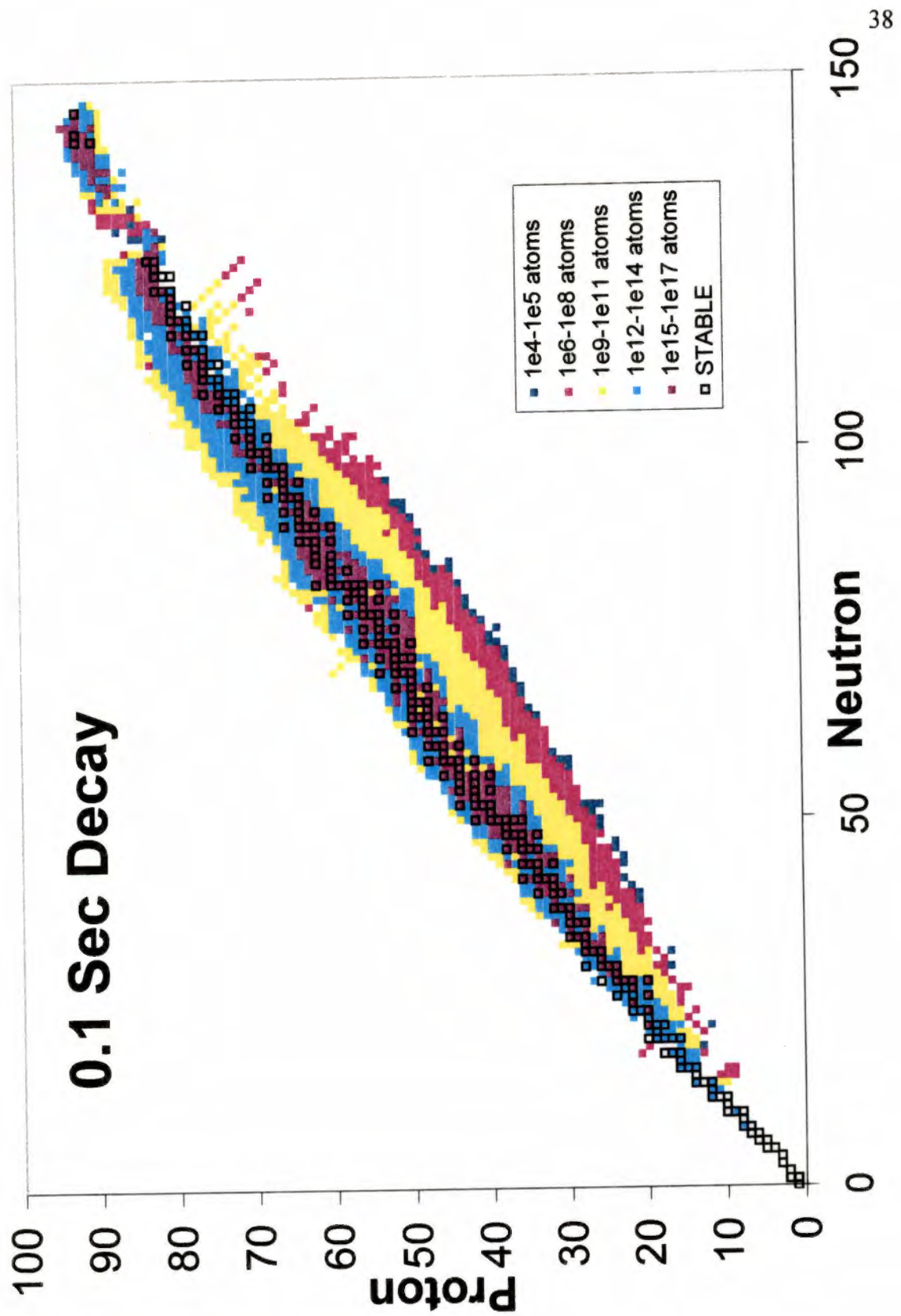


Figure 28. Decay of Uranium Yields: 0.1 sec

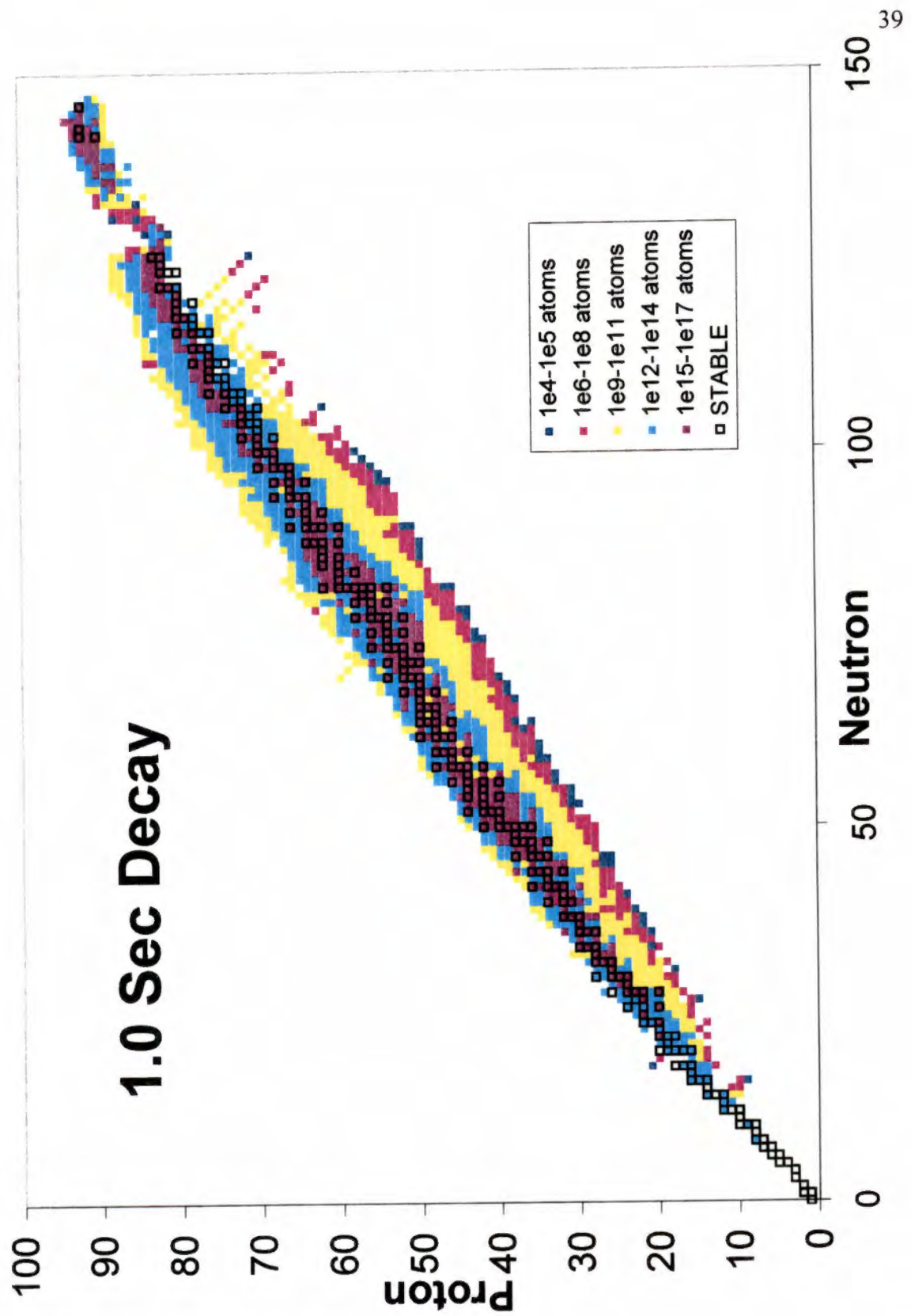


Figure 29. Decay of Uranium Yields: 1.0 sec

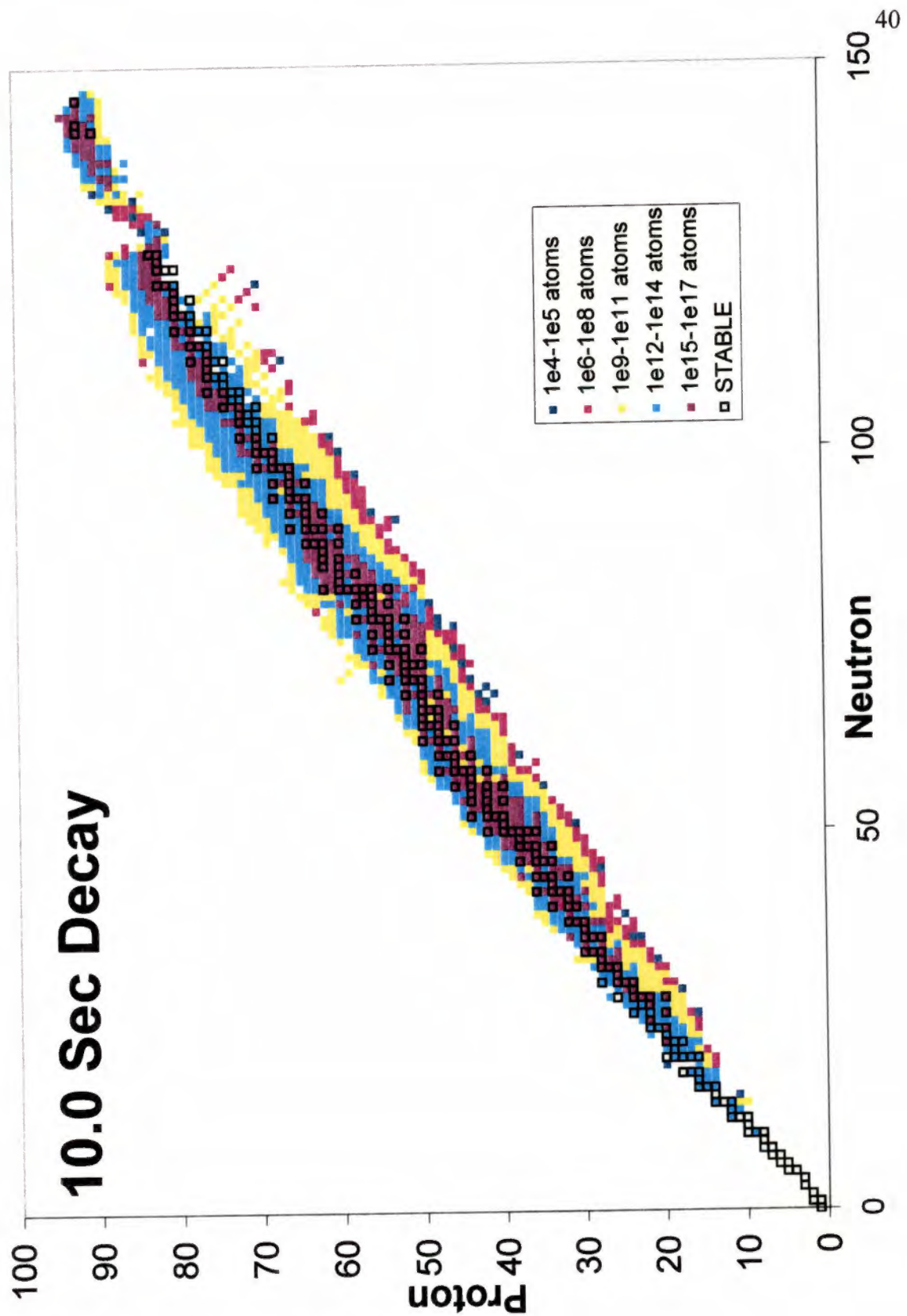


Figure 30. Decay of Uranium Yields: 10 sec

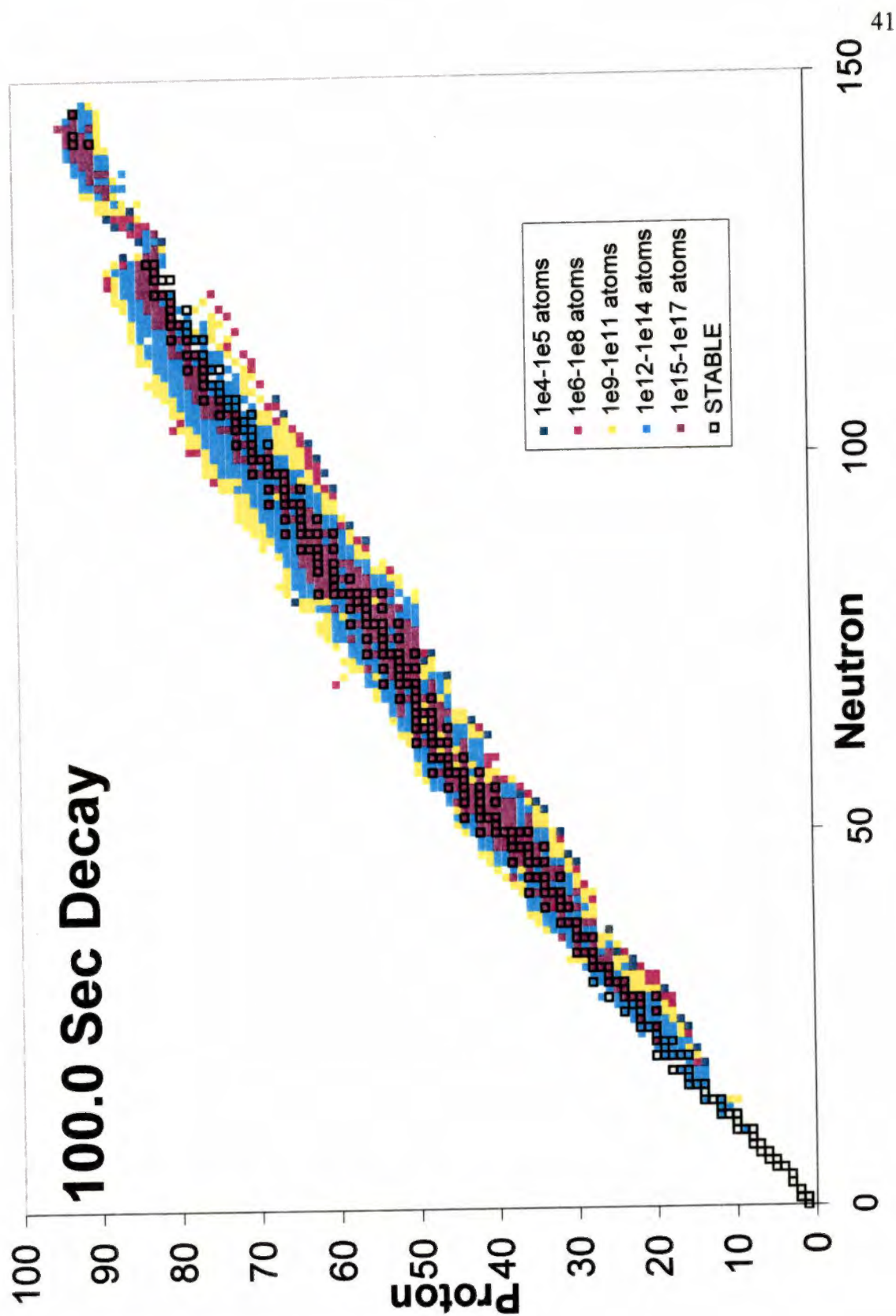


Figure 31. Decay of Uranium Yields: 100 sec

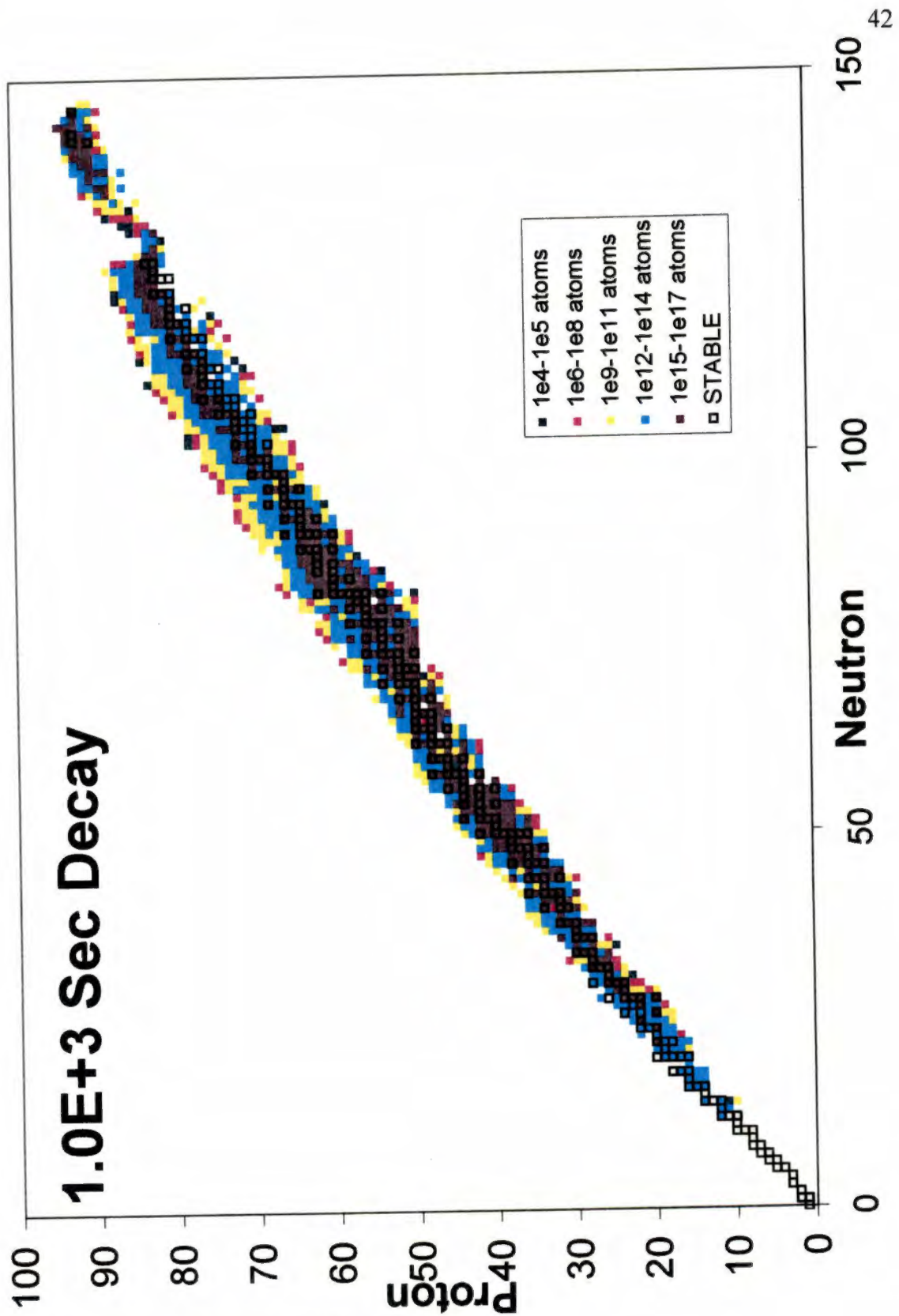


Figure 32. Decay of Uranium Yields: 1.0×10^3 sec

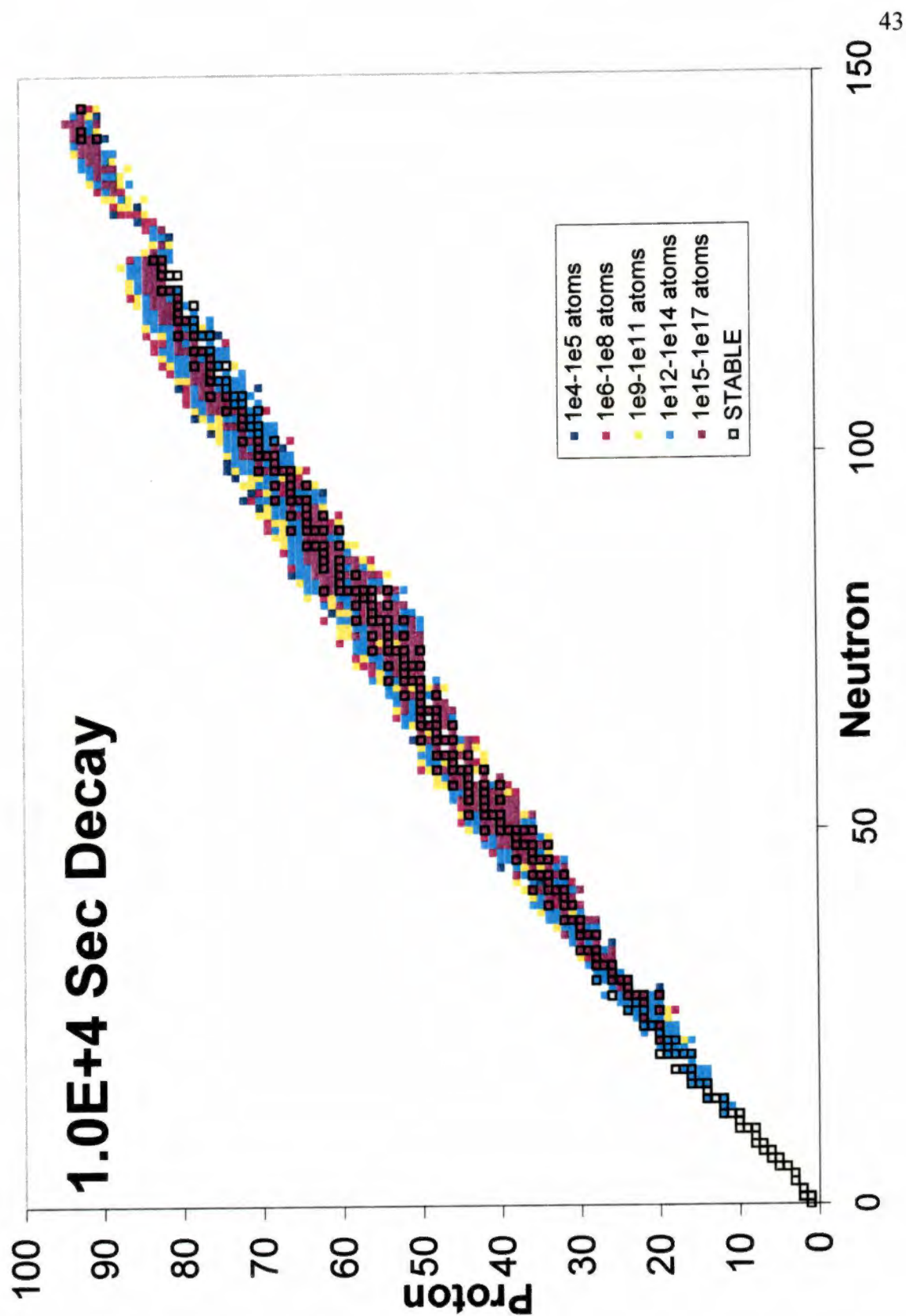


Figure 33. Decay of Uranium Yields: 1.0×10^4 sec

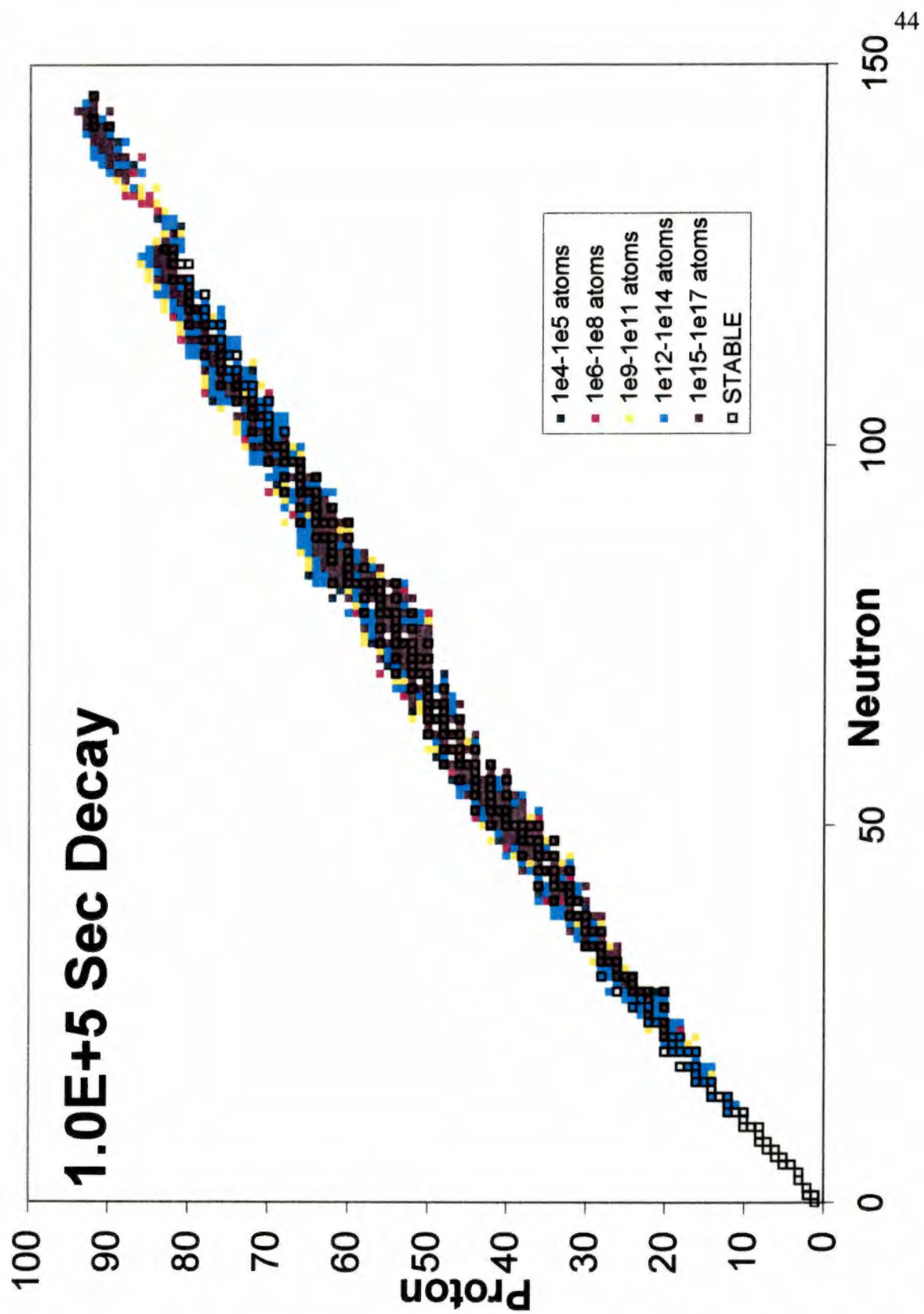


Figure 34. Decay of Uranium Yields: 1.0×10^5 sec

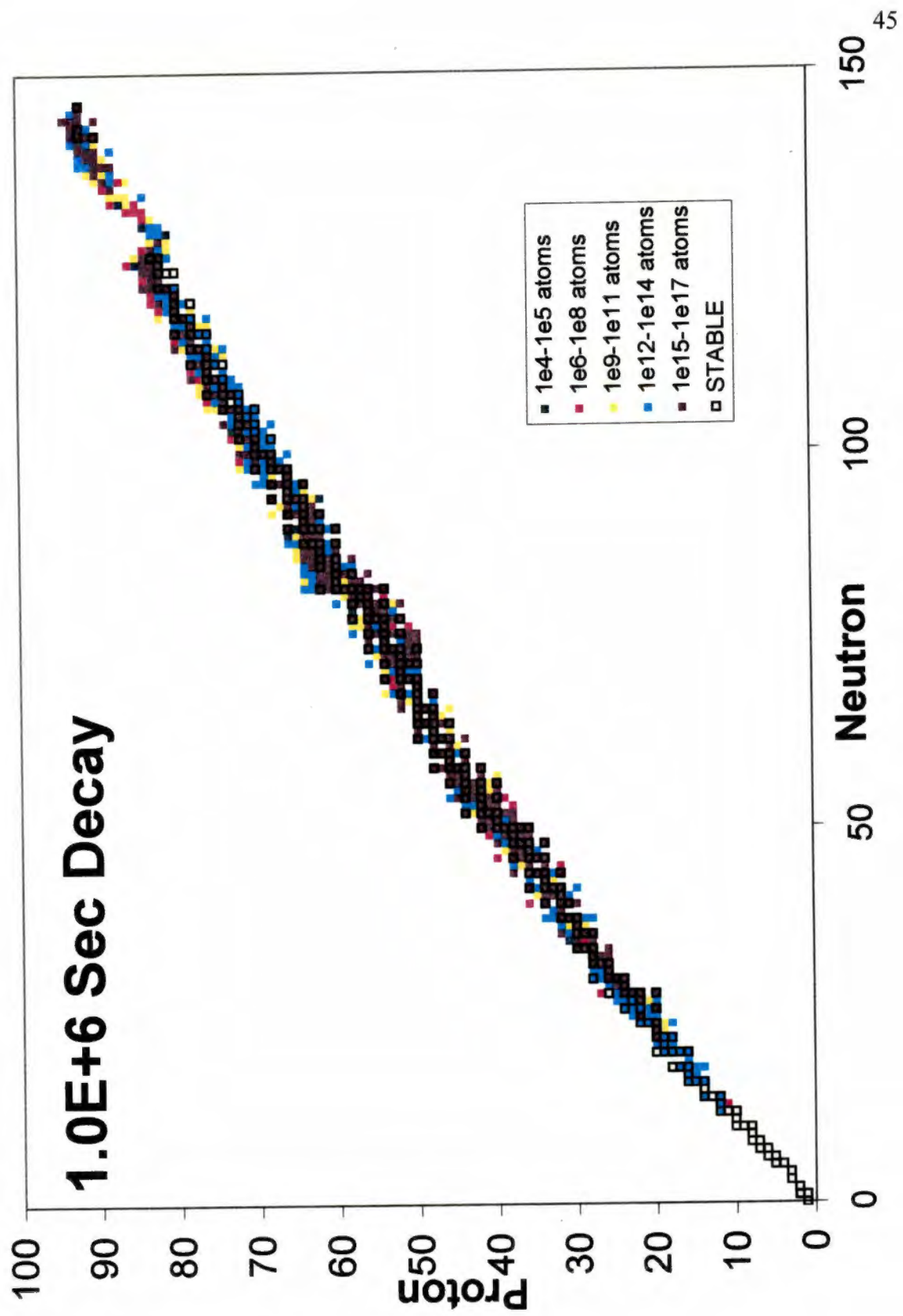


Figure 35. Decay of Uranium Yields: 1.0×10^6 sec

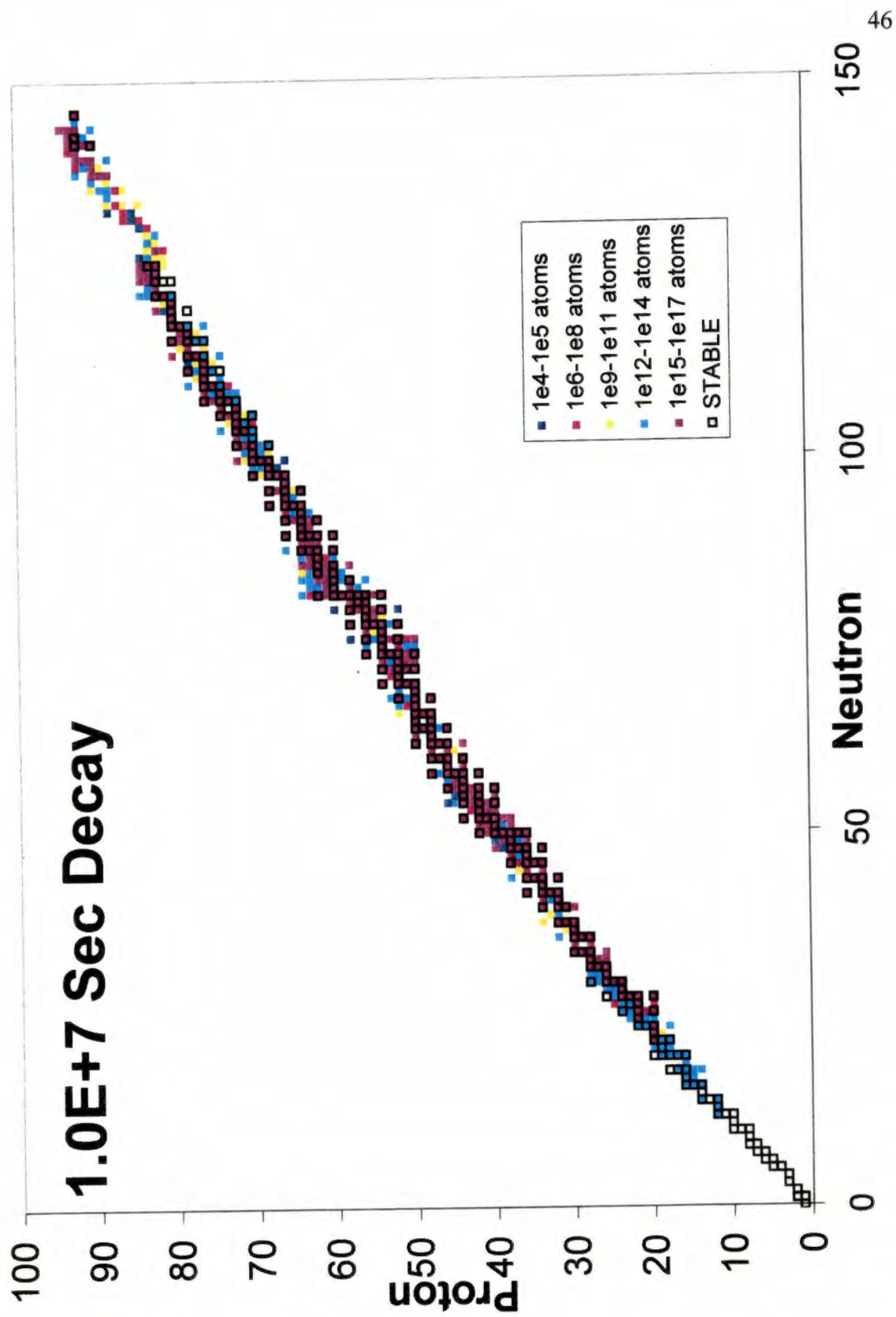


Figure 36. Decay of Uranium Yields: 1.0×10^7 sec

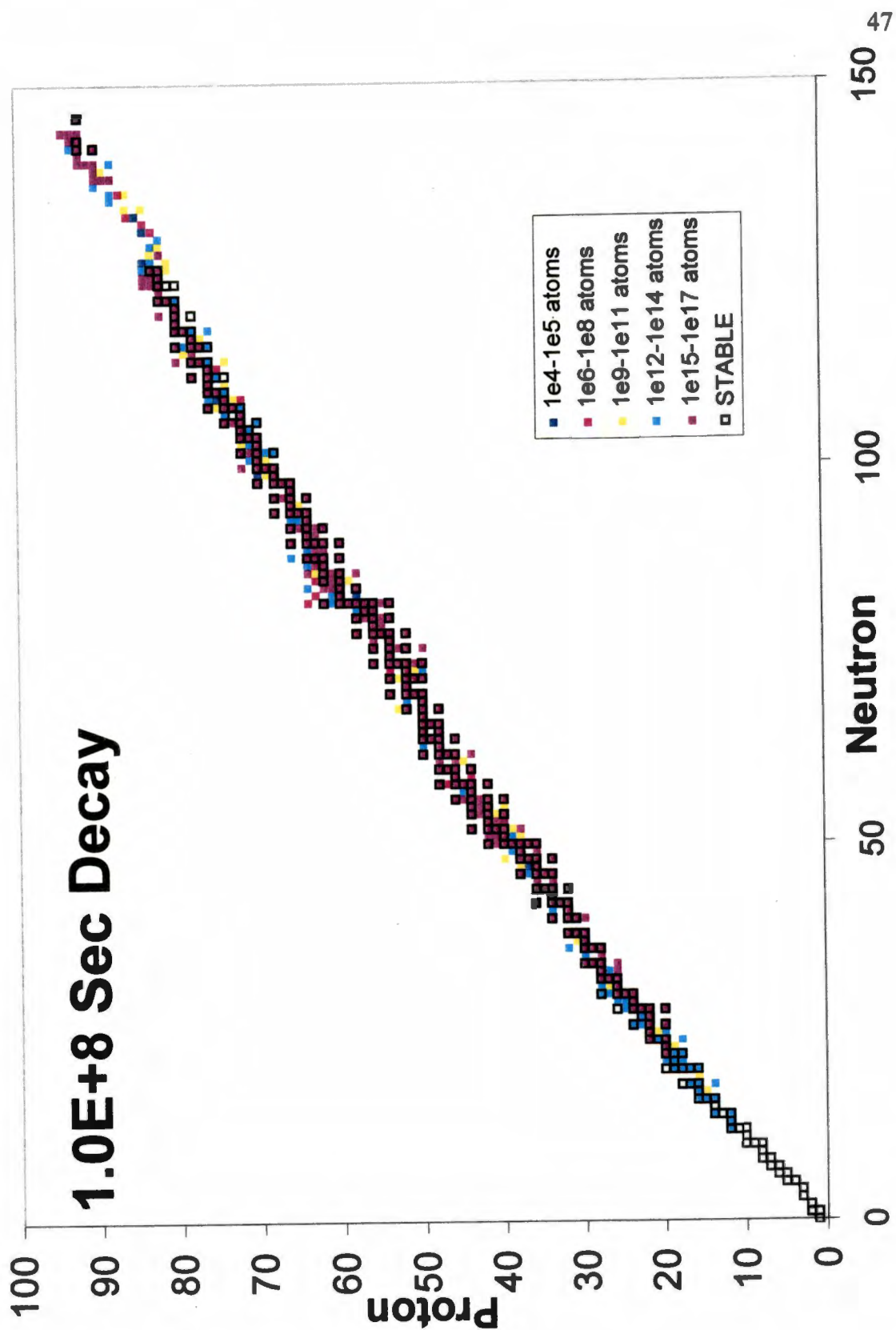


Figure 37. Decay of Uranium Yields: 1.0×10^8 sec

VI. How to Use SPALLDKZ

SPALLDKZ is presently designed to be used in conjunction with the LAHET code. For this work, LAHET is used to calculate spallation yields from high-energy protons bombarding a stationary target. When a LAHET calculation is performed, it creates a number of files that contain all of the information about the nuclear interactions involved. These files are then edited by a secondary code named HTAPE. HTAPE has several options for editing the files created by LAHET, and for this work the Detailed Residual Mass Edit is used. When HTAPE is run, a file named outt is created. The file outt contains the information that is used to run SPALLDKZ. In order to use this data in a SPALLDKZ calculation, it must first be normalized to a production rate and an input file created. A small code named Normalize is used to read the outt file, normalize the data, and write an input file named input.dat. The outt file must first be renamed to residuals. When executing the Normalize file, a manual input of the number of incident protons used in the LAHET calculation is required.

Once an input file is created SPALLDKZ is ready to run provided that all necessary files are resident in the directory or links to the appropriate files are made. The necessary files are the executable SPALLDKZ file, the input file inputs.dat, and the decay constants libraries: alpha2.dat, beta2.dat, betaneut.dat, epsilon2.dat, eprot.dat, and proton.dat.

Upon executing the SPALLDKZ code, two manual inputs are required. The first input is a description of the calculation which will appear as the first line of each output file. This description may contain up to 80 characters and must have single quotes

surrounding it. The second input is the number of micro-Amps for the beam to be simulated. There is no default, but the value of 1 has been used for all of the calculations in this work. Once these inputs have been made, SPALLDKZ will begin to perform the calculations. As it does this, a series of lines are written to the terminal screen displaying the amount of time elapsed during the calculation. The run time for SPALLDKZ is short, being ten seconds or less.

A total of eleven output files are written during a SPALLDKZ calculation:

0E+00.out, 1E-01.out, 1E+00.out, 1E+01.out, 1E+02.out, 1E+03.out, 1E+04.out, 1E+05.out, 1E+06.out, 1E+07.out, and 1E+08.out. The first line of each output file is the description that was input manually. The next line is blank, and then followed by a line stating the elapsed time. Then there two blank lines followed by a line of column headings. There are seven columns all together: Z, N, A, Number of Atoms, Activity 1, Activity 2, and Half-life.

The reason for two activity calculations is because of the short-lived nuclides whose decay constants are greater than 1. The textbook formula for activity in curies (Activity 1) is

$$ACT1(Z, N) = AMT(Z, N) \cdot \lambda_T(Z, N) / 3.7 \cdot 10^{10} \quad (14)$$

where the decay constant $\lambda_T(Z, N)$ is in units of sec^{-1} . This is an instantaneous rate.

Because the short-lived nuclides decay rapidly, the rate also changes rapidly. Using Eq. 14 results in calculating more atoms decaying over the period of a second than there is to start with. Therefore an alternate formula for calculating activity in curies (Activity 2) is used.

$$ACT2(Z, N) = AMT(Z, N) \cdot (1 - \text{EXP}(-\lambda_T(Z, N))) / 3.7 \cdot 10^{10} \quad (15)$$

A sample of an output file is included in Appendix D. A sample of how a terminal screen appears is included here. Notice the manual inputs and the display of elapsed time that follows.

```
leral> SPALLDKZ
ENTER INFO FOR OUTPUT (UP TO 80 CHRS)
'1 GeV protons on 14cm U-238 target of natural density.'
WHAT IS THE AMPERAGE OF THE BEAM (MICRO-AMPS)?
1
TOTAL TIME IS 8.9999998E-04
TOTAL TIME IS 9.8999999E-03
TOTAL TIME IS 9.9899866E-02
TOTAL TIME IS 0.9999001
TOTAL TIME IS 9.999905
TOTAL TIME IS 99.99986
TOTAL TIME IS 999.9996
TOTAL TIME IS 9999.992
TOTAL TIME IS 99999.98
TOTAL TIME IS 1000000.
TOTAL TIME IS 9999999.
TOTAL TIME IS 9.9999928E+07
leral>
```

VII. Conclusions

SPALLDKZ is developed to meet the need to calculate the decay of spallation products from high-energy accelerator applications. Departing from the majority of existing decay codes, SPALLDKZ uses a numerical algorithm as opposed to an analytical solution. The numerical algorithm is used to facilitate the use of an expandable library of decay constants. This is important because new and exotic nuclides may need to be added to the data libraries as they are discovered. The data libraries for SPALLDKZ already comprise over 2800 decay constants, many of which are extrapolated values from known data. This is the most complete single decay database currently available. The extrapolated values are needed if all predicted spallation products are to be included in the calculations. The extrapolated decay constants are not intended to be regarded as a standard, but merely as a device to include these nuclides in the calculations.

Through the use of another decay code, ORIHET, it has been demonstrated that SPALLDKZ is capable of accurately performing decay calculations and obtaining reasonable results. The presence of metastable states is a valid concern and future work needs to address this shortcoming, by treating them correctly in the decay process.

Information about sufficient yields of exotic nuclides by computer simulation is necessary to optimize target design for RIB studies, and is much more economical when compared to laboratory experimentation. SPALLDKZ is a capable tool for use in providing information about the build-up and decay of target yields for this purpose.

VIII. Recommendations for Future Work

Predictions of nuclide quantities are useful for determining if ample amounts of nuclides are being produced for RIB applications, but from a radiological standpoint, dose data are more useful. A gamma library must be constructed and incorporated into the SPALLDKZ code to obtain calculations of radiation dose given by the targets.

In real life applications, time decay is not the only loss term for the radionuclides. Because the targets are at near-melting point temperatures, many of the nuclides diffuse out of the target. This is a desired effect since these nuclides must be removed from the target before they may be used in any RIB experiment. Currently studies are being carried out to calculate the diffusion times for nuclides to escape from targets¹⁰. It is of considerable interest to include diffusion sub-routines in the SPALLDKZ code. With this enhancement, SPALLDKZ would be able to determine whether or not nuclide population lifetimes are sufficient for use in RIB applications without having to perform both diffusion time and decay time calculations separately.

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REFERENCES

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APPENDICES

APPENDIX A

APPENDIX A-1

The following pages contain decay constant data for the β^+ decay mode. Z denotes charge number (number of protons), N denotes neutron number, and λ (sec^{-1}) is the decay constant for the decaying nuclides. This notation is consistent for each of the Appendix A subsections.

Z	N	λ	Z	N	λ
1	2	9.431E-09	11	14	1.173E-02
2	4	7.993E+00	11	15	6.466E-01
2	6	4.891E+00	11	16	2.301E+00
3	5	8.270E-01	11	17	2.259E+01
3	6	1.963E+00	11	18	1.212E+01
3	8	8.153E+01	11	19	1.011E+01
4	7	4.862E-02	12	15	1.221E-03
4	8	2.936E+01	12	16	9.208E-06
5	7	3.431E+01	12	17	5.332E-01
5	8	3.992E+01	12	18	2.069E+00
5	9	5.022E+01	12	19	2.962E+00
5	10	6.600E+01	12	20	5.638E+00
6	8	4.089E-12	12	21	6.392E+00
6	9	2.830E-01	12	22	3.466E+01
6	10	9.277E-01	13	15	5.155E-03
6	11	2.442E+00	13	16	1.761E-03
6	12	7.875E+00	13	17	1.925E-01
6	13	5.516E+00	13	18	1.076E+00
7	9	9.719E-02	13	19	1.980E+01
7	10	1.661E-01	13	20	3.466E+00
7	11	1.111E+00	13	21	1.012E+01
7	12	8.573E-01	13	22	1.427E+00
7	13	2.703E+00	13	23	4.077E+00
7	14	1.167E+00	13	24	1.005E+01
7	15	1.877E+01	13	25	1.925E+01
7	16	3.654E+06	13	26	3.851E+01
8	11	2.570E-02	13	27	5.332E+01
8	12	5.130E-02	13	28	9.627E+01
8	13	2.026E-01	13	29	2.100E+02
8	14	3.080E-01	13	30	4.077E+02
8	15	5.831E+00	14	17	7.349E-05
8	16	4.771E+00	14	18	1.288E-10
9	11	6.301E-02	14	19	1.118E-01
9	12	1.667E-01	14	20	2.476E-01
9	13	1.639E-01	14	21	7.702E-01
9	14	3.108E-01	14	22	1.248E+00
9	15	2.039E+01	14	23	2.067E+00
9	17	8.638E+00	14	24	2.687E+00
9	18	4.102E+01	14	25	5.682E+00
10	13	1.861E-02	14	26	1.238E+01
10	14	3.418E-03	14	27	1.575E+01
10	15	1.151E+00	14	28	3.014E+01
10	16	3.014E+00	14	29	7.001E+01
10	17	2.166E+01	14	30	1.691E+02
10	18	4.159E+01	15	17	5.626E-07
10	19	8.337E+01	15	18	3.171E-07
10	20	1.232E+02	15	19	5.590E-02
11	13	1.287E-05	15	20	1.462E-02

15	21	1.175E-01	18	30	3.573E+00
15	22	3.014E-01	18	31	7.453E+00
15	23	1.040E+00	18	32	1.925E+01
15	24	2.556E+00	18	33	2.773E+01
15	25	1.866E+00	18	34	4.077E+01
15	26	4.043E+00	18	35	5.332E+01
15	27	3.151E+00	18	36	7.967E+01
15	28	8.887E+00	18	37	1.243E+02
15	29	2.567E+01	18	38	1.871E+02
15	30	7.877E+01	19	23	1.558E-05
15	31	9.242E+01	19	24	8.634E-06
15	32	1.777E+02	19	25	5.220E-04
15	33	2.100E+02	19	26	6.678E-04
15	34	2.773E+02	19	27	6.490E-03
16	19	9.169E-08	19	28	3.961E-02
16	21	2.288E-03	19	29	9.921E-02
16	22	6.780E-05	19	30	8.822E-02
16	23	6.027E-02	19	31	1.043E+00
16	24	7.702E-02	19	32	1.006E+00
16	25	2.876E-01	19	33	7.922E-01
16	26	5.639E-01	19	34	3.466E+00
16	27	1.890E+00	19	35	6.931E+01
16	28	4.697E+00	19	36	4.951E+01
16	29	5.373E+00	19	37	8.155E+01
16	30	2.773E+01	19	38	8.351E+01
16	31	2.888E+01	19	39	1.308E+02
16	32	6.931E+01	19	40	1.824E+02
16	33	8.252E+01	20	27	1.769E-06
16	34	1.175E+02	20	29	1.325E-03
17	21	3.102E-04	20	30	4.987E-02
17	22	2.078E-04	20	31	6.931E-02
17	23	8.557E-03	20	32	1.507E-01
17	24	1.805E-02	20	33	5.391E+00
17	25	1.019E-01	20	34	3.254E+00
17	26	2.100E-01	20	35	6.665E+00
17	27	1.483E+00	20	36	1.066E+01
17	28	1.301E+00	20	37	2.039E+01
17	29	1.373E+00	20	38	2.166E+01
17	30	1.978E+01	20	39	3.851E+01
17	31	2.100E+01	20	40	5.776E+01
17	32	4.951E+01	20	41	7.702E+01
17	33	6.027E+01	20	42	1.035E+02
17	34	8.351E+01	20	43	1.388E+02
18	21	8.165E-11	20	44	1.830E+02
18	23	1.052E-04	21	25	9.575E-08
18	24	6.676E-10	21	26	2.394E-06
18	25	2.151E-03	21	27	4.408E-06
18	26	9.708E-04	21	28	2.013E-04
18	27	3.301E-02	21	29	6.762E-03
18	28	7.788E-02	21	30	5.590E-02
18	29	6.539E-01	21	31	8.664E-02

21	32	5.924E-01	23	47	1.083E+02
21	33	9.120E-01	23	48	2.095E+02
21	34	4.674E+00	24	31	3.304E-03
21	35	3.667E+00	24	32	1.945E-03
21	36	5.874E+00	24	33	3.285E-02
21	37	1.238E+01	24	34	9.902E-02
21	38	1.260E+01	24	35	9.367E-01
21	39	2.390E+01	24	36	1.216E+00
21	40	3.851E+01	24	37	7.228E-01
21	41	5.332E+01	24	38	6.134E-01
21	42	7.296E+01	24	39	1.800E+00
21	43	1.035E+02	24	40	3.830E+00
21	44	1.100E+02	24	41	5.825E+00
22	29	2.006E-03	24	42	9.902E+00
22	30	6.796E-03	24	43	1.650E+01
22	31	2.120E-02	24	44	1.777E+01
22	32	7.668E-02	24	45	3.151E+01
22	33	2.577E-01	24	46	3.648E+01
22	34	5.682E-01	24	47	4.146E+01
22	35	1.305E+00	24	48	6.656E+01
22	36	2.334E+00	25	31	7.467E-05
22	37	6.251E+00	25	32	8.116E-03
22	38	5.458E+00	25	33	1.061E-02
22	39	1.100E+01	25	34	1.507E-01
22	40	1.980E+01	25	35	1.359E-02
22	41	2.666E+01	25	36	9.763E-01
22	42	4.077E+01	25	37	7.877E-01
22	43	5.776E+01	25	38	2.773E+00
22	44	6.301E+01	25	39	9.749E-01
22	45	6.826E+01	25	40	1.998E+00
22	46	9.271E+01	25	41	3.365E+00
22	47	1.556E+02	25	42	5.501E+00
22	48	2.760E+02	25	43	1.035E+01
23	29	3.086E-03	25	44	1.035E+01
23	30	7.175E-03	25	45	2.039E+01
23	31	1.392E-02	25	46	2.236E+01
23	32	1.060E-01	25	47	3.648E+01
23	33	9.959E-02	25	48	4.332E+01
23	34	1.964E-01	25	49	5.016E+01
23	35	5.590E-01	25	50	7.523E+01
23	36	9.267E-01	26	33	1.803E-10
23	37	2.521E+00	26	35	1.932E-03
23	38	2.243E+00	26	36	1.019E-02
23	39	5.635E+00	26	37	1.136E-01
23	40	1.019E+01	26	38	3.466E-01
23	41	1.475E+01	26	39	1.733E+00
23	42	2.310E+01	26	40	6.269E-01
23	43	3.466E+01	26	41	6.245E-01
23	44	3.648E+01	26	42	6.931E+00
23	45	3.831E+01	26	43	2.751E+00
23	46	5.771E+01	26	44	2.818E+00

26	45	6.796E+00	29	37	2.271E-03
26	46	7.702E+00	29	38	3.114E-06
26	47	1.415E+01	29	39	2.229E-02
26	48	1.873E+01	29	40	4.053E-03
26	49	2.666E+01	29	41	1.540E-01
26	50	3.648E+01	29	42	3.555E-02
26	51	4.630E+01	29	43	1.050E-01
26	52	5.493E+01	29	44	1.777E-01
27	33	4.167E-09	29	45	4.348E-01
27	34	1.167E-04	29	46	3.681E-01
27	35	7.702E-03	29	47	7.569E-01
27	36	2.530E-02	29	48	1.478E+00
27	37	2.310E+00	29	49	2.027E+00
27	38	5.545E-01	29	50	1.659E+00
27	39	3.014E+00	29	51	2.900E+00
27	40	1.650E+00	29	52	1.216E+01
27	41	3.851E+00	29	53	1.216E+01
27	42	2.567E+00	29	54	2.666E+01
27	43	2.586E+00	29	55	6.367E+01
27	44	2.586E+00	29	56	1.232E+02
27	45	5.975E+00	29	57	2.082E+02
27	46	6.478E+00	29	58	3.098E+02
27	47	1.238E+01	30	39	2.048E-04
27	48	1.540E+01	30	41	4.715E-03
27	49	2.166E+01	30	42	4.141E-06
27	50	2.666E+01	30	43	2.950E-02
27	51	3.166E+01	30	44	7.250E-03
27	52	4.060E+01	30	45	6.796E-02
27	53	5.744E+01	30	46	1.216E-01
28	35	2.194E-10	30	47	3.332E-01
28	37	7.678E-05	30	48	4.715E-01
28	38	3.526E-06	30	49	6.876E-01
28	39	3.301E-02	30	50	1.259E+00
28	40	3.648E-02	30	51	2.211E+00
28	41	6.080E-02	30	52	1.035E+01
28	42	2.285E-02	30	53	9.627E+00
28	43	3.727E-01	30	54	2.100E+01
28	44	3.365E-01	30	55	2.039E+01
28	45	7.702E-01	30	56	1.077E+01
28	46	6.301E-01	30	57	6.116E+01
28	47	1.605E+00	30	58	4.089E+01
28	48	2.229E+00	30	59	6.069E+01
28	49	3.610E+00	30	60	4.089E+01
28	50	4.951E+00	30	61	6.237E+02
28	51	1.260E+01	30	62	8.364E+02
28	52	4.077E+01	31	39	5.141E-04
28	53	3.466E+01	31	41	1.366E-05
28	54	6.301E+01	31	42	3.962E-05
28	55	9.137E+01	31	43	1.423E-03
28	56	4.736E+01	31	44	5.501E-03
29	35	5.913E-06	31	45	2.126E-02

31	46	5.251E-02	33	52	1.406E-01
31	47	1.362E-01	33	53	4.870E-01
31	48	2.432E-01	33	54	1.197E+00
31	49	4.048E-01	33	55	2.975E+00
31	50	4.979E-01	33	56	8.351E+00
31	51	8.991E-01	33	57	8.351E+00
31	52	1.342E+00	33	58	1.444E+01
31	53	2.446E+00	33	59	1.507E+01
31	54	9.902E+00	33	60	2.266E+01
31	55	1.005E+01	33	61	2.476E+01
31	56	2.236E+01	33	62	2.715E+01
31	57	2.390E+01	33	63	4.116E+01
31	58	3.648E+01	33	64	7.869E+01
31	59	6.783E+01	33	65	1.505E+02
31	60	1.179E+02	33	66	2.690E+02
31	61	1.868E+02	33	67	4.456E+02
31	62	2.745E+02	33	68	6.918E+02
31	63	3.809E+02	34	47	6.261E-04
31	64	5.061E+02	34	49	5.180E-04
32	43	1.396E-04	34	50	3.727E-03
32	45	1.704E-05	34	51	2.187E-02
32	46	1.313E-04	34	52	4.530E-02
32	47	3.652E-02	34	53	1.306E-01
32	48	2.350E-02	34	54	4.490E-01
32	49	9.120E-02	34	55	1.559E+00
32	50	1.207E-01	34	56	3.427E+00
32	51	3.747E-01	34	57	2.028E+00
32	52	6.348E-01	34	58	6.863E+00
32	53	1.104E+00	34	59	6.931E+00
32	54	5.635E+00	34	60	1.136E+01
32	55	5.332E+00	34	61	1.216E+01
32	56	1.359E+01	34	62	1.296E+01
32	57	1.333E+01	34	63	2.217E+01
32	58	2.236E+01	34	64	4.820E+01
32	59	4.698E+01	34	65	9.946E+01
32	60	8.720E+01	34	66	1.844E+02
32	61	1.430E+02	34	67	3.113E+02
32	62	2.144E+02	34	68	4.887E+02
32	63	3.014E+02	34	69	7.250E+02
32	64	4.040E+02	34	70	1.029E+03
33	40	3.397E-08	35	43	1.788E-07
33	41	4.515E-07	35	45	5.992E-04
33	43	7.443E-06	35	47	5.454E-06
33	44	4.959E-06	35	48	8.023E-05
33	45	1.274E-04	35	49	3.633E-04
33	46	1.282E-03	35	50	3.984E-03
33	47	4.560E-02	35	51	1.258E-02
33	48	2.082E-02	35	52	1.215E-02
33	49	3.629E-02	35	53	3.963E-02
33	50	5.173E-02	35	54	1.358E-01
33	51	1.719E-01	35	55	2.700E-01

35	56	1.025E+00	37	60	3.056E+00
35	57	1.352E+00	37	61	5.253E+00
35	58	1.563E+00	37	62	1.093E+01
35	59	6.931E+00	37	63	1.283E+01
35	60	7.296E+00	37	64	1.495E+01
35	61	7.453E+00	37	65	1.536E+01
35	62	1.066E+01	37	66	1.507E+01
35	63	1.284E+01	37	67	1.980E+01
35	64	2.390E+01	37	68	2.567E+01
35	65	4.677E+01	37	69	3.151E+01
35	66	8.145E+01	37	70	4.077E+01
35	67	1.279E+02	37	71	5.432E+01
35	68	1.862E+02	37	72	7.215E+01
35	69	2.563E+02	37	73	9.426E+01
35	70	3.382E+02	37	74	1.206E+02
36	49	2.039E-09	37	75	1.513E+02
36	51	1.514E-04	37	76	1.863E+02
36	52	6.780E-05	38	51	1.588E-07
36	53	3.667E-03	38	52	7.632E-10
36	54	2.145E-02	38	53	1.999E-05
36	55	8.088E-02	38	54	7.105E-05
36	56	3.766E-01	38	55	1.556E-03
36	57	5.282E-01	38	56	9.205E-03
36	58	3.268E+00	38	57	2.900E-02
36	59	8.887E-01	38	58	6.478E-01
36	60	2.166E+00	38	59	1.615E+00
36	61	2.187E+00	38	60	1.059E+00
36	62	3.483E+00	38	61	2.574E+00
36	63	3.094E+00	38	62	3.401E+00
36	64	8.351E+00	38	63	5.726E+00
36	65	1.050E+01	38	64	9.493E+00
36	66	1.575E+01	38	65	3.916E+00
36	67	2.656E+01	38	66	5.332E+00
36	68	4.292E+01	38	67	7.788E+00
36	69	6.480E+01	38	68	1.066E+01
36	70	9.230E+01	38	69	1.286E+01
36	71	1.253E+02	38	70	1.777E+01
36	72	1.639E+02	38	71	2.256E+01
36	73	2.080E+02	38	72	2.821E+01
36	74	2.577E+02	38	73	3.474E+01
37	47	9.303E-09	38	74	4.214E+01
37	49	4.306E-07	38	75	5.041E+01
37	51	6.497E-04	38	76	5.955E+01
37	52	7.625E-04	38	77	6.957E+01
37	53	4.387E-03	38	78	8.045E+01
37	54	1.187E-02	39	51	3.004E-06
37	55	1.543E-01	39	52	1.371E-07
37	56	1.171E-01	39	53	5.439E-05
37	57	2.309E-01	39	54	1.891E-05
37	58	1.676E+00	39	55	6.178E-04
37	59	2.939E+00	39	56	1.122E-03

39	57	1.298E-01	40	81	8.144E+02
39	58	1.847E-01	41	54	2.294E-07
39	59	1.261E+00	41	55	8.246E-06
39	60	4.626E-01	41	56	1.602E-04
39	61	9.334E-01	41	57	2.424E-01
39	62	1.517E+00	41	58	4.621E-02
39	63	2.310E+00	41	59	4.621E-01
39	64	3.014E+00	41	60	9.763E-02
39	65	2.937E+00	41	61	5.332E-01
39	66	3.629E+00	41	62	4.621E-01
39	67	5.776E+00	41	63	1.434E-01
39	68	7.453E+00	41	64	2.350E-01
39	69	1.005E+01	41	65	6.796E-01
39	70	1.284E+01	41	66	2.100E+00
39	71	1.563E+01	41	67	4.077E+00
39	72	1.858E+01	41	68	1.155E+00
39	73	2.188E+01	41	69	1.986E+00
39	74	2.567E+01	41	70	2.606E+00
39	75	3.013E+01	41	71	5.023E+00
39	76	3.543E+01	41	72	5.251E+00
39	77	4.174E+01	41	73	9.367E+00
39	78	4.921E+01	41	74	9.627E+00
39	79	5.802E+01	41	75	9.887E+00
39	80	6.834E+01	41	76	1.834E+01
39	81	8.032E+01	41	77	4.319E+01
39	82	9.415E+01	41	78	9.261E+01
40	55	1.253E-07	41	79	1.748E+02
40	57	1.139E-05	41	80	2.980E+02
40	58	2.258E-02	41	81	4.703E+02
40	59	3.301E-01	41	82	7.000E+02
40	60	9.763E-02	42	57	2.920E-06
40	61	3.301E-01	42	59	7.907E-04
40	62	2.390E-01	42	60	1.022E-03
40	63	5.332E-01	42	61	1.027E-02
40	64	5.776E-01	42	62	1.155E-02
40	65	6.931E-01	42	63	1.947E-02
40	66	2.094E+00	42	64	8.252E-02
40	67	3.483E+00	42	65	1.980E-01
40	68	4.715E+00	42	66	6.359E-01
40	69	6.245E+00	42	67	1.308E+00
40	70	8.155E+00	42	68	2.310E+00
40	71	1.238E+01	42	69	1.148E+00
40	72	1.208E+01	42	70	1.568E+00
40	73	1.378E+01	42	71	3.027E+00
40	74	2.110E+01	42	72	3.136E+00
40	75	4.168E+01	42	73	5.590E+00
40	76	8.213E+01	42	74	5.682E+00
40	77	1.491E+02	42	75	5.773E+00
40	78	2.492E+02	42	76	1.084E+01
40	79	3.890E+02	42	77	2.586E+01
40	80	5.752E+02	42	78	5.581E+01

42	79	1.057E+02	44	75	2.382E+00
42	80	1.804E+02	44	76	2.876E+00
42	81	2.850E+02	44	77	4.847E+00
42	82	4.244E+02	44	78	6.730E+00
42	83	6.037E+02	44	79	8.612E+00
42	84	8.277E+02	44	80	1.139E+01
43	57	4.387E-02	44	81	1.594E+01
43	58	8.124E-04	44	82	2.317E+01
43	59	1.313E-01	44	83	3.397E+01
43	60	1.279E-02	44	84	4.922E+01
43	61	6.313E-04	44	85	6.982E+01
43	62	1.520E-03	44	86	9.666E+01
43	63	1.947E-02	45	57	7.751E-09
43	64	3.270E-02	45	59	1.631E-02
43	65	1.341E-01	45	60	5.445E-06
43	66	7.967E-01	45	61	2.326E-02
43	67	7.534E-01	45	62	5.324E-04
43	68	2.310E+00	45	63	4.126E-02
43	69	2.476E+00	45	64	8.664E-03
43	70	5.332E+00	45	65	2.166E-01
43	71	2.146E+00	45	66	6.301E-02
43	72	2.063E+00	45	67	1.824E-01
43	73	4.252E+00	45	68	2.476E-01
43	74	4.201E+00	45	69	3.747E-01
43	75	6.931E+00	45	70	7.001E-01
43	76	8.155E+00	45	71	1.019E+00
43	77	9.378E+00	45	72	1.575E+00
43	78	1.451E+01	45	73	1.042E+00
43	79	3.746E+01	45	74	8.785E-01
43	80	5.215E+01	45	75	1.746E+00
43	81	9.247E+01	45	76	2.082E+00
43	82	1.523E+02	45	77	3.830E+00
43	83	2.357E+02	45	78	5.291E+00
43	84	3.464E+02	45	79	7.617E+00
43	85	4.883E+02	45	80	1.066E+01
43	86	6.655E+02	45	81	1.427E+01
44	59	2.043E-07	45	82	1.842E+01
44	61	4.337E-05	45	83	2.314E+01
44	62	2.147E-08	45	84	2.840E+01
44	63	3.081E-03	45	85	3.423E+01
44	64	2.539E-03	45	86	4.060E+01
44	65	2.009E-02	45	87	4.754E+01
44	66	4.748E-02	45	88	5.502E+01
44	67	3.270E-01	45	89	6.307E+01
44	68	3.270E-01	45	90	7.166E+01
44	69	8.664E-01	46	63	1.405E-05
44	70	1.216E+00	46	65	4.937E-04
44	71	1.733E+00	46	66	9.156E-06
44	72	5.635E-01	46	67	7.453E-03
44	73	1.384E+00	46	68	4.774E-03
44	74	1.323E+00	46	69	2.773E-02

46	70	5.874E-02	47	89	3.220E+02
46	71	1.612E-01	47	90	4.096E+02
46	72	3.648E-01	47	91	5.079E+02
46	73	7.534E-01	47	92	6.170E+02
46	74	1.386E+00	48	67	3.602E-06
46	75	3.707E-01	48	69	7.733E-05
46	76	4.530E-01	48	70	2.297E-04
46	77	9.316E-01	48	71	4.295E-03
46	78	1.507E+00	48	72	1.364E-02
46	79	2.334E+00	48	73	5.134E-02
46	80	3.591E+00	48	74	1.323E-01
46	81	5.319E+00	48	75	3.301E-01
46	82	7.516E+00	48	76	5.590E-01
46	83	1.018E+01	48	77	1.066E+00
46	84	1.332E+01	48	78	1.370E+00
46	85	1.693E+01	48	79	1.612E+00
46	86	2.100E+01	48	80	2.039E+00
46	87	2.555E+01	48	81	2.567E+00
46	88	3.056E+01	48	82	3.327E+00
46	89	3.605E+01	48	83	1.386E+01
46	90	4.200E+01	48	84	2.773E+01
46	91	4.843E+01	48	85	2.100E+01
46	92	5.532E+01	48	86	3.648E+01
47	59	2.411E-06	48	87	8.718E+01
47	61	4.736E-03	48	88	7.311E+01
47	63	2.809E-02	48	89	2.943E+02
47	64	1.077E-06	48	90	4.507E+02
47	65	6.151E-05	48	91	6.423E+02
47	66	6.151E-05	48	92	8.691E+02
47	67	3.585E-05	48	93	1.131E+03
47	68	1.507E-01	48	94	1.428E+03
47	69	5.776E-04	48	95	1.761E+03
47	70	4.311E-03	49	63	2.232E-04
47	71	9.521E-03	49	65	9.592E-03
47	72	1.843E-01	49	67	4.914E-02
47	73	3.301E-01	49	68	2.674E-04
47	74	5.635E-01	49	69	1.386E-01
47	75	8.879E-01	49	70	4.814E-03
47	76	1.441E+00	49	71	2.250E-01
47	77	2.231E+00	49	72	3.001E-02
47	78	4.443E+00	49	73	4.530E-01
47	79	7.146E+00	49	74	1.159E-01
47	80	6.359E+00	49	75	2.187E-01
47	81	5.924E+00	49	76	2.937E-01
47	82	9.120E+00	49	77	4.332E-01
47	83	2.166E+01	49	78	6.359E-01
47	84	4.492E+01	49	79	8.252E-01
47	85	7.890E+01	49	80	1.134E+00
47	86	1.236E+02	49	81	2.639E+00
47	87	1.790E+02	49	82	2.426E+00
47	88	2.452E+02	49	83	3.235E+00

49	84	6.418E+00	51	87	3.067E+00
49	85	1.359E+01	51	88	4.077E+00
49	86	2.390E+01	51	89	4.077E+00
49	87	4.733E+01	51	90	9.367E+00
49	88	1.925E+01	51	91	2.191E+01
49	89	3.788E+01	51	92	4.169E+01
49	90	7.322E+01	51	93	6.873E+01
49	91	1.253E+02	51	94	1.030E+02
49	92	1.940E+02	51	95	1.446E+02
49	93	2.795E+02	51	96	1.933E+02
49	94	3.816E+02	51	97	2.494E+02
50	71	7.115E-06	51	98	3.127E+02
50	73	6.209E-08	52	69	4.781E-07
50	75	8.322E-07	52	75	2.059E-05
50	77	9.169E-05	52	77	1.660E-04
50	78	1.956E-04	52	79	4.621E-04
50	79	5.180E-03	52	80	2.504E-06
50	80	3.106E-03	52	81	9.000E+00
50	81	1.238E-02	52	82	2.764E-04
50	82	1.746E-02	52	83	3.648E-02
50	83	5.775E-01	52	84	3.909E-02
50	84	5.137E-01	52	85	2.720E-01
50	85	2.773E+00	52	86	4.639E-01
50	86	6.987E+00	52	87	1.942E+00
50	87	6.301E+00	52	88	2.818E+00
50	88	7.967E+00	52	89	2.616E+00
50	89	1.441E+01	52	90	6.539E+00
50	90	2.564E+01	52	91	1.598E+01
50	91	4.164E+01	52	92	3.093E+01
50	92	6.242E+01	52	93	5.140E+01
50	93	8.798E+01	52	94	7.738E+01
50	94	1.183E+02	52	95	1.089E+02
50	95	1.534E+02	52	96	1.459E+02
50	96	1.933E+02	52	97	1.884E+02
50	97	2.830E+02	52	98	2.365E+02
50	98	2.875E+02	53	73	2.674E-07
51	71	2.874E-06	53	75	4.304E-04
51	73	1.333E-07	53	77	1.558E-05
51	74	7.963E-09	53	78	1.000E-06
51	75	6.439E-07	53	79	6.429E-05
51	76	2.084E-06	53	80	9.257E-06
51	77	2.137E-05	53	81	2.200E-04
51	78	4.376E-05	53	82	2.931E-05
51	79	2.925E-04	53	83	8.311E-03
51	80	4.141E-03	53	84	2.632E-02
51	81	4.621E-03	53	85	1.009E-01
51	82	8.887E-01	53	86	2.736E-01
51	83	3.437E-01	53	87	7.310E-01
51	84	6.424E-01	53	88	1.257E+00
51	85	6.429E-01	53	89	3.466E+00
51	86	3.365E+00	53	90	2.493E+00

53	91	1.225E+00	55	99	1.358E+01
53	92	4.987E+00	55	100	2.261E+01
53	93	3.687E+00	55	101	3.506E+01
53	94	2.387E+00	55	102	5.093E+01
53	95	1.133E+01	56	83	1.391E-04
53	96	4.076E+01	56	84	6.291E-07
53	97	1.009E+02	56	85	6.323E-04
53	98	2.021E+02	56	86	1.090E-03
53	99	3.544E+02	56	87	4.837E-02
53	100	5.682E+02	56	88	5.810E-02
54	79	1.529E-06	56	89	1.608E-01
54	81	2.107E-05	56	90	3.122E-01
54	83	3.026E-03	56	91	7.757E-01
54	84	8.205E-04	56	92	1.137E+00
54	85	1.747E-02	56	93	2.006E+00
54	86	5.097E-02	56	94	2.310E+00
54	87	4.005E-01	56	95	1.364E+00
54	88	5.567E-01	56	96	3.014E+00
54	89	2.310E+00	56	97	3.136E+00
54	90	6.027E-01	56	98	4.814E+00
54	91	7.702E-01	56	99	9.242E+00
54	92	1.695E+00	56	100	1.642E+01
54	93	1.608E+00	56	101	2.635E+01
54	94	2.586E+00	56	102	3.904E+01
54	95	2.751E+00	56	103	5.447E+01
54	96	5.501E+00	56	104	7.265E+01
54	97	1.193E+01	56	105	9.359E+01
54	98	2.203E+01	56	106	1.173E+02
54	99	3.582E+01	57	83	4.781E-06
54	100	5.328E+01	57	84	4.912E-05
55	75	6.328E-06	57	85	1.268E-04
55	77	2.316E-07	57	86	8.136E-04
55	79	1.064E-08	57	87	1.699E-02
55	81	3.648E-02	57	88	2.795E-02
55	82	7.304E-10	57	89	1.105E-01
55	83	3.458E-04	57	90	1.688E-01
55	84	1.246E-03	57	91	4.847E-01
55	85	1.088E-02	57	92	6.609E-01
55	86	2.778E-01	57	93	7.842E-01
55	87	4.074E-01	57	94	5.251E-01
55	88	3.831E-01	57	95	5.635E-01
55	89	6.643E-01	57	96	1.270E+00
55	90	1.000E+00	57	97	1.469E+00
55	91	1.853E+00	57	98	2.366E+00
55	92	2.109E+00	57	99	4.370E+00
55	93	3.708E+00	57	100	7.483E+00
55	94	2.852E+00	57	101	1.170E+01
55	95	2.975E+00	57	102	1.703E+01
55	96	5.545E+00	57	103	2.347E+01
55	97	5.776E+00	57	104	3.101E+01
55	98	7.967E+00	57	105	3.966E+01

57	106	4.942E+01	60	87	7.307E-07
58	83	2.468E-07	60	89	1.114E-04
58	85	5.828E-06	60	91	9.287E-04
58	86	2.816E-08	60	92	1.013E-03
58	87	3.838E-03	60	93	2.398E-02
58	88	8.545E-04	60	94	2.676E-02
58	89	1.229E-02	60	95	7.788E-02
58	90	1.238E-02	60	96	1.267E-01
58	91	1.308E-01	60	97	1.605E-01
58	92	1.733E-01	60	98	4.881E-01
58	93	6.796E-01	60	99	4.951E-01
58	94	4.951E-01	60	100	1.050E+00
58	95	2.626E-01	60	101	1.136E+00
58	96	7.986E-01	60	102	1.222E+00
58	97	8.785E-01	60	103	2.345E+00
58	98	1.796E+00	60	104	5.540E+00
58	99	3.995E+00	60	105	1.185E+01
58	100	7.477E+00	60	106	2.230E+01
58	101	1.224E+01	60	107	3.793E+01
58	102	1.829E+01	60	108	5.978E+01
58	103	2.562E+01	61	85	1.350E-09
58	104	3.423E+01	61	86	8.373E-09
58	105	4.412E+01	61	87	1.494E-06
58	106	6.530E+01	61	88	3.627E-06
58	107	6.775E+01	61	89	7.184E-05
59	83	1.007E-05	61	90	6.780E-06
59	84	5.912E-07	61	91	2.804E-03
59	85	6.685E-04	61	92	2.139E-03
59	86	3.218E-05	61	93	6.678E-03
59	87	4.784E-04	61	94	1.670E-02
59	88	8.621E-04	61	95	2.596E-02
59	89	5.089E-03	61	96	6.564E-02
59	90	5.112E-03	61	97	1.444E-01
59	91	1.120E-01	61	98	1.060E-01
59	92	3.667E-02	61	99	1.362E-01
59	93	1.910E-01	61	100	3.081E-01
59	94	1.612E-01	61	101	4.201E-01
59	95	3.014E-01	61	102	7.037E-01
59	96	4.951E-01	61	103	8.494E-01
59	97	5.682E-01	61	104	1.605E+00
59	98	1.142E+00	61	105	3.197E+00
59	99	1.242E+00	61	106	5.626E+00
59	100	2.075E+00	61	107	8.893E+00
59	101	2.222E+00	61	108	1.300E+01
59	102	7.157E+00	61	109	1.794E+01
59	103	1.141E+01	62	89	2.441E-10
59	104	1.679E+01	62	91	4.161E-06
59	105	2.332E+01	62	93	5.180E-04
59	106	3.098E+01	62	94	2.048E-05
59	107	3.979E+01	62	95	1.438E-03
59	108	4.973E+01	62	96	2.180E-03

62	97	6.096E-02	64	107	1.701E+00
62	98	7.220E-02	64	108	3.341E+00
62	99	4.332E-02	64	109	5.580E+00
62	100	1.058E-01	64	110	8.440E+00
62	101	1.325E-01	64	111	1.190E+01
62	102	2.988E-01	64	112	1.596E+01
62	103	3.349E-01	64	113	2.063E+01
62	104	8.050E-01	65	89	8.955E-09
62	105	1.884E+00	65	93	2.026E-11
62	106	3.572E+00	65	95	1.110E-07
62	107	5.869E+00	65	96	1.166E-06
62	108	8.774E+00	65	97	1.520E-03
62	109	1.229E+01	65	98	5.924E-04
62	110	1.641E+01	65	99	3.851E-03
62	111	2.115E+01	65	100	5.475E-03
62	112	2.649E+01	65	101	6.048E-03
63	89	4.527E-10	65	102	8.371E-03
63	91	2.556E-09	65	103	1.986E-02
63	92	4.613E-09	65	104	4.590E-02
63	93	5.281E-07	65	105	6.863E-02
63	94	1.268E-05	65	106	1.920E-01
63	95	2.517E-04	65	107	1.635E-01
63	96	6.383E-04	65	108	4.443E-01
63	97	1.824E-02	65	109	8.898E-01
63	98	2.666E-02	65	110	1.504E+00
63	99	6.539E-02	65	111	2.307E+00
63	100	3.349E-02	65	112	3.301E+00
63	101	6.080E-02	65	113	4.485E+00
63	102	1.055E-01	65	114	5.859E+00
63	103	1.478E-01	65	115	7.423E+00
63	104	3.326E-01	65	116	9.177E+00
63	105	3.851E-01	65	117	1.112E+01
63	106	9.193E-01	66	99	8.249E-05
63	107	7.625E-01	66	100	2.360E-06
63	108	6.060E-01	66	101	1.863E-03
63	109	1.786E+00	66	102	1.328E-03
63	110	5.642E+00	66	103	1.777E-02
63	111	1.351E+01	66	104	1.159E-02
63	112	2.673E+01	66	105	1.707E-02
63	113	4.663E+01	66	106	7.832E-02
64	95	1.042E-05	66	107	5.373E-02
64	97	3.156E-03	66	108	1.810E-01
64	98	1.375E-03	66	109	3.054E-01
64	99	1.019E-02	66	110	5.023E-01
64	100	1.540E-02	66	111	8.080E-01
64	101	2.258E-02	66	112	1.224E+00
64	102	6.478E-02	66	113	1.748E+00
64	103	7.642E-02	66	114	2.382E+00
64	104	2.350E-01	66	115	3.125E+00
64	105	2.382E-01	66	116	3.978E+00
64	106	6.665E-01	67	97	1.593E-04

67	99	7.194E-06	69	109	3.332E-02
67	100	6.211E-05	69	110	5.590E-02
67	101	3.864E-03	69	111	7.797E-02
67	102	2.358E-03	69	112	1.800E-01
67	103	4.186E-03	69	113	2.366E-01
67	104	1.308E-02	69	114	3.501E-01
67	105	2.773E-02	69	115	4.951E-01
67	106	2.467E-02	69	116	6.550E-01
67	107	3.014E-02	69	117	8.290E-01
67	108	8.155E-02	69	118	1.017E+00
67	109	2.303E-01	69	119	1.221E+00
67	110	4.053E-01	69	120	1.438E+00
67	111	4.652E-01	69	121	1.670E+00
67	112	9.354E-01	69	122	1.917E+00
67	113	9.316E-01	69	123	2.178E+00
67	114	9.280E-01	70	105	1.917E-06
67	115	1.876E+00	70	107	1.008E-04
67	116	4.729E+00	70	108	1.561E-04
67	117	1.044E+01	70	109	1.444E-03
68	101	8.535E-07	70	110	4.814E-03
68	103	2.562E-05	70	111	5.924E-03
68	104	3.905E-06	70	112	2.606E-02
68	105	8.252E-03	70	113	3.224E-02
68	106	3.501E-03	70	114	7.493E-02
68	107	2.852E-02	70	115	1.290E-01
68	108	5.875E-02	70	116	1.169E-01
68	109	9.846E-02	70	117	1.364E-01
68	110	9.073E-02	70	118	2.060E-01
68	111	2.666E-01	70	119	3.260E-01
68	112	2.586E-01	70	120	4.960E-01
68	113	2.586E-01	70	121	7.170E-01
68	114	2.510E-01	70	122	9.880E-01
68	115	6.230E-01	71	106	1.191E-06
68	116	1.756E+00	71	107	4.068E-04
68	117	4.031E+00	71	108	4.195E-05
68	118	7.826E+00	71	109	2.027E-03
68	119	1.352E+01	71	110	3.301E-03
68	120	2.150E+01	71	111	5.776E-03
68	121	3.247E+01	71	112	1.195E-02
68	122	4.583E+01	71	113	3.851E-02
68	123	6.294E+01	71	114	5.545E-02
69	70	9.230E+01	71	115	1.265E-01
69	99	8.617E-12	71	116	8.675E-02
69	101	6.229E-08	71	117	1.310E-01
69	102	1.144E-08	71	118	3.171E+08
69	103	3.027E-06	71	119	2.110E-01
69	104	2.337E-05	71	120	3.090E-01
69	105	2.139E-03	71	121	5.210E-01
69	106	7.600E-04	71	122	9.060E-01
69	107	6.080E-03	71	123	1.521E+00
69	108	8.155E-03	71	124	2.423E+00

71	125	3.670E+00	75	114	7.923E-06
71	126	5.319E+00	75	115	3.727E-03
72	109	1.893E-07	75	116	1.179E-03
72	110	1.805E-04	75	117	4.332E-02
72	111	4.673E-05	75	118	3.148E-03
72	112	3.301E-03	75	119	1.403E-02
72	113	1.050E-02	75	120	1.773E-02
72	114	3.165E-02	75	121	3.270E-02
72	115	2.708E-02	75	122	3.610E-02
72	116	4.126E-02	75	123	8.719E-02
72	117	7.213E-02	75	124	9.085E-02
72	118	9.230E-02	75	125	7.699E-01
72	119	2.015E-01	75	126	3.650E-01
72	120	2.015E-01	75	127	6.770E-01
72	121	4.280E-01	75	128	1.106E+00
72	122	7.720E-01	76	115	5.209E-07
72	123	1.233E+00	76	117	6.395E-06
72	124	1.812E+00	76	118	3.661E-09
72	125	2.508E+00	76	119	1.777E-03
73	107	3.307E-06	76	120	3.310E-04
73	109	7.011E-08	76	121	3.301E-03
73	110	1.573E-06	76	122	6.080E-03
73	111	2.213E-05	76	123	9.000E-03
73	112	2.339E-04	76	124	1.400E-02
73	113	1.100E-03	76	125	2.500E-02
73	114	2.970E-03	76	126	4.400E-02
73	115	2.003E-02	76	127	7.300E-02
73	116	9.708E-03	77	115	1.035E-07
73	117	3.122E-02	77	117	1.005E-05
73	118	3.501E-02	77	118	7.702E-05
73	119	7.073E-02	77	119	1.333E-02
73	120	1.155E-01	77	120	1.992E-03
73	121	1.406E-01	77	121	8.664E-02
73	122	1.666E-01	77	122	2.166E-01
73	123	2.220E-01	77	123	2.577E-02
73	124	3.400E-01	77	124	1.597E-02
73	125	5.510E-01	77	125	3.460E-01
74	111	1.068E-07	77	126	1.017E+00
74	113	8.117E-06	78	119	9.680E-06
74	114	1.156E-07	78	121	3.828E-04
74	115	1.005E-03	78	122	1.540E-05
74	116	3.851E-04	78	123	4.621E-03
74	117	3.329E-03	78	124	4.376E-06
74	118	6.918E-03	78	125	8.686E-03
74	119	1.381E-02	78	126	3.961E-02
74	120	3.808E-02	78	127	3.301E-01
74	121	8.300E-02	78	128	3.165E-01
74	122	1.490E-01	78	129	3.081E-01
74	123	2.360E-01	79	117	9.731E-08
75	111	2.008E-06	79	119	2.977E-06
75	113	1.131E-05	79	120	2.556E-06

79	121	2.387E-04	83	133	3.209E-03
79	122	4.443E-04	83	134	4.548E-03
79	123	2.407E-02	83	135	1.759E-02
79	124	1.155E-02	83	136	1.666E-02
79	125	1.742E-02	83	137	3.415E-02
79	126	2.236E-02	83	138	3.270E-02
79	127	2.139E-01	83	139	6.134E-02
79	128	1.658E-01	84	133	3.850E-03
79	129	2.153E-01	84	134	8.000E-07
79	130	3.094E-01	85	135	3.114E-03
79	131	3.001E-01	85	136	5.023E-03
79	132	5.825E-01	85	137	1.284E-02
79	133	6.796E-01	85	138	1.386E-02
80	123	1.721E-07	85	139	1.819E-02
80	125	2.222E-03	85	140	1.133E-02
80	126	1.417E-03	85	141	2.975E-02
80	127	3.984E-03	85	142	2.476E-02
80	128	2.751E-04	86	135	3.604E-04
80	129	1.031E-01	86	137	4.980E-04
80	130	1.523E-01	86	138	1.080E-04
80	131	1.343E-01	86	139	2.567E-03
80	132	2.888E-01	86	140	1.925E-03
80	133	3.014E-01	86	141	3.081E-02
81	123	5.642E-09	86	142	1.066E-02
81	125	2.751E-03	86	143	2.940E-03
81	126	2.422E-03	86	144	1.177E-02
81	127	3.784E-03	86	145	2.173E-02
81	128	5.251E-03	86	146	3.301E-02
81	129	8.887E-03	87	133	8.854E-05
81	130	6.245E-02	87	134	2.358E-06
81	131	7.832E-02	87	135	8.136E-04
81	132	1.392E-01	87	136	5.251E-04
81	133	1.986E-01	87	137	3.501E-03
81	134	2.280E-01	87	138	2.888E-03
81	135	3.239E-01	87	139	1.444E-02
81	136	4.560E-01	87	140	2.806E-01
82	127	5.919E-05	87	141	1.777E-02
82	128	9.850E-10	87	142	1.381E-02
82	129	3.200E-04	87	143	3.629E-02
82	130	1.810E-05	87	144	3.961E-02
82	131	1.133E-03	87	145	1.386E-01
82	132	4.311E-04	87	146	2.243E-02
82	133	2.222E-03	87	147	5.059E-02
82	134	6.459E-03	87	148	8.654E-02
82	135	8.955E-03	88	137	5.384E-07
83	127	1.600E-06	88	139	2.738E-04
83	128	1.512E-05	88	140	3.820E-09
83	129	1.222E-04	88	141	2.888E-03
83	130	2.481E-04	88	142	1.242E-04
83	131	5.804E-04	88	143	6.730E-03
83	132	1.520E-03	88	144	2.773E-03

88	145	2.310E-02	91	144	4.715E-04
88	146	2.310E-02	91	145	1.270E-03
88	147	1.318E-02	91	146	1.328E-03
88	148	3.961E-02	91	147	5.023E-03
88	149	3.830E-02	91	148	3.679E-03
89	137	5.436E-06	91	149	6.717E-03
89	138	9.949E-10	91	150	9.316E-03
89	139	3.131E-05	91	151	1.395E-02
89	140	1.843E-04	91	152	1.998E-02
89	141	5.682E-03	92	145	1.189E-06
89	142	1.540E-03	92	147	4.926E-04
89	143	5.825E-03	92	148	1.366E-05
89	144	4.780E-03	92	149	1.618E-04
89	145	1.575E-02	92	150	6.876E-04
89	146	5.691E-03	92	151	4.126E-04
89	147	2.215E-02	92	152	2.501E-03
89	148	3.094E-02	92	153	2.448E-03
89	149	3.830E-02	92	154	1.568E-02
90	141	7.545E-06	92	155	1.203E-02
90	143	5.180E-04	93	145	3.790E-06
90	144	3.329E-07	93	146	3.404E-06
90	145	1.627E-03	93	147	1.866E-04
90	146	3.081E-04	93	148	8.311E-04
90	147	2.310E-03	93	149	5.251E-03
90	148	1.840E-03	93	150	6.245E-03
90	149	1.583E-01	93	151	5.045E-03
91	139	3.872E-08	93	152	1.882E-03
91	141	6.124E-06	93	153	4.359E-03
91	142	2.975E-07	93	154	5.067E-03
91	143	2.874E-05	93	155	8.819E-03

APPENDIX A-2

The following pages contain decay constants data for the β^- mode.

Z	N	λ
4	3	1.505E-07
5	3	9.000E-01
6	3	5.478E+00
6	4	3.599E-02
6	5	5.665E-04
7	5	6.300E+01
7	6	1.159E-03
8	5	8.077E+01
8	6	9.815E-03
8	7	5.669E-03
9	8	1.071E-02
9	9	1.052E-04
10	7	6.348E+00
10	8	4.146E-01
10	9	4.025E-02
11	9	1.548E+00
11	10	3.082E-02
11	11	8.442E-09
12	8	7.077E+00
12	9	4.017E+00
12	10	1.797E-01
12	11	6.125E-02
13	8	1.750E+01
13	9	9.902E+00
13	10	1.475E+00
13	11	3.375E-01
13	12	9.654E-02
13	13	1.092E-01
14	8	4.652E+01
14	9	2.088E+01
14	10	6.529E+00
14	11	3.151E+00
14	12	3.136E-01
14	13	1.666E-01
15	10	1.420E+01
15	11	3.396E+01
15	12	2.506E+00
15	13	2.567E+00
15	14	1.674E-01
15	15	3.277E+08
16	10	4.530E+01
16	11	3.301E+01
16	12	5.545E+00
16	13	3.707E+00
16	14	5.590E-01
16	15	2.708E-01
17	14	4.601E+00
17	15	2.326E+00

Z	N	λ
17	16	2.762E-01
17	17	4.541E-01
18	14	7.073E+00
18	15	2.456E+00
18	16	8.213E-01
18	17	3.894E-01
18	19	2.290E-07
19	16	6.624E+00
19	17	2.026E+00
19	18	5.635E-01
19	19	1.513E-03
20	15	1.386E+01
20	16	5.452E+00
20	17	9.506E-01
20	18	1.579E+00
20	19	8.060E-01
21	18	6.189E+00
21	19	3.785E+00
21	20	1.163E+00
21	21	1.118E-02
21	22	4.948E-05
21	23	4.903E-05
22	18	1.238E+01
22	20	3.431E+00
22	21	1.351E+00
22	22	4.644E-10
22	23	6.251E-05
23	19	4.897E+01
23	20	2.360E+01
23	21	7.700E+00
23	22	1.267E+00
23	23	1.641E+00
23	24	3.543E-04
23	25	5.022E-07
23	26	2.431E-08
24	24	8.930E-06
24	25	2.731E-04
24	27	2.896E-07
25	23	4.383E+00
25	24	1.814E+00
25	25	2.441E+00
25	26	2.501E-04
25	27	1.435E-06
25	29	2.570E-08
26	23	9.240E+00
26	27	1.358E-03
26	29	8.046E-09
27	24	1.205E+01

27	25	1.810E+01	33	34	1.650E-02
27	26	2.606E+00	33	35	2.616E-01
27	27	3.588E+00	33	36	7.600E-04
27	28	1.098E-05	33	37	2.196E-04
27	29	1.038E-07	33	38	2.949E-06
27	30	2.952E-08	33	39	7.405E-06
27	31	1.133E-07	33	40	6.594E+00
28	24	1.534E+01	34	31	2.476E+01
28	25	1.540E+01	34	32	1.189E+01
28	26	6.730E+00	34	33	4.847E+00
28	27	3.270E+00	34	34	7.220E-03
28	28	1.315E-06	34	35	2.538E-02
28	29	5.337E-06	34	36	2.818E-04
29	26	1.953E+01	34	37	2.437E-03
29	27	3.180E+01	34	38	9.551E-07
29	28	3.151E+00	34	39	2.693E-05
29	29	2.163E-01	34	41	6.698E-08
29	30	8.432E-03	35	35	3.151E-01
29	31	4.980E-04	35	36	3.239E-02
29	32	5.777E-05	35	37	8.819E-03
29	33	1.186E-03	35	38	3.398E-03
29	35	9.248E-06	35	39	4.548E-04
30	27	6.065E+00	35	40	1.195E-04
30	28	1.024E+01	35	41	1.189E-05
30	29	3.763E+00	35	42	3.376E-06
30	30	4.854E-03	35	43	1.788E-03
30	31	7.753E-03	35	45	5.423E-05
30	32	2.079E-05	36	35	7.146E+00
30	33	3.032E-04	36	36	3.984E-02
30	35	3.284E-08	36	37	2.550E-02
31	30	1.742E+00	36	38	1.005E-03
31	31	5.975E+00	36	39	2.567E-03
31	32	2.139E-02	36	40	1.301E-05
31	33	4.393E-03	36	41	1.540E-04
31	34	9.227E-04	36	43	5.495E-06
31	35	2.029E-05	37	37	1.066E+01
31	36	2.460E-06	37	38	3.851E-02
31	37	1.708E-04	37	39	1.873E-02
31	39	2.241E-06	37	40	2.962E-03
32	29	3.466E+00	37	41	6.542E-04
32	30	1.042E+01	37	42	5.045E-04
32	31	2.521E+00	37	43	2.075E-02
32	32	1.083E-02	37	44	4.208E-05
32	33	2.243E-02	37	45	9.075E-03
32	34	8.482E-05	37	46	9.307E-08
32	35	6.112E-04	37	47	2.355E-07
32	36	2.962E-08	38	37	3.398E+00
32	37	4.931E-06	38	38	8.568E-04
32	39	7.019E-07	38	39	7.682E-02
33	32	2.113E+00	38	40	4.621E-03
33	33	7.235E+00	38	41	5.134E-03

38	42	1.088E-04	44	48	3.165E-03
38	43	5.204E-04	44	49	1.161E-02
38	44	3.140E-07	44	50	2.230E-04
38	45	5.941E-06	44	51	1.172E-04
38	47	1.237E-07	44	53	2.766E-06
39	40	4.652E-02	45	49	9.790E-03
39	41	2.051E-02	45	50	2.310E-03
39	42	9.627E-03	45	51	1.167E-03
39	43	7.296E-02	45	52	3.763E-04
39	44	1.632E-03	45	53	1.328E-03
39	45	1.507E-01	45	54	4.982E-07
39	46	7.184E-05	45	55	9.257E-06
39	47	1.306E-05	45	56	6.656E-09
39	48	2.413E-06	45	57	3.101E-08
39	49	7.522E-08	45	59	7.374E-05
40	41	4.621E-02	46	48	7.702E-02
40	42	2.166E-02	46	49	4.951E-02
40	43	1.575E-02	46	50	5.691E-03
40	44	4.460E-04	46	51	3.501E-03
40	45	1.470E-03	46	52	6.418E-04
40	46	1.167E-05	46	53	5.398E-04
40	47	1.146E-04	46	54	2.210E-06
40	48	9.619E-08	46	55	2.273E-05
40	49	2.456E-06	46	57	4.722E-07
41	42	1.691E-01	47	48	2.937E+00
41	43	5.776E-02	47	49	1.250E-01
41	44	3.316E-02	47	50	3.301E-02
41	45	8.252E-03	47	51	1.558E-02
41	46	3.122E-03	47	52	5.501E-03
41	47	7.967E-04	47	53	5.157E-03
41	48	1.632E-04	47	54	1.041E-03
41	49	1.319E-05	47	55	8.955E-04
41	50	3.230E-11	47	56	1.758E-04
42	43	1.238E-01	47	57	1.669E-04
42	44	3.536E-02	47	58	1.943E-07
42	45	4.780E-02	47	59	4.797E-04
42	46	1.444E-03	48	49	2.310E-01
42	47	5.663E-03	48	50	7.534E-02
42	48	3.396E-05	48	51	4.325E-02
42	49	7.458E-04	48	52	1.415E-02
43	45	7.273E-01	48	53	9.627E-03
43	46	5.415E-02	48	54	2.100E-03
43	47	7.967E-02	48	55	1.583E-03
43	48	3.679E-03	48	56	1.992E-04
43	49	2.731E-03	48	57	2.082E-04
43	50	7.001E-05	48	59	2.962E-05
43	51	3.943E-05	48	61	1.734E-08
43	52	9.627E-06	49	51	8.643E-02
43	53	1.874E-06	49	52	4.332E-02
44	46	1.674E-01	49	53	2.888E-02
44	47	7.702E-02	49	54	1.066E-02

49	55	6.418E-02	52	64	7.733E-05
49	56	2.279E-03	52	65	1.863E-04
49	57	1.863E-03	52	66	1.337E-06
49	58	3.566E-04	52	67	5.005E-07
49	59	1.992E-04	52	69	4.781E-07
49	60	4.584E-05	53	55	3.249E-01
49	61	3.929E-05	53	57	7.122E-01
49	62	2.860E-06	53	58	2.770E-01
49	63	2.841E-04	53	59	2.039E-01
49	65	4.820E-05	53	60	1.050E-01
49	67	1.475E-05	53	61	1.216E-01
50	50	5.825E-01	53	62	8.887E-03
50	51	9.667E-02	53	63	2.390E-01
50	52	1.066E-01	53	64	5.251E-03
50	53	9.902E-02	53	65	8.432E-04
50	54	3.301E-02	53	66	6.048E-04
50	55	2.236E-02	53	67	1.426E-04
50	56	6.080E-03	53	68	9.082E-05
50	57	3.984E-03	53	69	3.182E-03
50	58	1.122E-03	53	70	1.403E-05
50	59	6.418E-04	53	71	1.921E-06
50	60	4.685E-05	53	72	1.350E-07
50	61	3.273E-04	53	73	3.445E-07
50	63	6.971E-08	53	75	3.190E-05
51	53	1.868E+00	54	58	2.546E-01
51	54	5.134E-01	54	59	2.423E-01
51	55	4.590E-01	54	60	6.931E-02
51	56	1.873E-01	54	61	3.851E-02
51	57	9.902E-02	54	62	1.175E-02
51	58	3.788E-02	54	63	1.136E-02
51	59	3.014E-02	54	64	3.040E-03
51	60	9.242E-03	54	65	1.992E-03
51	61	1.349E-02	54	66	2.888E-04
51	62	1.732E-03	54	67	2.881E-04
51	63	3.310E-03	54	68	9.579E-06
51	64	3.599E-04	54	69	9.257E-05
51	65	7.312E-04	54	71	1.139E-05
51	66	6.876E-05	54	73	2.207E-07
51	67	3.209E-03	55	59	1.129E+00
51	68	5.042E-06	55	60	4.948E-01
51	69	7.270E-04	55	61	1.980E-01
51	71	7.098E-08	55	62	8.252E-02
52	55	5.776E+01	55	63	4.077E-02
52	56	1.683E-01	55	64	1.824E-02
52	57	1.623E-01	55	65	1.083E-02
52	58	3.727E-02	55	66	4.443E-03
52	59	3.591E-02	55	67	2.751E-03
52	60	6.418E-03	55	68	1.958E-03
52	61	6.796E-03	55	69	2.243E-02
52	62	6.796E-04	55	70	2.567E-04
52	63	1.992E-03	55	71	7.087E-03

55	72	3.081E-05	58	74	5.486E-05
55	73	3.186E-03	58	75	3.929E-05
55	74	6.006E-06	58	76	2.539E-06
55	75	3.892E-04	58	77	1.088E-05
55	76	8.129E-07	58	79	2.139E-05
55	77	1.215E-06	58	81	5.829E-08
56	58	1.731E+00	59	62	4.951E-01
56	59	1.631E+00	59	63	1.123E+00
56	60	9.145E-01	59	64	6.245E-01
56	61	3.648E-01	59	65	5.776E-01
56	62	1.260E-01	59	66	2.057E-01
56	63	1.284E-01	59	67	2.166E-01
56	64	2.166E-02	59	68	4.590E-02
56	65	2.310E-02	59	69	2.166E-01
56	66	5.776E-03	59	70	2.888E-02
56	67	4.279E-03	59	71	1.733E-02
56	68	9.708E-04	59	72	6.796E-03
56	69	3.301E-03	59	73	7.220E-03
56	70	1.155E-04	59	74	1.777E-03
56	71	9.096E-04	59	75	6.796E-04
56	72	3.301E-06	59	76	4.814E-04
56	73	8.634E-05	59	77	8.819E-04
56	75	6.976E-07	59	78	1.504E-04
56	77	2.082E-09	59	79	7.967E-03
57	63	2.476E-01	59	80	4.366E-05
57	64	1.308E-01	59	81	3.408E-03
57	65	7.967E-02	59	83	2.014E-09
57	66	4.077E-02	60	67	3.648E-01
57	67	2.390E-02	60	68	1.392E-01
57	68	8.887E-03	60	69	1.415E-01
57	69	1.155E-02	60	70	2.476E-02
57	70	3.040E-03	60	71	2.888E-02
57	71	2.358E-03	60	72	6.418E-03
57	72	1.328E-03	60	73	9.627E-03
57	73	1.328E-03	60	74	1.359E-03
57	74	1.958E-04	60	75	9.316E-04
57	75	4.011E-05	60	76	2.281E-04
57	76	4.922E-05	60	77	3.001E-04
57	77	1.791E-03	60	78	3.820E-05
57	78	9.874E-06	60	79	4.141E-04
57	79	1.170E-03	60	80	2.381E-06
58	64	2.288E-01	60	81	7.733E-05
58	65	1.824E-01	61	69	3.151E-01
58	66	1.155E-01	61	70	8.203E-02
58	67	7.702E-02	61	71	1.100E-01
58	68	1.386E-02	61	72	5.776E-02
58	69	2.166E-02	61	73	2.888E-02
58	70	2.100E-03	61	74	1.260E-02
58	71	3.301E-03	61	75	6.418E-03
58	72	4.621E-04	61	76	4.814E-03
58	73	1.133E-03	61	77	3.301E-03

61	78	2.784E-03	64	83	5.059E-06
61	79	7.534E-02	64	85	8.645E-07
61	80	5.527E-04	64	87	6.470E-08
61	81	1.711E-02	64	89	3.320E-08
61	82	3.027E-08	65	75	2.881E-01
61	83	2.210E-08	65	76	1.980E-01
61	84	1.241E-09	65	77	1.161E+00
61	85	2.621E-09	65	78	5.776E-02
62	69	5.776E-01	65	79	6.931E-01
62	70	1.733E-01	65	80	2.794E-02
62	71	2.476E-01	65	81	8.664E-02
62	72	5.776E-02	65	82	1.133E-04
62	73	6.931E-02	65	83	1.925E-04
62	74	1.650E-02	65	84	4.676E-05
62	75	1.575E-02	65	85	5.530E-05
62	76	3.851E-03	65	86	1.093E-05
62	77	4.621E-03	65	87	1.100E-05
62	78	7.806E-04	65	88	3.428E-06
62	79	1.133E-03	65	89	8.946E-06
62	80	1.594E-04	65	90	3.619E-05
62	81	1.308E-03	65	91	3.599E-05
62	83	5.663E-07	65	92	2.219E-10
63	71	1.386E+00	65	93	1.018E-10
63	72	4.621E-01	66	75	6.931E-01
63	73	1.776E-01	66	76	3.014E-01
63	74	6.301E-02	66	77	2.166E-01
63	75	5.728E-02	66	78	7.702E-02
63	76	3.851E-02	66	79	5.097E-02
63	77	3.301E-02	66	80	2.390E-02
63	78	1.733E-02	66	81	9.242E-03
63	79	2.888E-01	66	82	3.727E-03
63	80	4.495E-03	66	83	2.818E-03
63	81	6.796E-02	66	84	1.031E-03
63	82	1.359E-06	66	85	6.453E-04
63	83	1.748E-06	66	86	8.116E-05
63	84	3.329E-07	66	87	3.056E-05
63	85	1.472E-07	66	89	1.945E-05
63	86	8.617E-08	66	91	2.365E-05
63	87	5.952E-10	66	93	5.556E-08
63	89	1.170E-09	67	77	9.902E-01
63	91	5.112E-13	67	78	8.881E-02
64	73	9.902E-02	67	79	2.236E-01
64	74	9.749E-02	67	80	1.195E-01
64	75	1.415E-01	67	81	7.228E-02
64	76	4.951E-02	67	82	3.285E-02
64	77	2.829E-02	67	83	7.877E-03
64	78	9.874E-03	67	84	1.536E-02
64	79	6.189E-03	67	85	3.770E-03
64	80	2.567E-03	67	86	5.716E-03
64	81	5.023E-04	67	87	9.822E-04
64	82	1.662E-07	67	88	2.407E-04

67	89	2.063E-04	70	83	8.664E-02
67	90	9.169E-04	70	84	1.217E-01
67	91	1.022E-03	70	85	4.765E-02
67	92	3.495E-04	70	86	2.599E-02
67	93	4.513E-04	70	87	1.787E-02
67	94	7.764E-05	70	88	7.358E-03
67	95	7.702E-04	70	89	8.252E-03
67	97	2.390E-04	70	90	2.407E-03
68	78	3.573E-01	70	91	2.751E-03
68	79	2.773E-01	70	92	6.112E-04
68	80	1.540E-01	70	93	1.408E-03
68	81	5.969E-02	70	94	1.528E-04
68	82	3.747E-02	70	95	1.179E-03
68	83	2.950E-02	70	96	3.396E-06
68	84	6.730E-03	70	97	6.601E-04
68	85	9.049E-03	70	99	2.505E-07
68	86	3.026E-03	71	81	8.417E-01
68	87	2.179E-03	71	83	7.220E-01
68	88	5.776E-04	71	84	1.040E+00
68	89	4.814E-04	71	85	6.931E-01
68	90	8.371E-05	71	86	7.375E-02
68	91	3.209E-04	71	87	6.868E-02
68	92	6.737E-06	71	88	5.774E-02
68	93	5.998E-05	71	89	2.039E-02
68	95	1.540E-04	71	90	9.627E-03
68	97	1.859E-05	71	91	8.252E-03
69	78	1.114E+00	71	92	2.818E-03
69	79	9.902E-01	71	93	3.644E-03
69	80	7.686E-01	71	94	1.076E-03
69	81	1.980E-01	71	95	4.359E-03
69	82	2.773E-01	71	96	2.243E-04
69	83	8.664E-02	71	97	2.100E-03
69	84	1.386E-01	71	98	5.653E-06
69	85	7.763E-02	71	99	4.011E-06
69	86	1.449E-02	71	100	9.736E-07
69	87	8.681E-03	71	101	1.197E-06
69	88	3.209E-03	71	102	1.590E-09
69	89	2.888E-03	71	103	6.636E-09
69	90	1.263E-03	72	82	3.466E-01
69	91	1.256E-03	72	83	7.788E-01
69	92	3.040E-04	72	84	5.268E+00
69	93	5.324E-04	72	85	8.087E-01
69	94	1.064E-04	72	86	1.213E-01
69	95	5.776E-03	72	87	7.303E-02
69	96	6.405E-06	72	88	5.643E-02
69	97	2.501E-05	72	89	4.066E-02
69	98	8.673E-07	72	90	1.843E-02
69	99	8.647E-08	72	91	1.733E-02
69	101	9.358E-11	72	92	4.126E-03
70	81	4.332E-01	72	93	9.242E-03
70	82	2.236E-01	72	94	1.699E-03

72	95	5.635E-03	74	104	3.714E-07
72	96	4.452E-04	74	105	3.008E-04
72	97	3.566E-03	74	107	6.619E-08
72	98	1.203E-05	75	87	6.724E+00
72	99	1.591E-05	75	88	9.597E-01
72	100	1.175E-08	75	89	3.235E-01
72	101	8.159E-06	75	90	3.755E-02
72	103	1.146E-07	75	92	1.125E-01
73	83	1.733E+00	75	93	1.575E-01
73	84	3.008E+01	75	94	8.557E-02
73	85	1.311E+00	75	95	7.534E-02
73	86	2.310E-01	75	96	4.560E-02
73	87	3.812E-01	75	97	4.621E-02
73	88	2.439E-01	75	98	5.835E-03
73	89	1.979E-01	75	99	4.814E-03
73	90	6.583E-02	75	100	1.961E-03
73	91	5.097E-02	75	101	2.180E-03
73	92	1.136E-02	75	102	8.252E-04
73	93	1.118E-02	75	103	8.752E-04
73	94	8.686E-03	75	104	5.924E-04
73	95	5.776E-03	75	105	4.735E-03
73	96	2.358E-03	75	106	9.675E-06
73	97	1.709E-03	75	107	3.008E-06
73	98	4.958E-04	75	108	1.146E-07
73	99	3.139E-04	75	109	2.111E-07
73	100	6.132E-05	75	111	1.489E-07
73	101	1.834E-04	76	88	3.381E-01
73	102	1.834E-05	76	89	3.798E+00
73	103	2.380E-05	76	90	6.238E-01
73	104	3.404E-06	76	91	2.756E-01
73	105	1.241E-03	76	92	1.607E-01
73	106	1.207E-08	76	93	1.814E-01
73	107	2.031E-05	76	94	8.591E-02
74	86	4.279E-02	76	95	8.517E-02
74	87	7.777E-01	76	96	3.603E-02
74	88	8.976E-02	76	97	4.331E-02
74	89	1.225E-01	76	98	1.575E-02
74	90	6.491E-02	76	99	8.252E-03
74	91	1.324E-01	76	100	3.209E-03
74	92	4.332E-02	76	101	4.126E-03
74	93	3.482E-02	76	102	2.310E-03
74	94	1.359E-02	76	103	1.777E-03
74	95	8.664E-03	76	104	5.376E-04
74	96	4.774E-03	76	105	1.100E-04
74	97	4.854E-03	76	106	8.712E-06
74	98	1.750E-03	76	107	1.481E-05
74	99	1.520E-03	76	109	8.571E-08
74	100	3.727E-04	77	93	1.650E-01
74	101	3.282E-04	77	95	1.544E-01
74	102	7.702E-05	77	96	5.622E-02
74	103	8.557E-05	77	97	7.671E-02

77	98	7.636E-02	79	110	4.025E-04
77	99	8.482E-02	79	111	2.699E-04
77	100	2.309E-02	79	112	6.055E-05
77	101	5.776E-02	79	113	3.898E-05
77	102	8.774E-03	79	114	1.091E-05
77	103	7.702E-03	79	115	5.064E-06
77	104	2.358E-03	79	116	4.311E-08
77	105	7.702E-04	79	117	1.200E-06
77	106	2.027E-04	80	97	7.998E-01
77	107	6.231E-05	80	98	8.187E-01
77	108	1.337E-05	80	99	2.979E-01
77	109	1.157E-05	80	100	1.178E-01
77	110	1.834E-05	80	101	1.232E-01
77	111	4.640E-06	80	102	5.427E-02
77	112	6.078E-07	80	103	5.494E-02
77	113	6.810E-07	80	104	2.240E-02
77	115	5.172E-09	80	105	1.327E-02
78	93	2.773E-01	80	106	8.370E-03
78	94	3.999E-01	80	107	4.814E-03
78	95	3.243E-01	80	108	3.555E-03
78	96	1.309E-01	80	109	1.520E-03
78	97	6.302E-02	80	110	5.776E-04
78	98	4.161E-02	80	111	2.358E-04
78	99	5.948E-02	80	112	3.970E-05
78	100	3.032E-02	80	113	5.067E-05
78	101	3.262E-02	80	114	4.224E-11
78	102	1.329E-02	80	115	1.945E-05
78	103	1.358E-02	80	117	3.002E-06
78	104	5.249E-03	81	100	2.039E-01
78	105	1.777E-03	81	101	2.147E-01
78	106	6.678E-04	81	102	1.005E-01
78	107	1.629E-04	81	103	6.169E-02
78	108	9.627E-05	81	104	3.555E-02
78	109	8.193E-05	81	105	2.521E-02
78	110	7.865E-07	81	106	1.359E-02
78	111	1.771E-05	81	107	9.763E-03
78	113	2.710E-06	81	108	5.023E-03
78	115	4.393E-10	81	109	4.443E-03
79	96	2.079E-01	81	110	2.222E-03
79	98	3.524E-01	81	111	1.203E-03
79	99	1.600E-01	81	112	5.348E-04
79	100	7.615E-02	81	113	3.501E-04
79	101	8.403E-02	81	114	1.660E-04
79	102	5.989E-02	81	115	1.046E-04
79	103	4.437E-02	81	116	6.780E-05
79	104	1.644E-02	81	117	3.633E-05
79	105	5.776E-02	81	118	2.595E-05
79	106	2.712E-03	81	119	7.377E-06
79	107	1.080E-03	81	120	2.641E-06
79	108	1.375E-03	81	121	6.560E-07
79	109	1.307E-03	81	123	1.685E-10

82	99	3.081E-01	85	110	3.180E-02
82	101	1.386E-01	85	112	7.922E-02
82	106	2.120E-02	85	113	1.650E-02
82	107	1.354E-02	85	114	9.627E-03
82	108	9.540E-03	85	115	6.931E-03
82	109	8.685E-03	85	116	2.259E-03
82	110	3.301E-03	85	117	3.277E-03
82	111	1.992E-03	85	118	1.077E-02
82	112	9.627E-04	85	119	2.460E-03
82	113	7.702E-04	85	120	3.968E-04
82	114	3.122E-04	85	121	3.817E-04
82	115	1.444E-03	85	122	9.777E-05
82	116	4.814E-03	85	123	1.175E-04
82	117	1.284E-04	85	124	3.413E-05
82	118	8.955E-06	85	125	2.373E-05
82	119	2.064E-05	85	126	1.553E-05
82	121	3.712E-06	85	127	6.622E-04
83	106	5.097E-01	86	113	6.708E-02
83	107	1.216E-02	86	114	1.308E-02
83	108	2.310E-02	86	115	1.980E-02
83	109	1.763E-02	86	116	2.111E-02
83	110	9.828E-03	86	117	5.237E-03
83	111	7.263E-03	86	118	2.515E-03
83	112	3.787E-03	86	119	3.177E-03
83	113	2.250E-03	86	120	1.644E-03
83	114	1.238E-03	86	121	9.866E-04
83	115	1.122E-03	86	122	1.803E-04
83	116	4.328E+04	86	123	3.364E-04
83	117	3.174E-04	86	124	3.209E-06
83	118	1.070E-04	86	125	9.522E-06
83	119	1.119E-04	87	114	1.444E-01
83	120	1.637E-05	87	115	6.116E-02
83	121	1.716E-05	87	116	6.301E-02
83	122	5.240E-07	87	117	8.155E-02
83	123	1.285E-06	87	118	1.800E-03
83	124	6.396E-01	87	119	6.975E-03
84	108	2.039E-01	87	120	2.292E-03
84	111	3.725E-02	87	121	1.173E-03
84	112	2.400E-03	87	122	1.525E-03
84	113	7.280E-03	87	123	1.453E-03
84	114	3.010E-03	87	124	7.453E-04
84	115	1.850E-03	87	125	3.292E-04
84	116	8.890E-04	87	126	1.102E-04
84	117	7.430E-04	88	119	5.332E-02
84	118	2.532E-04	88	120	2.666E-02
84	119	3.113E-04	88	121	1.507E-02
84	120	5.418E-05	88	122	7.493E-03
84	121	1.160E-04	88	123	3.732E-03
84	122	8.620E-07	88	124	7.998E-03
84	123	3.319E-05	88	125	8.432E-04
84	125	1.033E-12	88	126	1.691E-04

89	120	6.931E-02
89	121	7.922E-02
89	123	2.236E-02
89	125	9.298E-03
89	126	3.670E-03
89	128	2.009E+05
89	133	1.386E-03
89	134	5.501E-05
89	135	6.035E-05
89	137	1.113E-06
90	135	1.325E-04
91	133	7.296E-03
91	135	1.669E-03
91	136	4.524E-05
91	137	8.590E-06
91	138	4.900E-06
91	139	4.222E-07

92	136	6.348E-05
92	137	3.984E-05
92	139	1.910E-06
93	135	1.080E-02
93	136	1.500E-03
93	137	2.436E-03
93	138	2.320E+00
93	139	7.859E-04
93	140	3.191E-04
93	141	1.823E-06
93	142	2.025E-08
94	138	2.710E-04
94	139	5.520E-04
94	140	2.056E-05
94	141	4.565E-04
94	143	1.775E-07

APPENDIX A-3

The following pages contain decay constant data for the α mode.

Z	N	λ
3	2	2.280E+21
4	4	1.033E+16
5	4	8.204E+17
52	54	1.155E+04
52	55	1.348E+02
52	56	1.617E-01
52	57	6.762E-03
53	55	3.285E+00
53	57	1.708E-01
53	58	2.773E-04
54	56	3.466E+00
54	57	7.702E-01
54	58	2.156E-03
54	59	5.892E-06
56	58	1.906E-03
64	84	2.944E-10
65	85	2.766E-08
66	84	5.800E-04
66	85	3.828E-05
66	86	8.124E-08
67	84	4.332E-03
67	85	5.141E-04
67	86	2.860E-06
67	87	1.967E-07
68	84	6.057E-02
68	85	1.020E-02
68	86	1.429E-05
68	87	4.359E-07
69	84	2.634E-01
69	85	6.100E-02
69	86	1.260E-03
69	87	5.212E-06
70	83	8.664E-02
70	84	1.569E+00
70	85	3.856E-01
70	86	2.888E-03
70	87	8.979E-06
71	84	3.911E+00
71	85	1.317E+00
71	86	4.288E-03
71	87	6.308E-04
71	88	2.315E-05
72	84	2.246E+01
72	85	4.968E+00
72	86	9.531E-02
72	87	5.075E-02
72	88	1.329E-02
72	89	1.182E-04

Z	N	λ
73	84	1.007E+02
73	85	1.742E+01
73	86	9.242E-01
73	87	1.964E-01
73	88	1.284E-02
73	89	1.584E-04
73	90	1.848E-04
74	84	7.702E+02
74	85	9.448E+01
74	86	4.621E+00
74	87	1.386E+00
74	88	2.344E-01
74	89	9.473E-02
74	90	2.861E-03
74	92	1.733E-05
74	93	3.483E-02
75	85	9.531E+01
75	86	6.931E+01
75	87	2.079E-01
75	88	1.706E+00
75	89	4.467E-01
75	90	3.755E-02
75	91	2.476E-01
75	92	1.136E-03
76	86	3.648E+02
76	87	3.916E-01
76	88	1.657E+01
76	89	5.697E+00
76	90	2.495E+00
76	91	5.595E-01
76	92	1.544E-01
76	93	2.243E-02
76	94	1.172E-02
76	95	1.473E-03
76	96	7.220E-05
76	97	8.664E-06
76	98	3.151E-06
77	89	1.386E+02
77	90	1.386E+02
77	91	4.916E-01
77	92	1.733E+00
77	93	4.951E-01
77	94	3.462E+08
77	95	3.151E-03
77	96	1.771E-02
77	97	3.081E-04
77	98	6.546E-04
77	99	1.820E-03

77	100	1.386E-05	82	104	1.475E-01
78	90	3.788E-01	82	105	4.560E-02
78	91	2.773E+02	82	106	5.980E-03
78	92	1.155E+02	82	107	5.436E-05
78	93	2.745E+01	82	108	8.664E-05
78	94	6.265E+00	82	109	8.686E-07
78	95	1.702E+00	83	104	1.980E+01
78	96	6.392E-01	83	105	1.575E+01
78	97	1.763E-01	83	106	5.097E-01
78	98	4.161E-02	83	107	1.094E-01
78	99	3.529E-03	83	108	3.466E-02
78	100	2.529E-03	83	109	2.404E-03
78	101	7.847E-05	83	110	5.173E-04
78	102	3.999E-05	83	111	3.356E-05
78	103	8.155E-06	83	112	1.136E+00
78	104	2.100E-06	83	128	5.383E-03
79	92	6.966E-01	83	129	6.857E-05
79	93	1.698E+02	83	130	5.296E-06
79	94	1.175E+01	83	131	1.161E-07
79	95	5.776E+00	84	106	7.220E+01
79	96	3.258E+00	84	107	4.472E+01
79	97	5.545E-02	84	108	2.018E+01
79	98	2.350E-01	84	109	1.540E+00
79	99	1.066E-01	84	110	1.768E+00
79	100	2.148E-02	84	111	1.118E-01
79	101	1.540E-03	84	112	1.176E-01
79	102	9.120E-04	84	113	5.720E-03
79	103	5.776E-05	84	114	3.990E-03
79	104	5.941E-05	84	115	1.500E-04
79	106	7.067E-06	84	116	1.110E-04
80	95	3.466E+01	84	117	1.208E-05
80	96	2.039E+01	84	118	5.160E-06
80	97	4.532E+00	84	119	3.463E-07
80	98	1.910E+00	84	120	3.600E-07
80	99	3.370E-01	84	121	4.640E-08
80	100	1.132E-01	84	122	4.969E-08
80	101	6.931E-02	84	123	6.640E-09
80	102	9.728E-03	84	124	7.579E-09
80	103	1.880E-02	84	125	2.143E-10
80	104	2.514E-04	84	126	5.798E-08
80	105	8.470E-04	84	127	1.343E+00
80	106	1.674E-06	84	128	2.318E+06
81	98	4.332E+00	84	129	1.650E+05
81	99	3.648E-01	84	130	4.219E+03
81	101	8.944E-03	84	131	3.892E+02
81	103	1.323E-03	84	132	4.780E+00
82	99	1.510E+01	84	133	7.315E-02
82	100	1.260E+01	85	109	3.851E+00
82	101	2.172E+00	85	110	9.539E-02
82	102	1.260E+00	85	111	2.310E+00
82	103	1.691E-01	85	112	1.901E+00

85	113	1.485E-01	87	118	1.782E-01
85	114	8.664E-02	87	119	3.662E-02
85	115	9.188E-03	87	120	4.449E-02
85	116	5.530E-03	87	121	1.056E-02
85	117	4.897E-04	87	122	1.234E-02
85	118	4.840E-04	87	123	2.177E-03
85	119	4.772E-05	87	124	2.981E-03
85	120	4.409E-05	87	125	2.484E-04
85	121	3.427E-06	87	126	1.992E-02
85	122	9.199E-06	87	127	1.386E+02
85	123	6.497E-07	87	128	8.060E+06
85	124	1.459E-06	87	129	9.902E+05
85	125	4.279E-08	87	130	4.332E+04
85	126	1.116E-05	87	131	6.931E+02
85	127	2.207E+00	87	132	3.466E+01
85	128	5.545E+06	87	133	2.521E-02
85	129	1.242E+06	87	134	2.355E-03
85	130	6.931E+03	88	116	1.540E+01
85	131	2.310E+03	88	117	3.151E+00
85	132	2.146E+01	88	118	2.888E+00
85	133	4.328E-01	88	119	4.799E-01
85	134	1.201E-02	88	120	5.065E-01
86	112	1.386E+01	88	121	1.356E-01
86	113	1.051E+00	88	122	1.760E-01
86	114	6.408E-01	88	123	4.959E-02
86	115	5.282E-02	88	124	4.266E-02
86	116	4.926E-02	88	125	3.373E-03
86	117	1.017E-02	88	126	2.816E-01
86	118	6.801E-03	88	127	4.359E+02
86	119	9.490E-04	88	128	3.809E+06
86	120	2.683E-03	88	129	4.077E+05
86	121	2.623E-04	88	130	4.443E+04
86	122	2.941E-04	88	131	6.931E+01
86	123	6.891E-05	88	132	4.077E+01
86	124	7.702E-05	88	133	2.476E-02
86	125	3.613E-06	88	134	1.824E-02
86	126	4.834E+00	88	135	7.016E-07
86	127	2.773E+01	88	136	2.192E-06
86	128	2.567E+06	88	138	1.373E-11
86	129	3.014E+08	89	118	3.151E+01
86	130	1.540E+07	89	119	7.296E+00
86	131	1.284E+03	89	120	6.862E+00
86	132	1.980E+01	89	121	1.901E+00
86	133	1.750E-01	89	122	2.883E+00
86	134	1.247E-02	89	123	7.230E-01
86	135	1.017E-04	89	124	8.664E-01
86	136	2.083E-06	89	125	7.523E-02
87	114	1.430E+01	89	126	4.074E+00
87	115	1.978E+00	89	127	2.100E+03
87	116	1.197E+00	89	128	1.025E+07
87	117	3.262E-01	89	129	6.354E+14

89	130	5.874E+04	91	130	1.175E+05
89	131	2.656E+01	91	131	2.100E+02
89	132	1.333E+01	91	132	1.386E+02
89	133	1.359E-01	91	133	7.289E-01
89	134	5.446E-03	91	134	4.077E-01
89	135	6.042E-06	91	135	4.749E-03
89	136	8.023E-07	91	136	2.564E-04
89	138	1.392E-11	91	137	1.619E-07
90	120	7.702E+01	91	138	2.567E-08
90	121	1.873E+01	92	126	4.621E+02
90	122	2.310E+01	92	127	1.650E+04
90	123	4.951E+00	92	128	4.696E-03
90	125	5.776E-01	92	129	4.530E-03
90	126	2.476E+01	92	130	6.931E+05
90	127	2.751E+03	92	131	3.851E+04
90	128	6.359E+06	92	132	6.931E+02
90	129	6.601E+05	92	133	7.296E+00
90	130	7.146E+04	92	134	3.466E+00
90	131	4.126E+02	92	135	1.050E-02
90	132	3.151E+02	92	136	1.206E-03
90	133	1.155E+00	92	137	3.984E-05
90	134	6.601E-01	92	138	3.857E-07
90	135	1.192E-03	92	140	3.188E-10
90	136	3.775E-04	93	133	2.236E+01
90	137	4.286E-07	93	134	1.359E+00
90	138	1.148E-08	93	136	1.500E-03
91	122	1.308E+02	93	137	7.534E-05
91	123	4.077E+01	93	138	4.735E-06
91	124	4.621E+01	94	138	6.774E-05
91	125	6.601E+00	94	139	6.632E-07
91	126	2.039E+02	94	140	1.312E-06
91	127	6.301E+03	94	142	7.689E-07
91	128	1.308E+07	94	144	2.506E-10
91	129	8.887E+05			

APPENDIX A-4

The following pages contain decay constant data for the β^-n mode.

Z	N	λ
2	6	9.317E-01
3	6	1.924E+00
6	11	1.149E+00
6	13	8.627E+00
7	12	1.423E+00
7	13	4.227E+00
7	14	6.128E+00
7	15	1.011E+01
8	15	2.620E+00
8	16	6.559E+00
9	16	5.874E+00
10	18	7.922E+00
11	16	1.842E-03
11	17	1.318E-01
11	18	3.319E+00
11	19	4.332E+00
12	19	5.123E-02
12	20	1.386E-01
12	21	1.309E+00
13	21	3.743E+00
13	22	2.650E+00
14	22	1.386E-01
14	23	3.648E-01
15	23	1.155E-01
15	24	1.776E+00
15	25	7.998E-01
15	26	1.733E+00
15	27	3.151E+00
16	26	2.350E-02
16	27	1.260E+00
16	28	1.031E+00
17	27	1.290E-01
17	28	4.108E-01
17	29	2.059E+00
17	30	6.116E-01
19	29	1.145E-03
19	30	5.419E-01
19	31	4.259E-01
19	32	8.925E-01
19	33	5.809E+00
19	34	1.964E+01
20	33	2.310E+00
29	46	1.982E-02
29	47	3.244E-02
29	50	2.028E+00
30	49	9.056E-03
30	50	1.272E-02
30	51	1.793E-01

Z	N	λ
31	48	2.167E-04
31	49	3.635E-03
31	50	6.983E-02
31	51	2.580E-01
31	52	8.944E-01
31	53	5.708E+00
32	52	7.686E-02
32	53	1.797E-01
33	51	4.828E-04
33	52	2.066E-01
33	53	2.465E-01
33	54	2.178E-01
34	53	4.717E-04
34	54	4.485E-03
34	55	1.319E-01
34	56	3.809E-01
34	57	5.391E-01
35	52	3.142E-04
35	53	2.791E-03
35	54	2.174E-02
35	55	9.098E-02
35	56	2.562E-01
35	57	6.689E-01
35	58	5.233E+00
35	59	2.971E+00
36	56	1.130E-04
36	57	1.083E-02
36	58	1.975E-01
37	55	1.543E-05
37	56	1.602E-03
37	57	2.568E-02
37	58	1.603E-01
37	59	4.785E-01
37	60	1.024E+00
37	61	8.269E-01
37	62	2.853E+00
37	63	7.611E-01
37	64	6.715E+00
37	65	3.372E+00
38	59	8.079E-04
38	60	2.654E-03
38	61	2.577E-03
38	62	3.363E-02
38	63	1.480E-01
38	64	5.525E-01
39	58	1.072E-04
39	59	4.187E-03
39	60	8.959E-03

39	61	9.619E-03	53	86	3.040E-02
39	62	3.002E-02	53	87	7.496E-02
41	63	1.025E-03	53	88	3.546E-01
47	74	7.109E-04	54	87	1.723E-04
47	75	2.686E-01	54	88	2.292E-03
47	76	1.234E-02	55	86	9.727E-06
47	77	1.284E-03	55	87	3.710E-04
48	82	1.386E-01	55	88	6.308E-03
49	80	2.614E-03	55	89	2.196E-02
49	81	2.693E-02	55	90	1.669E-01
49	82	4.951E-02	55	91	3.066E-01
49	83	2.138E-01	55	92	8.406E-01
50	83	1.698E-04	55	93	1.243E+00
50	84	1.052E-01	56	88	2.170E-03
51	84	7.340E-02	56	91	4.657E-04
51	85	2.029E-01	56	92	8.664E-03
52	84	5.149E-04	57	90	6.754E-05
52	85	7.518E-03	57	91	7.296E-04
52	86	3.119E-02	57	92	9.242E-03
53	84	1.972E-03	57	93	2.177E-02
53	85	5.874E-03			

APPENDIX A-5

The following page contains decay constant data for the β^+ p mode.

Z	N	λ
12	8	2.189E-01
12	9	1.665E+00
14	10	4.711E-01
15	11	6.931E-01
15	12	1.600E-01
17	14	2.033E-02
18	15	1.551E+00
19	16	1.350E-02
19	17	1.013E-03
20	16	1.386E+00
20	17	3.010E+00
21	19	1.673E-02
22	19	8.664E+00
28	24	3.142E+00
30	27	1.126E+01
30	29	3.767E-03
32	29	1.386E+01
34	35	1.270E-05
36	37	1.746E-04
38	39	1.925E-04
47	49	1.873E-02
48	51	7.365E-05
53	57	1.105E-01
54	59	1.062E-02
55	59	8.512E-02
55	60	3.466E-04
56	65	4.621E-06
63	73	1.600E-04
64	77	8.488E-06
68	81	4.493E-03
69	80	1.540E-03
71	81	1.485E-01
80	99	3.815E-04
80	103	4.424E-05

APPENDIX A-6

The following pages contain the extrapolated decay constant values. These have been presented in the previous appendices, but are separately displayed here for convenience. When these constants are experimentally determined, the correct values from the experiments should be incorporated into the data files.

Z	N	λ
9	17	8.638E+00
9	18	4.102E+01
10	19	8.337E+01
10	20	1.232E+02
18	37	1.243E+02
18	38	1.871E+02
20	43	1.388E+02
20	44	1.830E+02
22	45	6.826E+01
22	46	9.271E+01
22	47	1.556E+02
22	48	2.760E+02
23	45	3.831E+01
23	46	5.771E+01
23	47	1.083E+02
23	48	2.095E+02
24	47	4.146E+01
24	48	6.656E+01
25	49	5.016E+01
25	50	7.523E+01
26	51	4.630E+01
26	52	5.493E+01
27	51	3.166E+01
27	52	4.060E+01
27	53	5.744E+01
28	55	9.137E+01
28	56	4.736E+01
29	55	6.367E+01
29	56	1.232E+02
29	57	2.052E+02
29	58	3.098E+02
30	57	6.116E+01
30	58	4.089E+01
30	59	6.069E+01
30	60	4.089E+01
30	61	6.237E+02
30	62	8.364E+02
31	59	6.783E+01
31	60	1.179E+02
31	61	1.868E+02
31	62	2.745E+02
31	63	3.809E+02
31	64	5.061E+02
32	59	4.698E+01
32	60	8.720E+01
32	61	1.430E+02
32	62	2.144E+02
32	63	3.014E+02

Z	N	λ
32	64	4.040E+02
33	62	2.715E+01
33	63	4.116E+01
33	64	7.839E+01
33	65	1.505E+02
33	66	2.690E+02
33	67	4.456E+02
33	68	6.918E+02
34	62	1.296E+01
34	63	2.217E+01
34	64	4.820E+01
34	65	9.947E+01
34	66	1.844E+02
34	67	3.113E+02
34	68	4.887E+02
34	69	7.250E+02
34	70	1.029E+03
35	65	4.677E+01
35	66	8.145E+01
35	67	1.279E+02
35	68	1.862E+02
35	69	2.563E+02
35	70	3.382E+02
36	67	2.656E+01
36	68	4.292E+01
36	69	6.483E+01
36	70	9.230E+01
36	71	1.253E+02
36	72	1.639E+02
36	73	2.080E+02
36	74	2.577E+02
37	71	5.432E+01
37	72	7.215E+01
37	73	9.426E+01
37	74	1.206E+02
37	75	1.513E+02
37	76	1.863E+02
38	71	2.256E+01
38	72	2.821E+01
38	73	3.474E+01
38	74	4.214E+01
38	75	5.041E+01
38	76	5.955E+01
38	77	6.957E+01
38	78	8.045E+01
39	71	1.563E+01
39	72	1.855E+01
39	73	3.188E+01

39	74	2.567E+01	44	84	4.922E+01
39	75	3.013E+01	44	85	6.982E+01
39	76	3.543E+01	44	86	9.666E+01
39	77	4.174E+01	45	81	1.427E+01
39	78	4.921E+01	45	82	1.842E+01
39	79	5.802E+01	45	83	2.314E+01
39	80	6.834E+01	45	84	2.840E+01
39	81	8.032E+01	45	85	3.423E+01
39	82	9.415E+01	45	86	4.060E+01
40	73	1.378E+01	45	87	4.754E+01
40	74	2.110E+01	45	88	5.502E+01
40	75	4.168E+01	45	89	6.307E+01
40	76	8.213E+01	45	90	7.166E+01
40	77	1.491E+02	46	81	5.319E+00
40	78	2.492E+02	46	82	7.516E+00
40	79	3.890E+02	46	83	1.018E+01
40	80	5.752E+02	46	84	1.332E+01
40	81	8.144E+02	46	85	1.693E+01
41	75	9.887E+00	46	86	2.100E+01
41	76	1.834E+01	46	87	2.555E+01
41	77	4.319E+01	46	88	3.056E+01
41	78	9.261E+01	46	89	3.605E+01
41	79	1.748E+02	46	90	4.200E+01
41	80	2.980E+02	46	91	4.843E+01
41	81	4.703E+02	46	92	5.532E+01
41	82	7.000E+02	47	84	4.492E+01
42	75	5.773E+00	47	85	7.890E+01
42	76	1.084E+01	47	86	1.236E+02
42	77	2.586E+01	47	87	1.790E+02
42	78	5.581E+01	47	88	2.452E+02
42	79	1.057E+02	47	89	3.220E+02
42	80	1.804E+02	47	90	4.096E+02
42	81	2.850E+02	47	91	5.079E+02
42	82	4.244E+02	47	92	6.170E+02
42	83	6.037E+02	48	87	8.718E+01
42	84	8.277E+02	48	88	7.311E+01
43	77	9.378E+00	48	89	2.943E+02
43	78	1.451E+01	48	90	4.507E+02
43	79	2.746E+01	48	91	6.423E+02
43	80	5.215E+01	48	92	8.691E+02
43	81	9.247E+01	48	93	1.131E+03
43	82	1.523E+02	48	94	1.428E+03
43	83	2.357E+02	48	95	1.761E+03
43	84	3.464E+02	49	89	3.788E+01
43	85	4.883E+02	49	90	7.322E+01
43	86	6.655E+02	49	91	1.253E+02
44	79	8.612E+00	49	92	1.940E+02
44	80	1.139E+01	49	93	2.795E+02
44	81	1.594E+01	49	94	3.816E+02
44	82	2.317E+01	50	89	1.441E+01
44	83	3.397E+01	50	90	2.564E+01

50	91	4.164E+01	57	103	2.347E+01
50	92	6.242E+01	57	104	3.101E+01
50	93	8.798E+01	57	105	3.966E+01
50	94	1.183E+02	57	106	4.942E+01
50	95	1.534E+02	58	99	3.995E+00
50	96	1.933E+02	58	100	7.477E+00
50	97	2.830E+02	58	101	1.224E+01
50	98	2.875E+02	58	102	1.829E+01
51	91	2.191E+01	58	103	2.562E+01
51	92	4.169E+01	58	104	3.423E+01
51	93	6.873E+01	58	105	4.412E+01
51	94	1.030E+02	58	106	6.530E+01
51	95	1.446E+02	58	107	6.775E+01
51	96	1.933E+02	59	102	7.157E+00
51	97	2.494E+02	59	103	1.141E+01
51	98	3.127E+02	59	104	1.679E+01
52	91	1.598E+01	59	105	2.332E+01
52	92	3.093E+01	59	106	3.098E+01
52	93	5.138E+01	59	107	3.979E+01
52	94	7.738E+01	59	108	4.973E+01
52	95	1.089E+02	60	102	1.222E+00
52	96	1.459E+02	60	103	2.345E+00
52	97	1.884E+02	60	104	5.540E+00
52	98	2.365E+02	60	105	1.185E+01
53	94	2.387E+00	60	106	2.230E+01
53	95	1.133E+01	60	107	3.793E+01
53	96	4.076E+01	60	108	5.978E+01
53	97	1.009E+02	61	105	3.197E+00
53	98	2.021E+02	61	106	5.626E+00
53	99	3.544E+02	61	107	8.893E+00
53	100	5.682E+02	61	108	1.300E+01
54	97	1.193E+01	61	109	1.794E+01
54	98	2.203E+01	62	105	1.884E+00
54	99	3.582E+01	62	106	3.572E+00
54	100	5.328E+01	62	107	5.869E+00
55	99	1.358E+01	62	108	8.774E+00
55	100	2.261E+01	62	109	1.229E+01
55	101	3.506E+01	62	110	1.641E+01
55	102	5.093E+01	62	111	2.115E+01
56	99	9.242E+00	62	112	2.649E+01
56	100	1.642E+01	63	108	6.060E-01
56	101	2.635E+01	63	109	1.786E+00
56	102	3.904E+01	63	110	5.642E+00
56	103	5.447E+01	63	111	1.351E+01
56	104	7.265E+01	63	112	2.673E+01
56	105	9.359E+01	63	113	4.663E+01
56	106	1.173E+02	64	107	1.701E+00
57	99	4.370E+00	64	108	3.341E+00
57	100	7.438E+00	64	109	5.580E+00
57	101	1.170E+01	64	110	8.440E+00
57	102	1.703E+01	64	111	1.190E+01

64	112	1.596E+01	69	123	2.178E+00
64	113	2.063E+01	70	118	2.060E-01
65	111	2.307E+00	70	119	3.260E-01
65	112	3.301E+00	70	120	4.960E-01
65	113	4.485E+00	70	121	7.170E-01
65	114	5.859E+00	70	122	9.880E-01
65	115	7.423E+00	71	119	2.110E-01
65	116	9.117E+00	71	120	3.090E-01
65	117	1.112E+01	71	121	5.210E-01
66	111	8.080E-01	71	122	9.060E-01
66	112	1.224E+00	71	123	1.521E+00
66	113	1.748E+00	71	124	2.423E+00
66	114	2.382E+00	71	125	3.670E+00
66	115	3.125E+00	71	126	5.319E+00
66	116	3.978E+00	72	121	4.280E-01
67	114	9.280E-01	72	122	7.720E-01
67	115	1.876E+00	72	123	1.233E+00
67	116	4.729E+00	72	124	1.812E+00
67	117	1.044E+01	72	125	2.508E+00
68	114	2.510E-01	73	122	1.660E-01
68	115	6.230E-01	73	123	2.220E-01
68	116	1.756E+00	73	124	3.400E-01
68	117	4.031E+00	73	125	5.510E-01
68	118	7.826E+00	74	121	8.300E-02
68	119	1.352E+01	74	122	1.490E-01
68	120	2.156E+01	74	123	2.360E-01
68	121	3.247E+01	75	126	3.690E-01
68	122	4.583E+01	75	127	6.770E-01
68	123	6.292E+01	75	128	1.106E+00
69	116	6.550E-01	76	123	9.000E-03
69	117	8.290E-01	76	124	1.400E-02
69	118	1.017E+00	76	125	2.500E-02
69	119	1.221E+00	76	126	4.400E-02
69	120	1.438E+00	76	127	7.300E-02
69	121	1.670E+00	77	125	3.460E-01
69	122	1.917E+00	77	126	1.017E+00

APPENDIX B

```
C      SPALLDKZ CODE
C
c2345678910
    REAL LAMBDA(94,156),LAMBDAE(94,156),
    *     LAMBDABN(94,156),LAMBDAP(94,156),LAMBDAAEA(94,156),
    *     DUMMY(95,157),ADELAY,BDEAY,BNDEAY,
    *     PDEAY,EAP,EAPALPH,EAPPROT,BEAMPD(94,156),
    *     AMT(95,157),TIMEINC,LAMDAP(94,156),W,RESIDUAL,
    *     NEWAMT,BEAM,AMPS,LAMDAE(94,156)

C
CHARACTER*80 INFO

C
C
INTEGER Z,N,I,J,K

C
C
C
OPEN(10,FILE='alpha2.dat',STATUS='OLD')
OPEN(11,FILE='beta2.dat',STATUS='OLD')
OPEN(12,FILE='epsilon2.dat',STATUS='OLD')
OPEN(13,FILE='betaneut.dat',STATUS='OLD')
OPEN(14,FILE='eprot.dat',STATUS='OLD')
c   OPEN(15,FILE='ealpha.dat',STATUS='OLD')
OPEN(16,FILE='proton.dat',STATUS='OLD')
OPEN(17,FILE='inputs.dat',STATUS='OLD')
OPEN(20,FILE='1E-01.out',STATUS='UNKNOWN')
OPEN(21,FILE='1E+00.out',STATUS='UNKNOWN')
OPEN(22,FILE='1E+01.out',STATUS='UNKNOWN')
OPEN(23,FILE='1E+02.out',STATUS='UNKNOWN')
OPEN(24,FILE='1E+03.out',STATUS='UNKNOWN')
OPEN(25,FILE='1E+04.out',STATUS='UNKNOWN')
OPEN(26,FILE='1E+05.out',STATUS='UNKNOWN')
OPEN(27,FILE='1E+06.out',STATUS='UNKNOWN')
OPEN(28,FILE='1E+07.out',STATUS='UNKNOWN')
OPEN(29,FILE='1E+08.out',STATUS='UNKNOWN')
OPEN(32,FILE='0E+00.out',STATUS='UNKNOWN')

C
C
WRITE(*,*)'ENTER INFO FOR OUTPUT (UP TO 80 CHRS)'
READ(*,*)INFO

C
WRITE(*,*)'WHAT IS THE AMPERAGE OF THE BEAM (MICRO-AMPS)?'
READ(*,*)AMPS

C
C
DO 10 Z=1,94
  DO 20 N=1,156
    AMT(Z,N)=0
    LAMBDA(Z,N)=0
    LAMBDAB(Z,N)=0
    LAMDAE(Z,N)=0
    LAMBDABN(Z,N)=0
    LAMDAEP(Z,N)=0
c    LAMDAEA(Z,N)=0
    LAMDAP(Z,N)=0
```

```

20      CONTINUE
10      CONTINUE
C23456789
25      READ(10,*,END=30) Z
        READ(10,*,END=30) N
        READ(10,*,END=30) LAMBDAA(Z,N)
        GOTO 25
30      CONTINUE
35      READ(11,*,END=40) Z
        READ(11,*,END=40) N
        READ(11,*,END=40) LAMBDA B(Z,N)
        GOTO 35
40      CONTINUE
45      READ(12,*,END=50) Z
        READ(12,*,END=50) N
        READ(12,*,END=50) LAMBDAE(Z,N)
        GOTO 45
50      CONTINUE
55      READ(13,*,END=60) Z,N,LAMBDA BN(Z,N)
        GOTO 55
60      CONTINUE
65      READ(14,*,END=70) Z,N,LAMBDAEP(Z,N)
        GOTO 65
70      CONTINUE
c 75      READ(15,*,END=80) Z,N,LAMBDAEA(Z,N)
c          GOTO 75
c 80      CONTINUE
85      READ(16,*,END=90) Z,N,LAMBDA P(Z,N)
        GOTO 85
90      CONTINUE
95      READ(17,*,END=99) Z,N,BEAMPROD(Z,N)
        GOTO 95
99      CONTINUE
C
C
C
        DO 140 J=1,95
            DO 150 K=1,157
                DUMMY(J,K)=0
150      CONTINUE
140      CONTINUE
C
C
C
C      BUILD UP: 2 WEEKS BEAMTIME ON TARGET!!
C
C
        DO 510 I=1,12
            TIME=100000
C          CALL BUILD(AMT,BEAMPROD,TIME,AMPS)
            CALL BUILD(AMT,DUMMY,TIME,LAMBDA A,LAMBDA B,LAMBDA E,LAMBDA BN,
                *      LAMBDAEP,LAMBDA P,BEAMPROD)
C234567
            CALL MERGE(AMT,DUMMY)
510      CONTINUE

```

```

C      DO 520 I=1,9
        TIME=1000
C      CALL BUILD(AMT, BEAMPROD, TIME, AMPS)
        CALL BUILD(AMT, DUMMY, TIME, LAMBDA A, LAMBDA B, LAMBDA E, LAMBDA BN,
*          LAMBDA EP, LAMBDA P, BEAMPROD)
        CALL MERGE(AMT, DUMMY)
520    CONTINUE
C      DO 530 I=1,59
        TIME=10
C      CALL BUILD(AMT, BEAMPROD, TIME, AMPS)
        CALL BUILD(AMT, DUMMY, TIME, LAMBDA A, LAMBDA B, LAMBDA E, LAMBDA BN,
*          LAMBDA EP, LAMBDA P, BEAMPROD)
        CALL MERGE(AMT, DUMMY)
530    CONTINUE
C      DO 540 I=1,9
        TIME=1
C      CALL BUILD(AMT, BEAMPROD, TIME, AMPS)
        CALL BUILD(AMT, DUMMY, TIME, LAMBDA A, LAMBDA B, LAMBDA E, LAMBDA BN,
*          LAMBDA EP, LAMBDA P, BEAMPROD)
        CALL MERGE(AMT, DUMMY)
540    CONTINUE
C      DO 550 I=1,9
        TIME=.1
C      CALL BUILD(AMT, BEAMPROD, TIME, AMPS)
        CALL BUILD(AMT, DUMMY, TIME, LAMBDA A, LAMBDA B, LAMBDA E, LAMBDA BN,
*          LAMBDA EP, LAMBDA P)
        CALL MERGE(AMT, DUMMY)
550    CONTINUE
C      DO 560 I=1,9
        TIME=.01
C      CALL BUILD(AMT, BEAMPROD, TIME, AMPS)
        CALL BUILD(AMT, DUMMY, TIME, LAMBDA A, LAMBDA B, LAMBDA E, LAMBDA BN,
*          LAMBDA EP, LAMBDA P, BEAMPROD)
        CALL MERGE(AMT, DUMMY)
560    CONTINUE
C      DO 570 I=1,10
        TIME=.001
C      CALL BUILD(AMT, BEAMPROD, TIME, AMPS)
        CALL BUILD(AMT, DUMMY, TIME, LAMBDA A, LAMBDA B, LAMBDA E, LAMBDA BN,
*          LAMBDA EP, LAMBDA P, BEAMPROD)
        CALL MERGE(AMT, DUMMY)
570    CONTINUE
C
C      I=15
        TIME=0
        CALL MAKEFILE(AMT, I, TIME, LAMBDA A, LAMBDA B, LAMBDA E,
*          LAMBDA BN, LAMBDA EP, LAMBDA P, INFO)
C

```

```

C      DECAY OF RESIDUAL NUCLIDES FOLLOWING 2 WEEK BEAM TIME
C      OUTPUT FILES GENERATED FOR TIMES OF .1 SEC, 1 SEC, 10 SEC,
100 SEC,
C      1000 SEC, 10000 SEC, 100000 SEC, 1000000 SEC, 10000000
SEC,
C      100000000 SEC
C
C
C

```

```

      TOTTIME=0
      TIME=.0001
      DO 600 I=1,12
        IF (I.GT.2) THEN
          STOP=8
        ELSE
          STOP=9
        ENDIF
        DO 610 J=1,STOP
          CALL DECAY(AMT,DUMMY,TIME,LAMBDAALAMBDAAB,LAMBDAE,
*          LAMBDAABN,LAMBDAEP,LAMBDAAP)
          CALL MERGE(AMT,DUMMY)
          TOTTIME=TOTTIME+TIME
610      CONTINUE
          IF (STOP.EQ.8) THEN
            TIME2=TIME*.1
            DO 650 K=1,I+2
              DO 660 L=1,9
                CALL DECAY(AMT,DUMMY,TIME2,LAMBDAALAMBDAAB,
*                LAMBDAE,LAMBDAABN,LAMBDAEP,LAMBDAAP)
                CALL MERGE(AMT,DUMMY)
                TOTTIME=TIME2+TOTTIME
660          CONTINUE
              TIME2=TIME2*.1
650          CONTINUE
            ENDIF
            CALL MAKEFILE(AMT,I,TIME,LAMBDAALAMBDAAB,LAMBDAE,
*            LAMBDAABN,LAMBDAEP,LAMBDAAP,INFO)
            WRITE(*,*) 'TOTAL TIME IS',TOTTIME
            TIME=TIME*10
600      CONTINUE
          STOP
        END

```

```

C
C
C
C

```

```

      SUBROUTINE BUILD(AMT,DUMMY,TIME,LAMBDAALAMBDAAB,LAMBDAE,
*      LAMBDAABN,LAMBDAEP,LAMBDAAP,BEAMPROD)
      REAL AMT(95,157),BEAMPROD(94,156),TIME,BEAM,
*      LAMBDAAL(94,156),LAMBDAAB(94,156),LAMBDAE(94,156),
*      LAMBDAABN(94,156),LAMBDAEP(94,156),LAMBDAAP(94,156),W,
*      DUMMY(95,157),ADEDAY,PDECAY,BDECAY,
*      ECAP,ECAPROT,BNDECAY,AMPS
      DOUBLE PRECISION NEWAMT,RESIDUAL
      INTEGER Z,N
      DO 200 Z=1,95

```

```

DO 300 N=1,157
C
  IF (BEAMPROD(Z,N).EQ.0.AND.AMT(Z,N).EQ.0) THEN
    GOTO 300
  ENDIF
C
  W=LAMBDAB(Z,N)+LAMBDA(Z,N)+LAMBDA(BN(Z,N)
  *    +LAMBDAE(Z,N)+LAMBDAEP(Z,N)+LAMBDA(P(Z,N)
C
    BEAM=BEAMPROD(Z,N)*TIME
  IF (W.EQ.0) THEN
    NEWAMT=AMT(Z,N)+BEAM
    AMT(Z,N)=NEWAMT
    GOTO 300
  ENDIF
C
  NEWAMT=(BEAMPROD(Z,N)/W)*(1-EXP(-1*W*TIME))
  *    +AMT(Z,N)*EXP(-1*W*TIME)
  RESIDUAL=(BEAMPROD(Z,N)*TIME)+AMT(Z,N)-NEWAMT
  AMT(Z,N)=NEWAMT
  IF (AMT(Z,N).LT.0) THEN
    AMT(Z,N)=0
  ENDIF
C
  BDECAY=RESIDUAL*(LAMBDAB(Z,N)/W)
  DUMMY(Z+1,N-1)=DUMMY(Z+1,N-1)+BDECAY
C
  ADECAY=RESIDUAL*(LAMBDA(Z,N)/W)
  DUMMY(Z-2,N-2)=DUMMY(Z-2,N-2)+ADECAY
C
  BNDECAY=RESIDUAL*(LAMBDA(BN(Z,N)/W)
  DUMMY(Z+1,N-2)=DUMMY(Z+1,N-2)+BNDECAY
C
  ECAP=RESIDUAL*(LAMBDAE(Z,N)/W)
  DUMMY(Z-1,N+1)=DUMMY(Z-1,N+1)+ECAP
C
  ECAPROT=RESIDUAL*(LAMBDAEP(Z,N)/W)
  DUMMY(Z-2,N+1)=DUMMY(Z-2,N+1)+ECAPROT
C
  PDECAY=RESIDUAL*(LAMBDA(P(Z,N)/W)
  DUMMY(Z-1,N)=DUMMY(Z-1,N)+PDECAY
C
  300 CONTINUE
  200 CONTINUE
  RETURN
  END
C
C
C
C
  SUBROUTINE DECAY(AMT,DUMMY,TIME,LAMBDA(LAMBDA(BN,LAMBDAE,
  *    LAMBDA(BN,LAMBDAEP,LAMBDA(P)
  REAL LAMBDA(LAMBDA(BN,LAMBDAE(LAMBDAEP,LAMBDA(P)
  *    LAMBDA(BN(LAMBDAEP,LAMBDA(P)
  *    AMT(95,157),DUMMY(95,157),TIME,LAMBDAE(94,156),ECAP,

```

```

      *      ECAPPROT,ADECAY,BDECAY,BNDECAY,PDECAY,W
      INTEGER Z,N
      DOUBLE PRECISION RESIDUAL, NEWAMT

C
C
      DO 20 Z=1,95
      DO 30 N=1,157
      IF (AMT(Z,N).LE.0) THEN
      GOTO 30
      ENDIF

C
      W=LAMBDA B(Z,N)+LAMBDA A(Z,N)+LAMBDA B N(Z,N)
      *      +LAMBDA E(Z,N)+LAMBDA A E P(Z,N)+LAMBDA P(Z,N)
      IF (W.EQ.(0.0)) THEN
      GOTO 30
      ENDIF

C
C
      NEWAMT=AMT(Z,N)*EXP(-1*W*TIME)
      RESIDUAL=AMT(Z,N)*(1-EXP(-1*W*TIME))
      AMT(Z,N)=NEWAMT
      IF (AMT(Z,N).LT.0) THEN
      AMT(Z,N)=0
      ENDIF

C
C
      BDECAY=RESIDUAL*(LAMBDA B(Z,N)/W)
      DUMMY(Z+1,N-1)=DUMMY(Z+1,N-1)+BDECAY

C
      ADECAY=RESIDUAL*(LAMBDA A(Z,N)/W)
      DUMMY(Z-2,N-2)=DUMMY(Z-2,N-2)+ADECAY

C
      BNDECAY=RESIDUAL*(LAMBDA B N(Z,N)/W)
      DUMMY(Z+1,N-2)=DUMMY(Z+1,N-2)+BNDECAY

C
      ECAP=RESIDUAL*(LAMBDA E(Z,N)/W)
      DUMMY(Z-1,N+1)=DUMMY(Z-1,N+1)+ECAP

C
C
      ECAPALPH=RESIDUAL*(LAMBDA E A(Z,N)/W)
      DUMMY(Z-3,N-1)=DUMMY(Z-3,N-1)+ECAPALPH

C
      ECAPPROT=RESIDUAL*(LAMBDA E A P(Z,N)/W)
      DUMMY(Z-2,N+1)=DUMMY(Z-2,N+1)+ECAPPROT

C
      PDECAY=RESIDUAL*(LAMBDA P(Z,N)/W)
      DUMMY(Z-1,N)=DUMMY(Z-1,N)+PDECAY

C23456789
C
C
C
      30      CONTINUE
      20      CONTINUE
      RETURN
      END

C

```

C
C
C

```

SUBROUTINE MERGE (AMT, DUMMY)
REAL CAT, AMT (95, 157), DUMMY (95, 157)
INTEGER Z, N
DO 400 Z=1, 95
    DO 500 N=1, 157

```

C

```

    CAT=AMT (Z, N)
    AMT (Z, N)=AMT (Z, N)+DUMMY (Z, N)
    DUMMY (Z, N)=0

```

C

```

500        CONTINUE
400        CONTINUE
            RETURN
            END

```

C23456789

C
C

```

SUBROUTINE MAKEFILE (AMT, K, TIME, LAMBDA A, LAMBDA B, LAMBDA E,
*                   LAMBDA BN, LAMBDA EP, LAMBDA P, INFO)
REAL AMT (95, 157), TIME, LAMBDA A (94, 156),
*   LAMBDA E (94, 156), LAMBDA BN (94, 156), LAMBDA EP (94, 156),
*   LAMBDA P (94, 156), W, ACTIVITY, TOTATV TY, LAMBDA B (94, 156),
*   ACT2, TOT2, THALF
INTEGER Z, N
CHARACTER*80 INFO
CHARACTER*6 STBL
CHARACTER*1 L1, L2, L3
CHARACTER*10 L4, L6
CHARACTER*11 L7
CHARACTER*17 L5
L1='Z'
L2='N'
L3='A'
L4='# OF ATOMS'
L5='ACTIVITY (CURIES)'
L6='ACTIVITY 2'
L7='T 1/2 (SEC)'

```

C

```

    STBL='STABLE'
IF (K.GE.3) THEN
WRITE (17+K, *) INFO
WRITE (17+K, *) TIME*10, 'SECONDS DECAY FOLLOWING 2 WEEK BEAMTIME'
WRITE (17+K, *)
WRITE (17+K, *)
WRITE (17+K, 11) L1, L2, L3, L4, L5, L6, L7
11  FORMAT (1X, A, 5X, A, 5X, A, 5X, A, 3X, A, 3X, A, 5X, A)
    TOTATV TY=0
    TOT2=0
    DO 600 Z=1, 95
        DO 700 N=1, 157
            IF (AMT (Z, N).NE.0.0) THEN
                W=LAMBDA A (Z, N)+LAMBDA B (Z, N)+LAMBDA E (Z, N)+LAMBDA BN (Z, N)+

```

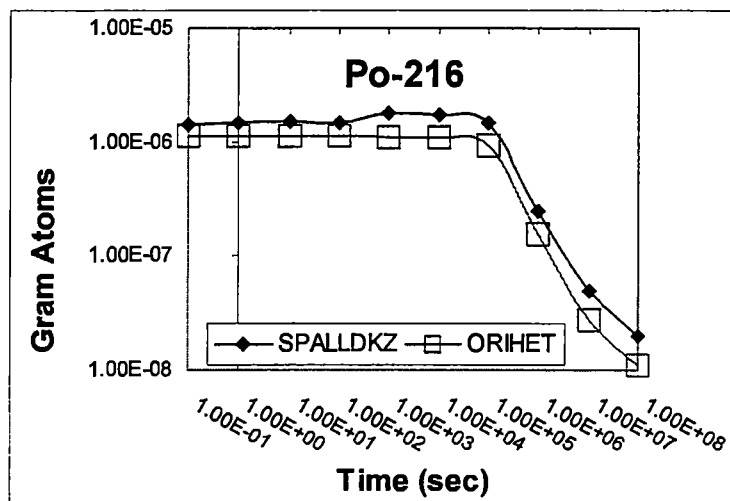
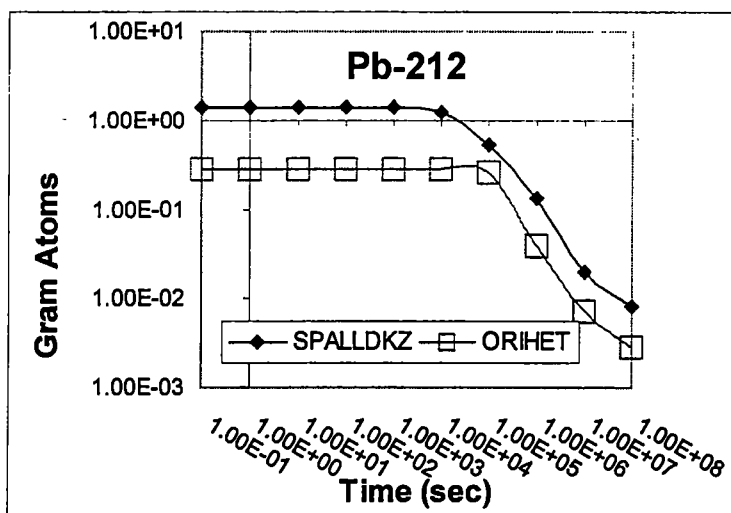
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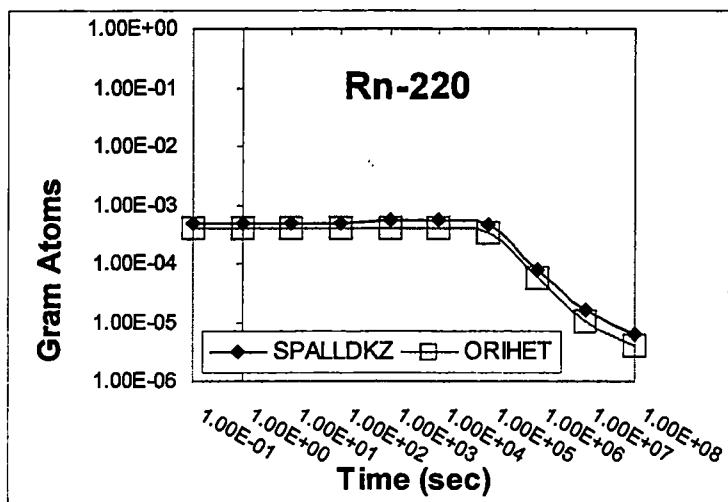
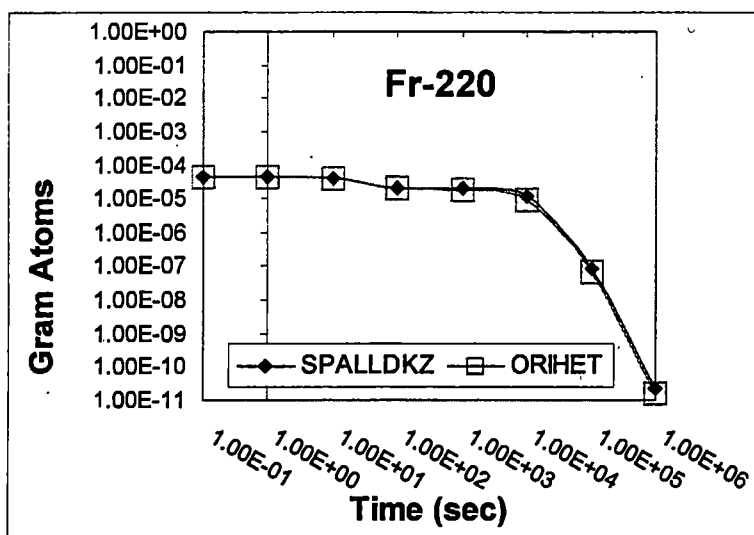
      *          LAMBDAEP(Z,N)+LAMBDAEP(Z,N)
C      WRITE(*,*)Z,N,W
      IF (W.EQ.0.0) THEN
21      WRITE(17+K,21)Z,N,Z+N,AMT(Z,N),STBL
      FORMAT(I2,3X,I3,3X,I3,5X,1PD10.4,7X,A)
C      WRITE(17+K,*)Z,N,AMT(Z,N)
      ELSE
      ACTIVITY=AMT(Z,N)*W/3.7E+10
      TOTATVTY=TOTATVTY+ACTIVITY
      ACT2=(AMT(Z,N)*(1-EXP(-1*W)))/3.7E+10
      TOT2=TOT2+ACT2
      THALF=.693/W
      WRITE(17+K,31)Z,N,Z+N,AMT(Z,N),ACTIVITY,
      *          ACT2,THALF
31      FORMAT(I2,3X,I3,3X,I3,5X,1PD10.4,5X,1PD10.4,
      *          5X,1PD10.4,5X,1PD10.4)
C      WRITE(17+K,*)Z,N,AMT(Z,N)
      ENDIF
      ENDIF
700      CONTINUE
600      CONTINUE
      WRITE(17+K,*)
      WRITE(17+K,*)'TOTAL ACTIVITY  =',TOTATVTY,'  CURIES'
      WRITE(17+K,*)'TOTAL ACTIVITY2 =',TOT2,'  CURIES'
      ENDIF
      RETURN
      END

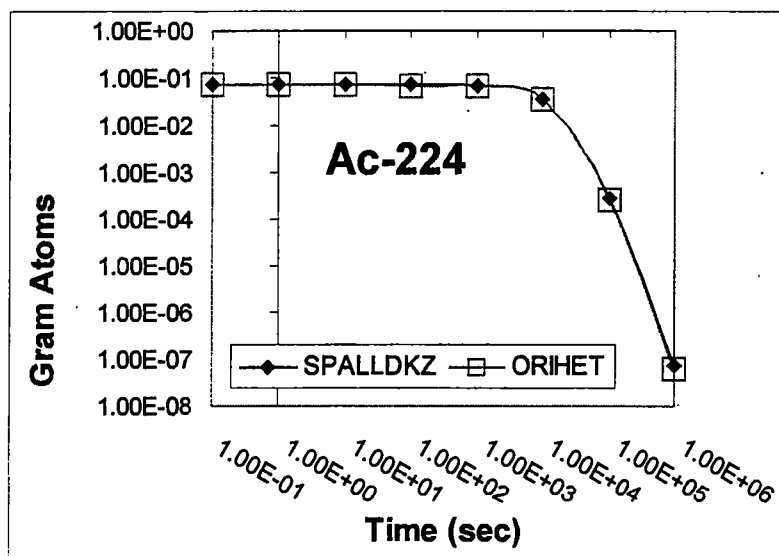
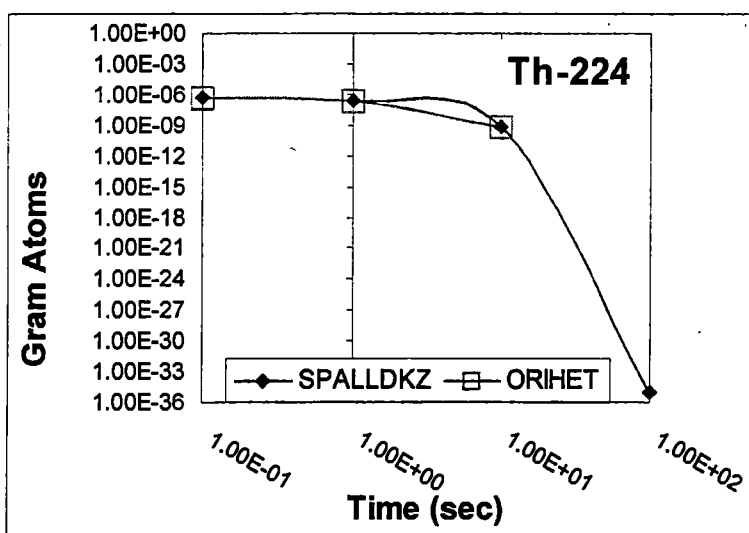
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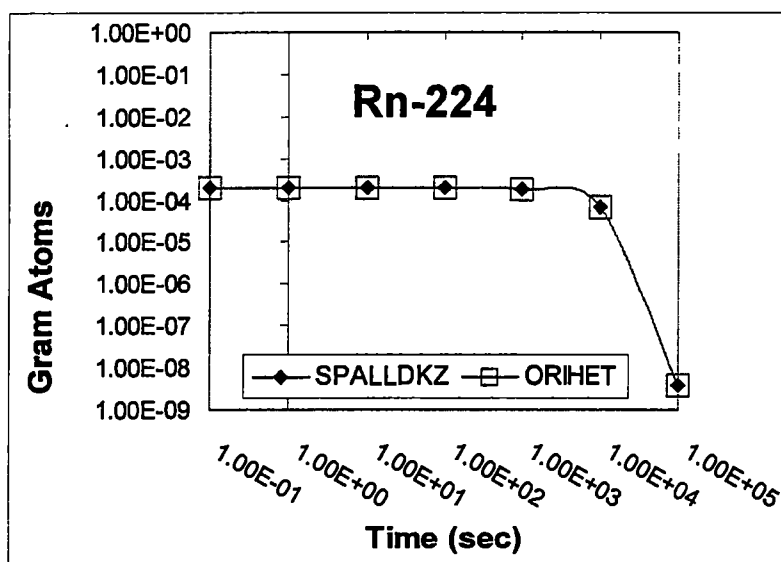
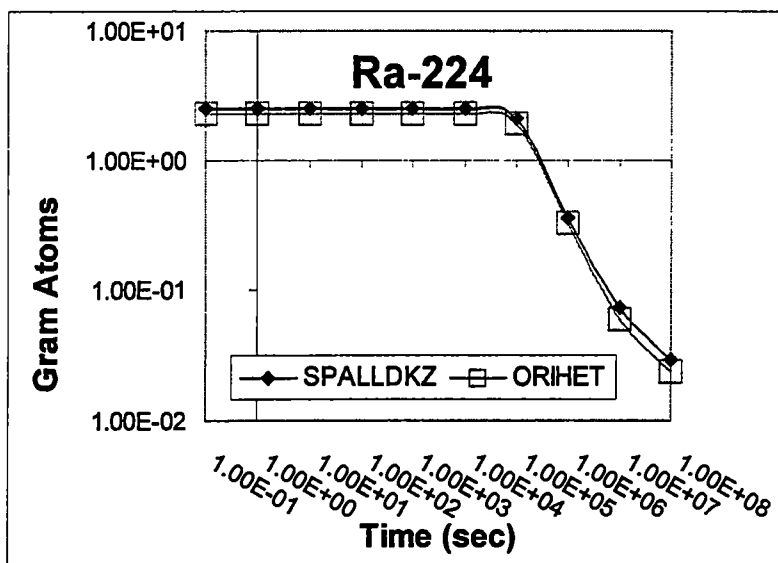
APPENDIX C

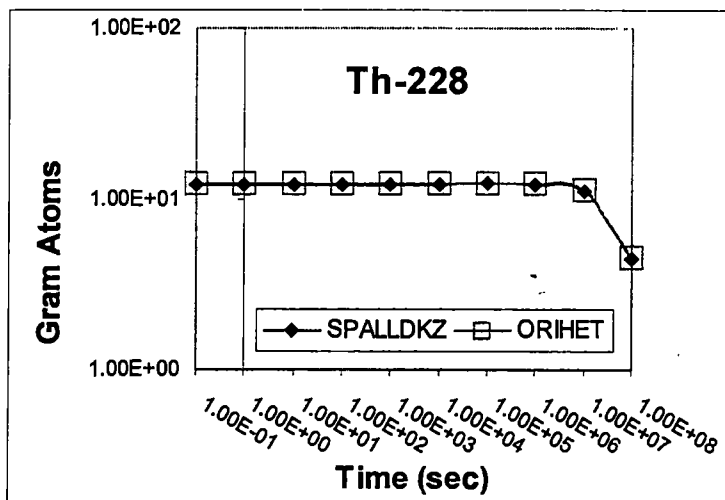
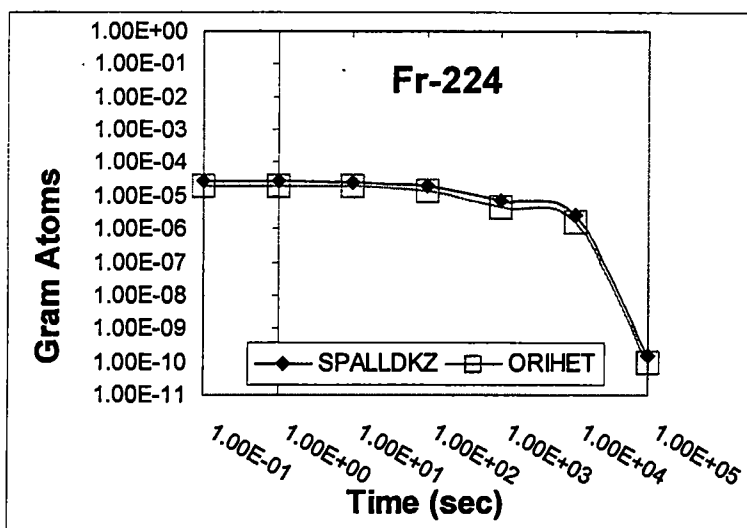
The following pages contain plots of decay chain members that are a part of the Uranium calculation but were not discussed in Chapter IV. The nuclides with even A belong to the decay chain containing Pb-208. The odd A nuclides belong to the chain containing Pb-207. They are included here for completeness.

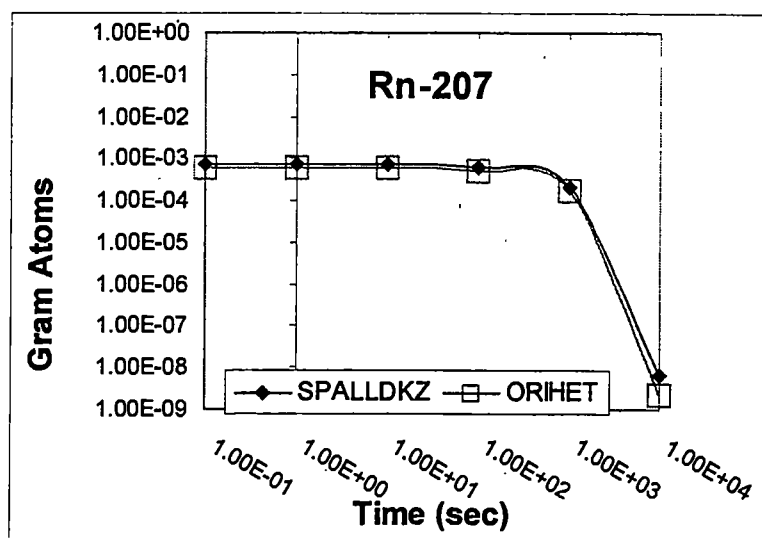
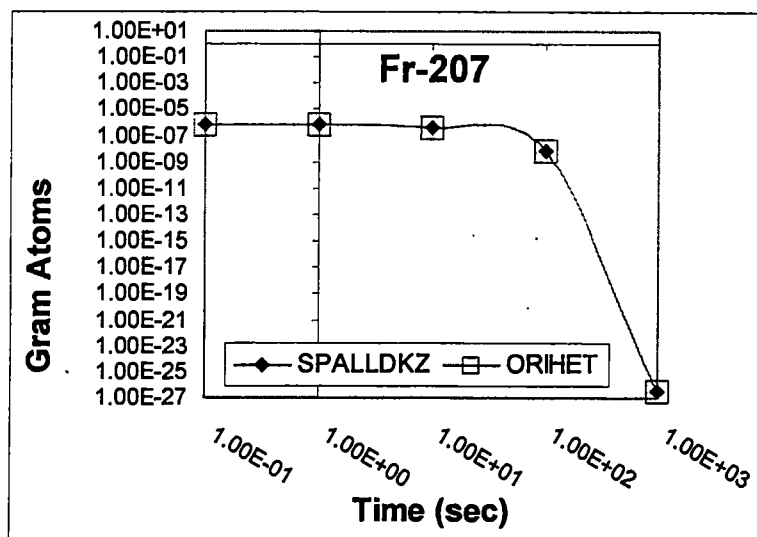


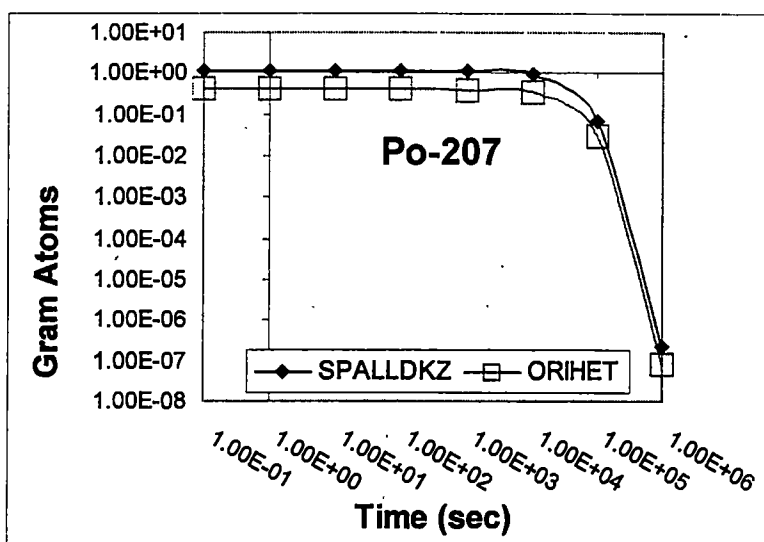
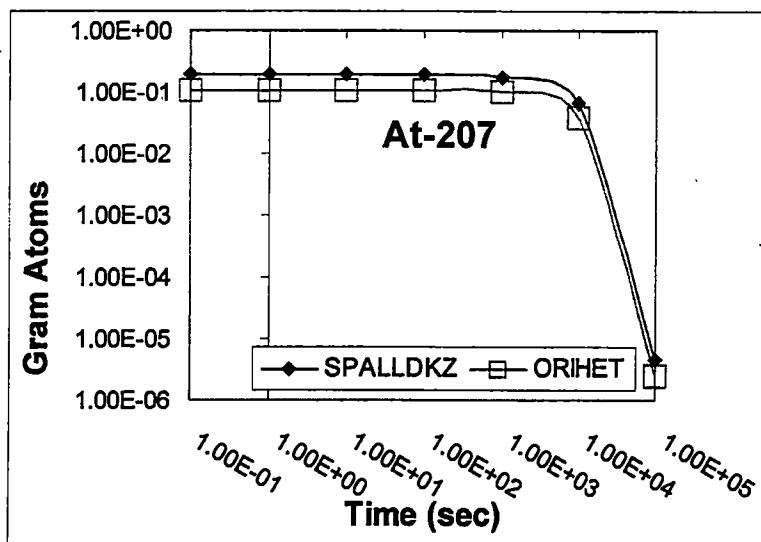


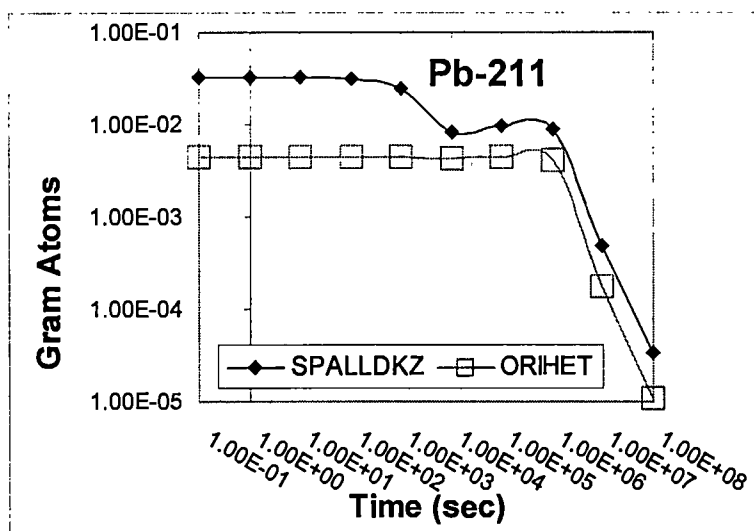
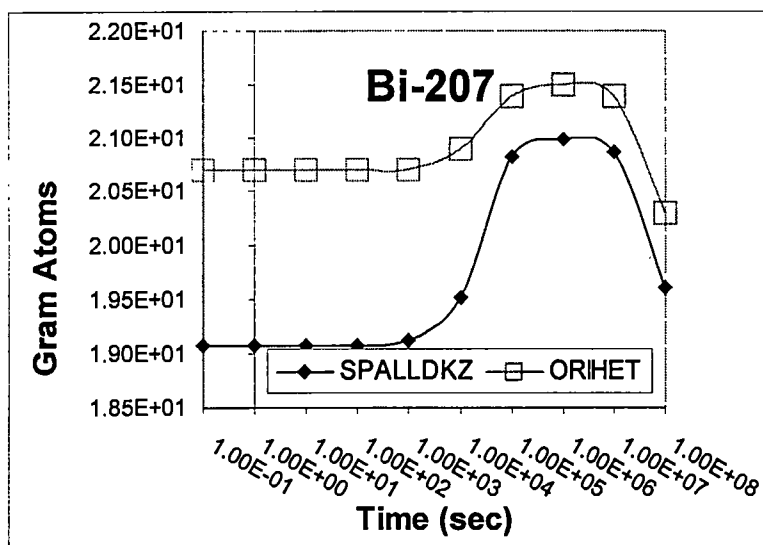


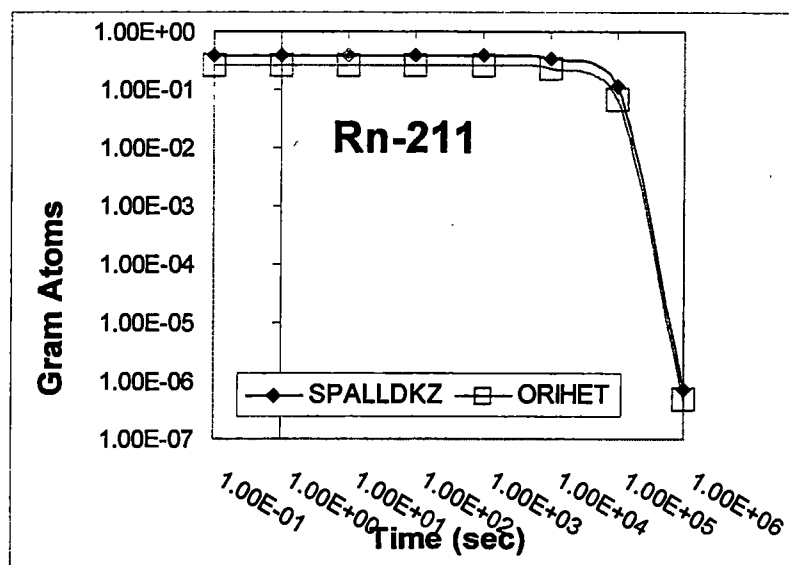
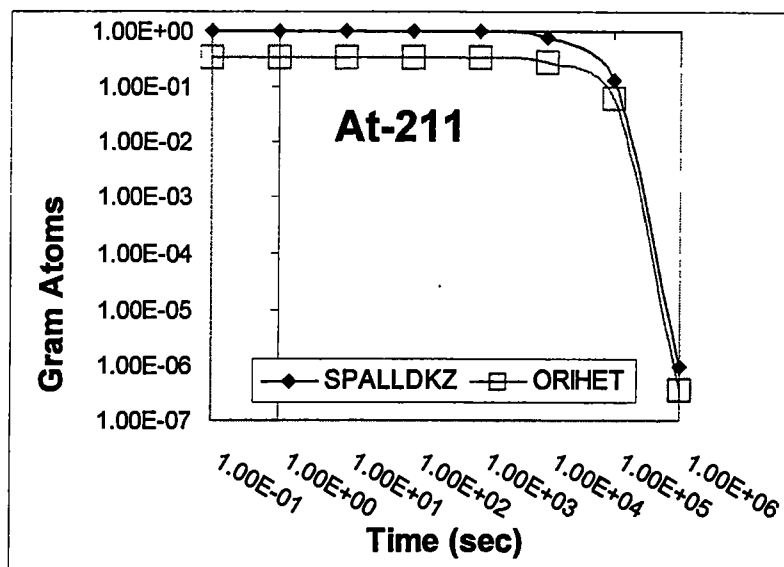


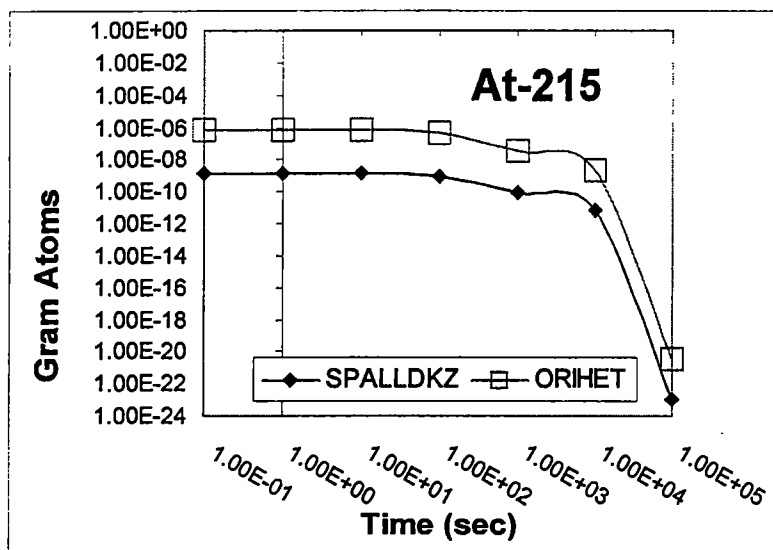
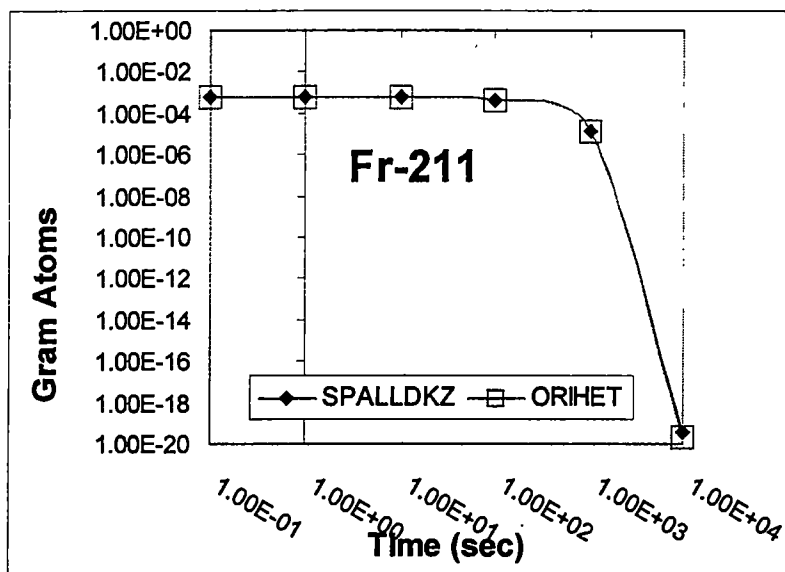


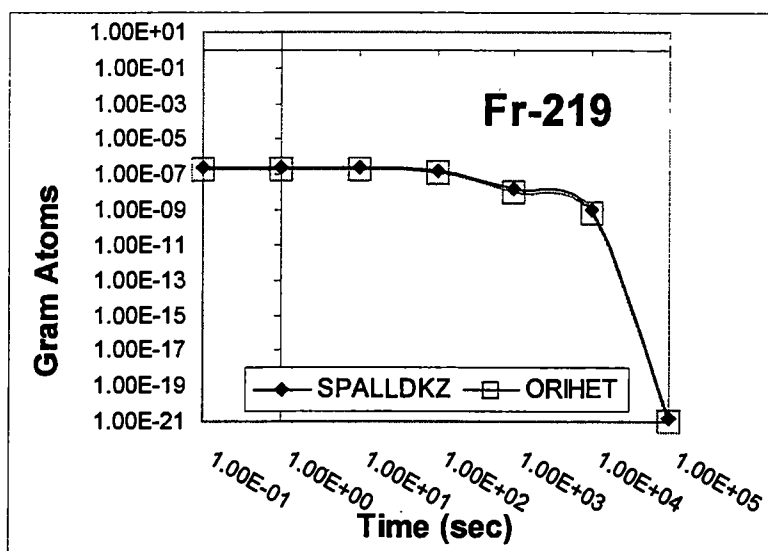
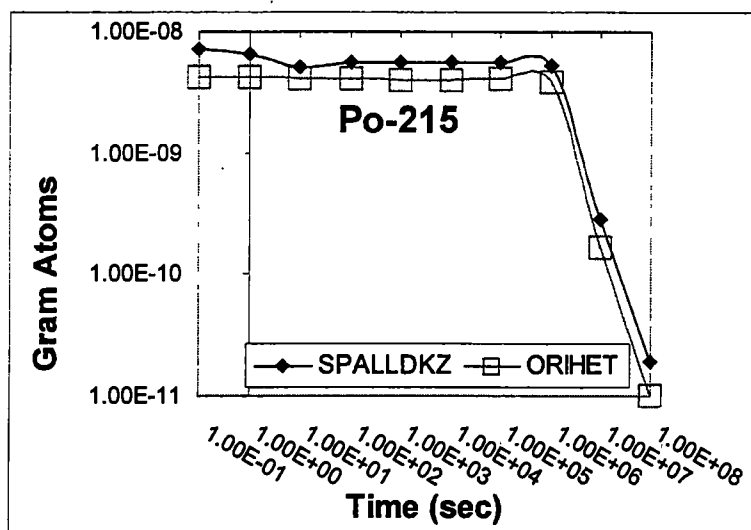


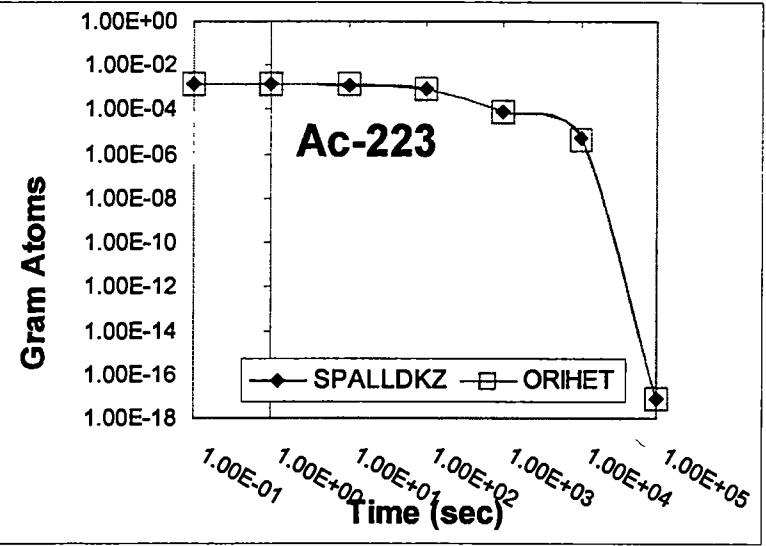
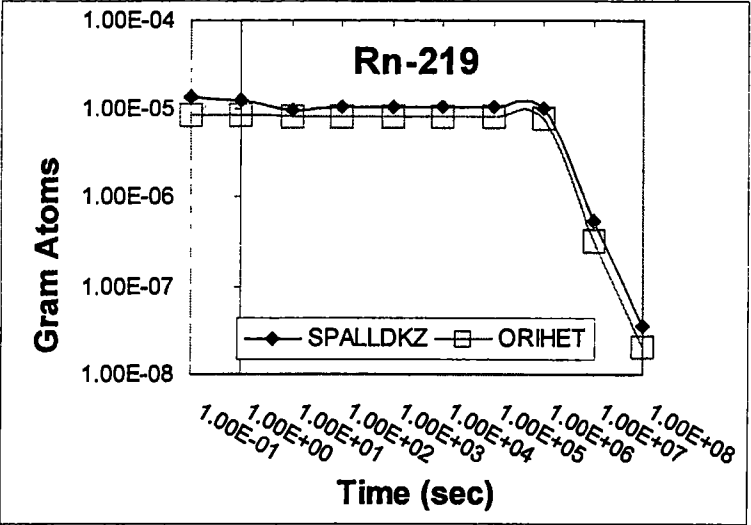


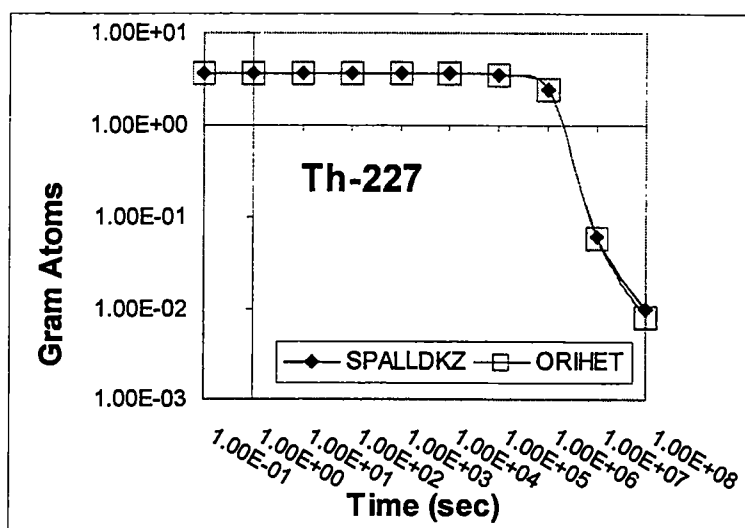
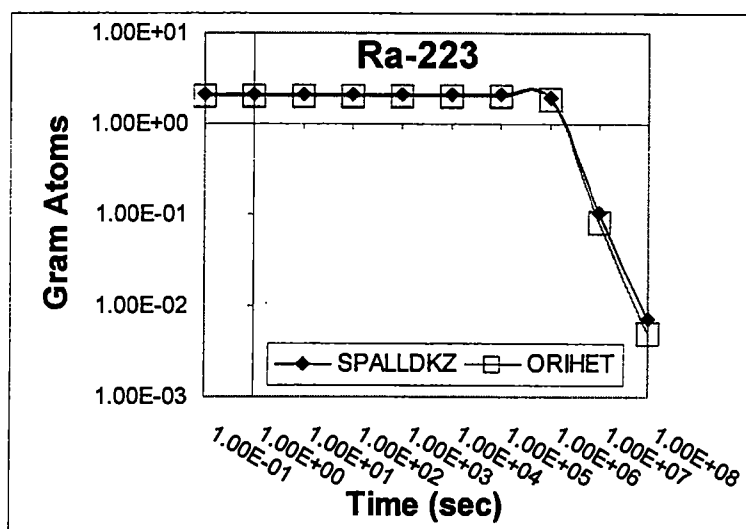


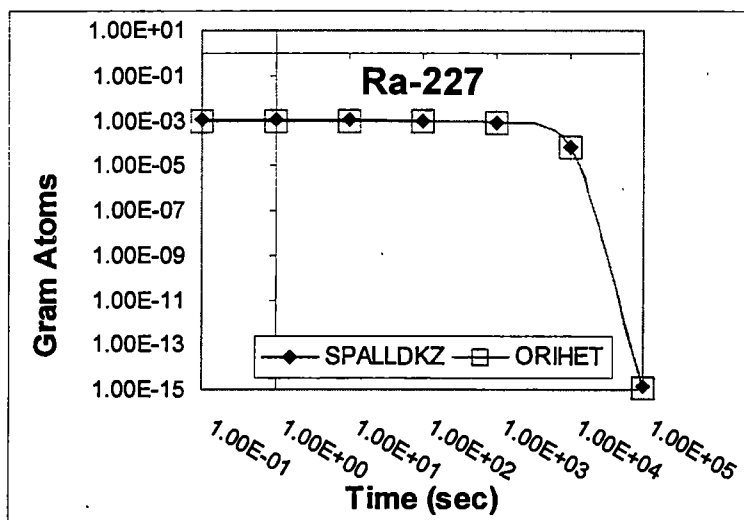
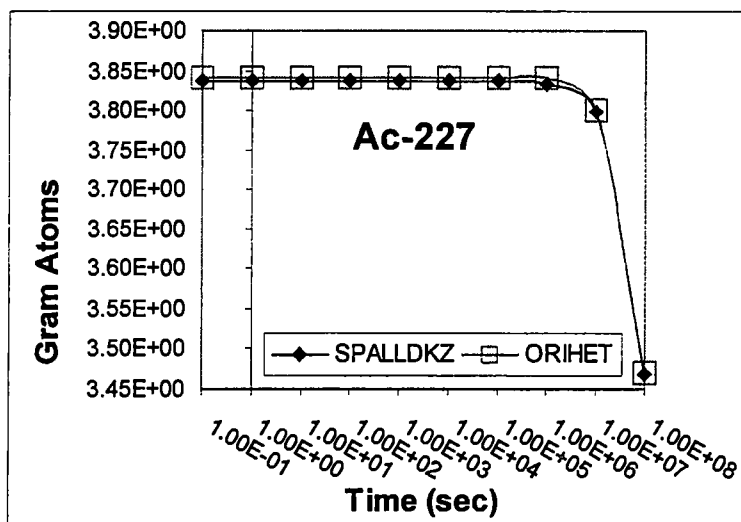


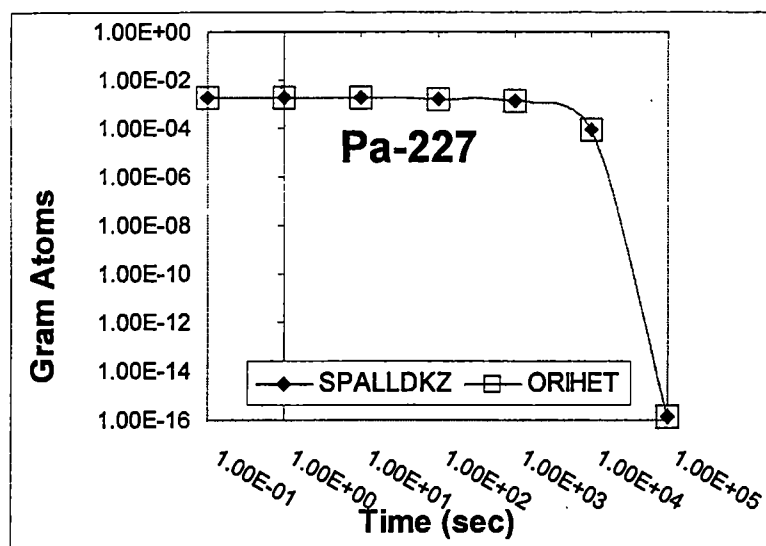
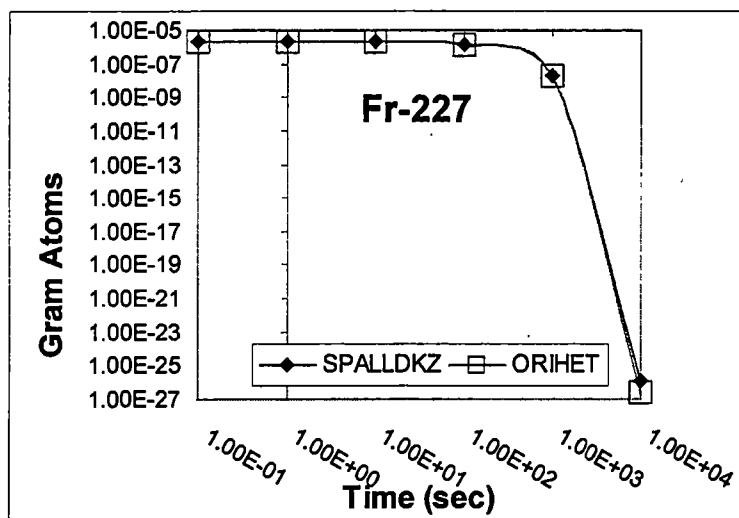












APPENDIX D

The following pages contain excerpts from a typical output file from SPALLDKZ. The file is the 0E+00.out file from the Uranium calculations discussed in Chapter V.

1 GeV protons on 14cm U-238 target of natural density.

0.0000000E+00SECONDS DECAY FOLLOWING 2 WEEK BEAMTIME

Z	N	A	# OF ATOMS	ACTIVITY (CURIES)	ACTIVITY 2	T 1/2 (SEC)
5	10	15	1.8916D+06	3.3742D-03	5.1124D-05	1.0500D-02
6	9	15	5.4019D+08	4.1317D-03	3.5985D-03	2.4488D+00
7	8	15	1.5101D+14	STABLE		
8	8	16	1.5101D+14	STABLE		
9	10	19	1.5101D+14	STABLE		
9	15	24	1.2248D+07	6.7483D-03	3.3102D-04	3.3993D-02
9	16	25	2.1253D+07	3.3742D-03	5.7280D-04	1.1797D-01
10	14	24	1.4688D+11	1.3568D-02	1.3545D-02	2.0276D+02
10	15	25	1.0843D+08	3.3742D-03	2.0039D-03	6.0187D-01
10	16	26	8.2851D+07	6.7483D-03	2.1293D-03	2.2995D-01
11	13	24	8.2560D+13	2.8720D-02	2.8728D-02	5.3841D+04
11	14	25	1.1317D+10	3.5872D-03	3.5662D-03	5.9087D+01
11	15	26	4.6692D+08	8.1596D-03	6.0090D-03	1.0718D+00
12	12	24	3.7033D+14	STABLE		
12	13	25	1.5100D+14	STABLE		
12	14	26	3.0202D+14	STABLE		
12	22	34	7.2045D+06	6.7483D-03	1.9472D-04	1.9996D-02
13	18	31	1.1599D+08	3.3742D-03	2.0664D-03	6.4386D-01
13	19	32	6.3039D+06	3.3742D-03	1.7038D-04	3.4993D-02
13	21	34	2.2640D+07	8.4827D-03	6.1190D-04	4.9989D-02
14	14	28	1.5101D+14	STABLE		
14	16	30	3.0202D+14	STABLE		
14	17	31	7.0587D+12	1.4020D-02	1.4021D-02	9.4300D+03
14	18	32	1.5100D+14	5.2565D-07	0.0000D+00	5.3804D+09
14	19	33	1.0309D+09	3.1148D-03	2.9470D-03	6.1987D+00
14	20	34	1.2216D+09	8.1731D-03	7.2400D-03	2.7994D+00
14	22	36	9.0056D+07	3.3742D-03	1.8255D-03	4.9990D-01
14	24	38	4.6469D+07	3.3742D-03	1.1704D-03	2.5794D-01
.	.	.	.	.	.	.
40	45	85	8.4941D+10	3.3742D-03	3.3717D-03	4.7150D+02
40	46	86	7.4891D+13	2.3619D-02	2.3646D-02	5.9388D+04
40	47	87	2.6179D+13	8.1091D-02	8.1099D-02	6.0467D+03
40	48	88	7.2709D+15	1.8903D-02	2.3426D-02	7.2042D+06
40	49	89	3.6373D+15	2.4139D-01	2.4023D-01	2.8222D+05
40	50	90	2.7153D+16	STABLE		
40	51	91	1.5202D+16	STABLE		
40	52	92	8.7132D+16	STABLE		
40	53	93	6.2778D+16	STABLE		
40	54	94	8.9187D+16	STABLE		
40	55	95	7.2209D+16	2.4456D-01	2.3265D-01	5.5302D+06
40	56	96	7.8205D+16	STABLE		
40	57	97	7.8278D+15	2.4103D+00	2.4085D+00	6.0827D+04
40	58	98	2.2376D+12	1.3654D+00	1.3501D+00	3.0693D+01
40	59	99	1.2924D+11	1.1529D+00	9.8197D-01	2.0996D+00
40	60	100	4.4959D+11	1.1863D+00	1.1302D+00	7.0985D+00
40	61	101	9.4455D+10	8.4261D-01	7.1767D-01	2.0996D+00
40	62	102	1.0318D+11	6.6650D-01	5.9283D-01	2.8994D+00
40	63	103	3.3284D+10	4.7965D-01	3.7177D-01	1.2997D+00
40	64	104	2.3577D+10	3.6808D-01	2.7960D-01	1.1997D+00
40	65	105	1.6659D+10	3.1209D-01	2.2512D-01	9.9979D-01
40	66	106	4.4700D+09	2.5299D-01	1.0593D-01	3.3093D-01
40	67	107	1.7791D+09	1.6748D-01	4.6606D-02	1.9896D-01
40	68	108	1.1887D+09	1.5149D-01	3.1839D-02	1.4697D-01
40	69	109	5.3464D+08	9.0232D-02	1.4422D-02	1.1098D-01
40	70	110	3.2347D+08	7.1292D-02	8.7400D-03	8.4982D-02
40	71	111	1.8966D+08	6.3447D-02	5.1260D-03	5.5988D-02
40	72	112	1.0087D+08	3.2927D-02	2.7262D-03	5.7376D-02
40	73	113	3.8570D+07	1.4363D-02	1.0424D-03	5.0294D-02
40	74	114	5.9157D+06	3.3742D-03	1.5988D-04	3.2837D-02
40	75	115	6.5916D+06	7.4253D-03	1.7815D-04	1.6627D-02
40	79	119	3.2095D+05	3.3742D-03	8.6744D-06	1.7816D-03

VITA

Roger A. Gard was born in Minot, North Dakota on September 25, 1973. After attending a plethora of schools, he graduated from Franklin High School; Franklin, Ohio in June 1991. He then entered Carson-Newman College in the fall of 1991 and graduated in December, 1995 with a Bachelor of Arts degree in Physics and Mathematics. In the fall of 1996, he entered the Master of Science degree program in Nuclear Engineering with Radiological Safety emphasis at The University of Tennessee. During that time, he worked for the Physics Division of the Oak Ridge National Laboratory as a graduate research assistant. He received a Master of Science Degree in August, 1999.