AN ABSTRACT OF THE THESIS OF

Todd Koelsch for the degree of Master of Science in Physical Sciences presented on Friday, March 11, 2016.

Title: <u>Uranium-235 Fission: Energy and Daughter Pair Products</u>

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Abstract

Nuclear energy production uses the nature of a fissionable isotope to produce thermal energy. Uranium-235 is the most prevalent fuel used for nuclear energy and is used in 99 U.S. facilities and over 300 more operating around the world. When uranium-235 is struck by a free neutron there is a probability that the nucleus will split into two daughter nuclei, multiple excess neutrons and approximately 200 MeV of energy. These neutrons, liberated from the nucleus, are free to induce the fission of other uranium-235 nuclei so that a continued chain reaction of fission events occurs. Sizes of the two large pieces follow a distinct bimodal distribution but are completely random within that distribution. The energy released by fission varies for each individual unique pair of daughter nuclei. This thesis explores the links between unique daughter pairs, number of liberated neutrons, and the energy associated with each. A detailed explanation of a fission event is presented to support tables of fission energy.

Key Words: Fission, Liberated Neutron, Daughter Nuclei

A Thesis

Presented To

The Department of Physical Sciences

Emporia State University

In Partial Fulfilment

of the Requirements for the Degree

Master of Science

By

Todd William Koelsch

May 2016

Approved by the Department Chair

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Dean of the Graduate School and Distance Education

Acknowledgements

I would like to express my appreciation to my advisor and thesis committee chair, Dr. Jorge Ballester for his insight and leadership. I began my undergraduate career at Emporia State University in 2009 as an art student who was lost and overwhelmed. After two semesters of searching, I found my home in physics. Dr. B was there through it all to encourage me in my trials, failures, and ultimately, my academic achievements. His open door policy and flexible schedule was instrumental to the completion of this thesis. Thanks to Dr. B, without his guidance and friendship, I would not have made it this far.

I would also like to thank my committee members. Dr. Chris Pettit, who taught most of my introductory physics classes, was always willing to help. His ability to ask "why did you do this" or "what are you actually looking for", and then sit patiently while I fumbled through words until I realized my problem, is phenomenal. Secondly, Dr. Robert Jones, whose input into my thesis was very supportive and constructive. Although I only had one class with him, I am grateful for his introduction to scientific analytical writing. My third committee member, Dr. Eric Trump, was the first person I went to when I began researching fission. His insight into calculating fission energy was the beginning of the tabulation of over 800 individual fission event energies. Dr. Christine Morales might have been my scariest committee member. She taught me Physical Chemistry 1 and 2, which I can say were challenging. Her attention to detail and passion for thorough scientific explanation were invaluable to the success of this thesis.

Additionally I would like to thank the Department of Physical Sciences. The Graduate Teaching Assistantship awarded by the department gave me the financial means to continue my education. I want to thank Ginger Tabares for always being in the office to help with whatever I needed. Without Ginger to keep track of things, I would have lost my mind. Thank you to Dr. Kenneth Thompson, who's TA class emphasized the importance of beginning research early and pushed me to submit my proposal. I am appreciative of Dr. Alivia Allison for her enthusiastic support of my interest in uranium soil research, although it never… panned out. She also unknowingly supplied many of the sources for this thesis. I must say thank you to Mr. Scott Capes. In addition to a daily checkup on my thesis progress, he was also my high school physics teacher. I think he gave me a B. His positive vibe and love for science was and still is, contagious. Thank you to Dr. DeWayne Backhus, who was my space science teacher in my second semester of college. He was the teacher that told me I should major in physics and gave me the confidence to give it a try.

Lastly I would like to thank my family and friends. Thank you to my parents, who raised me to work hard and supported me throughout college. My brother Tyler, who was the first person to explain to me what nuclear power was and started my obsession with fission. Finally I want to say thank you to my friends and fraternity who all supported me. I will always be grateful for Doc, Roy and Courtney for buying me a cold beer to relax after defending this thesis.

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Uranium-235 Fission: Energy and Daughter Pair Products

Chapter 1

Introduction to Fission

Fission is the atomic process that provides the ability to produce nuclear energy. The topic itself is unfortunately as controversial as it is misunderstood. This thesis explores the process of nuclear fission, the multiple possible unique fission products and the associated energy. This discussion will cover the important details of fission, elaborate on the findings of literature research, and provide mathematical support. General discussions of nuclear terminology, nuclear energy, and fission processes may be found in references 1, 2, and 3.

Fission is an event in which the nucleus of an atom breaks into smaller nuclei. Isotopes that are *fissionable*, meaning they are capable of fission, are among the largest existing nuclei. Fission events most commonly result from a neutron impacting a fissionable nucleus, causing it to become unstable and deform. The deformed nucleus then fissions into two smaller nuclei and a few neutrons that have a tremendous amount of kinetic energy. Figure 1 is a simple diagram of the fission process. Uranium-235 is a rare fissionable isotope that is the main focus of this thesis.

From an economic perspective the crucial components of fission are the energy and the liberated neutrons. The liberated neutrons allow for a *chain reaction* in which the fission of one nucleus results in the subsequent fission of another. When exactly one liberated neutron per fission event causes a new fission event, the system has reached *criticality*. Given the large and violent release of energy in the fission process, the liberated neutrons will have a significant amount of kinetic energy. As will be discussed in Chapter 4, many of these neutrons will pass by fissionable nuclei without inducing more fission events. Fortunately, fission events liberate an average of more than two neutrons, creating an increased probability that further fissions will occur to sustain a chain reaction. When criticality is achieved, the system only requires outside intervention to limit the number of fission events to maintain criticality.

In nuclear power facilities, reactors at criticality are the energy source used to boil water to produce steam. The steam then turns a turbine which generates electricity. However, criticality is not automatically achieved because the number of liberated neutrons varies for each individual event. There are multiple processes to tune the reactor to criticality, all of which depend on being able to determine the energy and number of liberated neutrons in the fission events. The fission energy and number of liberated neutrons for a particular fission event is dependent on two variables: the original fissioning *parent* nucleus and the pieces it splits into, the *daughter nuclei*.

Parent nuclei are the fissionable isotopes that hold all of the potential fission energy. These isotopes are fissionable partially due to the enormous number of nucleons they have. However, there is not a set number of nucleons that makes a nucleus fissionable.

Fission is like carrying a large number of tennis balls. You may pick them up carefully, slowly and strategically adding them until your arms are full. Then someone throws one more ball at you. In the chaos you are likely to drop all the balls because the ball was not added as carefully or precisely as the rest. When uranium-235, for example, is struck by a neutron, it briefly becomes uranium-236 in an excited state before fissioning. The addition of the neutron makes the uranium-236 nucleus too energetic to hold itself together. For this reason, uranium-236 makes up less than 0.01% of all uranium isotopes. The uranium-236 isotopes that do exist have a half-life over 20 million years and are mostly created by the *beta decay* of protactinium-236. It is possible to create uranium-236 by the addition of a neutron to uranium-235, but it is rare due to the increased probability of neutron induced fission. The increased probability of neutron induced fission will be discussed further in Chapter 4.

Most fissionable isotopes have extremely long half-lives but are on the verge of not holding themselves together. It is important to realize the difference between an atom with a long half-life and a fissionable atom. Many isotopes have long half-lives, but few of them are fissionable. Just like in the tennis ball scenario, a nucleus may be able to hold its pieces together for a long time, but the system is very fragile. Addition of an extra neutron is too energetic and chaotic, forcing the nucleus to break into two daughter nuclei.

The parent nucleus determines the number of nucleons that will be available in the fission event. Daughter nuclei are the second determining factor of the number of liberated neutrons. These nuclei often have very short half-lives and are, therefore, highly radioactive. This is part of why nuclear waste is so dangerous. Daughter nuclei vary in size but are around half the size of the parent nucleus. A given set of daughter nuclei that are the products of the same fission event are referred to as a *daughter pair*. This pair of daughter nuclei will account for all of the protons and most of the neutrons in the parent nucleus. The combination of the parent and daughter nuclei will determine the energy of the fission event and the number of liberated neutrons. Knowing the parent nucleus and the fission products allows the total fission energy released to be calculated, which is important to know when setting up an energy production system.

Chapter 2

Fission Energy Calculations

In any energy system it is useful to be able to calculate the energy produced. For nuclear fission the energy produced is extremely important, given that the energy release is so large per event. There are three different ways to calculate fission energy: binding energy, mass difference, and the mass excess/defect. Each of the three methods uses values unique to the parent nucleus and the daughter nuclei. A majority of fission energy comes from the kinetic energy of the daughter nuclei, but this is not obvious in any of the calculation methods.

Standard nuclear notation ($^{A}_{Z}X$) will be used to denote isotopes in most calculations. In this notation A, Z, and X represent the mass number, atomic number, and chemical symbol respectively. The number of neutrons in an isotope is included in the binding energy calculation notation so that it becomes ($^{A}_{Z}X_N$).

$$N = A - Z \tag{2.1}$$

This will identify each isotope's number of neutrons and is done because the excess neutrons are indirectly incorporated into the calculation. Notation for fission events will only denote the atomic mass number and the chemical symbol (^{A}X). Each method for calculating fission energy will first be set up similar to the structure of a chemical equation to show the overall event.

2.1 Binding Energy Method

The first method of calculating the energy released from fission is to use the binding energy of the parent nucleus and the daughter nuclei. Binding energy of a given nucleus is the energy input required to separate that nucleus into all of its individual protons and neutrons, or the energy released to form the nucleus. Binding energy is converted from some of the mass of the original individual nucleons. The ability to convert mass into energy was first proposed in 1905 by Albert Einstein as part of his theory of special relativity. In 1935 Einstein simplified this relationship to his mass-energy equivalence.[4]

$$E = mc^2 \tag{2.2}$$

Equation (2.2) allows for the mass converted to binding energy (*BE*) to be calculated from the original mass (m_X), number of neutrons (*N*), and the number of protons (*Z*). Multiplying this mass by the speed of light squared results in an energy unit equal to the binding energy, as will be shown in this section.

$$BE = [N(m_n) + Z(m_H) - m_X]c^2 \tag{2.3}$$

The values m_n, m_H, and m_X are the masses of the neutron, hydrogen nucleus, and the measured mass of the nucleus, respectively. Nuclear energies are usually expressed in MeV and nuclear masses are usually tabulated using the atomic mass unit (u), but can also be described using the units MeV/c^2. This mass unit makes sense when substituting these mass and energy units into Eq. (2.2). Given the two different units of nuclear masses, the c^2 factor in Eq. (2.3) uses the conversion of atomic mass units to MeV/c^2.

$$1\,u = 931.5\ {}^{MeV}\!/_{c^2} \tag{2.4}$$

Solving Eq. (2.4) for c^2 gives the energy per atomic mass unit. This allows the equivalent energy in MeV to be calculated from the mass expressed in u.

$$c^2 = 931.5\ {}^{MeV}\!/_{u}$$

Using Eq. (2.3) the binding energy can be determined for uranium-236 in which Z = 92 and N = 144. Values for the masses m_n, m_H, and m_X were calculated from the National Nuclear Data Center (NNDC).[5]

$$BE\ ({}^{236}_{92}U_{144}) = [(144 \times 1.008665\ u) + (92 \times 1.007825\ u) - 236.045568\ u] \times\ 931.5\ {}^{MeV}\!/_{u}$$

$$= 1790.4\ MeV$$

Dividing the binding energy of a nucleus by the number of nucleons in the nucleus yields the binding energy per nucleon. Figure 2 is referred to as the curve of binding energy,[6] which shows the binding energy per nucleon for all elements. The first half of the curve increases from hydrogen up to helium and eventually to iron at the peak of the curve. Iron and nickel isotopes are among the nuclei with the most energy per nucleon. This high binding energy per nucleon of these isotopes make it impossible to create a larger nucleus by normal fusion. Fissionable nuclei are found on the far right of iron. These nuclei are originally created in supernovae, where there is sufficient energy to fuse elements heavier than iron, but have less binding energy per nucleon.

The difference in the total binding energies of the daughter nuclei and the parent nucleus is equal to the energy released in fission. When fissionable isotopes undergo fission they break into the two daughter nuclei, which have slightly more binding energy per nucleon than the parent. Overall the binding energy released by the formation of the daughter pair is greater than the binding energy of the parent nucleus. Equation (2.5) is the general equation for calculating fission energy using binding energy. Only the binding energies of the parent nucleus and the daughter nuclei are needed. For simplicity the parent nucleus will be labeled nucleus P, while the daughter nuclei will be nucleus A and nucleus B.

$$BE_P = BE_A + BE_B + \text{Energy} \tag{2.5}$$

Solving for energy in Eq. (2.5), the energy released in fission is equal to

$$\text{Energy} = BE_P - (BE_A + BE_B). \tag{2.6}$$

When calculating fission energy it is important to pay close attention to what isotope the parent nucleus is. In uranium-235 fission events, the fissionable isotope is uranium-235. However, when calculating fission energy, uranium-236 has to be used as the parent nucleus. This is because when the uranium-235 nucleus captures the incident neutron, it becomes uranium-236 before fission occurs. Therefore, the physical properties of uranium-236 must be used, not the combination of uranium-235 and the incident neutron. This underscores the importance of the location of neutrons in fission systems. Although technically the fissioning isotope is uranium-236, fission events will still be referred to as the fission of uranium-235 in this thesis, to be consistent with common fission language.

A potential uranium-235 fission events results in the production of cesium-137, rubidium-96, and three liberated neutrons. Written similar to a chemical equation of products and reactants the fission event looks like,

$$^{235}U + n \rightarrow {}^{236}U \rightarrow {}^{137}Cs + {}^{96}Rb + 3n + \text{Energy}$$

Notice that there are four neutrons which Eq. (2.6) does not directly account for. This is because single neutrons do not have binding energy. Therefore neutrons are indirectly included when using the binding energy method.

$$\text{Energy} = BE({}^{236}_{92}U_{144}) - [BE({}^{137}_{55}Cs_{82}) + BE({}^{96}_{37}Rb_{59})]$$

Substituting values for binding energies of each nucleus calculated using Eq. (2.3) into Eq. (2.6), the fission energy can be determined.

$$\text{Energy} = 1790.415\ MeV - (\ 1149.382\ MeV\ +\ 807.135\ MeV\ )$$

$$\text{Energy} = \text{-166.1}\ MeV$$

The energy is negative, meaning more energy was released to form the daughter nuclei than what was taken to tear the parent nucleus apart, resulting in a release of energy. An issue with the binding energy method is that it completely ignores the liberated neutrons and must indirectly include the incident neutron. The next calculation method will include the liberated neutrons directly.

2.2 Mass Energy Method

Using the mass difference of the parent and daughter isotopes is a second method for calculating fission energy. Thanks to Albert Einstein we know that mass may be converted into energy. Given the masses of the parent nucleus and the fission products, fission energy can be calculated by the difference in the initial and final mass of the system. If the parent nucleus and the daughter nuclei are known, this is simple. To find the number of neutrons released in fission, subtract the mass number of the daughter nuclei from the mass number of the original nucleus. The parent nucleus contains all of the available mass for the fission products; therefore, the parent nucleus also contains all the available energy. The advantage of calculating fission energy using the mass energy method is that it directly accounts for the liberated neutrons, as opposed to the indirect inclusion by the binding energy method. Equation (2.7) uses the mass of the parent nucleus (m_P), daughter nuclei masses (m_A and m_B), and the neutron mass (m_n).

$$m_P = m_A + m_B + N(m_n) + \frac{\text{Energy}}{c^2} \tag{2.7}$$

Then solving for energy released in fission

$$\frac{\text{Energy}}{c^2} = m_P - [m_A + m_B + N(m_n)] \tag{2.8}$$

Using Eq. (2.8) the energy of the same fission event as used in the binding energy example can be calculated.

$$^{235}U + n \rightarrow {}^{236}U \rightarrow {}^{137}Cs + {}^{96}Rb + 3n + \text{Energy}$$

$$\frac{\text{Energy}}{c^2} = m({}^{236}_{92}U) - [m({}^{137}_{55}Cs) + m({}^{96}_{37}Rb) + 3m_n]$$

$$\frac{\text{Energy}}{c^2} = 236.0455\,u - [136.9071\,u\ +\ 95.9341\,u\ +\ 3(1.008665\,u)]$$

$$\frac{\text{Energy}}{c^2} = -01783\text{ u}$$

The energy is the total mass difference from the parent to the daughter products. One atomic mass unit is equal to 931.5 MeV/c^2. After converting the "missing" mass into energy the total energy released is determined.

$$\text{Energy} = \text{-166.1 MeV}$$

Again the calculated fission energy released is 166.1 MeV. Using the mass differences to calculate fission energy is more descriptive than binding energy because it directly accounts for the liberated neutrons.

In these first two methods the mass/energy of the entire nucleus was taken into account to find a small difference. Using either of these methods is analogous to calculating a building's height by measuring from the center of the Earth to the top of the building, then subtracting the Earth's radius. This represents a large amount of unnecessary work when tabulating energies for a large quantity of daughter pairs.

2.3 Mass Excess/Defect Method

The mass of a nucleus cannot be determined by the sum of the masses of its individual nucleons. For example the mass of deuterium is less than the combined mass of its components, the hydrogen atoms and a neutron. This relates back to binding energy, mass must be converted into energy to "bind" the individual nucleons together. For this reason many isotopes actually have less mass than is expected based on the definition of the atomic mass unit (u). One u is defined as one twelfth the mass of a carbon-12 nucleus. This definition negates the mass converted into energy to bind the nucleus together. Therefore, the actual mass of either a proton or a neutron is slightly larger than one twelfth the mass of carbon-12. This difference in the measured mass and the expected mass is known as the mass excess/defect. To calculate the mass excess/defect of a nucleus, subtract the total mass of the individual protons and neutrons of the nucleus from the measured mass value as shown in Eq. (2.9)

$$\Delta_X = m_X - A_X \quad (2.9)$$

Determining if the isotope has an excess or defect is based solely on the sign of Δ_X. A positive result indicates the isotope's mass is larger than expected and therefore has a mass excess. A negative value denotes a mass defect due to the isotope having less mass than expected.

Mass excess/defect is the third method of calculating fission energy. This method subtracts the mass defect of the daughter nuclei and mass excess of the liberated neutrons from the mass excess of the parent nucleus. Using this method still requires the assumption that the parent already includes the incident neutron like the binding energy and mass difference methods. However, the fission products may be considered separately and only the energy directly involved needs to be considered. The advantage of the mass excess/defect method is using smaller numbers for easier and faster calculations.

$$\Delta_P = \Delta_A + \Delta_B + N(\Delta_n) + \text{Energy} \tag{2.10}$$

Equation (2.10) is analogous to Eqs. (2.6) and (2.8), using subscript *P* for the parent nucleus as well as daughter nuclei *A* and *B*.

$$\text{Energy} = \Delta_P - [\Delta_A + \Delta_B + N(\Delta_n)] \tag{2.11}$$

Below is an energy calculation using Eq. (2.11) to calculate the energy of the same fission event calculated previously using binding energy and mass difference.

$$^{235}U + n \rightarrow {}^{236}U \rightarrow {}^{137}Cs + {}^{96}Rb + 3n + \text{Energy}$$

$$\text{Energy} = \Delta({}^{236}_{92}U) - [\Delta({}^{137}_{55}Cs) + \Delta({}^{96}_{37}Rb) + 3(\Delta_n)]$$

Substituting the mass excess/defect energies found in Appendix A the fission energy can be calculated.

$$\text{Energy} = 42.4476\ MeV - [-86.5459\ MeV\ +\ -61.3543\ MeV\ +\ 3(8.0713\ MeV)]$$

When using this method it is important to pay attention to the sign of the energy. Notice the daughter nuclei have negative Δ but the parent and neutrons have positive Δ. As in the previous examples the released energy can be determined by solving for energy.

$$\textit{Energy} = 166.1 \text{ MeV}$$

Again the calculated energy release is 166.1 MeV. However, the mass excess/defect method returns a positive energy value as opposed to the negative value returned by the first two methods. The reason for this difference is merely the perspective of the initial condition. The binding energy and mass difference methods use actual quantities which may be calculated or measured. On the other hand, mass excess/defect method uses values that represent a difference from an expected value based on definition. Essentially the mass excess/defect is a hypothetical quantity created to correct for the "missing" mass expected by the number of nucleons.

It is clear then that the particular method of determining the energy released is solely a preference. No method is fundamentally superior given the source of data is accurate. For the sake of simplicity and ability to quickly tabulate many event energies, hereafter, energy calculations will be done using the mass excess/defect method. Now that the energy release and calculation has been formally introduced, it is necessary to focus on the carriers of the energy, the fission products.

Chapter 3

Fission Products

Products of nuclear fission as stated previously are the daughter nuclei, the liberated neutrons, and thermal energy. There are also a few gamma rays released that add to the overall energy output. From an economic standpoint the energy is the most important product because it is ultimately produces electricity and in turn, money. According to the Nuclear Energy Institute,[7] in the United States, nearly 20% of electricity is generated by nuclear facilities. Scientifically the liberated neutrons are the most important because without free neutrons to carry on further fissions, the process would not be self-sustaining. Environmentally and medically the crucial products are the daughter nuclei. These are the highly radioactive isotopes that cause nuclear waste to be dangerous to those handling it as well as whatever environment it is eventually stored in. Counter to the danger, these radioactive isotopes are used in medicine. Radioactive isotopes created by fission are used as tracers for detection techniques and also in radiotherapy to combat cancer. Whichever product may be the most important is simply a point of view. Understanding each is important to any point of view because they are all related.

3.1 Range of Daughter Nuclei

Daughter nuclei atomic mass numbers range from 74 up to 160 and have between 29 and 63 protons. This does not mean that all of the isotopes in this range of elements are possible daughter nuclei. In fact, all of the possible daughter nuclei are the same size as or larger than the most stable isotope of that particular element. For example, cesium has 35 isotopes ranging from cesium-112 up to cesium-146. The single stable cesium isotope is cesium-133 and the smallest cesium daughter isotope is cesium-135. A complete database of the possible nuclides is able to be found individually at the NNDC or visually on the U.S. Navy nuclide chart.[8] Additionally, the mass defect energy of each possible daughter isotope has been listed in Appendix A. Each daughter isotope compared to their mass defect energy is shown in Fig. 3.

As shown in Fig. 3 there are 383 possible fission daughter nuclei. In each band of isotopes, the mass defect energy decreases by increasing the number of nucleons. Figures 4 and 5 show cesium and rubidium isotopes individually. When the smaller isotopes of each element are included (see Figs. 6 and 7), the curve resembles a second order polynomial. This curve shows that the mass defect energy of an isotope is not dependent on the number of nucleons, but instead on the stability of the isotope. The stability of an isotope is related to the length of its half-life. Most daughter nuclei are very unstable as a result of their short half-lives. A stable isotope does not undergo any decay. In each example the most stable isotopes for that particular element also have the largest mass defect energies. This means that the more stable isotopes will provide more initial energy to the system; however, this also means these isotopes will undergo fewer beta decays.

3.2 Daughter Isotope Decay

Unstable daughter nuclei have incredibly short half-lives. Although the half-life time varies between seconds and years, most daughter nuclei have half-lives shorter than a minute. When these isotopes are produced they *beta decay* until a stable nucleus is reached. Most fission daughter nuclei will go through beta decay in which an electron and an anti-neutrino are emitted from the nucleus. The result is the transformation of a neutron into a proton. Therefore, in beta decay the nucleus maintains the same number of nucleons, but will gain a proton to become a different element. Consider the *beta decay chain* example in Fig. 8 in which rubidium-96 decays into zirconium-96.

$$^{96}Rb \rightarrow {}^{96}Sr \rightarrow {}^{96}Y \rightarrow {}^{96}Zr$$

The chain represents the path in which daughter nuclei will beta decay to reach a stable nucleus. Due to the short half-lives of fission daughter nuclei, it is impossible to determine with certainty which is the original daughter isotope, unless it is at the beginning of the chain. Therefore, the probability of the chain is used as the probability that is attributed to individual isotopes. The beta decay of isotopes can add a significant amount of energy to the overall fission event. Beta decay energy can be found on a nuclide chart with the decay modes and decay energies, or it can be calculated.[1]

Calculating beta decay energy is similar to calculating fission energy. Beta decay energy may be calculated using the binding energy, mass difference, or mass defect energy of the isotopes. For this example the mass defect energy method will be used.

Equation (3.1) shows the energy released (Q_β) is equal to the difference in the mass defect energy of the daughter nucleus (Δ_D) and the nucleus it decays into ($\Delta_{D'}$).

$$Q_\beta = \Delta_D - \Delta_{D'} \tag{3.1}$$

For example, energy of the previously introduced cesium-137 isotope will be calculated as it beta decays to the stable barium-137. Although the electron and anti-neutrino are products of beta decay, they are not included in calculating the beta decay energy.

$$^{137}_{55}Cs \longrightarrow {}^{137}_{56}Ba + e^- + \bar{\nu}$$

$$Q_\beta = \Delta(^{137}_{55}Cs) - \Delta(^{137}_{56}Ba)$$

Substituting in mass defect energies located in Appendix A, the energy of cesium-137 beta decay can be calculated.

$$Q_\beta = (-86.5459 \text{ MeV}) - (-87.7215 \text{ MeV})$$

$$Q_\beta = 1.1756 \text{ MeV}$$

Beta decays provide extra energy to the system that is beneficial for energy production. Decaying daughter isotopes will ultimately provide multiple MeV's of energy to the system through beta decay. In Chapter 5, beta decay energy will be added to the total energy released in fission for a more complete energy calculation.

Decaying daughter nuclei also increase the radiation of nuclear waste and pose a hazard in handling and storage. These isotopes output large amounts of radiation in a very short amount of time. Fortunately nuclear waste like this can be stored until it has decayed into more stable isotopes. Since most of the decaying daughter isotopes have short half-lives, most of them will decay into stable isotopes within a few years. These are dangerous to life for large exposures, which is why they have to be handled and disposed of carefully. On the other hand, isotopes with considerably longer half-lives (thousands of years), will not decay at any appreciable rate to cause harm. These simply do not emit enough radiation to affect life significantly. For example, uranium-235 has a 700 million year half-life. No living thing lives close to that long. The time it takes to release a dose of radiation that would cause significant harm to living organism is far too long. The most dangerous daughter nuclei are those with intermediate half-lives (5-50 years). These nuclei decay at a low enough rate to stick around for long enough for living organisms to have a significant interaction with them but still decay fast enough to release a significant number of high energy particles.

Generally, as daughter nuclei beta decay they become more stable and decay into isotopes with longer half-lives. Nuclei with short half-lives release energy through beta decay over a very short period of time, meaning they are highly radioactive. The longer the half-life becomes, energy is released at a slower rate and becomes less radioactive.

3.3 Other Fission Products

Thus far the only fission products discussed at length have been the daughter nuclei. Although these nuclei are important there are other products which have a large role in the fission process. Aside from the energetic daughter nuclei there are the liberated neutrons, and gamma rays that are produced by fission.

Liberated neutrons are both important to a sustained chain reaction and are the most dangerous products of fission. Neutrons are special in that they have no charge and therefore can easily impact the nucleus to cause fission. This fact is the single most important aspect of nuclear fission. If protons were liberated instead of neutrons, fission could not work; the Coulombic repulsion between the proton and the incident nucleus is too strong.

For uranium-235 fission an average of 2.4 neutrons are liberated per event.[2] These neutrons are then capable of inducing more fission events so that the chain reaction can be sustained. The danger of liberated neutrons is in their kinetic energy and large number. Inside a reactor there is enough moderation and shielding to slow the neutrons down. However, in the event that someone is exposed to the core without shielding, neutrons will cause irreversible damage and almost certain death. Further information on the danger of neutron radiation can be found in Los Alamos' Review of Criticality Accidents.[9] This article recounts two events in which neutron shielding was used to increase neutron activity in a plutonium core. Liberated neutrons also interact with nuclei other than those which result in fission. Each neutron has a probability that it may interact with different nuclei based on its kinetic energy. Neutrons that do not cause fission may be absorbed by other non-fissionable nuclei within the system. Stable nuclei that absorb neutrons may form other radioactive isotopes and therefore create more radioactive waste. Lastly, liberated neutrons smashing into the components of the reactor itself can cause metals to become brittle over time. Components that become brittle compromise strength required to control the massive energy released by fission.

Roughly 200 MeV are ultimately produced by the average fission event. Between 80 and 90 percent of the energy is released instantly as the kinetic energy of the daughter nuclei. Initial energy release varies dependent on which daughter nuclei are produced. Also emitted in a fission event that contribute to the initial energy are gamma rays. Gamma rays may be produced by the fission event itself, or by the decay of daughter products. In daughter product gamma decay the nucleus is in an excited state and must emit a gamma ray, similar to photon emission by electron orbitals. However, gamma decay of daughter isotopes is far less common than beta decay. Gamma rays that are produced by the fission event, not by gamma decay of daughter nuclei, are referred to as *prompt gamma rays*. A gamma ray has at least 100 KeV, typically 1 MeV for uranium-235 fission, although there is no defined upper limit for gamma ray energy. According to scientists at Oak Ridge National Lab,[10] an average of six prompt gamma rays are emitted per uranium-235 fission event.

Following the initial energy release, there is a delayed energy produced by the decay of the daughter nuclei. Each daughter isotope has a unique set of decay modes. Beta decay is the most probable decay mode for any isotope and all unstable daughter isotopes will undergo beta decay. Energy produced by beta decay is dependent on each isotope, but generally accounts for 5 to 10 percent of the total energy. Most daughter isotopes may also emit delayed gamma rays as they experience gamma decay. Delayed gamma rays are generally less than one MeV and like beta decay, the energy is dependent on the isotope. The last mode of decay of daughter isotopes is neutron decay. In this process a *delayed neutron* is emitted from the daughter isotope's nucleus[2]. Delayed neutrons do not contribute significant energy to the total due to their small kinetic energy and the rarity of neutron decay. Decay modes and decay energies of daughter isotopes are listed on the U.S. Navy nuclide chart.

Chapter 4

Probability Distribution of Daughter Products

Fission daughter nuclei of any fissionable isotope is bi-modally distributed in a range of medium sized nuclei. As previously stated, daughter nuclei range between mass number of 74 to 160. Although there are 383 possible daughter nuclei, there are constraints for daughter nuclei pairs. Each daughter nuclei pair is bound by the mass number of the isotope and the number of protons in the nucleus.

4.1 Bimodal Distribution

A set of data with bimodal distribution displays two regions of increased probability. The probability distribution of uranium-235 fission daughter products is bi-modally distributed among the mid-mass isotopes, centered at roughly half the atomic mass of uranium. Figure 9 shows the bimodal distribution of fission daughter products, produced using data from the U.S. Navy nuclide chart. Daughter nuclei generally are either slightly larger or slightly smaller than half the mass of the parent. The probability of fission pairs is not evaluated by the specific isotope, but instead dependent on the number of nucleons in the nucleus. This is because the majority of daughter isotopes undergo beta decay. When each daughter isotope beta decays, it will retain the same number of nucleons in the nucleus, but convert a neutron into a proton. As stated in Section 3.2, many of the daughter isotopes have half-lives shorter than a minute. This makes it difficult to definitively say what the probability of each specific isotope is. Instead the probability of isomers can be determined by the percent of waste found with that atomic number. For example approximately 6.2% of daughter isotopes are part of the chain beginning with rubidium-96, which beta decay to zirconium-96.

As the isotopes beta decay they become more stable as they gain more protons to become a new element. Daughter nuclei are always the same size as or larger than the most stable isotope of each element. Therefore, they have too many neutrons for the nucleus to be stable. The transformation of the neutron to a proton is the process of the nucleus attaining a proton-neutron ratio which is stable. Beta decay along lines of isomers also produces isotopes that are not possible as direct fission daughter nuclei. Instead they are the products of daughter nuclei beta decay. Each of the possible daughter isotopes have multiple possible isotopes which they may be part of a daughter nuclei pair with. This possibility of multiple pairs will be shown in the next section. Individual daughter nuclei pairs are dependent on the protons in the daughter nuclei and the liberated neutrons.

4.2 Proton Conservation

Fission daughter pairs must conserve the number of protons from the parent nucleus. Uranium has 92 protons in its nucleus and so the daughter isotopes must have a combined 92 protons. This is to say that each element that may be a fission product can only be produced with one other element. For example cesium, which has 55 protons, can only be in a fission pair with rubidium because it has the remaining 37 protons.

$$^{235}_{92}U + n \longrightarrow {}^{236}_{92}U \longrightarrow {}^{137}_{55}Cs + {}^{96}_{37}Rb + 3n + Energy$$

Notice that the total number of protons of the parent nucleus are conserved by the two daughter nuclei. The second example which pairs cesium-137 with rubidium-97, liberating one less neutron, will again conserve the protons.

$$^{235}_{92}U + n \longrightarrow {}^{236}_{92}U \longrightarrow {}^{137}_{55}Cs + {}^{97}_{37}Rb + 2n + Energy$$

This result holds true for all possible isotopes of each element given that they are possible fission products. Proton conservation only applies to the daughter nuclei produced directly by the fission event. After the daughter nuclei are produced by fission, they will quickly begin to beta decay. The beta decay of each daughter nuclei will emit an electron from the nucleus and a neutron will convert into a proton, which will increase the total number of protons contained within the daughter nuclei.

Proton conservation is the first factor in determining daughter nuclei. Table 1 lists all of the possible uranium-235 fission daughter pairs based on proton conservation. The probability of any of these pairs roughly follows the bimodal probability distribution, but that probability is based solely on the number of total nucleons in the nucleus. All pairs based on proton conservation are the general elements and do not specify any isotopes. Individual isotopes involved in a fission event are identified by the number of liberated neutrons.

4.3 Liberated Neutron Dependence

In addition to proton conservation, the number of liberated neutrons determines which daughter pairs are possible. Just like the parent nucleus' protons need to be conserved within the daughter nuclei, the parent's neutrons must be conserved within the system. Most will be conserved within the daughter nuclei, while an average of 2.4 neutrons will become liberated neutrons. Although the daughter pair actually determines how many neutrons are liberated, it is much simpler to select the daughter nuclei as the dependent variable when calculating fission energies.

Most fission events will liberate either two or three neutrons, but other events are possible. This indicates that one isotope does not have just one specific isotope it must be paired with. Any given daughter isotope has multiple possible pairs dependent on the number of liberated neutrons. Previously, an example of a cesium-rubidium daughter pair was used in which three neutrons were liberated. There also exists other cesium-rubidium pairs which liberate three neutrons as well as pairs which liberate only two neutrons. The previous example showed how cesium-137 and rubidium-96 resulted in a release of three neutrons and 166.1 MeV of energy. In the case that cesium-137 is still a daughter product but only two neutrons are liberated, the other daughter nuclide must conserve the third neutron and will be rubidium-97.

$$^{235}\text{U} + \text{n} \rightarrow {}^{236}\text{U} \rightarrow {}^{137}\text{Cs} + {}^{97}\text{Rb} + 2\text{n} + \text{Energy}$$

The energy released with rubidium-97 and the two neutrons will be different from rubidium-96 and three liberated neutrons. This is because energy is involved in binding that extra neutron as opposed to leaving it free. Using Eq. (2.11) the energy of this new fission event may be calculated using the mass excess/defect method.

$$\text{Energy} = \Delta_P - [\Delta_A + \Delta_B + N(\Delta_n)]$$

The parent uranium-236 and cesium-137 as daughter A are the same, but now rubidium-97 is daughter B and there are two liberated neutrons as opposed to three.

$$\text{Energy} = \Delta({}^{236}_{92}U) - [\Delta({}^{137}_{55}Cs) + \Delta({}^{97}_{37}Rb) + 2(\Delta_n)]$$

$$\text{Energy} = 42.4476\ MeV\ - [-58.5182\ MeV\ +\ -86.5459 MeV\ +\ 2(8.0713\ MeV)]$$

Energy = 171.3691 MeV

The energy released when two neutrons are liberated is larger than the energy released when three neutrons are liberated. This is generally true in fission for individual reactions as shown in Fig. 10 for all cesium-rubidium pairs and in Appendix B for all other fission daughter pairs. Notice that although some pairs with two liberated neutrons release less energy than particular pairs with three liberated neutrons, the overall average energy is larger when fewer neutrons are liberated. Extra energy released comes from the extra binding energy required to contain the additional neutron within a nucleus. However, the difference in energy is small compared to the overall energy released in the fission event.

Furthermore the self-sustainability of the system is dependent on the number of free neutrons available to induce more fission events. Liberating fewer neutrons in exchange for a slight increase of released energy ultimately results in an overall decrease in energy yield in the system as shown in Figs. 11 and 12. After multiple fission events, the number of neutrons available to induce more fissions is greater if three neutrons are liberated in each event, than for events that liberate two neutrons. Additional fission events, due to additional liberated neutrons, will ultimately contribute far more energy than extra energy released with only two neutrons. As discussed in the introduction, liberated neutrons also may be absorbed by elements of the reactor by design to keep the chain reaction under control. In the case of a nuclear weapon, neutron deflectors are part of the design to maximize the number of liberated neutrons to induce further fission events.

Chapter 5

Liberated Neutron Energy

Neutrons liberated from a fission event carry kinetic energy away from the parent nucleus. Newly liberated neutrons are referred to as *fast neutrons*[2] because their velocities reach up to 20 km/s. Kinetic energy of fast neutrons must be reduced through elastic collisions. Slowing down liberated neutrons will improve the probability that they will interact with a fissionable nuclei and cause a fission event. During this process of colliding with other nuclei to give away kinetic energy, some neutrons may be lost.

5.1 Moderating Neutrons

A neutron is considered to be a fast neutron when its kinetic energy is greater than 0.1 MeV. These neutrons are moving too fast to have a significant probability of interacting with the fissionable uranium-235. To slow down fast neutrons and increase the probability that they might induce a fission, the neutrons must collide with other nuclei to give away their kinetic energy in a process called moderation. A moderator is a material that surrounds the fuel and acts to quickly decrease the kinetic energy of liberated neutrons. Moderation is necessary because the non-fissionable nuclei in the fuel are far too large to take away a significant amount of kinetic energy through elastic collisions. The role of moderators is easily demonstrated by two one-dimensional classical conservation of energy and momentum examples from elementary mechanics.[11]

In the first example, a fast moving mass collides elastically with a much larger stationary mass. The mass rebounds in the opposite direction with close to its initial velocity, while giving the large mass very little velocity. This is the same result as a fast neutron striking a large, non-fissioning nucleus. Fast neutrons will most likely bounce off the large nucleus without losing a significant amount of kinetic energy.

In the second example, the fast moving mass now collides elastically with a mass of equal size. In a one-dimensional example, the incident mass would transfer all of its kinetic energy and momentum to the second mass. When applied to a fast neutron, the result is similar. Particles of similar mass will quickly slow down the neutron, ideally in less than 20 collisions, to increase the probability of interacting with a fissionable nucleus. For this reason, moderators should consist of molecules made from small atoms with masses close to that of a single neutron. Water is a common moderator for uranium-235 fueled reactors. The hydrogen atoms in each water molecule are approximately the same size as a neutron. Slowing down liberated neutrons quickly is important so that they interact with the fissionable uranium-235 instead of neutron-absorbing nuclei.

Uranium-235 is usually no greater than 3% of the entire mass of the fuel.[13] The rest of the fuel's mass is predominantly uranium-238. Fast neutrons will either bounce off the large uranium-238 nuclei without losing very much kinetic energy, or will be absorbed. Fast neutron absorption by uranium-238 does take neutrons away that might cause a fission event, but is still beneficial to the overall energy output. Neutron absorption by uranium-238 will either induce fission, or more likely will be captured and eventually beta decay into the fissionable isotope plutonium-239.

The moderator decreases the energy of the neutrons to an energy low enough to cause fission and decreases the energy quickly to reduce the probability of absorption. A neutron with sufficiently low energy to interact with fissionable nuclei and cause fission is called a "thermal neutron." A neutron is said to be thermal because it is in thermal equilibrium with its environment. Thermal neutrons are defined to have less than 0.01 MeV energy. Most thermal neutrons that induce fission have around 0.025 eV, which corresponds to the average kinetic energy of molecules at 300 K.

5.2 Neutron Cross Section

The probability that a neutron will interact with a nucleus is determined by the neutron *cross section.*[2] This quantity is determined by the energy of the neutron, not the physical size of the nucleus. The neutron cross section is measured in *barns*, a unit which represents the probability of an interaction as an area and is defined to be 10^{-28} m^2. In addition to the neutron's energy, a neutron cross section is also dependent on the type of interaction that may occur. Two main modes of interaction are capture and scattering. In this case, uranium-235 has a high scattering and low capture cross section for fast neutrons, but the reverse for thermal neutrons.

Neutron capture includes two types of events, fission and absorption. In both types of events the nucleus takes in the incident neutron, but only in absorption is the nucleus able to hold the additional neutron without splitting. Fission capture occurs when a neutron is captured and the energy of the neutron causes fission. Although a neutron may have more than enough energy to cause fission, it may be moving too fast to have a significant probability of interaction. The figure caption of Fig. 13 describes three regions: 1/v region, resonance region, and the fast neutron region.[12] The first two regions lie in the thermal neutron range. The 1/v region is named for the inverse relationship between the velocity of the neutron and the fission cross section.

As the velocity of the neutron increases, the fission neutron cross section increases linearly. In the resonance region a number of specific energies correspond to specific cross sections. In this region a small change in neutron energy can result in a large increase or decrease in cross section.

Table 2 is a list of neutron cross sections for fast and thermal neutrons of moderators, reactor components, and fuel isotopes. Values for individual cross sections of isotopes must be determined experimentally. The fission cross section may then be used to determine the probability of a fission for a fuel. Since the cross section is a used to calculate the chance that an interaction will occur in a given space over a given period of time. Probability of fission (P_f) is a product of the fission cross section (σ_f), the density of nuclei (*N*), and the distance (*x*) the neutron will travel in the material.

$$P_f = \sigma_f N x \tag{5.1}$$

The probability of fission can also be expressed as the number of incident fissions per time (I_f), divided by the number of neutrons present in the defined volume at the same time (I_0).

$$P_f = \frac{I_f}{I_0} \tag{5.2}$$

Setting the two equations for P_f equal to each other, the fission cross section can be determined.

$$\sigma_f N x = \frac{I_f}{I_0} \tag{5.3}$$

$$\sigma_f = \frac{I_f}{I_0 N x} \tag{5.4}$$

In the process of losing kinetic energy to improve the probability of a fission event, the energy is given to the environment and must be accounted for. The energy given to the environment to lower the neutron energy sufficiently to increase the fission cross section varies, but will be discussed further in the next chapter.

Chapter 6

Total Picture of Fission

Finding the total energy released by a fission event requires consideration of all the fission products and subsequent interactions with the environment. The kinetic energy of the daughter nuclei accounts for 80-90 percent of the overall energy. The remainder is contributed by the fission products and interactions already discussed in Chapter 3. Additionally, recall that there is more kinetic energy released when two neutrons are liberated than there is when three neutrons are liberated. However, a larger initial fission energy does not necessarily result in a larger total energy release by the fission event. Therefore, in order to determine optimal fission events, the remaining energy and interactions contributed by the fission products will be considered.

6.1 All Fission Products and Energy Contributors

Daughter nuclei have been the main focus of fission events. They simplify fission energy calculations and offer definitive evidence that fission actually occurs. As discussed previously, daughter nuclei are medium mass isotopes that generally have short half-lives. The short half-lives of daughter nuclei means they are highly radioactive. Beta decay of daughter nuclei contributes a secondary energy source after the initial fission event occurs. This is why nuclear waste is radioactive. The daughter nuclei will continue to beta decay until stable nuclei are reached. For example, cesium-137 has a 30 year half-life, which means these nuclei will supply additional beta decay energy years after the initial fission event.

Beta decay energy is dependent on each daughter nucleus. Each daughter isotope will have a unique beta decay energy. Therefore, each possible pair of daughter nuclei has a unique beta decay energy, which can be calculated as shown in Section 3.2. However, this calculation was done for a nucleus which only has to beta decay once to reach a stable isotope. The energy contributed by beta decay includes both the beta decay of the original daughter nucleus and subsequent beta decays leading to a stable isotope. Including beta decay energy adds a varying amount of energy to the total fission process dependent on the daughter nuclei. The energy of daughter nuclei that undergo multiple beta decays must be calculated or referenced one decay at a time. As shown in Appendix A and Figs. 6 and 7, the more stable isotopes of each element have the largest mass defect energies. These are also the most stable nuclei of each particular element. This means that although there is a larger amount of initial energy release from these isotopes, they do not beta decay as much as the larger, more unstable isotopes. Consequently the more stable daughter nuclei, contribute more energy initially, but will release very little beta decay energy over time.

Next, it is necessary to address the subject of the previous chapter, the liberated neutrons. Thus far, in all calculations of the energy released in fission, the neutrons have played a secondary role because they lack binding energy. However, liberated neutrons have kinetic energy. Lowering the energy of fast neutrons to the thermal range requires elastic collisions with the moderator. Collisions take energy away from the neutrons and transfer it to the rest of the system. Liberated neutrons are initially fast neutrons, with kinetic energy ranging from 0.1 MeV to 10+ MeV, with an average of 2 MeV per neutron. Thermal neutrons have a kinetic energy less than 0.1 MeV, but as Fig. 13 shows, the fission cross section greatly increases at neutron energies less than 1 eV. In the process of slowing the fast neutrons to the thermal range, an energy of 2 MeV per neutron is contributed to the system.

Previously in Section 3.3, prompt gamma ray emissions were discussed. These are the gamma rays created as a direct result of a fission event. Oak Ridge National Laboratory found that in uranium-235 fission, an average of 6 prompt gamma rays per event are emitted. Each prompt gamma ray has an average energy of 1 MeV. In addition to prompt gamma rays, daughter nuclei may experience gamma decay, and produce a secondary gamma emission. Unlike the beta decay mode, not all daughter isotopes undergo gamma decay; those that do are listed on the U.S. Navy nuclide chart. Similar to beta decay energies, secondary gamma decay energies cannot be described by an average. Secondary gamma decay energies must be individually considered for each isotope as well as for the subsequent decay products the original daughter nuclei decay into. The last energy contributor is the kinetic energy of the daughter pair. As stated previously, the kinetic energy of the daughter nuclei make up 80 to 90% of the total fission energy.

6.2 Total Energy Calculation

Now that all of the energy contributors have been identified with associated energies, the total energy of specific fission events can be calculated. Due to the varying number of liberated neutrons, it is necessary to calculate the energy for events with both two and three liberated neutrons. Similar to previous examples, the event will first be shown like a chemical equation with the reactants on the left and the products on the right. The first example will be the same isotopes as in Chapter 2, but will now include the energy components previously ignored, with two exceptions. The delayed gamma decay energy will be ignored because it is small and relies on the excited state of the nucleus. Delayed neutron decay energies will also be ignored for the reason that delayed neutrons are rare and have little kinetic energy.

$$^{235}U + n \rightarrow {}^{236}U \rightarrow {}^{137}Cs + {}^{96}Rb + 3n + \gamma_p + \beta^- + \text{Energy}$$

Notice that the kinetic energy is not directly listed in the event equation. The kinetic energy of the daughter isotopes, liberated neutrons and prompt gamma rays are products of the same initial energy. Their kinetic energy is produced by the combination of the daughter nuclei's mass defect energy as well as the mass excess of the liberated neutrons and parent nucleus. Total kinetic energy (KE_{A+B}) of the two daughter nuclei can be calculated by the mass excess/defect method, Eq. (2.10), without the neutron mass excess energy as shown in Eq. (6.1).

$$KE_{A+B} \cong \Delta_P - \Delta_A - \Delta_B \tag{6.1}$$

The mass excess/defect method with the addition of the average prompt gamma ray energy(γ_P), beta decay energy (β^-), and the kinetic energy of the neutrons (KE_n); accounts for total fission energy.

$$\Delta_P = \Delta_A + \Delta_B + [N(\Delta_n) + \gamma_P + \beta^-{}_A + \beta^-{}_B + KE_n] + \text{Energy} \tag{6.2}$$

By solving Eq. (6.2) for energy and substituting in Eq. (6.1) for KE_{A+B} , the total energy released by an individual event can be calculated using Eq. (6.3).

$$\text{Energy} = KE_{A+B} - N(\Delta_n) + \gamma_P + \beta^-{}_A + \beta^-{}_B + N(KE_n) \tag{6.3}$$

Substituting in known values yields the total energy. The beta decay energies for each isotope were found on the U.S. Navy nuclide chart and include all beta decay energies until a stable isotope is reached.

$$\text{Energy} = KE({}^{137}_{55}Cs + {}^{96}_{37}Rb) - 3(\Delta_n) + \gamma_{Avg} + \beta^-({}^{137}_{55}Cs) + \beta^-({}^{96}_{37}Rb) + N(KE_n)$$

Gamma decay energy used is the average of six 1.0 MeV gamma rays as discussed in Chapter 4. The calculation is written in detail due to the large number of energy contributors. The neutron mass excess will subtract energy from the system as it converts energy into mass because the neutron is no longer bound within a nucleus.

$\text{Energy} = (178.3478\ MeV)$	Daughter Isotopes *KE*
$-3(8.0713\ MeV)$	Neutron Mass Excess Energy
$+3(2.0\ MeV)$	Neutron *KE*
$+(6.0\ MeV)$	Prompt Gamma Energy
$+(1.1756\ MeV) + (20.3\ MeV)$	Beta Decay Energies

$$\text{Energy} = 187.6\ MeV$$

Notice that the total fission energy is now closer to the 200 MeV approximation alluded to earlier. Additionally it is important to appreciate the beta decay energy range. Cesium-137 has a low beta decay energy because it must only decay once to achieve the stable nucleus barium-137. On the other hand, rubidium-96 must undergo three beta decays to reach the stable zirconium-96 isotope. The second example of total fission energy will be the example used in Section 4.3 in which only two neutrons were liberated.

$$^{235}U + n \rightarrow {}^{236}U \rightarrow {}^{137}Cs + {}^{97}Rb + 2n + \gamma_p + \beta^- + \text{Energy}$$

$$\text{Energy} = KE({}^{137}_{55}Cs + {}^{97}_{37}Rb) - 2(\Delta_n) + \gamma_P + \beta^-({}^{137}_{55}Cs) + \beta^-({}^{97}_{37}Rb) + N(KE_n)$$

Again the equation will be itemized to express each of the separate components. Note that the same cesium-137 beta decay energy and neutron kinetic energy are used as in the example in which three neutrons were liberated. This is done because the two values as well as the number of neutrons liberated are averages.

$\text{Energy} = (177.5117\ MeV)$	Daughter Isotopes *KE*
$-2(8.0713\ MeV)$	Neutron Mass Excess Energy
$+2(2.0\ MeV)$	Neutron *KE*
$+(6.0\ MeV)$	Prompt Gamma Energy
$+(0.512\ MeV) + (15.2\ MeV)$	Beta Decay Energies

$$\text{Energy} = 187.7\ MeV$$

Again the final result is closer to the estimated 200 MeV produced by a fission event. This result contrasts with the result from Section 4.3 that showed that appreciably more energy is released overall. Although there is still the larger daughter isotope *KE* and one less neutrons converting energy into mass, there is less beta and gamma decay energy.

6.3 Fission Generations and Applications

Now a complete picture of a fission event has been defined, and most of the energy contributors have been accounted. A fission event will release an average of 200 MeV and 2.4 neutrons. As shown in the last section, the total energy released is roughly the same regardless of whether there are two or three neutrons liberated. In Section 4.3 the issue of continued fission events as part of a chain reaction was discussed. Fission events that liberate three neutrons will ultimately generate more energy than events liberating only two neutrons because of successive fission events.

Each set of successive fission events is referred to as a *generation.*[13] One generation includes the energy of all the fission products as well as the decay energy of the daughter isotopes. Figure 15 shows the division of two generations of fission events. Every additional neutron liberated has the potential to generate another 200 MeV by inducing another fission event. Multiple generations of liberating additional neutrons will lead to a large increase to the energy produced. However, this is an idealized scenario in which each liberated neutron induces an additional fission event. As stated in Chapter 3, not every liberated neutron will induce fission in the next generation.

In nuclear power production the number of fission events is purposefully kept to a 1:1 ratio, meaning that each fission event will result in just one fission event in the next generation. This is done so that the chain reaction does not multiply the number of fission events to a level that produces more energy than can be regulated safely. Operators are able to regulate the number of free neutrons inside the reactor by inserting and removing control rods. Control rods are made of materials that have a high neutron absorption cross section such as cadmium so that they readily absorb excess neutrons. This does not mean that the excess liberated neutrons are useless in nuclear power production. The control rods reduce the rate of fission events, to make nuclear power extremely reliable. Consistency of power production at nuclear facilities is why they are used to provide the base load of electricity to the grid. Other clean energy producing facilities such as wind and solar cannot output a steady level of electricity 24 hours a day like nuclear power facilities can.

There are nuclear reactors that specifically utilize the excess liberated neutrons. Breeder reactors are nuclear reactors that produce more nuclear fuel than they use. Most of the fuel in a reactor is uranium-238, which is capable of capturing a neutron to become uranium-239. Eventually uranium-239 will beta decay into plutonium-239, which is a fissionable isotope but is not a naturally occurring element. Additionally plutonium-239 fission liberates a higher number of neutrons per fission event than uranium-235. The reason plutonium fuel is not used in the U.S. is that it must be reprocessed out of the waste to be used, which is more expensive than mining and enriching uranium.

Another application of nuclear fission that takes full advantage of the excess neutrons is nuclear weapons. Nuclear fission bombs use the extra neutrons to cause as many fission events in as few generations as possible. The concentration of fissionable isotope used (uranium-235 or plutonium-239) is highly enriched above 90%, compared to the 3% enriched fuel used in nuclear power facilities. High concentration of fissionable isotopes in a nuclear weapon guarantees that multiple fission events will result from each generation. The result is referred to as *doublings* in each generation, which describes the number of fission events doubling every generation.[3] With each generation lasting less than one millionth of a second, the number of fission events grows very rapidly, each one releasing approximately 200 MeV.

Aside from the obvious danger of nuclear weapons, the nuclear fission process presents other dangers. To conclude, the last section will cover the daughter isotopes which are the most useful and the most deadly.

6.4 Key Daughter Isotopes

As stated before there is a wide range of fission daughter nuclei. Many radioactive isotopes are used in medicine. Often these radioisotopes are actually reprocessed from nuclear waste. Reactors that produce these isotopes are not in large commercial power plants but instead are smaller research reactors.

Of the possible daughter isotopes created by uranium-235 fission there are a few that actually could be useful if extracted from spent fuel. According to the World Nuclear Association[15] the fission products iodine-131, strontium-89, and samarium-153 are all used in nuclear medicine. These isotopes have half-lives of 8 days, 50 days, and 46 hours respectively. These are highly radioactive but have relatively short half-lives. This is part of the design of nuclear medicine. Radiotherapy operates on the premise that cancerous cells are more vulnerable to radiation than normal healthy cells. Therefore the introduction of a radioactive source will destroy the cancerous cells while decaying to a stable isotope. The hope is that this is done before damaging too many healthy cells, and thus causing radiation sickness.

Strontium-89 and samarium-153 isotopes are used to relieve pain for bone cancer patients.[15] Strontium-89 is used because strontium mimics calcium. When strontium is taken in by the body. It is delivered to the bones. Unfortunately this means that other strontium isotopes will also be concentrated in bones as well. Strontium-90 also will mimic calcium and be delivered to the bones to be stored. In contrast to the short half-life of strontium-89, strontium-90 has a medium length half-life of 29 years. Slow decay of these isotopes results in mutation of healthy cells, potentially causing cancer.

Even more of a paradox is iodine-131. This isotope is used to treat thyroid cancer. The human thyroid collects iodine which will then be used to create growth and regulate hormones. When thyroid cancer develops, iodine-131 is used to irradiate the cancerous cells. The thyroid collects iodine, and will actively intake the medicine. Unfortunately iodine-131 also causes thyroid cancer for the same reason. Although iodine-131 has a short half-life, large doses can flood the thyroid with large quantities and increase radiation exposure. Fortunately in the event of a major nuclear catastrophe, taking regular iodine tablets will fill up the thyroid and the radioactive iodine will be not be collected.

One additional daughter isotope which is dangerous and worthy of recognition is cesium-137. This cesium isotope has a half-life of 30 years and occurs at a fairly high 6 percent of fission daughter nuclei. The danger of cesium-137 is the length of its half-life. Much like strontium-90, the half-life is long enough for significant exposure time, yet short enough to release a dangerous amount of radiation. Isotopes with short half-lives, less than one year, output a large amount of radiation quickly. Therefore the risk of exposure over time is low. On the other hand, isotopes with half-lives longer than 100 years also carry low risk of exposure because they cannot output high doses of radiation.

These are just 5 of the 383 possible uranium-235 daughter isotopes. All together there are over 841 possible unique fission daughter pairs for events in which up to four neutrons are liberated. Given that it is possible to liberate less than two and more than three neutrons, there are well over a thousand possible daughter pairs.

Chapter 7

Concluding Remarks

Fission events liberate the energy that drives nuclear power facilities and creates the life-saving isotopes used in nuclear medicine. Being able to determine the fission energy and fission products raises the opportunity for research to optimize the process. Beneficial future research would explore the ability to control the fission products to maximize the output for individual industries.

Opposition to nuclear energy stems from fear and common misunderstanding. Nuclear power is held to very high safety and regulation standards in the energy industry, in part due to this fear. Misunderstanding of fission is the largest obstacle to the growth of nuclear energy technology. Therefore, general education about fission must be a high priority to correct harmful common misconceptions. The ability of nuclear power facilities to run with a steady, high energy output, provides the base of a constant energy demand. As stated in Chapter 3, nuclear facilities only contribute 20% of the total power production in the United States, as of 2015. Potential for nuclear energy as the clean, reliable, and sustainable energy source of the future is high.

Fission products that are used in nuclear medicine are as poorly understood as nuclear energy, but do not generally evoke the same fear. The negative stigma of radioactive isotopes seem to disappear when it's called medicine, despite the fact that many isotopes used in medicine are produced by fission. Unfortunately, nuclear waste from commercial reactors is not used for the production of nuclear medicine. Instead the isotopes used in nuclear medicine are mostly produced in small research reactors. Again the underlying cause of this is the general misunderstanding of fission. Nuclear waste, similar to that which is used to produce medicine, must sit unused due to a lack of action by the U.S. government. Pounds of life-saving medicine is literally wasting away in storage containers and will continue to do so until new policy or new technology is created.[15]

The many possible daughter isotopes were discussed in Chapter 3 and their probability distribution was covered in Chapter 4. Daughter isotopes have multiple limiting factors that narrow the range of isotopes, but not a real way of controlling them. Future research into nuclear fission should focus on methods of controlling the products of reactions. The most likely method might be controlling the kinetic energy of the incident neutron to select a smaller range of potential daughter nuclei. Capability of daughter nuclei selection would benefit the economic, medical, and environmental aspects of nuclear fission. Choosing the daughter nuclei would allow a reactor to be tuned to generate a maximum amount of energy, produce more medical isotopes, or to minimize the danger of waste.

The inspiration for this thesis was to advance the general education about fission and daughter nuclei; and to help move past fear that hinders overall growth of fission technology. Fission has provided some of the largest advancements in science and medicine in the past 80 years. Exploring fission further can lead to a safer and more effective use of this amazing technology.

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Figures and Tables

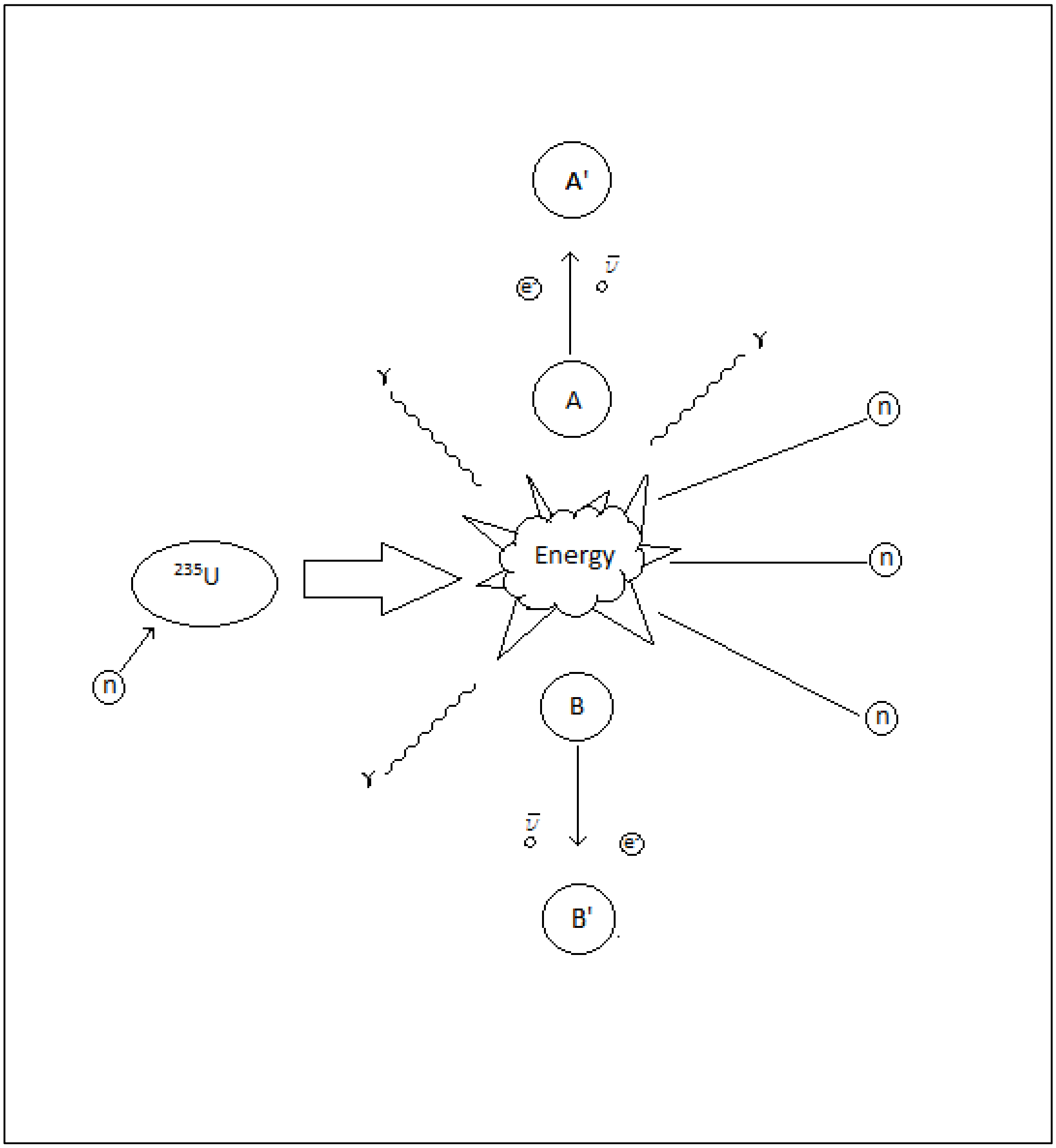


Fig. 1. Uranium-235 fission event. The fission event creates nuclei A and B, three neutrons, and gamma rays. Subsequently nuclei A and B become A^1 and B^1 after each emits an electron and an anti-neutrino during beta decay.

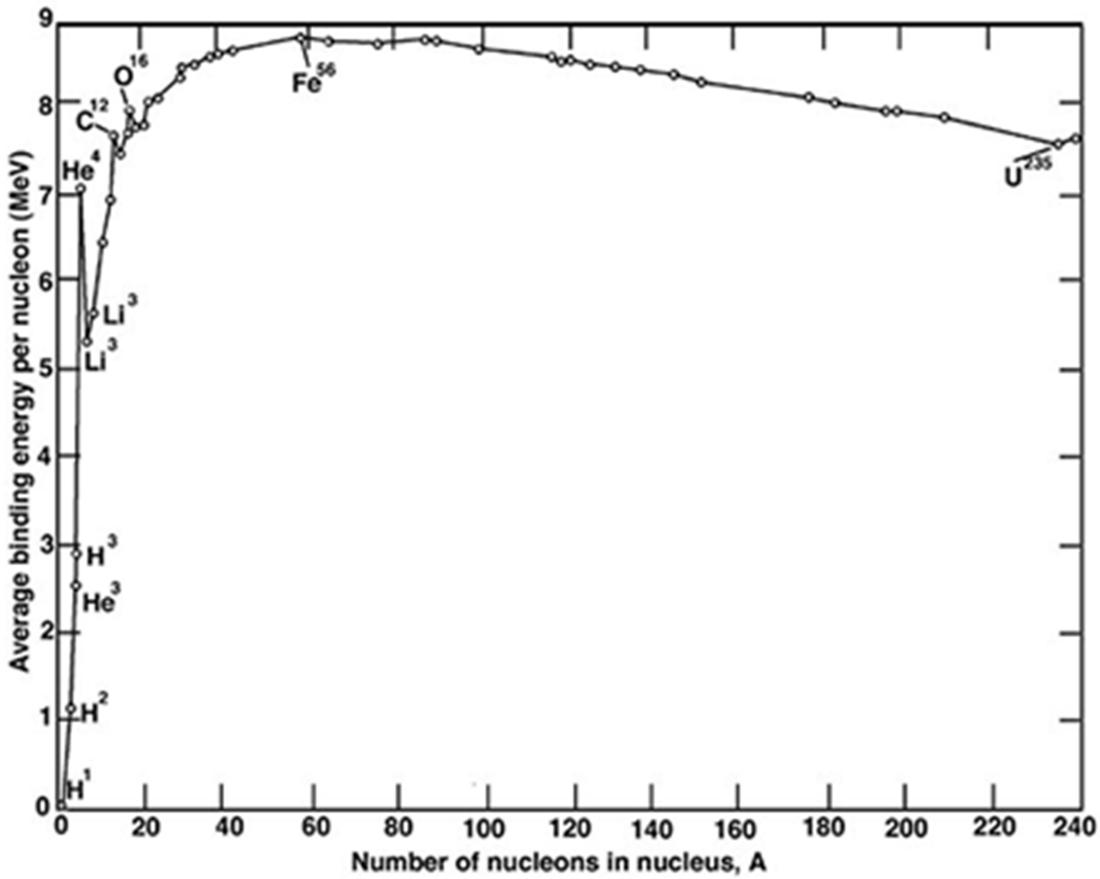


Fig. 2. Curve of binding energy per nucleon[6]. Fissionable uranium-235 lies to the far right of the graph. All of the possible daughter nuclei lie between iron-56, the most stable nucleus, and uranium-235.

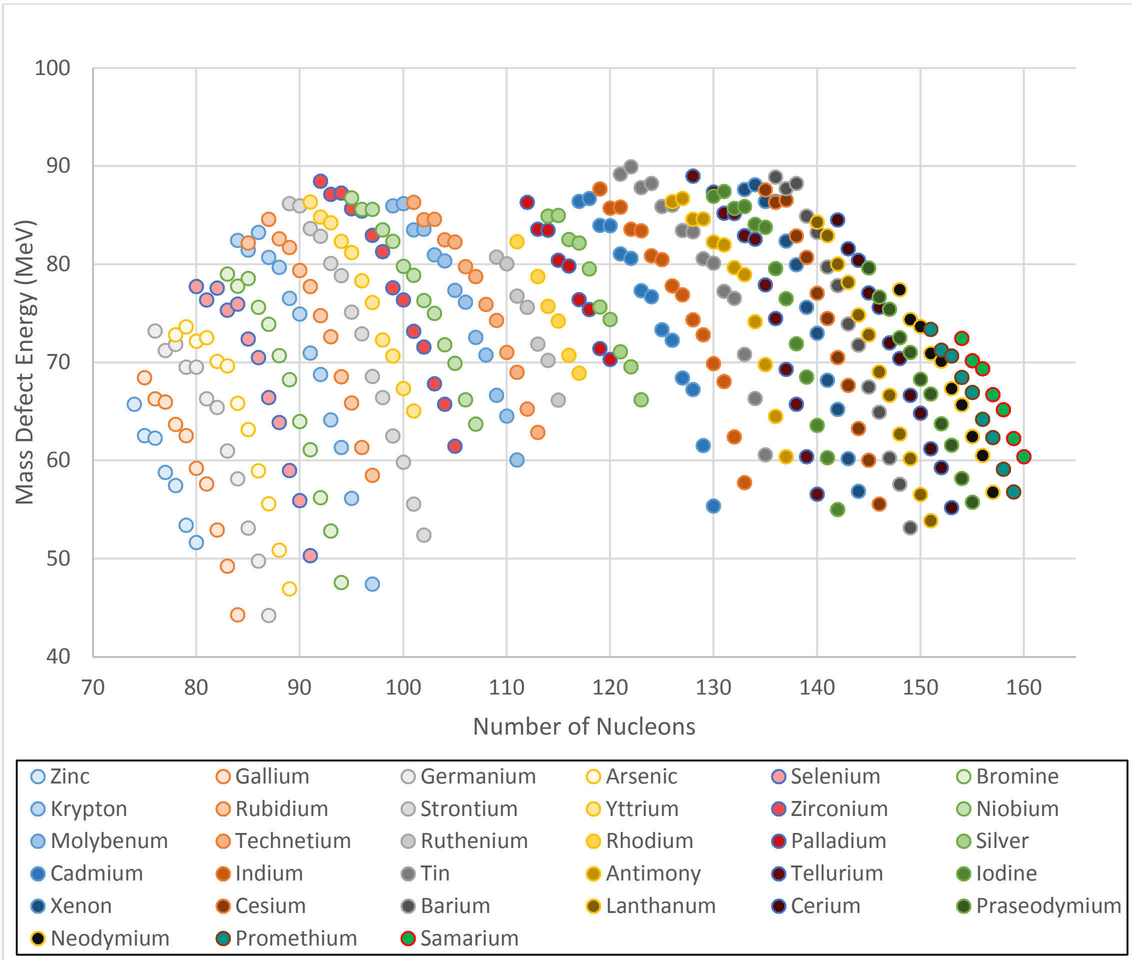


Fig. 3. Mass defect energy for fission daughter isotopes. Each colored band represents a set of isotopes of an individual element. This shows that in general isotopes of each element with more nucleons have less mass defect energy.

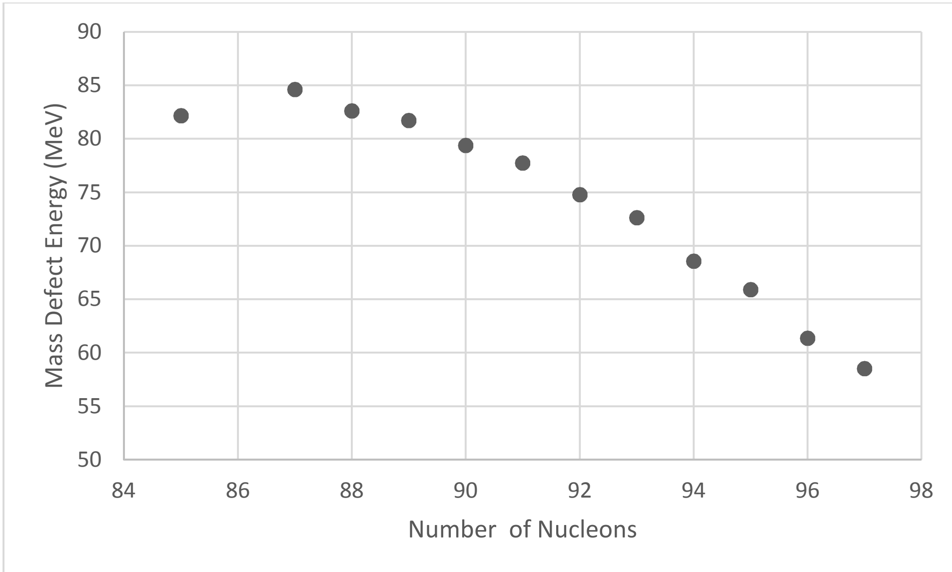


Fig. 4 Rubidium uranium-235 fission daughter isotopes' mass defect energy. Rubidium is the smaller of the two daughter isotopes in this pair with 37 protons in its nucleus.

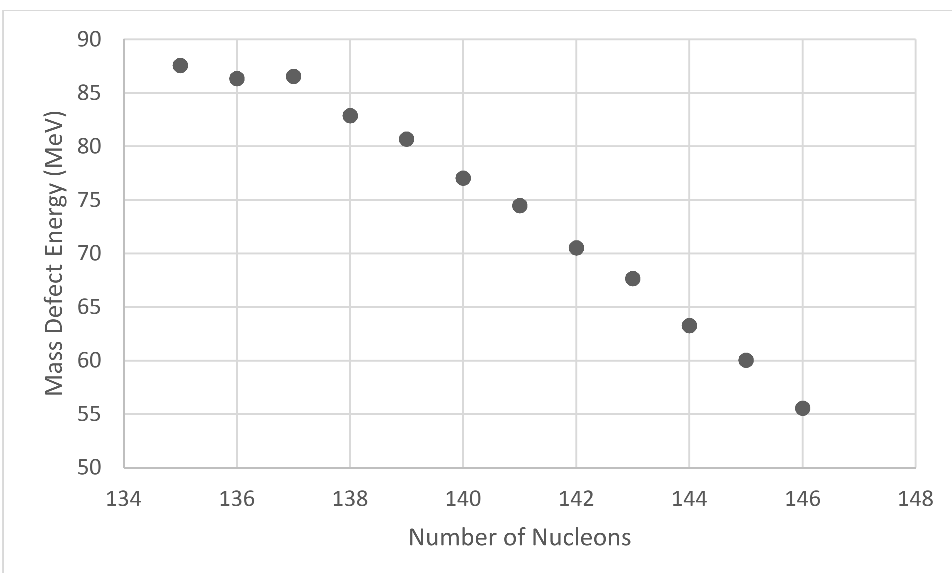


Fig. 5 Cesium uranium-235 fission daughter isotopes' mass defect energy.

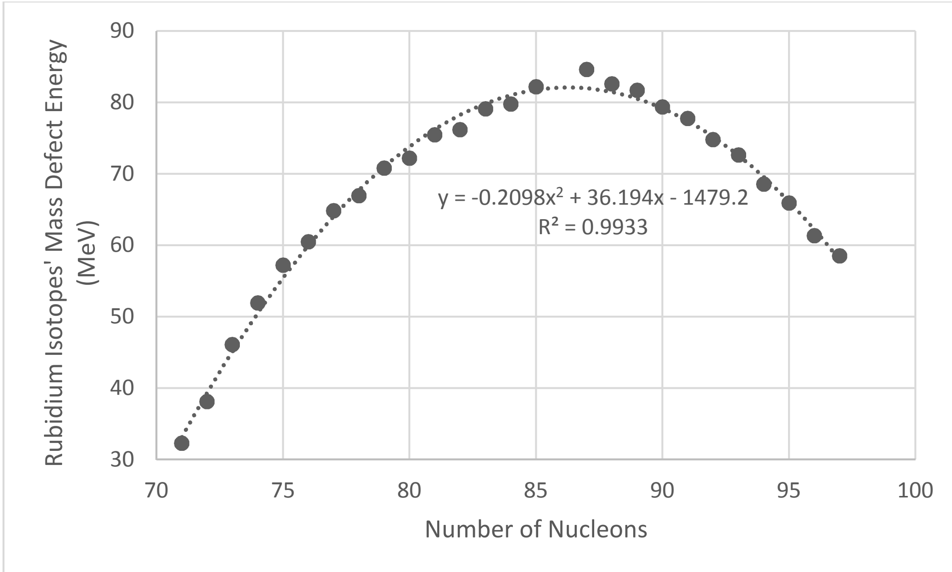


Fig. 6. All rubidium isotope mass defects. The last isotope that results from uranium-235 fission is rubidium-85. Each isotope to the left on this graph demonstrates the same decrease in mass defect as they move further from the stable nucleus.

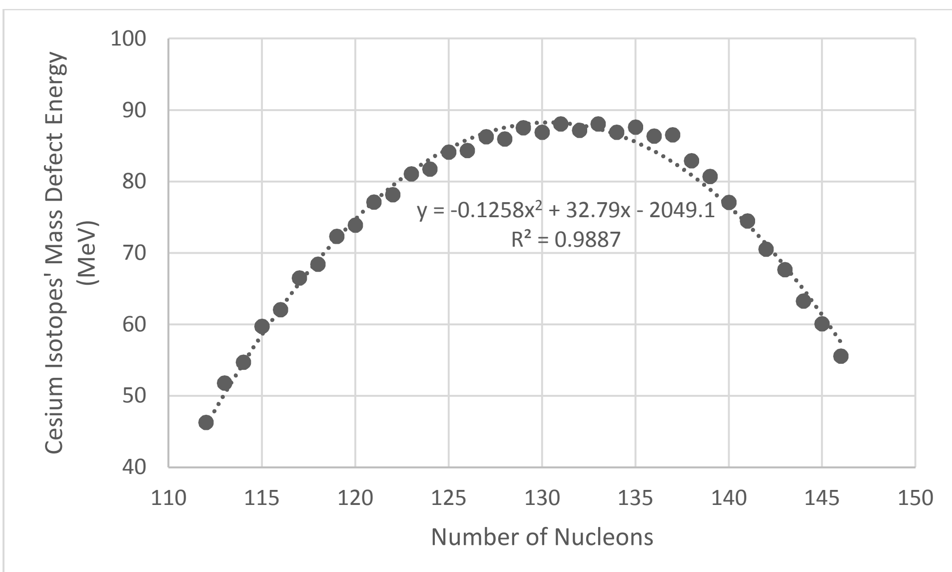


Fig. 7. All cesium isotope mass defects. Cesium-135 is the smallest cesium isotope that results from uranium-235 fission.

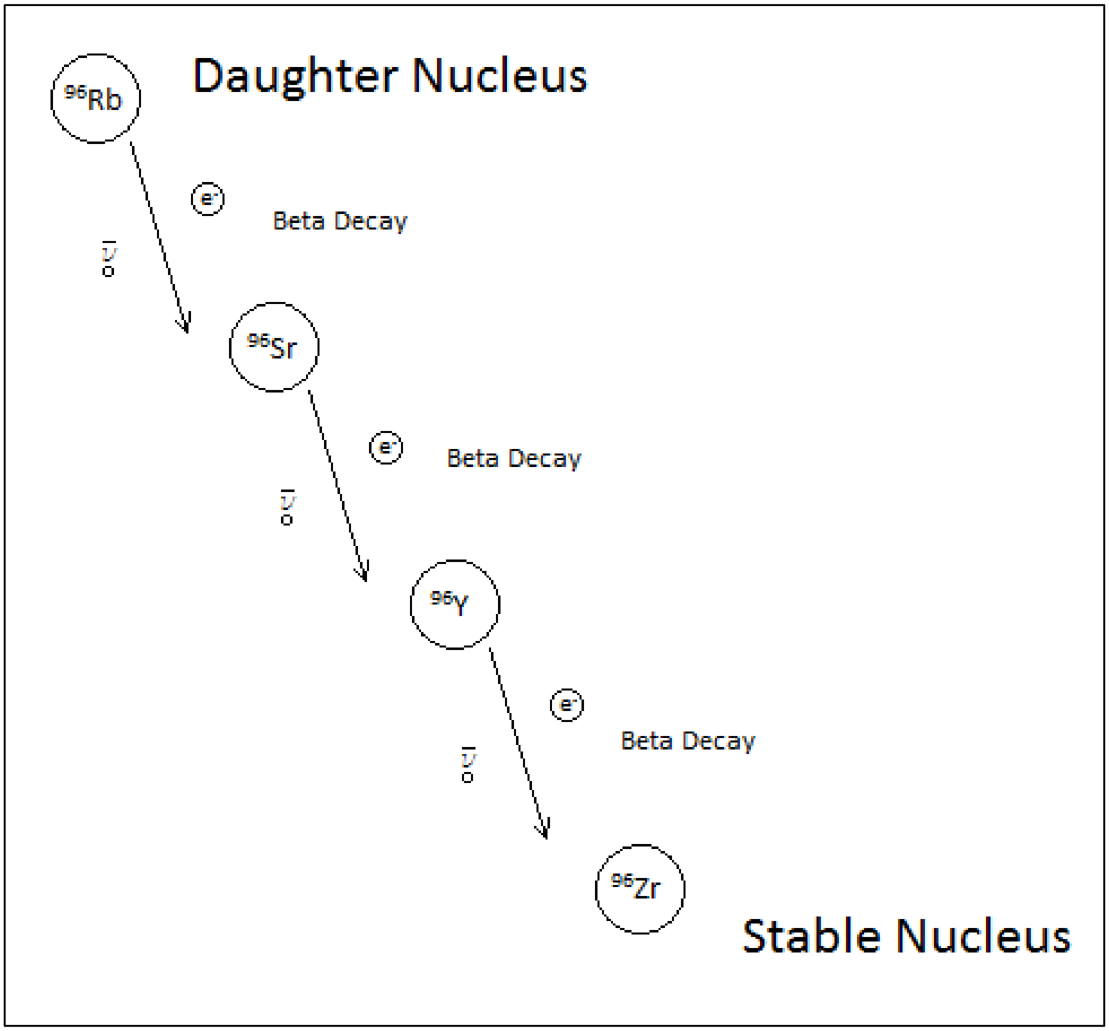


Fig. 8. Rubidium beta decay. In each beta decay event there is an electron and anti-neutrino emitted directly from the nucleus. Rubidium-96 undergoes three beta decays in less than ten seconds to release around 20 MeV of beta decay energy.

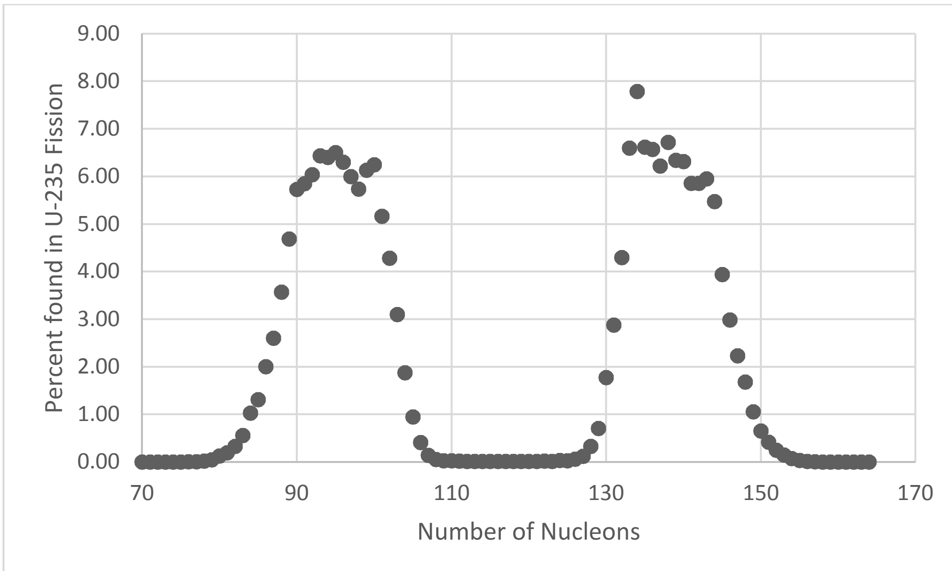


Fig. 9. Bimodal probability distribution of isotopes based on number of nucleons. Notice there are two individual ranges with increased probability of being produced in uranium-235 fission. A fission daughter pair will consist of one nucleus from each range.

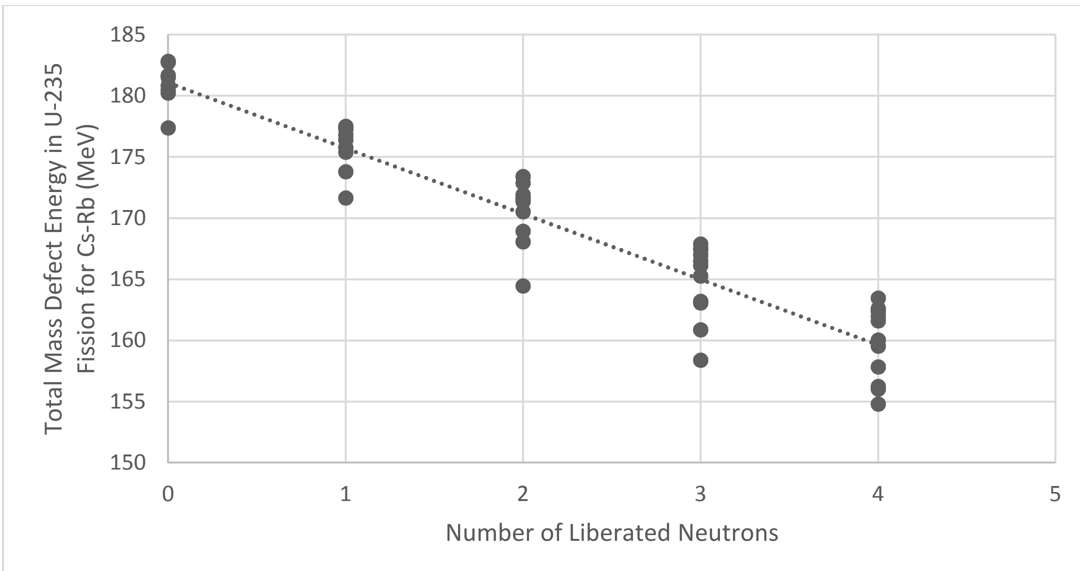


Fig. 10. Cesium-Rubidium pairs energy plot dependent on liberated neutrons. Liberating more neutrons reduces the initial energy released by fission events. Each bar of data points for each number of neutrons actually forms a parabola.

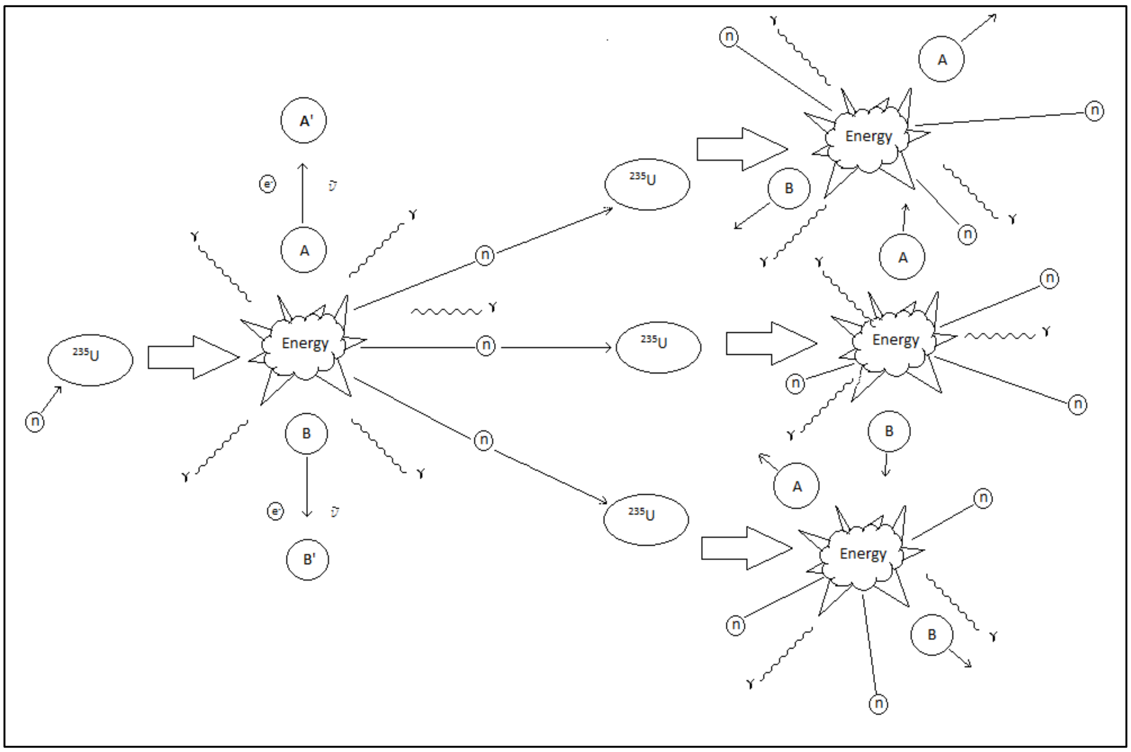


Fig. 11. Successive fission events with three liberated neutrons. Liberating three neutrons allows for a maximum of three additional fission events to result of the first.

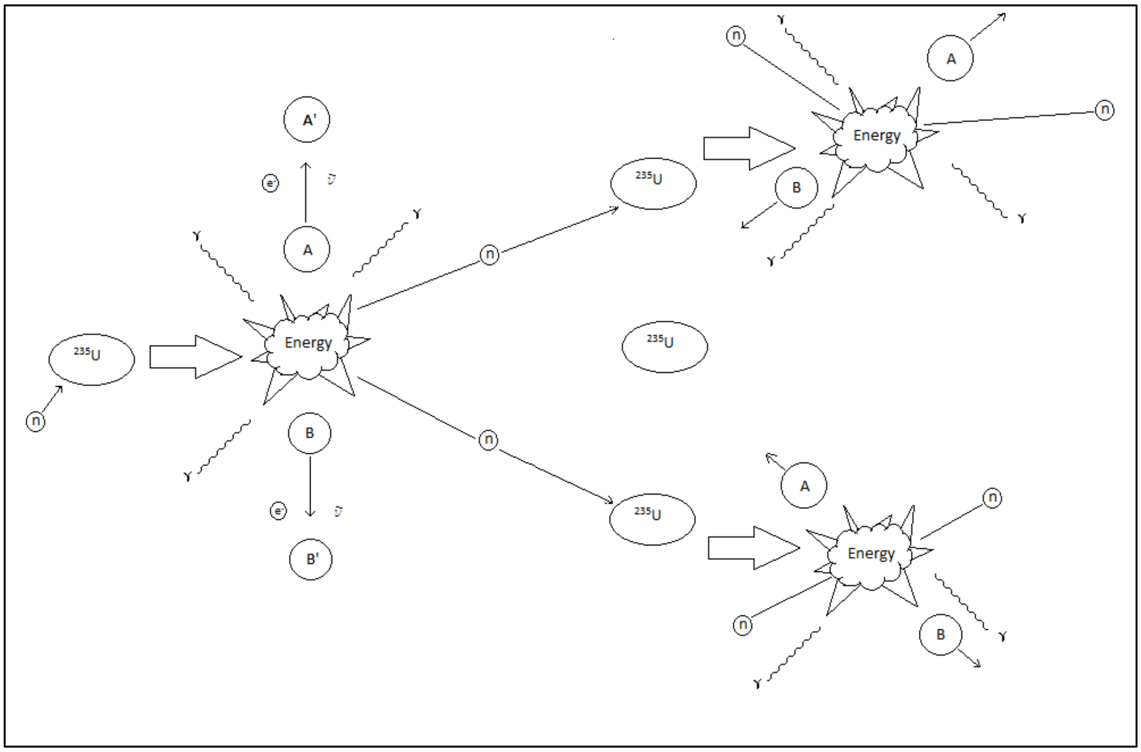


Fig. 12. Successive fission events with two liberated neutrons. A system with two liberated neutron fission events has potentially 200 MeV less than a system with three liberated neutron events as result of the first fission.

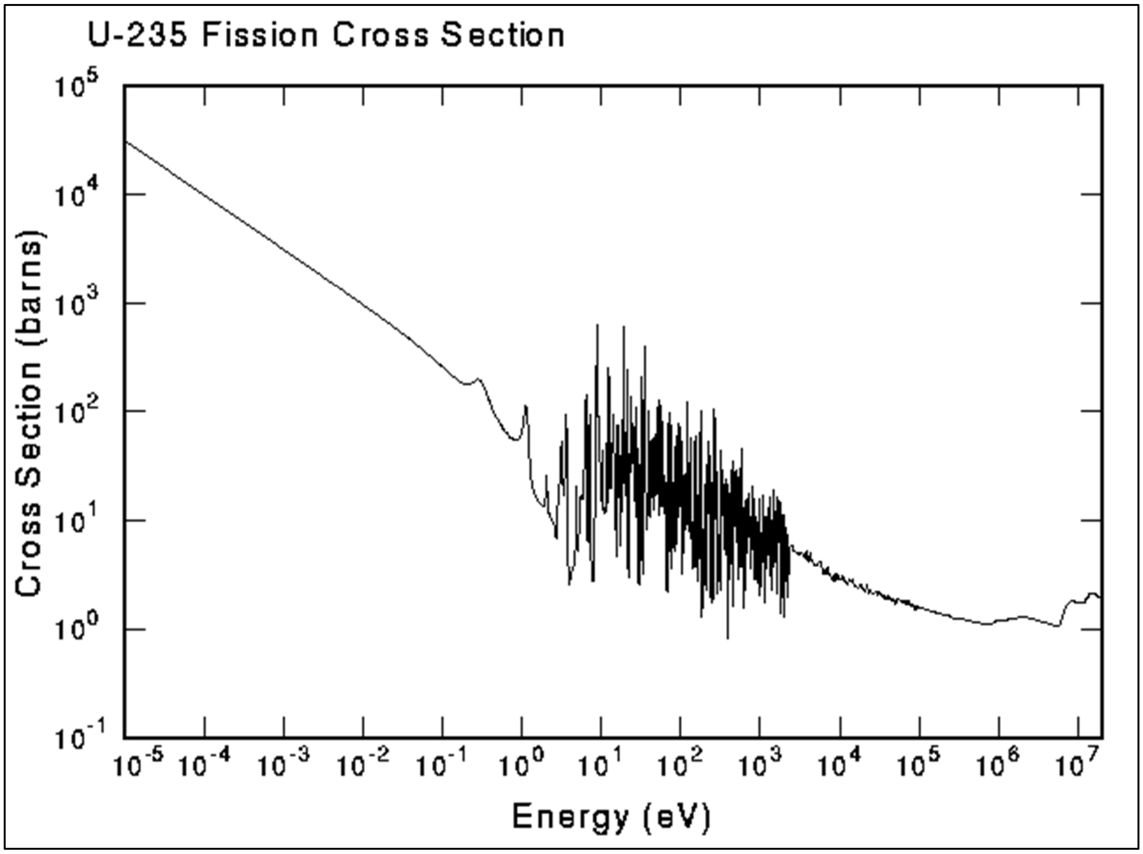


Fig. 13. Uranium-235 fission neutron cross section[15]. Notice the increased cross section in the 1/v region, which represents neutron energies lower than 0.1 eV. The variable cross sections in the resonance region stretch from 0.1 eV neutrons up to those with more than 1000 eV of kinetic energy. The fast neutron region extends from neutron energies above 10^5 eV.

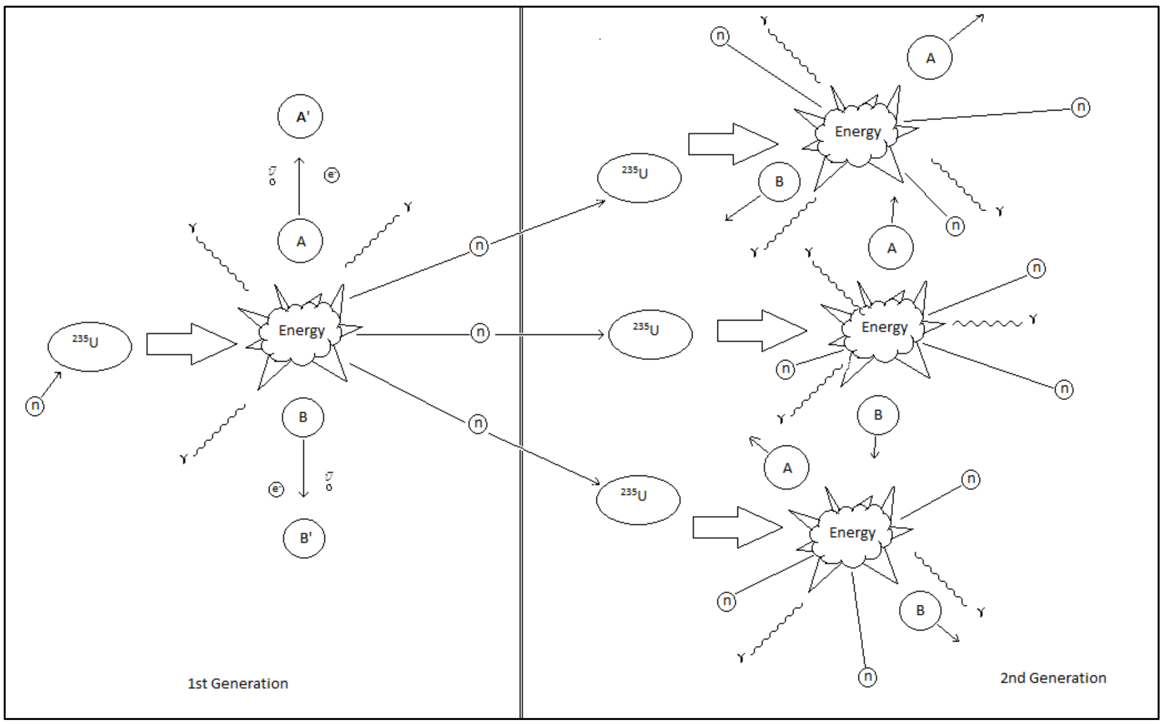


Fig. 14. First and second fission generations. The first generation includes all of the fission products, their kinetic energy, and the decay energy of the daughter nuclei. Neutrons liberated in the first generation then begin the second generation of fission events after moderation has slowed them sufficiently enough to induce fission.

Fission Daughter Pair Elements			
Element of Daughter Isotope A	Number of Protons in Isotope A	Element of Daughter Isotope B	Number of Protons in Isotope B
Copper	29	Europium	63
Zink	30	Samarium	62
Gallium	31	Promethium	61
Germanium	32	Neodymium	60
Arsenic	33	Praseodymium	59
Selenium	34	Cerium	58
Bromine	35	Lanthanum	57
Krypton	36	Barium	56
Rubidium	37	Cesium	55
Strontium	38	Xenon	54
Yttrium	39	Iodine	53
Zirconium	40	Tellurium	52
Niobium	41	Antimony	51
Molybdenum	42	Tin	50
Technetium	43	Indium	49
Ruthenium	44	Cadmium	48
Rhodium	45	Silver	47
Palladium	46	Palladium	46

Table 1. Fission daughter pair elements. Each row shows the element A and B of every possible fission daughter pair. Each element has multiple isotopes which allows for many possible daughter pairs.

		Thermal neutron			Fast neutron		
		Scattering	Capture	Fission	Scattering	Capture	Fission
Moderator	H-1	20	0.2	-	4	0.00004	-
	H-2	4	0.0003	-	3	0.000007	-
	C-12	5	0.002	-	2	0.00001	-
Structural materials, others	Zr-90	5	0.006	-	5	0.006	-
	Fe-56	10	2	-	20	0.003	-
	Cr-52	3	0.5	-	3	0.002	-
	Ni-58	20	3	-	3	0.008	-
	O-16	4	0.0001	-	3	0.00000003	-
Absorber	B-10	2	200	-	2	0.4	-
	Cd-113	100	30	-	4	0.05	-
	Xe-135	400	2,000,000	-	5	0.0008	-
	In-115	2	100	-	4	0.02	-
Fuel	U-235	10	99	583	4	0.09	1
	U-238	9	2	0.00002	5	0.07	0.3
	Pu-239	8	269	748	5	0.05	2

Table 2. Neutron cross sections of moderators, reactor components, and fuels[14]. Uranium-235 has a much higher fission cross section than uranium-238 for thermal neutrons. This makes it exceedingly special, particularly when considering it only makes up 0.72% of all uranium isotopes compared to uranium-238, which makes up 99.72%.

Appendix A

Uranium-235 Fission Daughter Isotopes

Element	A	N	Isotope	Mass Defect Energy (MeV)
Copper	29	46	Cu 75	54.4710
Zinc	30	44	Zn 74	65.7567
	30	45	Zn 75	62.5589
	30	46	Zn 76	62.3030
	30	47	Zn 77	58.7891
	30	48	Zn 78	57.4832
	30	49	Zn 79	53.4322
	30	50	Zn 80	51.6486
Gallium	31	44	Ga 75	68.4645
	31	45	Ga 76	66.2966
	31	46	Ga 77	65.9923
	31	47	Ga 78	63.7059
	31	48	Ga 79	62.5476
	31	49	Ga 80	59.2236
	31	50	Ga 81	57.6279
	31	51	Ga 82	52.9307
	31	52	Ga 83	49.2571
	31	53	Ga 84	44.2830
Germanium	32	44	Ge 76	73.2128
	32	45	Ge 77	71.2138
	32	46	Ge 78	71.8620
	32	47	Ge 79	69.5266
	32	48	Ge 80	69.5353
	32	49	Ge 81	66.2916
	32	50	Ge 82	65.4150
	32	51	Ge 83	60.9764
	32	52	Ge 84	58.1484
	32	53	Ge 85	53.1234
	32	54	Ge 86	49.7600
	32	55	Ge 87	44.2370
Arsenic	33	45	As 78	72.8173
	33	46	As 79	73.6364
	33	47	As 80	72.1715
	33	48	As 81	72.5333

Element	A	N	Isotope	Mass Defect Energy (MeV)
	33	49	As 82	70.1030
	33	50	As 83	69.6693
	33	51	As 84	65.8535
	33	52	As 85	63.1891
	33	53	As 86	58.9621
	33	54	As 87	55.6179
	33	55	As 88	50.8880
	33	56	As 89	46.9380
Selenium	34	46	Se 80	77.7598
	34	47	Se 81	76.3894
	34	48	Se 82	77.5940
	34	49	Se 83	75.3406
	34	50	Se 84	75.9476
	34	51	Se 85	72.4136
	34	52	Se 86	70.5031
	34	53	Se 87	66.4261
	34	54	Se 88	63.8841
	34	55	Se 89	58.9923
	34	56	Se 90	55.9270
	34	57	Se 91	50.3380
Bromine	35	48	Br 83	79.0064
	35	49	Br 84	77.7893
	35	50	Br 85	78.5754
	35	51	Br 86	75.6322
	35	52	Br 87	73.8916
	35	53	Br 88	70.7159
	35	54	Br 89	68.2742
	35	55	Br 90	64.0003
	35	56	Br 91	61.1072
	35	57	Br 92	56.2328
	35	58	Br 93	52.8530
	35	59	Br 94	47.5990
Krypton	36	48	Kr 84	82.4393
	36	49	Kr 85	81.4803
	36	50	Kr 86	83.2656
	36	51	Kr 87	80.7095
	36	52	Kr 88	79.6912
	36	53	Kr 89	76.5357
	36	54	Kr 90	74.9592

Element	A	N	Isotope	Mass Defect Energy (MeV)
	36	55	Kr 91	70.9739
	36	56	Kr 92	68.7693
	36	57	Kr 93	64.1359
	36	58	Kr 94	61.3477
	36	59	Kr 95	56.1589
	36	61	Kr 97	47.4234
Rubidium	37	48	Rb 85	82.1673
	37	50	Rb 87	84.5977
	37	51	Rb 88	82.6089
	37	52	Rb 89	81.7122
	37	53	Rb 90	79.3649
	37	54	Rb 91	77.7464
	37	55	Rb 92	74.7726
	37	56	Rb 93	72.6200
	37	57	Rb 94	68.5619
	37	58	Rb 95	65.8944
	37	59	Rb 96	61.3543
	37	60	Rb 97	58.5182
Strontium	38	51	Sr 89	86.2087
	38	52	Sr 90	85.9493
	38	53	Sr 91	83.6528
	38	54	Sr 92	82.8674
	38	55	Sr 93	80.0860
	38	56	Sr 94	78.8431
	38	57	Sr 95	75.1238
	38	58	Sr 96	72.9329
	38	59	Sr 97	68.5916
	38	60	Sr 98	66.4366
	38	61	Sr 99	62.5295
	38	62	Sr 100	59.8333
	38	63	Sr 101	55.5652
	38	64	Sr 102	52.4000
Yttrium	39	52	Y 91	86.3529
	39	53	Y 92	84.8179
	39	54	Y 93	84.2285
	39	55	Y 94	82.3529
	39	56	Y 95	81.2131
	39	57	Y 96	78.3447
	39	58	Y 97	76.1303

Element	A	N	Isotope	Mass Defect Energy (MeV)
	39	59	Y 98	72.3037
	39	60	Y 99	70.6589
	39	61	Y 100	67.3365
	39	62	Y 101	65.0702
Zirconium	40	52	Zr 92	88.4607
	40	53	Zr 93	87.1238
	40	54	Zr 94	87.2725
	40	55	Zr 95	85.6633
	40	56	Zr 96	85.4477
	40	57	Zr 97	82.9515
	40	58	Zr 98	81.2956
	40	59	Zr 99	77.6265
	40	60	Zr 100	76.3844
	40	61	Zr 101	73.1733
	40	62	Zr 102	71.5954
	40	63	Zr 103	67.8247
	40	64	Zr 104	65.7335
	40	65	Zr 105	61.4743
Niobium	41	54	Nb 95	86.7863
	41	55	Nb 96	85.6081
	41	56	Nb 97	85.6103
	41	57	Nb 98	83.5334
	41	58	Nb 99	82.3301
	41	59	Nb 100	79.8065
	41	60	Nb 101	78.8863
	41	61	Nb 102	76.3139
	41	62	Nb 103	75.0234
	41	63	Nb 104	71.8285
	41	64	Nb 105	69.9102
	41	65	Nb 106	66.1979
	41	66	Nb 107	63.7183
Molybdenum	42	57	Mo 99	85.9702
	42	58	Mo 100	86.1878
	42	59	Mo 101	83.5147
	42	60	Mo 102	83.5729
	42	61	Mo 103	80.9700
	42	62	Mo 104	80.3591
	42	63	Mo 105	77.3465
	42	64	Mo 106	76.1441

Element	A	N	Isotope	Mass Defect Energy (MeV)
	42	65	Mo 107	72.5613
	42	66	Mo 108	70.7657
	42	67	Mo 109	66.6759
	42	68	Mo 110	64.5525
	42	69	Mo 111	60.0630
Technetium	43	57	Tc 101	86.3390
	43	58	Tc 102	84.5691
	43	59	Tc 103	84.6004
	43	60	Tc 104	82.5091
	43	61	Tc 105	82.2943
	43	62	Tc 106	79.7737
	43	63	Tc 107	78.7464
	43	64	Tc 108	75.9193
	43	65	Tc 109	74.2792
	43	66	Tc 110	71.0309
	43	67	Tc 111	69.0210
	43	68	Tc 112	65.2532
	43	69	Tc 113	62.8777
Ruthenium	44	65	Ru 109	80.7348
	44	66	Ru 110	80.0695
	44	67	Ru 111	76.7816
	44	68	Ru 112	75.6272
	44	69	Ru 113	71.8743
	44	70	Ru 114	70.2154
	44	71	Ru 115	66.1895
Rhodium	45	66	Rh 111	82.3042
	45	68	Rh 113	78.7673
	45	69	Rh 114	75.7131
	45	70	Rh 115	74.2296
	45	71	Rh 116	70.7412
	45	72	Rh 117	68.8972
Palladium	46	66	Pd 112	86.3232
	46	67	Pd 113	83.5909
	46	68	Pd 114	83.4907
	46	69	Pd 115	80.4262
	46	70	Pd 116	79.8314
	46	71	Pd 117	76.4243
	46	72	Pd 118	75.3910
	46	73	Pd 119	71.4077

Element	A	N	Isotope	Mass Defect Energy (MeV)
	46	74	Pd 120	70.3099
Silver	47	67	Ag 114	84.9307
	47	68	Ag 115	84.9832
	47	69	Ag 116	82.5426
	47	70	Ag 117	82.1819
	47	71	Ag 118	79.5537
	47	73	Ag 120	75.6515
	47	74	Ag 121	74.4028
	47	75	Ag 122	71.1061
	47	76	Ag 123	69.5480
	47	77	Ag 124	66.2001
Cadmium	48	69	Cd 117	86.4223
	48	70	Cd 118	86.7056
	48	71	Cd 119	83.9770
	48	72	Cd 120	83.9573
	48	73	Cd 121	81.0577
	48	74	Cd 122	80.6165
	48	75	Cd 123	77.3187
	48	76	Cd 124	76.6974
	48	77	Cd 125	73.3479
	48	78	Cd 126	72.2564
	48	79	Cd 127	68.4354
	48	80	Cd 128	67.2503
	48	82	Cd 130	61.5382
	48	83	Cd 131	55.3770
Indium	49	70	In 119	87.6991
	49	71	In 120	85.7281
	49	72	In 121	85.8377
	49	73	In 122	83.5740
	49	74	In 123	83.4276
	49	75	In 124	80.8687
	49	76	In 125	80.4787
	49	77	In 126	77.8137
	49	78	In 127	76.8920
	49	79	In 128	74.3606
	49	80	In 129	72.8138
	49	81	In 130	69.8882
	49	82	In 131	68.0497
	49	83	In 132	62.4135

Element	A	N	Isotope	Mass Defect Energy (MeV)
	49	84	In 133	57.7620
Tin	50	71	Sn 121	89.1971
	50	72	Sn 122	89.9426
	50	73	Sn 123	87.8176
	50	74	Sn 124	88.2370
	50	75	Sn 125	85.8988
	50	76	Sn 126	86.0207
	50	77	Sn 127	83.4699
	50	78	Sn 128	83.3362
	50	79	Sn 129	80.5937
	50	80	Sn 130	80.1372
	50	81	Sn 131	77.2717
	50	82	Sn 132	76.5485
	50	83	Sn 133	70.8469
	50	84	Sn 134	66.3234
	50	85	Sn 135	60.6120
Antimony	51	75	Sb 126	86.3987
	51	76	Sb 127	86.7007
	51	77	Sb 128	84.6101
	51	78	Sb 129	84.6293
	51	79	Sb 130	82.2902
	51	80	Sb 131	81.9760
	51	81	Sb 132	79.6687
	51	82	Sb 133	78.9425
	51	83	Sb 134	74.1657
	51	84	Sb 135	69.7872
	51	85	Sb 136	64.5250
	51	86	Sb 137	60.3980
Tellurium	52	76	Te 128	88.9937
	52	78	Te 130	87.3529
	52	79	Te 131	85.2110
	52	80	Te 132	85.1803
	52	81	Te 133	82.9445
	52	82	Te 134	82.5595
	52	83	Te 135	77.9035
	52	84	Te 136	74.4790
	52	85	Te 137	69.2901
	52	86	Te 138	65.7551
	52	87	Te 139	60.3890

Element	A	N	Isotope	Mass Defect Energy (MeV)
	52	88	Te 140	56.5980
Iodine	53	77	I 130	86.9361
	53	78	I 131	87.4427
	53	79	I 132	85.6981
	53	80	I 133	85.8865
	53	81	I 134	84.0725
	53	82	I 135	83.7913
	53	83	I 136	79.5721
	53	84	I 137	76.5068
	53	85	I 138	71.9050
	53	86	I 139	68.5272
	53	87	I 140	63.5958
	53	88	I 141	60.3011
	53	89	I 142	55.0230
Xenon	54	79	Xe 133	87.6435
	54	80	Xe 134	88.1245
	54	81	Xe 135	86.4176
	54	82	Xe 136	86.4291
	54	83	Xe 137	82.3833
	54	84	Xe 138	79.9750
	54	85	Xe 139	75.6445
	54	86	Xe 140	72.9864
	54	87	Xe 141	68.1973
	54	88	Xe 142	65.2296
	54	89	Xe 143	60.2028
	54	90	Xe 144	56.8722
Cesium	55	80	Cs 135	87.5818
	55	81	Cs 136	86.3390
	55	82	Cs 137	86.5459
	55	83	Cs 138	82.8870
	55	84	Cs 139	80.7012
	55	85	Cs 140	77.0503
	55	86	Cs 141	74.4803
	55	87	Cs 142	70.5253
	55	88	Cs 143	67.6749
	55	89	Cs 144	63.2712
	55	90	Cs 145	60.0557
	55	91	Cs 146	55.5691
Barium	56	80	Ba 136	88.8872

Element	A	N	Isotope	Mass Defect Energy (MeV)
	56	81	Ba 137	87.7215
	56	82	Ba 138	88.2619
	56	83	Ba 139	84.9140
	56	84	Ba 140	83.2703
	56	85	Ba 141	79.7331
	56	86	Ba 142	77.8450
	56	87	Ba 143	73.9371
	56	88	Ba 144	71.7671
	56	89	Ba 145	67.5161
	56	90	Ba 146	64.9407
	56	91	Ba 147	60.2640
	56	92	Ba 148	57.5937
	56	93	Ba 149	53.1700
Lanthanum	57	83	La 140	84.3179
	57	84	La 141	82.9341
	57	85	La 142	80.0220
	57	86	La 143	78.1713
	57	87	La 144	74.8335
	57	88	La 145	72.8324
	57	89	La 146	69.0490
	57	90	La 147	66.6783
	57	91	La 148	62.7087
	57	92	La 149	60.2199
	57	93	La 150	56.5510
	57	94	La 151	53.8870
Cerium	57	85	Ce 142	84.5320
	57	86	Ce 143	81.6055
	57	87	Ce 144	80.4312
	57	88	Ce 145	77.0929
	57	89	Ce 146	75.6409
	57	90	Ce 147	72.0138
	57	91	Ce 148	70.3982
	57	92	Ce 149	66.6699
	57	93	Ce 150	64.8493
	57	94	Ce 151	61.2250
	57	95	Ce 152	59.3080
	57	96	Ce 153	55.2280
Praseodymium	58	87	Pr 145	79.6260
	58	88	Pr 146	76.6852

Element	A	N	Isotope	Mass Defect Energy (MeV)
	58	89	Pr 147	75.4437
	58	90	Pr 148	72.5350
	58	91	Pr 149	71.0393
	58	92	Pr 150	68.2995
	58	93	Pr 151	66.7804
	58	94	Pr 152	63.7580
	58	95	Pr 153	61.5815
	58	96	Pr 154	58.1947
	58	97	Pr 155	55.7780
Neodymium	59	89	Nd 148	77.4068
	59	90	Nd 149	74.3743
	59	91	Nd 150	73.6832
	59	92	Nd 151	70.9465
	59	93	Nd 152	70.1516
	59	94	Nd 153	67.3420
	59	95	Nd 154	65.6847
	59	96	Nd 155	62.4670
	59	97	Nd 156	60.5227
	59	98	Nd 157	56.7930
Promethium	60	91	Pm 151	73.3887
	60	92	Pm 152	71.2558
	60	93	Pm 153	70.6780
	60	94	Pm 154	68.4917
	60	95	Pm 155	66.9665
	60	96	Pm 156	64.2127
	60	97	Pm 157	62.3659
	60	98	Pm 158	59.1250
	60	99	Pm 159	56.8158
Samarium	61	93	Sm 154	72.4549
	61	94	Sm 155	70.1905
	61	95	Sm 156	69.3628
	61	96	Sm 157	66.7259
	61	97	Sm 158	65.2050
	61	98	Sm 159	62.2458
	61	99	Sm 160	60.4170
Europium	62	96	Eu 158	67.2040
	62	97	Eu 159	66.0458

Daughter Pairs of Uranium-235 Fission

For Events Liberating up to Four Neutrons

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Cu 75	54.471	Eu 159	66.0458	2	146.8218
Cu 75	54.471	Eu 158	67.204	3	139.9087
Zn 76	62.303	Sm 160	60.417	0	165.1676
Zn 77	58.7891	Sm 159	62.2458	0	163.4825
Zn 78	57.4832	Sm 158	65.205	0	165.1358
Zn 79	53.4322	Sm 157	66.7259	0	162.6057
Zn 80	51.6486	Sm 156	69.3628	0	163.459
Zn 75	62.5589	Sm 160	60.417	1	157.3522
Zn 76	62.303	Sm 159	62.2458	1	158.9251
Zn 77	58.7891	Sm 158	65.205	1	158.3704
Zn 78	57.4832	Sm 157	66.7259	1	158.5854
Zn 79	53.4322	Sm 156	69.3628	1	157.1713
Zn 80	51.6486	Sm 155	70.1905	1	156.2154
Zn 74	65.7567	Sm 160	60.417	2	152.4787
Zn 75	62.5589	Sm 159	62.2458	2	151.1097
Zn 76	62.303	Sm 158	65.205	2	153.813
Zn 77	58.7891	Sm 157	66.7259	2	151.82
Zn 78	57.4832	Sm 156	69.3628	2	153.151
Zn 79	53.4322	Sm 155	70.1905	2	149.9277
Zn 80	51.6486	Sm 154	72.4549	2	150.4085
Zn 74	65.7567	Sm 159	62.2458	3	146.2362
Zn 75	62.5589	Sm 158	65.205	3	145.9976
Zn 76	62.303	Sm 157	66.7259	3	147.2626
Zn 77	58.7891	Sm 156	69.3628	3	146.3856
Zn 78	57.4832	Sm 155	70.1905	3	145.9074
Zn 79	53.4322	Sm 154	72.4549	3	144.1208
Zn 74	65.7567	Sm 158	65.205	4	141.1241
Zn 75	62.5589	Sm 157	66.7259	4	139.4472
Zn 76	62.303	Sm 156	69.3628	4	141.8282
Zn 77	58.7891	Sm 155	70.1905	4	139.142

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Zn 78	57.4832	Sm 154	72.4549	4	140.1005
Ga 77	65.9923	Pm 159	56.8158	0	165.2557
Ga 78	63.7059	Pm 158	59.125	0	165.2785
Ga 79	62.5476	Pm 157	62.3659	0	167.3611
Ga 80	59.2236	Pm 156	64.2127	0	165.8839
Ga 81	57.6279	Pm 155	66.9665	0	167.042
Ga 82	52.9307	Pm 154	68.4917	0	163.87
Ga 83	49.2571	Pm 153	70.678	0	162.3827
Ga 84	44.283	Pm 152	71.2558	0	157.9864
Ga 76	66.2966	Pm 159	56.8158	1	157.4887
Ga 77	65.9923	Pm 158	59.125	1	159.4936
Ga 78	63.7059	Pm 157	62.3659	1	160.4481
Ga 79	62.5476	Pm 156	64.2127	1	161.1366
Ga 80	59.2236	Pm 155	66.9665	1	160.5664
Ga 81	57.6279	Pm 154	68.4917	1	160.4959
Ga 82	52.9307	Pm 153	70.678	1	157.985
Ga 83	49.2571	Pm 152	71.2558	1	154.8892
Ga 84	44.283	Pm 151	73.3887	1	152.048
Ga 75	68.4645	Pm 159	56.8158	2	151.5853
Ga 76	66.2966	Pm 158	59.125	2	151.7266
Ga 77	65.9923	Pm 157	62.3659	2	154.6632
Ga 78	63.7059	Pm 156	64.2127	2	154.2236
Ga 79	62.5476	Pm 155	66.9665	2	155.8191
Ga 80	59.2236	Pm 154	68.4917	2	154.0203
Ga 81	57.6279	Pm 153	70.678	2	154.6109
Ga 82	52.9307	Pm 152	71.2558	2	150.4915
Ga 83	49.2571	Pm 151	73.3887	2	148.9508
Ga 75	68.4645	Pm 158	59.125	3	145.8232
Ga 76	66.2966	Pm 157	62.3659	3	146.8962
Ga 77	65.9923	Pm 156	64.2127	3	148.4387
Ga 78	63.7059	Pm 155	66.9665	3	148.9061
Ga 79	62.5476	Pm 154	68.4917	3	149.273
Ga 80	59.2236	Pm 153	70.678	3	148.1353
Ga 81	57.6279	Pm 152	71.2558	3	147.1174
Ga 82	52.9307	Pm 151	73.3887	3	144.5531
Ga 75	68.4645	Pm 157	62.3659	4	140.9928
Ga 76	66.2966	Pm 156	64.2127	4	140.6717
Ga 77	65.9923	Pm 155	66.9665	4	143.1212

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Ga 78	63.7059	Pm 154	68.4917	4	142.36
Ga 79	62.5476	Pm 153	70.678	4	143.388
Ga 80	59.2236	Pm 152	71.2558	4	140.6418
Ga 81	57.6279	Pm 151	73.3887	4	141.179
Ge 79	69.5266	Nd 157	56.793	0	168.7672
Ge 80	69.5353	Nd 156	60.5227	0	172.5056
Ge 81	66.2916	Nd 155	62.467	0	171.2062
Ge 82	65.415	Nd 154	65.6847	0	173.5473
Ge 83	60.9764	Nd 153	67.342	0	170.766
Ge 84	58.1484	Nd 152	70.1516	0	170.7476
Ge 85	53.1234	Nd 151	70.9465	0	166.5175
Ge 86	49.76	Nd 150	73.6832	0	165.8908
Ge 87	44.237	Nd 149	74.3743	0	161.0589
Ge 78	71.862	Nd 157	56.793	1	163.0313
Ge 79	69.5266	Nd 156	60.5227	1	164.4256
Ge 80	69.5353	Nd 155	62.467	1	166.3786
Ge 81	66.2916	Nd 154	65.6847	1	166.3526
Ge 82	65.415	Nd 153	67.342	1	167.1333
Ge 83	60.9764	Nd 152	70.1516	1	165.5043
Ge 84	58.1484	Nd 151	70.9465	1	163.4712
Ge 85	53.1234	Nd 150	73.6832	1	161.1829
Ge 86	49.76	Nd 149	74.3743	1	158.5106
Ge 87	44.237	Nd 148	77.4068	1	156.0201
Ge 77	71.2138	Nd 157	56.793	2	154.3118
Ge 78	71.862	Nd 156	60.5227	2	158.6897
Ge 79	69.5266	Nd 155	62.467	2	158.2986
Ge 80	69.5353	Nd 154	65.6847	2	161.525
Ge 81	66.2916	Nd 153	67.342	2	159.9386
Ge 82	65.415	Nd 152	70.1516	2	161.8716
Ge 83	60.9764	Nd 151	70.9465	2	158.2279
Ge 84	58.1484	Nd 150	73.6832	2	158.1366
Ge 85	53.1234	Nd 149	74.3743	2	153.8027
Ge 86	49.76	Nd 148	77.4068	2	153.4718
Ge 76	73.2128	Nd 157	56.793	3	148.2395
Ge 77	71.2138	Nd 156	60.5227	3	149.9702
Ge 78	71.862	Nd 155	62.467	3	152.5627
Ge 79	69.5266	Nd 154	65.6847	3	153.445
Ge 80	69.5353	Nd 153	67.342	3	155.111

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Ge 81	**66.2916**	**Nd 152**	**70.1516**	**3**	**154.6769**
Ge 82	**65.415**	**Nd 151**	**70.9465**	**3**	**154.5952**
Ge 83	**60.9764**	**Nd 150**	**73.6832**	**3**	**152.8933**
Ge 84	**58.1484**	**Nd 149**	**74.3743**	**3**	**150.7564**
Ge 85	**53.1234**	**Nd 148**	**77.4068**	**3**	**148.7639**
Ge 76	**73.2128**	**Nd 156**	**60.5227**	**4**	**143.8979**
Ge 77	**71.2138**	**Nd 155**	**62.467**	**4**	**143.8432**
Ge 78	**71.862**	**Nd 154**	**65.6847**	**4**	**147.7091**
Ge 79	**69.5266**	**Nd 153**	**67.342**	**4**	**147.031**
Ge 80	**69.5353**	**Nd 152**	**70.1516**	**4**	**149.8493**
Ge 81	**66.2916**	**Nd 151**	**70.9465**	**4**	**147.4005**
Ge 82	**65.415**	**Nd 150**	**73.6832**	**4**	**149.2606**
Ge 83	**60.9764**	**Nd 149**	**74.3743**	**4**	**145.5131**
Ge 84	**58.1484**	**Nd 148**	**77.4068**	**4**	**145.7176**
Ge 79	**69.5266**	**Nd 157**	**56.793**	**0**	**168.7672**
Ge 80	**69.5353**	**Nd 156**	**60.5227**	**0**	**172.5056**
Ge 81	**66.2916**	**Nd 155**	**62.467**	**0**	**171.2062**
Ge 82	**65.415**	**Nd 154**	**65.6847**	**0**	**173.5473**
Ge 83	**60.9764**	**Nd 153**	**67.342**	**0**	**170.766**
Ge 84	**58.1484**	**Nd 152**	**70.1516**	**0**	**170.7476**
Ge 85	**53.1234**	**Nd 151**	**70.9465**	**0**	**166.5175**
Ge 86	**49.76**	**Nd 150**	**73.6832**	**0**	**165.8908**
Ge 87	**44.237**	**Nd 149**	**74.3743**	**0**	**161.0589**
Ge 78	**71.862**	**Nd 157**	**56.793**	**1**	**163.0313**
Ge 79	**69.5266**	**Nd 156**	**60.5227**	**1**	**164.4256**
Ge 80	**69.5353**	**Nd 155**	**62.467**	**1**	**166.3786**
Ge 81	**66.2916**	**Nd 154**	**65.6847**	**1**	**166.3526**
Ge 82	**65.415**	**Nd 153**	**67.342**	**1**	**167.1333**
Ge 83	**60.9764**	**Nd 152**	**70.1516**	**1**	**165.5043**
Ge 84	**58.1484**	**Nd 151**	**70.9465**	**1**	**163.4712**
Ge 85	**53.1234**	**Nd 150**	**73.6832**	**1**	**161.1829**
Ge 86	**49.76**	**Nd 149**	**74.3743**	**1**	**158.5106**
Ge 87	**44.237**	**Nd 148**	**77.4068**	**1**	**156.0201**
Ge 77	**71.2138**	**Nd 157**	**56.793**	**2**	**154.3118**
Ge 78	**71.862**	**Nd 156**	**60.5227**	**2**	**158.6897**
Ge 79	**69.5266**	**Nd 155**	**62.467**	**2**	**158.2986**
Ge 80	**69.5353**	**Nd 154**	**65.6847**	**2**	**161.525**
Ge 81	**66.2916**	**Nd 153**	**67.342**	**2**	**159.9386**
Ge 82	**65.415**	**Nd 152**	**70.1516**	**2**	**161.8716**

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Ge 83	60.9764	Nd 151	70.9465	2	158.2279
Ge 84	58.1484	Nd 150	73.6832	2	158.1366
Ge 85	53.1234	Nd 149	74.3743	2	153.8027
Ge 86	49.76	Nd 148	77.4068	2	153.4718
Ge 76	73.2128	Nd 157	56.793	3	148.2395
Ge 77	71.2138	Nd 156	60.5227	3	149.9702
Ge 78	71.862	Nd 155	62.467	3	152.5627
Ge 79	69.5266	Nd 154	65.6847	3	153.445
Ge 80	69.5353	Nd 153	67.342	3	155.111
Ge 81	66.2916	Nd 152	70.1516	3	154.6769
Ge 82	65.415	Nd 151	70.9465	3	154.5952
Ge 83	60.9764	Nd 150	73.6832	3	152.8933
Ge 84	58.1484	Nd 149	74.3743	3	150.7564
Ge 85	53.1234	Nd 148	77.4068	3	148.7639
Ge 76	73.2128	Nd 156	60.5227	4	143.8979
Ge 77	71.2138	Nd 155	62.467	4	143.8432
Ge 78	71.862	Nd 154	65.6847	4	147.7091
Ge 79	69.5266	Nd 153	67.342	4	147.031
Ge 80	69.5353	Nd 152	70.1516	4	149.8493
Ge 81	66.2916	Nd 151	70.9465	4	147.4005
Ge 82	65.415	Nd 150	73.6832	4	149.2606
Ge 83	60.9764	Nd 149	74.3743	4	145.5131
Ge 84	58.1484	Nd 148	77.4068	4	145.7176
Se 83	75.3406	Ce 153	55.228	0	173.0162
Se 84	75.9476	Ce 152	59.308	0	177.7032
Se 85	72.4136	Ce 151	61.225	0	176.0862
Se 86	70.5031	Ce 150	64.8493	0	177.8
Se 87	66.4261	Ce 149	66.6699	0	175.5436
Se 88	63.8841	Ce 148	70.3982	0	176.7299
Se 89	58.9923	Ce 147	72.0138	0	173.4537
Se 90	55.927	Ce 146	75.6409	0	174.0155
Se 91	50.338	Ce 145	77.0929	0	169.8785
Se 82	77.594	Ce 153	55.228	1	167.1983
Se 83	75.3406	Ce 152	59.308	1	169.0249
Se 84	75.9476	Ce 151	61.225	1	171.5489
Se 85	72.4136	Ce 150	64.8493	1	171.6392
Se 86	70.5031	Ce 149	66.6699	1	171.5493
Se 87	66.4261	Ce 148	70.3982	1	171.2006

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Se 88	63.8841	Ce 147	72.0138	1	170.2742
Se 89	58.9923	Ce 146	75.6409	1	169.0095
Se 90	55.927	Ce 145	77.0929	1	167.3962
Se 91	50.338	Ce 144	80.4312	1	165.1455
Se 81	76.3894	Ce 153	55.228	2	157.9224
Se 82	77.594	Ce 152	59.308	2	163.207
Se 83	75.3406	Ce 151	61.225	2	162.8706
Se 84	75.9476	Ce 150	64.8493	2	167.1019
Se 85	72.4136	Ce 149	66.6699	2	165.3885
Se 86	70.5031	Ce 148	70.3982	2	167.2063
Se 87	66.4261	Ce 147	72.0138	2	164.7449
Se 88	63.8841	Ce 146	75.6409	2	165.83
Se 89	58.9923	Ce 145	77.0929	2	162.3902
Se 90	55.927	Ce 144	80.4312	2	162.6632
Se 91	50.338	Ce 143	81.6055	2	158.2485
Se 80	77.7598	Ce 153	55.228	3	151.2215
Se 81	76.3894	Ce 152	59.308	3	153.9311
Se 82	77.594	Ce 151	61.225	3	157.0527
Se 83	75.3406	Ce 150	64.8493	3	158.4236
Se 84	75.9476	Ce 149	66.6699	3	160.8512
Se 85	72.4136	Ce 148	70.3982	3	161.0455
Se 86	70.5031	Ce 147	72.0138	3	160.7506
Se 87	66.4261	Ce 146	75.6409	3	160.3007
Se 88	63.8841	Ce 145	77.0929	3	159.2107
Se 89	58.9923	Ce 144	80.4312	3	157.6572
Se 90	55.927	Ce 143	81.6055	3	155.7662
Se 91	50.338	Ce 142	84.532	3	153.1037
Se 80	77.7598	Ce 152	59.308	4	147.2302
Se 81	76.3894	Ce 151	61.225	4	147.7768
Se 82	77.594	Ce 150	64.8493	4	152.6057
Se 83	75.3406	Ce 149	66.6699	4	152.1729
Se 84	75.9476	Ce 148	70.3982	4	156.5082
Se 85	72.4136	Ce 147	72.0138	4	154.5898
Se 86	70.5031	Ce 146	75.6409	4	156.3064
Se 87	66.4261	Ce 145	77.0929	4	153.6814
Se 88	63.8841	Ce 144	80.4312	4	154.4777
Se 89	58.9923	Ce 143	81.6055	4	150.7602
Se 90	55.927	Ce 142	84.532	4	150.6214

Daughter Isotope A	**Mass Defect Energy (MeV)**	**Daughter Isotope B**	**Mass Defect Energy (MeV)**	**Liberated Neutrons**	**Total Defect Energy (MeV)**
Br 85	**78.5754**	**La 151**	**53.887**	**0**	**174.91**
Br 86	**75.6322**	**La 150**	**56.551**	**0**	**174.6308**
Br 87	**73.8916**	**La 149**	**60.2199**	**0**	**176.5591**
Br 88	**70.7159**	**La 148**	**62.7087**	**0**	**175.8722**
Br 89	**68.2742**	**La 147**	**66.6783**	**0**	**177.4001**
Br 90	**64.0003**	**La 146**	**69.049**	**0**	**175.4969**
Br 91	**61.1072**	**La 145**	**72.8324**	**0**	**176.3872**
Br 92	**56.2328**	**La 144**	**74.8335**	**0**	**173.5139**
Br 93	**52.853**	**La 143**	**78.1713**	**0**	**173.4719**
Br 94	**47.599**	**La 142**	**80.022**	**0**	**170.0686**
Br 84	**77.7893**	**La 151**	**53.887**	**1**	**166.0526**
Br 85	**78.5754**	**La 150**	**56.551**	**1**	**169.5027**
Br 86	**75.6322**	**La 149**	**60.2199**	**1**	**170.2284**
Br 87	**73.8916**	**La 148**	**62.7087**	**1**	**170.9766**
Br 88	**70.7159**	**La 147**	**66.6783**	**1**	**171.7705**
Br 89	**68.2742**	**La 146**	**69.049**	**1**	**171.6995**
Br 90	**64.0003**	**La 145**	**72.8324**	**1**	**171.209**
Br 91	**61.1072**	**La 144**	**74.8335**	**1**	**170.317**
Br 92	**56.2328**	**La 143**	**78.1713**	**1**	**168.7804**
Br 93	**52.853**	**La 142**	**80.022**	**1**	**167.2513**
Br 94	**47.599**	**La 141**	**82.9341**	**1**	**164.9094**
Br 83	**79.0064**	**La 151**	**53.887**	**2**	**159.1984**
Br 84	**77.7893**	**La 150**	**56.551**	**2**	**160.6453**
Br 85	**78.5754**	**La 149**	**60.2199**	**2**	**165.1003**
Br 86	**75.6322**	**La 148**	**62.7087**	**2**	**164.6459**
Br 87	**73.8916**	**La 147**	**66.6783**	**2**	**166.8749**
Br 88	**70.7159**	**La 146**	**69.049**	**2**	**166.0699**
Br 89	**68.2742**	**La 145**	**72.8324**	**2**	**167.4116**
Br 90	**64.0003**	**La 144**	**74.8335**	**2**	**165.1388**
Br 91	**61.1072**	**La 143**	**78.1713**	**2**	**165.5835**
Br 92	**56.2328**	**La 142**	**80.022**	**2**	**162.5598**
Br 93	**52.853**	**La 141**	**82.9341**	**2**	**162.0921**
Br 94	**47.599**	**La 140**	**84.3179**	**2**	**158.2219**
Br 83	**79.0064**	**La 150**	**56.551**	**3**	**153.7911**
Br 84	**77.7893**	**La 149**	**60.2199**	**3**	**156.2429**
Br 85	**78.5754**	**La 148**	**62.7087**	**3**	**159.5178**
Br 86	**75.6322**	**La 147**	**66.6783**	**3**	**160.5442**
Br 87	**73.8916**	**La 146**	**69.049**	**3**	**161.1743**
Br 88	**70.7159**	**La 145**	**72.8324**	**3**	**161.782**

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Br 89	**68.2742**	**La 144**	**74.8335**	**3**	**161.3414**
Br 90	**64.0003**	**La 143**	**78.1713**	**3**	**160.4053**
Br 91	**61.1072**	**La 142**	**80.022**	**3**	**159.3629**
Br 92	**56.2328**	**La 141**	**82.9341**	**3**	**157.4006**
Br 93	**52.853**	**La 140**	**84.3179**	**3**	**155.4046**
Br 83	**79.0064**	**La 149**	**60.2199**	**4**	**149.3887**
Br 84	**77.7893**	**La 148**	**62.7087**	**4**	**150.6604**
Br 85	**78.5754**	**La 147**	**66.6783**	**4**	**155.4161**
Br 86	**75.6322**	**La 146**	**69.049**	**4**	**154.8436**
Br 87	**73.8916**	**La 145**	**72.8324**	**4**	**156.8864**
Br 88	**70.7159**	**La 144**	**74.8335**	**4**	**155.7118**
Br 89	**68.2742**	**La 143**	**78.1713**	**4**	**156.6079**
Br 90	**64.0003**	**La 142**	**80.022**	**4**	**154.1847**
Br 91	**61.1072**	**La 141**	**82.9341**	**4**	**154.2037**
Br 92	**56.2328**	**La 140**	**84.3179**	**4**	**150.7131**
Kr 87	**80.7095**	**Ba 149**	**53.17**	**0**	**176.3271**
Kr 88	**79.6912**	**Ba 148**	**57.5937**	**0**	**179.7325**
Kr 89	**76.5357**	**Ba 147**	**60.264**	**0**	**179.2473**
Kr 90	**74.9592**	**Ba 146**	**64.9407**	**0**	**182.3475**
Kr 91	**70.9739**	**Ba 145**	**67.5161**	**0**	**180.9376**
Kr 92	**68.7693**	**Ba 144**	**71.7671**	**0**	**182.984**
Kr 93	**64.1359**	**Ba 143**	**73.9371**	**0**	**180.5206**
Kr 94	**61.3477**	**Ba 142**	**77.845**	**0**	**181.6403**
Kr 95	**56.1589**	**Ba 141**	**79.7331**	**0**	**178.3396**
Kr 86	**83.2656**	**Ba 149**	**53.17**	**1**	**170.8119**
Kr 87	**80.7095**	**Ba 148**	**57.5937**	**1**	**172.6795**
Kr 88	**79.6912**	**Ba 147**	**60.264**	**1**	**174.3315**
Kr 89	**76.5357**	**Ba 146**	**64.9407**	**1**	**175.8527**
Kr 90	**74.9592**	**Ba 145**	**67.5161**	**1**	**176.8516**
Kr 91	**70.9739**	**Ba 144**	**71.7671**	**1**	**177.1173**
Kr 92	**68.7693**	**Ba 143**	**73.9371**	**1**	**177.0827**
Kr 93	**64.1359**	**Ba 142**	**77.845**	**1**	**176.3572**
Kr 94	**61.3477**	**Ba 141**	**79.7331**	**1**	**175.4571**
Kr 95	**56.1589**	**Ba 140**	**83.2703**	**1**	**173.8055**
Kr 85	**81.4803**	**Ba 149**	**53.17**	**2**	**160.9553**
Kr 86	**83.2656**	**Ba 148**	**57.5937**	**2**	**167.1643**
Kr 87	**80.7095**	**Ba 147**	**60.264**	**2**	**167.2785**
Kr 88	**79.6912**	**Ba 146**	**64.9407**	**2**	**170.9369**

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Kr 89	**76.5357**	**Ba 145**	**67.5161**	**2**	**170.3568**
Kr 90	**74.9592**	**Ba 144**	**71.7671**	**2**	**173.0313**
Kr 91	**70.9739**	**Ba 143**	**73.9371**	**2**	**171.216**
Kr 92	**68.7693**	**Ba 142**	**77.845**	**2**	**172.9193**
Kr 93	**64.1359**	**Ba 141**	**79.7331**	**2**	**170.174**
Kr 94	**61.3477**	**Ba 140**	**83.2703**	**2**	**170.923**
Kr 95	**56.1589**	**Ba 139**	**84.914**	**2**	**167.3779**
Kr 84	**82.4393**	**Ba 149**	**53.17**	**3**	**153.843**
Kr 85	**81.4803**	**Ba 148**	**57.5937**	**3**	**157.3077**
Kr 86	**83.2656**	**Ba 147**	**60.264**	**3**	**161.7633**
Kr 87	**80.7095**	**Ba 146**	**64.9407**	**3**	**163.8839**
Kr 88	**79.6912**	**Ba 145**	**67.5161**	**3**	**165.441**
Kr 89	**76.5357**	**Ba 144**	**71.7671**	**3**	**166.5365**
Kr 90	**74.9592**	**Ba 143**	**73.9371**	**3**	**167.13**
Kr 91	**70.9739**	**Ba 142**	**77.845**	**3**	**167.0526**
Kr 92	**68.7693**	**Ba 141**	**79.7331**	**3**	**166.7361**
Kr 93	**64.1359**	**Ba 140**	**83.2703**	**3**	**165.6399**
Kr 94	**61.3477**	**Ba 139**	**84.914**	**3**	**164.4954**
Kr 95	**56.1589**	**Ba 138**	**88.2619**	**3**	**162.6545**
Kr 84	**82.4393**	**Ba 148**	**57.5937**	**4**	**150.1954**
Kr 85	**81.4803**	**Ba 147**	**60.264**	**4**	**151.9067**
Kr 86	**83.2656**	**Ba 146**	**64.9407**	**4**	**158.3687**
Kr 87	**80.7095**	**Ba 145**	**67.5161**	**4**	**158.388**
Kr 88	**79.6912**	**Ba 144**	**71.7671**	**4**	**161.6207**
Kr 89	**76.5357**	**Ba 143**	**73.9371**	**4**	**160.6352**
Kr 90	**74.9592**	**Ba 142**	**77.845**	**4**	**162.9666**
Kr 91	**70.9739**	**Ba 141**	**79.7331**	**4**	**160.8694**
Kr 92	**68.7693**	**Ba 140**	**83.2703**	**4**	**162.202**
Kr 93	**64.1359**	**Ba 139**	**84.914**	**4**	**159.2123**
Kr 94	**61.3477**	**Ba 138**	**88.2619**	**4**	**159.772**
Kr 95	**56.1589**	**Ba 137**	**87.7215**	**4**	**154.0428**
Kr 84	**82.4393**	**Ba 147**	**60.264**	**5**	**144.7944**
Kr 85	**81.4803**	**Ba 146**	**64.9407**	**5**	**148.5121**
Kr 86	**83.2656**	**Ba 145**	**67.5161**	**5**	**152.8728**
Kr 87	**80.7095**	**Ba 144**	**71.7671**	**5**	**154.5677**
Kr 88	**79.6912**	**Ba 143**	**73.9371**	**5**	**155.7194**
Kr 90	**76.5357**	**Ba 142**	**77.845**	**5**	**156.4718**
Kr 91	**70.9739**	**Ba 140**	**83.2703**	**5**	**156.3353**
Kr 92	**68.7693**	**Ba 139**	**84.914**	**5**	**155.7744**

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Kr 93	**64.1359**	**Ba 138**	**88.2619**	**5**	**154.4889**
Kr 95	**56.1589**	**Ba 136**	**88.8872**	**5**	**147.1372**
Kr 84	**82.4393**	**Ba 146**	**64.9407**	**6**	**141.3998**
Kr 85	**81.4803**	**Ba 145**	**67.5161**	**6**	**143.0162**
Kr 86	**83.2656**	**Ba 144**	**71.7671**	**6**	**149.0525**
Kr 87	**80.7095**	**Ba 143**	**73.9371**	**6**	**148.6664**
Kr 88	**79.6912**	**Ba 142**	**77.845**	**6**	**151.556**
Kr 89	**76.5357**	**Ba 141**	**79.7331**	**6**	**150.2886**
Kr 90	**74.9592**	**Ba 140**	**83.2703**	**6**	**152.2493**
Kr 91	**70.9739**	**Ba 139**	**84.914**	**6**	**149.9077**
Kr 92	**68.7693**	**Ba 138**	**88.2619**	**6**	**151.051**
Kr 93	**64.1359**	**Ba 137**	**87.7215**	**6**	**145.8772**
Kr 84	**82.4393**	**Ba 145**	**67.5161**	**7**	**135.9039**
Kr 85	**81.4803**	**Ba 144**	**71.7671**	**7**	**139.1959**
Kr 86	**83.2656**	**Ba 143**	**73.9371**	**7**	**143.1512**
Kr 87	**80.7095**	**Ba 142**	**77.845**	**7**	**144.503**
Kr 88	**79.6912**	**Ba 141**	**79.7331**	**7**	**145.3728**
Kr 89	**76.5357**	**Ba 140**	**83.2703**	**7**	**145.7545**
Kr 90	**74.9592**	**Ba 139**	**84.914**	**7**	**145.8217**
Kr 91	**70.9739**	**Ba 138**	**88.2619**	**7**	**145.1843**
Kr 92	**68.7693**	**Ba 137**	**87.7215**	**7**	**142.4393**
Kr 93	**64.1359**	**Ba 136**	**88.8872**	**7**	**138.9716**
Rb 90	**79.3649**	**Cs 146**	**55.5691**	**0**	**177.3816**
Rb 91	**77.7464**	**Cs 145**	**60.0557**	**0**	**180.2497**
Rb 92	**74.7726**	**Cs 144**	**63.2712**	**0**	**180.4914**
Rb 93	**72.62**	**Cs 143**	**67.6749**	**0**	**182.7425**
Rb 94	**68.5619**	**Cs 142**	**70.5253**	**0**	**181.5348**
Rb 95	**65.8944**	**Cs 141**	**74.4803**	**0**	**182.8223**
Rb 96	**61.3543**	**Cs 140**	**77.0503**	**0**	**180.8522**
Rb 97	**58.5182**	**Cs 139**	**80.7012**	**0**	**181.667**
Rb 89	**81.7122**	**Cs 146**	**55.5691**	**1**	**171.6576**
Rb 90	**79.3649**	**Cs 145**	**60.0557**	**1**	**173.7969**
Rb 91	**77.7464**	**Cs 144**	**63.2712**	**1**	**175.3939**
Rb 92	**74.7726**	**Cs 143**	**67.6749**	**1**	**176.8238**
Rb 93	**72.62**	**Cs 142**	**70.5253**	**1**	**177.5216**
Rb 94	**68.5619**	**Cs 141**	**74.4803**	**1**	**177.4185**
Rb 95	**65.8944**	**Cs 140**	**77.0503**	**1**	**177.321**
Rb 96	**61.3543**	**Cs 139**	**80.7012**	**1**	**176.4318**

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Rb 97	**58.5182**	**Cs 138**	**82.887**	**1**	**175.7815**
Rb 88	**82.6089**	**Cs 146**	**55.5691**	**2**	**164.483**
Rb 89	**81.7122**	**Cs 145**	**60.0557**	**2**	**168.0729**
Rb 90	**79.3649**	**Cs 144**	**63.2712**	**2**	**168.9411**
Rb 91	**77.7464**	**Cs 143**	**67.6749**	**2**	**171.7263**
Rb 92	**74.7726**	**Cs 142**	**70.5253**	**2**	**171.6029**
Rb 93	**72.62**	**Cs 141**	**74.4803**	**2**	**173.4053**
Rb 94	**68.5619**	**Cs 140**	**77.0503**	**2**	**171.9172**
Rb 95	**65.8944**	**Cs 139**	**80.7012**	**2**	**172.9006**
Rb 96	**61.3543**	**Cs 138**	**82.887**	**2**	**170.5463**
Rb 97	**58.5182**	**Cs 137**	**86.5459**	**2**	**171.3691**
Rb 87	**84.5977**	**Cs 146**	**55.5691**	**3**	**158.4005**
Rb 88	**82.6089**	**Cs 145**	**60.0557**	**3**	**160.8983**
Rb 89	**81.7122**	**Cs 144**	**63.2712**	**3**	**163.2171**
Rb 90	**79.3649**	**Cs 143**	**67.6749**	**3**	**165.2735**
Rb 91	**77.7464**	**Cs 142**	**70.5253**	**3**	**166.5054**
Rb 92	**74.7726**	**Cs 141**	**74.4803**	**3**	**167.4866**
Rb 93	**72.62**	**Cs 140**	**77.0503**	**3**	**167.904**
Rb 94	**68.5619**	**Cs 139**	**80.7012**	**3**	**167.4968**
Rb 95	**65.8944**	**Cs 138**	**82.887**	**3**	**167.0151**
Rb 96	**61.3543**	**Cs 137**	**86.5459**	**3**	**166.1339**
Rb 97	**58.5182**	**Cs 136**	**86.339**	**3**	**163.0909**
Rb 87	**84.5977**	**Cs 145**	**60.0557**	**4**	**154.8158**
Rb 88	**82.6089**	**Cs 144**	**63.2712**	**4**	**156.0425**
Rb 89	**81.7122**	**Cs 143**	**67.6749**	**4**	**159.5495**
Rb 90	**79.3649**	**Cs 142**	**70.5253**	**4**	**160.0526**
Rb 91	**77.7464**	**Cs 141**	**74.4803**	**4**	**162.3891**
Rb 92	**74.7726**	**Cs 140**	**77.0503**	**4**	**161.9853**
Rb 93	**72.62**	**Cs 139**	**80.7012**	**4**	**163.4836**
Rb 94	**68.5619**	**Cs 138**	**82.887**	**4**	**161.6113**
Rb 95	**65.8944**	**Cs 137**	**86.5459**	**4**	**162.6027**
Rb 96	**61.3543**	**Cs 136**	**86.339**	**4**	**157.8557**
Rb 97	**58.5182**	**Cs 135**	**87.5818**	**4**	**156.2624**
Sr 92	**82.8674**	**Xe 144**	**56.8722**	**0**	**182.1872**
Sr 93	**80.086**	**Xe 143**	**60.2028**	**0**	**182.7364**
Sr 94	**78.8431**	**Xe 142**	**65.2296**	**0**	**186.5203**
Sr 95	**75.1238**	**Xe 141**	**68.1973**	**0**	**185.7687**
Sr 96	**72.9329**	**Xe 140**	**72.9864**	**0**	**188.3669**

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Sr 97	68.5916	Xe 139	75.6445	0	186.6837
Sr 98	66.4366	Xe 138	79.975	0	188.8592
Sr 99	62.5295	Xe 137	82.3833	0	187.3604
Sr 100	59.8333	Xe 136	86.4291	0	188.71
Sr 101	55.5652	Xe 135	86.4176	0	184.4304
Sr 102	52.4	Xe 134	88.1245	0	182.9
Sr 91	83.6528	Xe 144	56.8722	1	174.9013
Sr 92	82.8674	Xe 143	60.2028	1	177.4465
Sr 93	80.086	Xe 142	65.2296	1	179.6919
Sr 94	78.8431	Xe 141	68.1973	1	181.4167
Sr 95	75.1238	Xe 140	72.9864	1	182.4865
Sr 96	72.9329	Xe 139	75.6445	1	182.9537
Sr 97	68.5916	Xe 138	79.975	1	182.9429
Sr 98	66.4366	Xe 137	82.3833	1	183.1962
Sr 99	62.5295	Xe 136	86.4291	1	183.3349
Sr 100	59.8333	Xe 135	86.4176	1	180.6272
Sr 101	55.5652	Xe 134	88.1245	1	178.066
Sr 102	52.4	Xe 133	87.6435	1	174.4
Sr 90	85.9493	Xe 144	56.8722	2	169.1265
Sr 91	83.6528	Xe 143	60.2028	2	170.1606
Sr 92	82.8674	Xe 142	65.2296	2	174.402
Sr 93	80.086	Xe 141	68.1973	2	174.5883
Sr 94	78.8431	Xe 140	72.9864	2	178.1345
Sr 95	75.1238	Xe 139	75.6445	2	177.0733
Sr 96	72.9329	Xe 138	79.975	2	179.2129
Sr 97	68.5916	Xe 137	82.3833	2	177.2799
Sr 98	66.4366	Xe 136	86.4291	2	179.1707
Sr 99	62.5295	Xe 135	86.4176	2	175.2521
Sr 100	59.8333	Xe 134	88.1245	2	174.2628
Sr 101	55.5652	Xe 133	87.6435	2	169.5137
Sr 89	86.2087	Xe 144	56.8722	3	161.3146
Sr 90	85.9493	Xe 143	60.2028	3	164.3858
Sr 91	83.6528	Xe 142	65.2296	3	167.1161
Sr 92	82.8674	Xe 141	68.1973	3	169.2984
Sr 93	80.086	Xe 140	72.9864	3	171.3061
Sr 94	78.8431	Xe 139	75.6445	3	172.7213
Sr 95	75.1238	Xe 138	79.975	3	173.3325
Sr 96	72.9329	Xe 137	82.3833	3	173.5499
Sr 97	68.5916	Xe 136	86.4291	3	173.2544

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Sr 98	**66.4366**	**Xe 135**	**86.4176**	**3**	**171.0879**
Sr 99	**62.5295**	**Xe 134**	**88.1245**	**3**	**168.8877**
Sr 100	**59.8333**	**Xe 133**	**87.6435**	**3**	**165.7105**
Sr 89	**86.2087**	**Xe 143**	**60.2028**	**4**	**156.5739**
Sr 90	**85.9493**	**Xe 142**	**65.2296**	**4**	**161.3413**
Sr 91	**83.6528**	**Xe 141**	**68.1973**	**4**	**162.0125**
Sr 92	**82.8674**	**Xe 140**	**72.9864**	**4**	**166.0162**
Sr 93	**80.086**	**Xe 139**	**75.6445**	**4**	**165.8929**
Sr 94	**78.8431**	**Xe 138**	**79.975**	**4**	**168.9805**
Sr 95	**75.1238**	**Xe 137**	**82.3833**	**4**	**167.6695**
Sr 96	**72.9329**	**Xe 136**	**86.4291**	**4**	**169.5244**
Sr 97	**68.5916**	**Xe 135**	**86.4176**	**4**	**165.1716**
Sr 98	**66.4366**	**Xe 134**	**88.1245**	**4**	**164.7235**
Sr 99	**62.5295**	**Xe 133**	**87.6435**	**4**	**160.3354**
Y 94	**82.3529**	**I 142**	**55.023**	**0**	**179.8235**
Y 95	**81.2131**	**I 141**	**60.3011**	**0**	**183.9618**
Y 96	**78.3447**	**I 140**	**63.5958**	**0**	**184.3881**
Y 97	**76.1303**	**I 139**	**68.5272**	**0**	**187.1051**
Y 98	**72.3037**	**I 138**	**71.905**	**0**	**186.6563**
Y 99	**70.6589**	**I 137**	**76.5068**	**0**	**189.6133**
Y 100	**67.3365**	**I 136**	**79.5721**	**0**	**189.3562**
Y 101	**65.0702**	**I 135**	**83.7913**	**0**	**191.3091**
Y 93	**84.2285**	**I 142**	**55.023**	**1**	**173.6278**
Y 94	**82.3529**	**I 141**	**60.3011**	**1**	**177.0303**
Y 95	**81.2131**	**I 140**	**63.5958**	**1**	**179.1852**
Y 96	**78.3447**	**I 139**	**68.5272**	**1**	**181.2482**
Y 97	**76.1303**	**I 138**	**71.905**	**1**	**182.4116**
Y 98	**72.3037**	**I 137**	**76.5068**	**1**	**183.1868**
Y 99	**70.6589**	**I 136**	**79.5721**	**1**	**184.6073**
Y 100	**67.3365**	**I 135**	**83.7913**	**1**	**185.5041**
Y 101	**65.0702**	**I 134**	**84.0725**	**1**	**183.519**
Y 92	**84.8179**	**I 142**	**55.023**	**2**	**166.1459**
Y 93	**84.2285**	**I 141**	**60.3011**	**2**	**170.8346**
Y 94	**82.3529**	**I 140**	**63.5958**	**2**	**172.2537**
Y 95	**81.2131**	**I 139**	**68.5272**	**2**	**176.0453**
Y 96	**78.3447**	**I 138**	**71.905**	**2**	**176.5547**
Y 97	**76.1303**	**I 137**	**76.5068**	**2**	**178.9421**
Y 98	**72.3037**	**I 136**	**79.5721**	**2**	**178.1808**

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Y 99	**70.6589**	**I 135**	**83.7913**	**2**	**180.7552**
Y 100	**67.3365**	**I 134**	**84.0725**	**2**	**177.714**
Y 101	**65.0702**	**I 133**	**85.8865**	**2**	**177.2617**
Y 91	**86.3529**	**I 142**	**55.023**	**3**	**159.6096**
Y 92	**84.8179**	**I 141**	**60.3011**	**3**	**163.3527**
Y 93	**84.2285**	**I 140**	**63.5958**	**3**	**166.058**
Y 94	**82.3529**	**I 139**	**68.5272**	**3**	**169.1138**
Y 95	**81.2131**	**I 138**	**71.905**	**3**	**171.3518**
Y 96	**78.3447**	**I 137**	**76.5068**	**3**	**173.0852**
Y 97	**76.1303**	**I 136**	**79.5721**	**3**	**173.9361**
Y 98	**72.3037**	**I 135**	**83.7913**	**3**	**174.3287**
Y 99	**70.6589**	**I 134**	**84.0725**	**3**	**172.9651**
Y 100	**67.3365**	**I 133**	**85.8865**	**3**	**171.4567**
Y 101	**65.0702**	**I 132**	**85.6981**	**3**	**169.002**
Y 91	**86.3529**	**I 141**	**60.3011**	**4**	**156.8164**
Y 92	**84.8179**	**I 140**	**63.5958**	**4**	**158.5761**
Y 93	**84.2285**	**I 139**	**68.5272**	**4**	**162.9181**
Y 94	**82.3529**	**I 138**	**71.905**	**4**	**164.4203**
Y 95	**81.2131**	**I 137**	**76.5068**	**4**	**167.8823**
Y 96	**78.3447**	**I 136**	**79.5721**	**4**	**168.0792**
Y 97	**76.1303**	**I 135**	**83.7913**	**4**	**170.084**
Y 98	**72.3037**	**I 134**	**84.0725**	**4**	**166.5386**
Y 99	**70.6589**	**I 133**	**85.8865**	**4**	**166.7078**
Y 100	**67.3365**	**I 132**	**85.6981**	**4**	**163.197**
Y 101	**65.0702**	**I 131**	**87.4427**	**4**	**162.6753**
Zr 96	**85.4477**	**Te 140**	**56.598**	**0**	**184.4933**
Zr 97	**82.9515**	**Te 139**	**60.389**	**0**	**185.7881**
Zr 98	**81.2956**	**Te 138**	**65.7551**	**0**	**189.4983**
Zr 99	**77.6265**	**Te 137**	**69.2901**	**0**	**189.3642**
Zr 100	**76.3844**	**Te 136**	**74.479**	**0**	**193.311**
Zr 101	**73.1733**	**Te 135**	**77.9035**	**0**	**193.5244**
Zr 102	**71.5954**	**Te 134**	**82.5595**	**0**	**196.6025**
Zr 103	**67.8247**	**Te 133**	**82.9445**	**0**	**193.2168**
Zr 104	**65.7335**	**Te 132**	**85.1803**	**0**	**193.3614**
Zr 105	**61.4743**	**Te 131**	**85.211**	**0**	**189.1329**
Zr 95	**85.6633**	**Te 140**	**56.598**	**1**	**176.6376**
Zr 96	**85.4477**	**Te 139**	**60.389**	**1**	**180.213**
Zr 97	**82.9515**	**Te 138**	**65.7551**	**1**	**183.0829**

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Zr 98	81.2956	Te 137	69.2901	1	184.962
Zr 99	77.6265	Te 136	74.479	1	186.4818
Zr 100	76.3844	Te 135	77.9035	1	188.6642
Zr 101	73.1733	Te 134	82.5595	1	190.1091
Zr 102	71.5954	Te 133	82.9445	1	188.9162
Zr 103	67.8247	Te 132	85.1803	1	187.3813
Zr 104	65.7335	Te 131	85.211	1	185.3208
Zr 105	61.4743	Te 130	87.3529	1	183.2035
Zr 94	87.2725	Te 140	56.598	2	170.1755
Zr 95	85.6633	Te 139	60.389	2	172.3573
Zr 96	85.4477	Te 138	65.7551	2	177.5078
Zr 97	82.9515	Te 137	69.2901	2	178.5466
Zr 98	81.2956	Te 136	74.479	2	182.0796
Zr 99	77.6265	Te 135	77.9035	2	181.835
Zr 100	76.3844	Te 134	82.5595	2	185.2489
Zr 101	73.1733	Te 133	82.9445	2	182.4228
Zr 102	71.5954	Te 132	85.1803	2	183.0807
Zr 103	67.8247	Te 131	85.211	2	179.3407
Zr 104	65.7335	Te 130	87.3529	2	179.3914
Zr 93	87.1238	Te 140	56.598	3	161.9555
Zr 94	87.2725	Te 139	60.389	3	165.8952
Zr 95	85.6633	Te 138	65.7551	3	169.6521
Zr 96	85.4477	Te 137	69.2901	3	172.9715
Zr 97	82.9515	Te 136	74.479	3	175.6642
Zr 98	81.2956	Te 135	77.9035	3	177.4328
Zr 99	77.6265	Te 134	82.5595	3	178.4197
Zr 100	76.3844	Te 133	82.9445	3	177.5626
Zr 101	73.1733	Te 132	85.1803	3	176.5873
Zr 102	71.5954	Te 131	85.211	3	175.0401
Zr 103	67.8247	Te 130	87.3529	3	173.4113
Zr 105	61.4743	Te 128	88.9937	3	168.7017
Zr 92	88.4607	Te 140	56.598	4	155.2211
Zr 93	87.1238	Te 139	60.389	4	157.6752
Zr 94	87.2725	Te 138	65.7551	4	163.19
Zr 95	85.6633	Te 137	69.2901	4	165.1158
Zr 96	85.4477	Te 136	74.479	4	170.0891
Zr 97	82.9515	Te 135	77.9035	4	171.0174
Zr 98	81.2956	Te 134	82.5595	4	174.0175
Zr 99	77.6265	Te 133	82.9445	4	170.7334

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Zr 100	76.3844	Te 132	85.1803	4	171.7271
Zr 101	73.1733	Te 131	85.211	4	168.5467
Zr 102	71.5954	Te 130	87.3529	4	169.1107
Zr 104	65.7335	Te 128	88.9937	4	164.8896
Nb 99	82.3301	Sb 137	60.398	0	185.1757
Nb 100	79.8065	Sb 136	64.525	0	186.7791
Nb 101	78.8863	Sb 135	69.7872	0	191.1211
Nb 102	76.3139	Sb 134	74.1657	0	192.9272
Nb 103	75.0234	Sb 133	78.9425	0	196.4135
Nb 104	71.8285	Sb 132	79.6687	0	193.9448
Nb 105	69.9102	Sb 131	81.976	0	194.3338
Nb 106	66.1979	Sb 130	82.2902	0	190.9357
Nb 107	63.7183	Sb 129	84.6293	0	190.7952
Nb 98	83.5334	Sb 137	60.398	1	178.3077
Nb 99	82.3301	Sb 136	64.525	1	181.2314
Nb 100	79.8065	Sb 135	69.7872	1	183.97
Nb 101	78.8863	Sb 134	74.1657	1	187.4283
Nb 102	76.3139	Sb 133	78.9425	1	189.6327
Nb 103	75.0234	Sb 132	79.6687	1	189.0684
Nb 104	71.8285	Sb 131	81.976	1	188.1808
Nb 105	69.9102	Sb 130	82.2902	1	186.5767
Nb 106	66.1979	Sb 129	84.6293	1	185.2035
Nb 107	63.7183	Sb 128	84.6101	1	182.7047
Nb 97	85.6103	Sb 137	60.398	2	172.3133
Nb 98	83.5334	Sb 136	64.525	2	174.3634
Nb 99	82.3301	Sb 135	69.7872	2	178.4223
Nb 100	79.8065	Sb 134	74.1657	2	180.2772
Nb 101	78.8863	Sb 133	78.9425	2	184.1338
Nb 102	76.3139	Sb 132	79.6687	2	182.2876
Nb 103	75.0234	Sb 131	81.976	2	183.3044
Nb 104	71.8285	Sb 130	82.2902	2	180.4237
Nb 105	69.9102	Sb 129	84.6293	2	180.8445
Nb 106	66.1979	Sb 128	84.6101	2	177.113
Nb 107	63.7183	Sb 127	86.7007	2	176.724
Nb 96	85.6081	Sb 137	60.398	3	164.2398
Nb 97	85.6103	Sb 136	64.525	3	168.369
Nb 98	83.5334	Sb 135	69.7872	3	171.5543
Nb 99	82.3301	Sb 134	74.1657	3	174.7295

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Nb 100	79.8065	Sb 133	78.9425	3	176.9827
Nb 101	78.8863	Sb 132	79.6687	3	176.7887
Nb 102	76.3139	Sb 131	81.976	3	176.5236
Nb 103	75.0234	Sb 130	82.2902	3	175.5473
Nb 104	71.8285	Sb 129	84.6293	3	174.6915
Nb 105	69.9102	Sb 128	84.6101	3	172.754
Nb 106	66.1979	Sb 127	86.7007	3	171.1323
Nb 107	63.7183	Sb 126	86.3987	3	168.3507
Nb 95	86.7863	Sb 137	60.398	4	157.3467
Nb 96	85.6081	Sb 136	64.525	4	160.2955
Nb 97	85.6103	Sb 135	69.7872	4	165.5599
Nb 98	83.5334	Sb 134	74.1657	4	167.8615
Nb 99	82.3301	Sb 133	78.9425	4	171.435
Nb 100	79.8065	Sb 132	79.6687	4	169.6376
Nb 101	78.8863	Sb 131	81.976	4	171.0247
Nb 102	76.3139	Sb 130	82.2902	4	168.7665
Nb 103	75.0234	Sb 129	84.6293	4	169.8151
Nb 104	71.8285	Sb 128	84.6101	4	166.601
Nb 105	69.9102	Sb 127	86.7007	4	166.7733
Nb 106	66.1979	Sb 126	86.3987	4	162.759
Mo 101	83.5147	Sn 135	60.612	0	186.5743
Mo 102	83.5729	Sn 134	66.3234	0	192.3439
Mo 103	80.97	Sn 133	70.8469	0	194.2645
Mo 104	80.3591	Sn 132	76.5485	0	199.3552
Mo 105	77.3465	Sn 131	77.2717	0	197.0658
Mo 106	76.1441	Sn 130	80.1372	0	198.7289
Mo 107	72.5613	Sn 129	80.5937	0	195.6026
Mo 108	70.7657	Sn 128	83.3362	0	196.5495
Mo 109	66.6759	Sn 127	83.4699	0	192.5934
Mo 110	64.5525	Sn 126	86.0207	0	193.0208
Mo 111	60.063	Sn 125	85.8988	0	188.4094
Mo 100	86.1878	Sn 135	60.612	1	181.1761
Mo 101	83.5147	Sn 134	66.3234	1	184.2144
Mo 102	83.5729	Sn 133	70.8469	1	188.7961
Mo 103	80.97	Sn 132	76.5485	1	191.8948
Mo 104	80.3591	Sn 131	77.2717	1	192.0071
Mo 105	77.3465	Sn 130	80.1372	1	191.86
Mo 106	76.1441	Sn 129	80.5937	1	191.1141

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Mo 107	**72.5613**	**Sn 128**	**83.3362**	**1**	**190.2738**
Mo 108	**70.7657**	**Sn 127**	**83.4699**	**1**	**188.6119**
Mo 109	**66.6759**	**Sn 126**	**86.0207**	**1**	**187.0729**
Mo 110	**64.5525**	**Sn 125**	**85.8988**	**1**	**184.8276**
Mo 111	**60.063**	**Sn 124**	**88.237**	**1**	**182.6763**
Mo 99	**85.9702**	**Sn 135**	**60.612**	**2**	**172.8872**
Mo 100	**86.1878**	**Sn 134**	**66.3234**	**2**	**178.8162**
Mo 101	**83.5147**	**Sn 133**	**70.8469**	**2**	**180.6666**
Mo 102	**83.5729**	**Sn 132**	**76.5485**	**2**	**186.4264**
Mo 103	**80.97**	**Sn 131**	**77.2717**	**2**	**184.5467**
Mo 104	**80.3591**	**Sn 130**	**80.1372**	**2**	**186.8013**
Mo 105	**77.3465**	**Sn 129**	**80.5937**	**2**	**184.2452**
Mo 106	**76.1441**	**Sn 128**	**83.3362**	**2**	**185.7853**
Mo 107	**72.5613**	**Sn 127**	**83.4699**	**2**	**182.3362**
Mo 108	**70.7657**	**Sn 126**	**86.0207**	**2**	**183.0914**
Mo 109	**66.6759**	**Sn 125**	**85.8988**	**2**	**178.8797**
Mo 110	**64.5525**	**Sn 124**	**88.237**	**2**	**179.0945**
Mo 111	**60.063**	**Sn 123**	**87.8176**	**2**	**174.1856**
Mo 99	**85.9702**	**Sn 134**	**66.3234**	**3**	**170.5273**
Mo 100	**86.1878**	**Sn 133**	**70.8469**	**3**	**175.2684**
Mo 101	**83.5147**	**Sn 132**	**76.5485**	**3**	**178.2969**
Mo 102	**83.5729**	**Sn 131**	**77.2717**	**3**	**179.0783**
Mo 103	**80.97**	**Sn 130**	**80.1372**	**3**	**179.3409**
Mo 104	**80.3591**	**Sn 129**	**80.5937**	**3**	**179.1865**
Mo 105	**77.3465**	**Sn 128**	**83.3362**	**3**	**178.9164**
Mo 106	**76.1441**	**Sn 127**	**83.4699**	**3**	**177.8477**
Mo 107	**72.5613**	**Sn 126**	**86.0207**	**3**	**176.8157**
Mo 108	**70.7657**	**Sn 125**	**85.8988**	**3**	**174.8982**
Mo 109	**66.6759**	**Sn 124**	**88.237**	**3**	**173.1466**
Mo 110	**64.5525**	**Sn 123**	**87.8176**	**3**	**170.6038**
Mo 111	**60.063**	**Sn 122**	**89.9426**	**3**	**168.2393**
Mo 99	**85.9702**	**Sn 133**	**70.8469**	**4**	**166.9795**
Mo 100	**86.1878**	**Sn 132**	**76.5485**	**4**	**172.8987**
Mo 101	**83.5147**	**Sn 131**	**77.2717**	**4**	**170.9488**
Mo 102	**83.5729**	**Sn 130**	**80.1372**	**4**	**173.8725**
Mo 103	**80.97**	**Sn 129**	**80.5937**	**4**	**171.7261**
Mo 104	**80.3591**	**Sn 128**	**83.3362**	**4**	**173.8577**
Mo 105	**77.3465**	**Sn 127**	**83.4699**	**4**	**170.9788**
Mo 106	**76.1441**	**Sn 126**	**86.0207**	**4**	**172.3272**

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Mo 107	**72.5613**	**Sn 125**	**85.8988**	**4**	**168.6225**
Mo 108	**70.7657**	**Sn 124**	**88.237**	**4**	**169.1651**
Mo 109	**66.6759**	**Sn 123**	**87.8176**	**4**	**164.6559**
Mo 110	**64.5525**	**Sn 122**	**89.9426**	**4**	**164.6575**
Mo 111	**60.063**	**Sn 121**	**89.1971**	**4**	**159.4225**
Tc 103	**84.6004**	**In 133**	**57.762**	**0**	**184.81**
Tc 104	**82.5091**	**In 132**	**62.4135**	**0**	**187.3702**
Tc 105	**82.2943**	**In 131**	**68.0497**	**0**	**192.7916**
Tc 106	**79.7737**	**In 130**	**69.8882**	**0**	**192.1095**
Tc 107	**78.7464**	**In 129**	**72.8138**	**0**	**194.0078**
Tc 108	**75.9193**	**In 128**	**74.3606**	**0**	**192.7275**
Tc 109	**74.2792**	**In 127**	**76.892**	**0**	**193.6188**
Tc 110	**71.0309**	**In 126**	**77.8137**	**0**	**191.2922**
Tc 111	**69.021**	**In 125**	**80.4787**	**0**	**191.9473**
Tc 112	**65.2532**	**In 124**	**80.8687**	**0**	**188.5695**
Tc 113	**62.8777**	**In 123**	**83.4276**	**0**	**188.7529**
Tc 102	**84.5691**	**In 133**	**57.762**	**1**	**176.7074**
Tc 103	**84.6004**	**In 132**	**62.4135**	**1**	**181.3902**
Tc 104	**82.5091**	**In 131**	**68.0497**	**1**	**184.9351**
Tc 105	**82.2943**	**In 130**	**69.8882**	**1**	**186.5588**
Tc 106	**79.7737**	**In 129**	**72.8138**	**1**	**186.9638**
Tc 107	**78.7464**	**In 128**	**74.3606**	**1**	**187.4833**
Tc 108	**75.9193**	**In 127**	**76.892**	**1**	**187.1876**
Tc 109	**74.2792**	**In 126**	**77.8137**	**1**	**186.4692**
Tc 110	**71.0309**	**In 125**	**80.4787**	**1**	**185.8859**
Tc 111	**69.021**	**In 124**	**80.8687**	**1**	**184.266**
Tc 112	**65.2532**	**In 123**	**83.4276**	**1**	**183.0571**
Tc 113	**62.8777**	**In 122**	**83.574**	**1**	**180.828**
Tc 101	**86.339**	**In 133**	**57.762**	**2**	**170.406**
Tc 102	**84.5691**	**In 132**	**62.4135**	**2**	**173.2876**
Tc 103	**84.6004**	**In 131**	**68.0497**	**2**	**178.9551**
Tc 104	**82.5091**	**In 130**	**69.8882**	**2**	**178.7023**
Tc 105	**82.2943**	**In 129**	**72.8138**	**2**	**181.4131**
Tc 106	**79.7737**	**In 128**	**74.3606**	**2**	**180.4393**
Tc 107	**78.7464**	**In 127**	**76.892**	**2**	**181.9434**
Tc 108	**75.9193**	**In 126**	**77.8137**	**2**	**180.038**
Tc 109	**74.2792**	**In 125**	**80.4787**	**2**	**181.0629**
Tc 110	**71.0309**	**In 124**	**80.8687**	**2**	**178.2046**

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Tc 111	**69.021**	**In 123**	**83.4276**	**2**	**178.7536**
Tc 112	**65.2532**	**In 122**	**83.574**	**2**	**175.1322**
Tc 113	**62.8777**	**In 121**	**85.8377**	**2**	**175.0204**
Tc 101	**86.339**	**In 132**	**62.4135**	**3**	**166.9862**
Tc 102	**84.5691**	**In 131**	**68.0497**	**3**	**170.8525**
Tc 103	**84.6004**	**In 130**	**69.8882**	**3**	**172.7223**
Tc 104	**82.5091**	**In 129**	**72.8138**	**3**	**173.5566**
Tc 105	**82.2943**	**In 128**	**74.3606**	**3**	**174.8886**
Tc 106	**79.7737**	**In 127**	**76.892**	**3**	**174.8994**
Tc 107	**78.7464**	**In 126**	**77.8137**	**3**	**174.7938**
Tc 108	**75.9193**	**In 125**	**80.4787**	**3**	**174.6317**
Tc 109	**74.2792**	**In 124**	**80.8687**	**3**	**173.3816**
Tc 110	**71.0309**	**In 123**	**83.4276**	**3**	**172.6922**
Tc 111	**69.021**	**In 122**	**83.574**	**3**	**170.8287**
Tc 112	**65.2532**	**In 121**	**85.8377**	**3**	**169.3246**
Tc 113	**62.8777**	**In 120**	**85.7281**	**3**	**166.8395**
Tc 101	**86.339**	**In 131**	**68.0497**	**4**	**164.5511**
Tc 102	**84.5691**	**In 130**	**69.8882**	**4**	**164.6197**
Tc 103	**84.6004**	**In 129**	**72.8138**	**4**	**167.5766**
Tc 104	**82.5091**	**In 128**	**74.3606**	**4**	**167.0321**
Tc 105	**82.2943**	**In 127**	**76.892**	**4**	**169.3487**
Tc 106	**79.7737**	**In 126**	**77.8137**	**4**	**167.7498**
Tc 107	**78.7464**	**In 125**	**80.4787**	**4**	**169.3875**
Tc 108	**75.9193**	**In 124**	**80.8687**	**4**	**166.9504**
Tc 109	**74.2792**	**In 123**	**83.4276**	**4**	**167.8692**
Tc 110	**71.0309**	**In 122**	**83.574**	**4**	**164.7673**
Tc 111	**69.021**	**In 121**	**85.8377**	**4**	**165.0211**
Tc 112	**65.2532**	**In 120**	**85.7281**	**4**	**161.1437**
Tc 113	**62.8777**	**In 119**	**87.6991**	**4**	**160.7392**
Ru 109	**80.7348**	**Cd 127**	**68.4354**	**0**	**191.6178**
Ru 110	**80.0695**	**Cd 126**	**72.2564**	**0**	**194.7735**
Ru 111	**76.7816**	**Cd 125**	**73.3479**	**0**	**192.5771**
Ru 112	**75.6272**	**Cd 124**	**76.6974**	**0**	**194.7722**
Ru 113	**71.8743**	**Cd 123**	**77.3187**	**0**	**191.6406**
Ru 114	**70.2154**	**Cd 122**	**80.6165**	**0**	**193.2795**
Ru 115	**66.1895**	**Cd 121**	**81.0577**	**0**	**189.6948**
Ru 109	**80.7348**	**Cd 126**	**72.2564**	**1**	**187.3675**
Ru 110	**80.0695**	**Cd 125**	**73.3479**	**1**	**187.7937**

Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Ru 111	**76.7816**	**Cd 124**	**76.6974**	**1**	**187.8553**
Ru 112	**75.6272**	**Cd 123**	**77.3187**	**1**	**187.3222**
Ru 113	**71.8743**	**Cd 122**	**80.6165**	**1**	**186.8671**
Ru 114	**70.2154**	**Cd 121**	**81.0577**	**1**	**185.6494**
Ru 115	**66.1895**	**Cd 120**	**83.9573**	**1**	**184.5231**
Ru 109	**80.7348**	**Cd 125**	**73.3479**	**2**	**180.3877**
Ru 110	**80.0695**	**Cd 124**	**76.6974**	**2**	**183.0719**
Ru 111	**76.7816**	**Cd 123**	**77.3187**	**2**	**180.4053**
Ru 112	**75.6272**	**Cd 122**	**80.6165**	**2**	**182.5487**
Ru 113	**71.8743**	**Cd 121**	**81.0577**	**2**	**179.237**
Ru 114	**70.2154**	**Cd 120**	**83.9573**	**2**	**180.4777**
Ru 115	**66.1895**	**Cd 119**	**83.977**	**2**	**176.4715**
Ru 109	**80.7348**	**Cd 124**	**76.6974**	**3**	**175.6659**
Ru 110	**80.0695**	**Cd 123**	**77.3187**	**3**	**175.6219**
Ru 111	**76.7816**	**Cd 122**	**80.6165**	**3**	**175.6318**
Ru 112	**75.6272**	**Cd 121**	**81.0577**	**3**	**174.9186**
Ru 113	**71.8743**	**Cd 120**	**83.9573**	**3**	**174.0653**
Ru 114	**70.2154**	**Cd 119**	**83.977**	**3**	**172.4261**
Ru 115	**66.1895**	**Cd 118**	**86.7056**	**3**	**171.1288**
Ru 109	**80.7348**	**Cd 123**	**77.3187**	**4**	**168.2159**
Ru 110	**80.0695**	**Cd 122**	**80.6165**	**4**	**170.8484**
Ru 111	**76.7816**	**Cd 121**	**81.0577**	**4**	**168.0017**
Ru 112	**75.6272**	**Cd 120**	**83.9573**	**4**	**169.7469**
Ru 113	**71.8743**	**Cd 119**	**83.977**	**4**	**166.0137**
Ru 114	**70.2154**	**Cd 118**	**86.7056**	**4**	**167.0834**
Ru 115	**66.1895**	**Cd 117**	**86.4223**	**4**	**162.7742**
Rh 113	**78.7673**	**Ag 123**	**69.548**	**0**	**190.7629**
Rh 114	**75.7131**	**Ag 122**	**71.1061**	**0**	**189.2668**
Rh 115	**74.2296**	**Ag 121**	**74.4028**	**0**	**191.08**
Rh 116	**70.7412**	**Ag 120**	**75.6515**	**0**	**188.8403**
Rh 111	**82.3042**	**Ag 124**	**66.2001**	**1**	**182.8806**
Rh 113	**78.7673**	**Ag 122**	**71.1061**	**1**	**184.2497**
Rh 114	**75.7131**	**Ag 121**	**74.4028**	**1**	**184.4922**
Rh 115	**74.2296**	**Ag 120**	**75.6515**	**1**	**184.2574**
Rh 117	**68.8972**	**Ag 118**	**79.5537**	**1**	**182.8272**
Rh 111	**82.3042**	**Ag 123**	**69.548**	**2**	**178.1572**
Rh 113	**78.7673**	**Ag 121**	**74.4028**	**2**	**179.4751**
Rh 114	**75.7131**	**Ag 120**	**75.6515**	**2**	**177.6696**

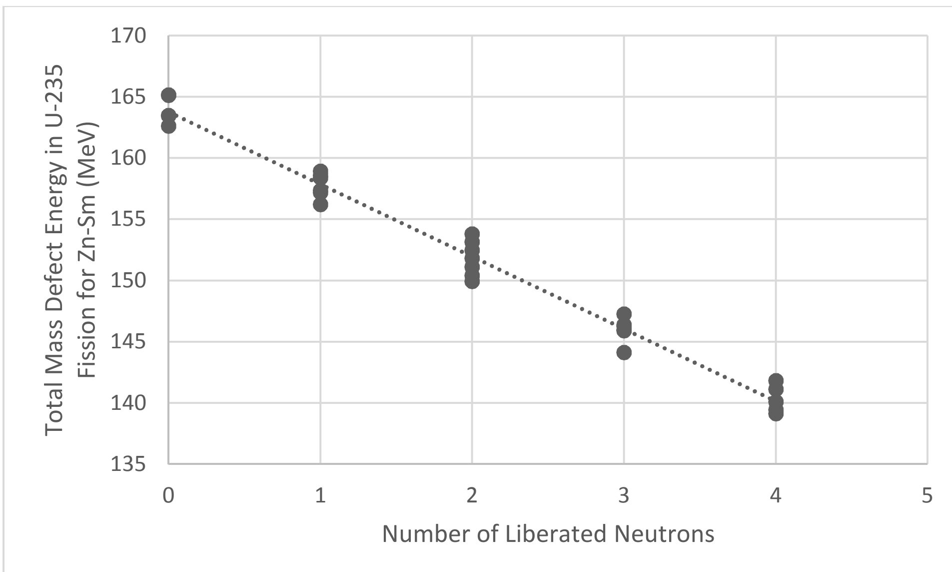
Daughter Isotope A	Mass Defect Energy (MeV)	Daughter Isotope B	Mass Defect Energy (MeV)	Liberated Neutrons	Total Defect Energy (MeV)
Rh 116	**70.7412**	**Ag 118**	**79.5537**	**2**	**176.5999**
Rh 117	**68.8972**	**Ag 117**	**82.1819**	**2**	**177.3841**
Rh 111	**82.3042**	**Ag 122**	**71.1061**	**3**	**171.644**
Rh 113	**78.7673**	**Ag 120**	**75.6515**	**3**	**172.6525**
Rh 115	**74.2296**	**Ag 118**	**79.5537**	**3**	**172.017**
Rh 116	**70.7412**	**Ag 117**	**82.1819**	**3**	**171.1568**
Rh 117	**68.8972**	**Ag 116**	**82.5426**	**3**	**169.6735**
Rh 111	**82.3042**	**Ag 121**	**74.4028**	**4**	**166.8694**
Rh 114	**75.7131**	**Ag 118**	**79.5537**	**4**	**165.4292**
Rh 115	**74.2296**	**Ag 117**	**82.1819**	**4**	**166.5739**
Rh 116	**70.7412**	**Ag 116**	**82.5426**	**4**	**163.4462**
Rh 117	**68.8972**	**Ag 115**	**84.9832**	**4**	**164.0428**
Pd 116	**79.8314**	**Pd 120**	**70.3099**	**0**	**192.5889**
Pd 117	**76.4243**	**Pd 119**	**71.4077**	**0**	**190.2796**
Pd 118	**75.391**	**Pd 118**	**75.391**	**0**	**193.2296**
Pd 119	**71.4077**	**Pd 117**	**76.4243**	**0**	**190.2796**
Pd 120	**70.3099**	**Pd 116**	**79.8314**	**0**	**192.5889**
Pd 115	**80.4262**	**Pd 120**	**70.3099**	**1**	**185.1124**
Pd 116	**79.8314**	**Pd 119**	**71.4077**	**1**	**185.6154**
Pd 117	**76.4243**	**Pd 118**	**75.391**	**1**	**186.1916**
Pd 118	**75.391**	**Pd 117**	**76.4243**	**1**	**186.1916**
Pd 119	**71.4077**	**Pd 116**	**79.8314**	**1**	**185.6154**
Pd 120	**70.3099**	**Pd 115**	**80.4262**	**1**	**185.1124**
Pd 114	**83.4907**	**Pd 120**	**70.3099**	**2**	**180.1056**
Pd 115	**80.4262**	**Pd 119**	**71.4077**	**2**	**178.1389**
Pd 116	**79.8314**	**Pd 118**	**75.391**	**2**	**181.5274**
Pd 117	**76.4243**	**Pd 117**	**76.4243**	**2**	**179.1536**
Pd 118	**75.391**	**Pd 116**	**79.8314**	**2**	**181.5274**
Pd 119	**71.4077**	**Pd 115**	**80.4262**	**2**	**178.1389**
Pd 120	**70.3099**	**Pd 114**	**83.4907**	**2**	**180.1056**
Pd 113	**83.5909**	**Pd 120**	**70.3099**	**3**	**172.1345**
Pd 114	**83.4907**	**Pd 119**	**71.4077**	**3**	**173.1321**
Pd 115	**80.4262**	**Pd 118**	**75.391**	**3**	**174.0509**
Pd 116	**79.8314**	**Pd 117**	**76.4243**	**3**	**174.4894**
Pd 117	**76.4243**	**Pd 116**	**79.8314**	**3**	**174.4894**
Pd 118	**75.391**	**Pd 115**	**80.4262**	**3**	**174.0509**
Pd 119	**71.4077**	**Pd 114**	**83.4907**	**3**	**173.1321**
Pd 120	**70.3099**	**Pd 113**	**83.5909**	**3**	**172.1345**

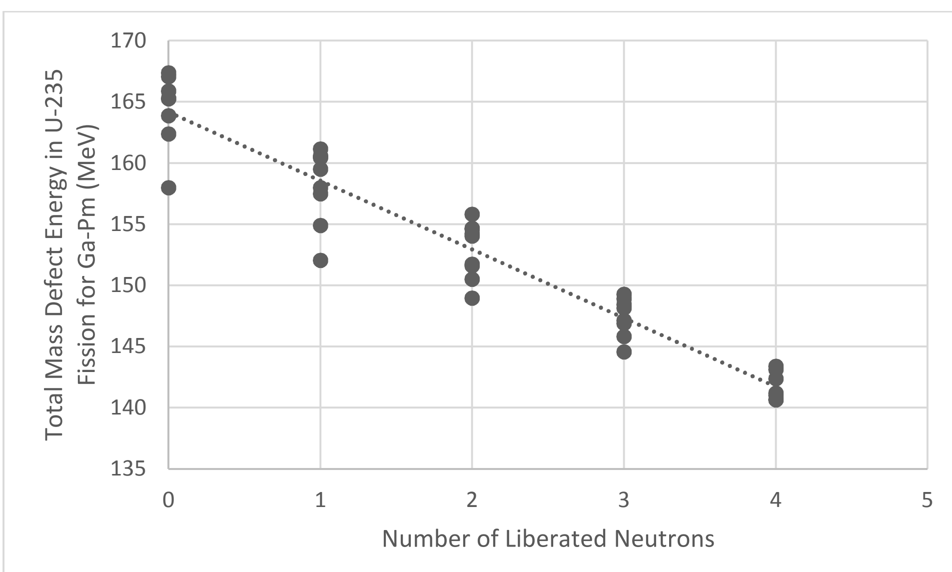
Daughter Isotope A	**Mass Defect Energy (MeV)**	**Daughter Isotope B**	**Mass Defect Energy (MeV)**	**Liberated Neutrons**	**Total Defect Energy (MeV)**
Pd 112	**86.3232**	**Pd 120**	**70.3099**	**4**	**166.7955**
Pd 113	**83.5909**	**Pd 119**	**71.4077**	**4**	**165.161**
Pd 114	**83.4907**	**Pd 118**	**75.391**	**4**	**169.0441**
Pd 115	**80.4262**	**Pd 117**	**76.4243**	**4**	**167.0129**
Pd 116	**79.8314**	**Pd 116**	**79.8314**	**4**	**169.8252**

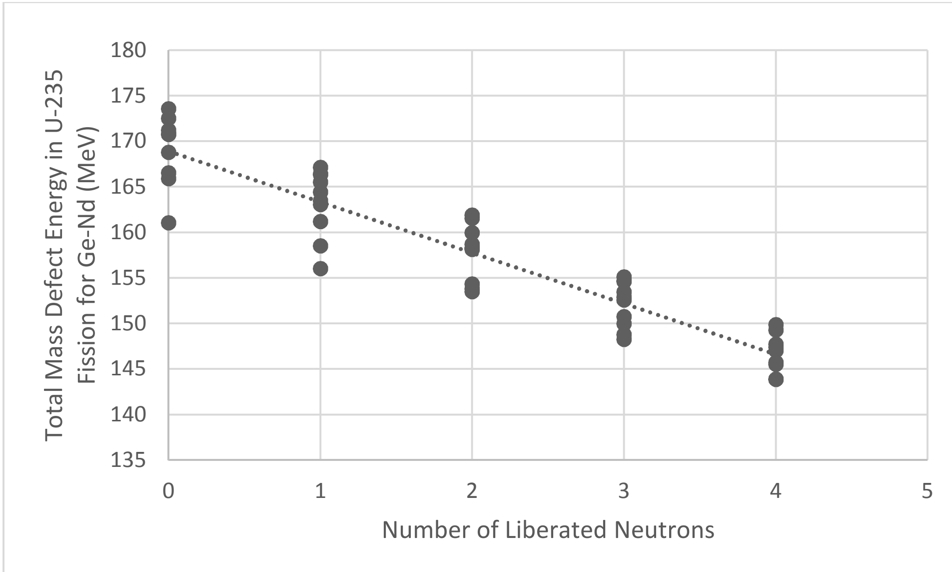
Appendix B

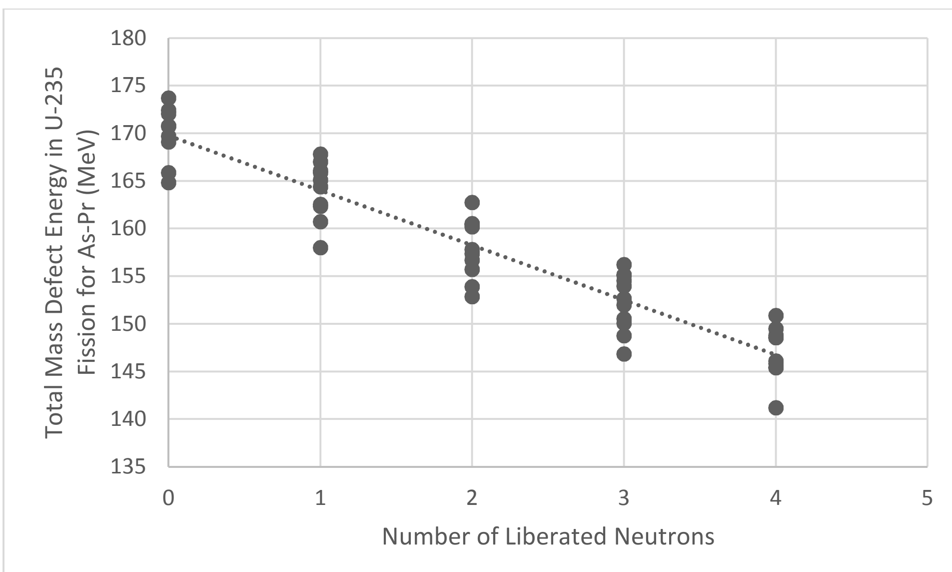
Daughter Pair Energy Graphs of Uranium-235 Fission

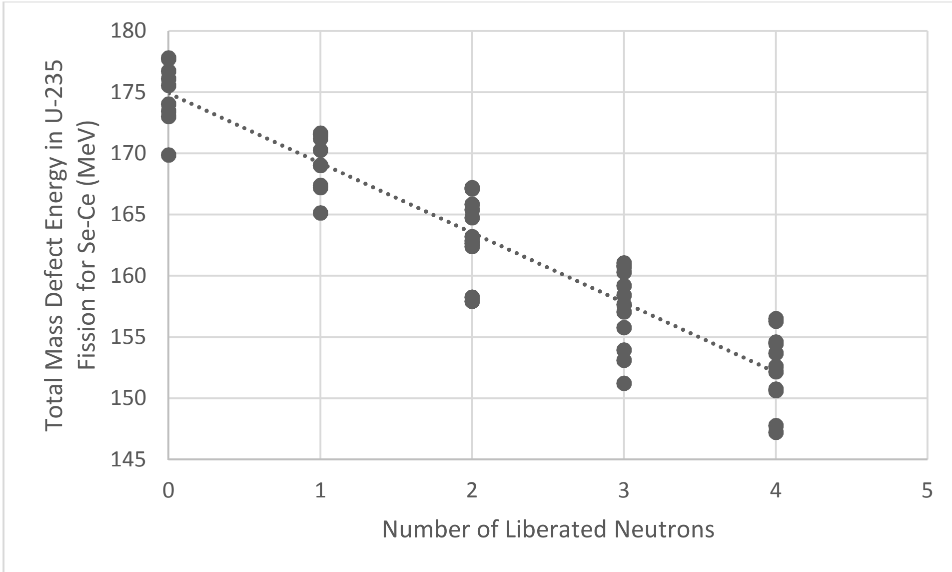
For Events Liberating up to Four Neutrons



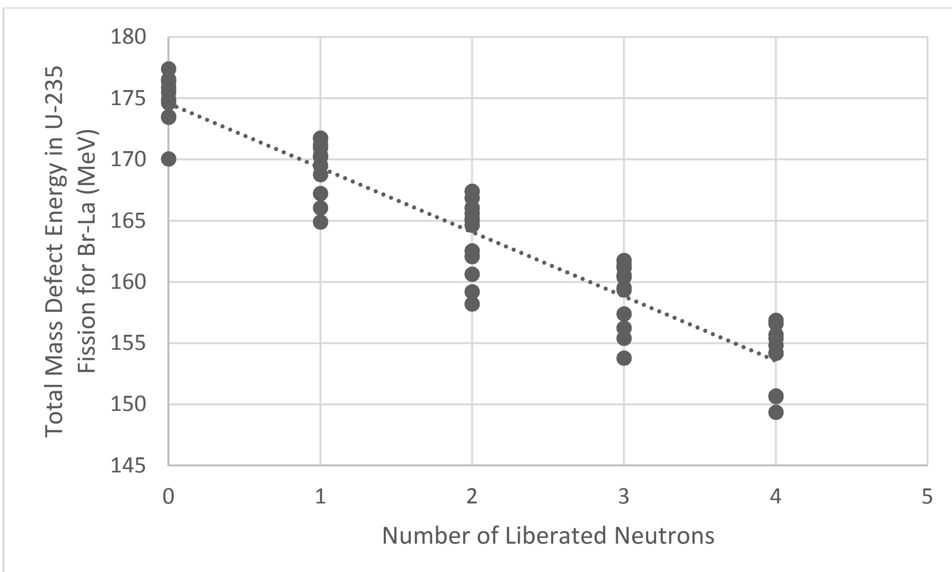



Total Mass Defect Energy in U-235 Fission for Ge-Nd (MeV)
180
175
170
165
160
155
150
145
140
135
0
1
2
3
4
5
Number of Liberated Neutrons

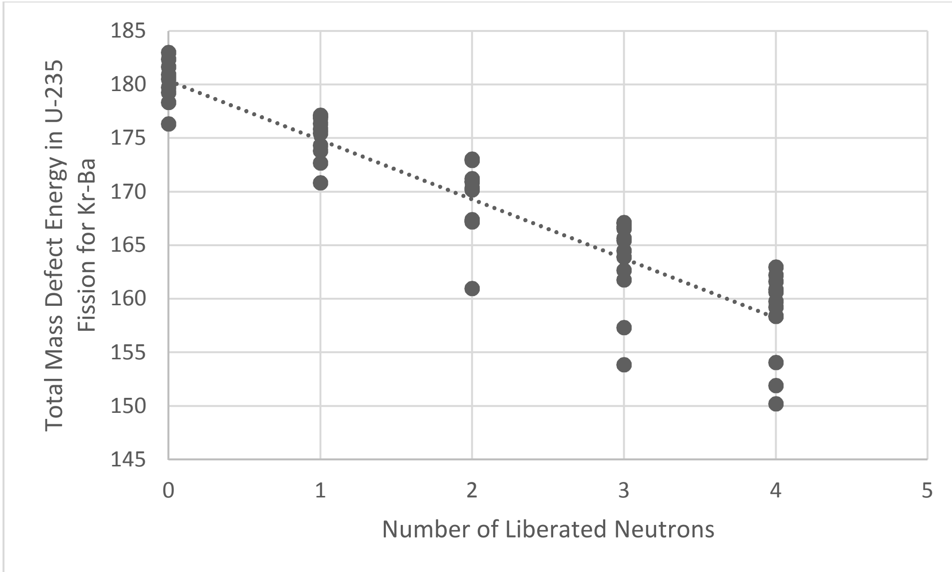

Total Mass Defect Energy in U-235 Fission for As-Pr (MeV)
180
175
170
165
160
155
150
145
140
135
0
1
2
3
4
5
Number of Liberated Neutrons



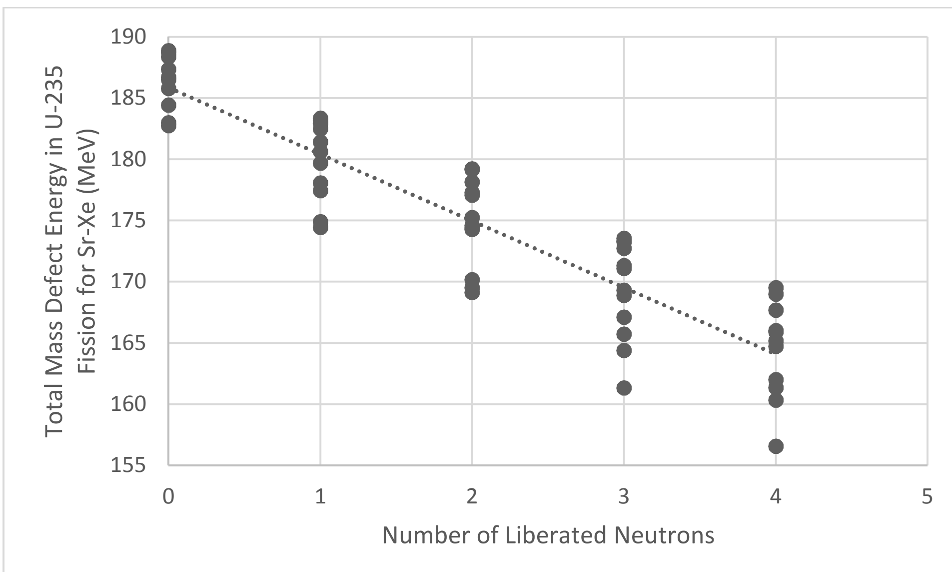
180
175
170
165
160
155
150
145
0
1
2
3
4
5
Total Mass Defect Energy in U-235 Fission for Se-Ce (MeV)
Number of Liberated Neutrons



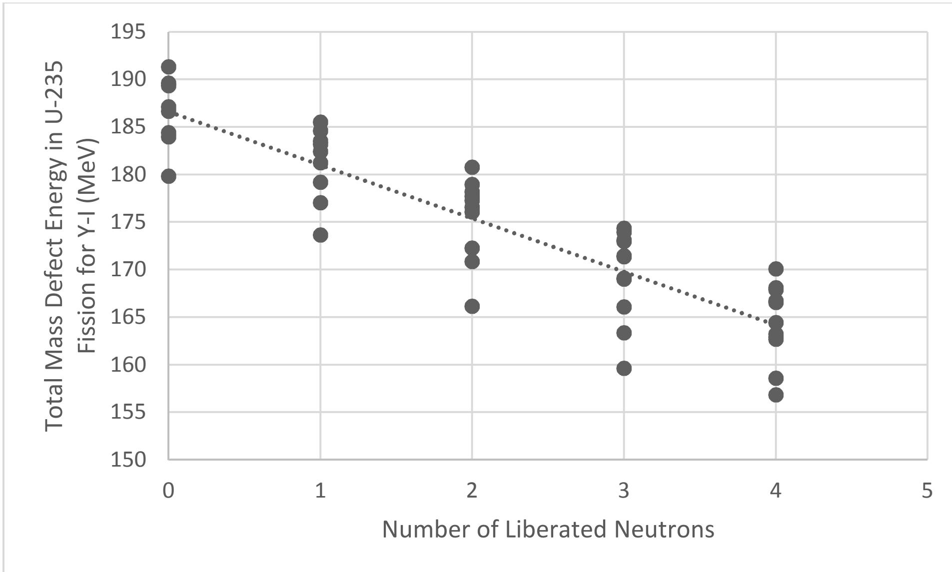
180
175
170
165
160
155
150
145
0
1
2
3
4
5
Total Mass Defect Energy in U-235 Fission for Br-La (MeV)
Number of Liberated Neutrons

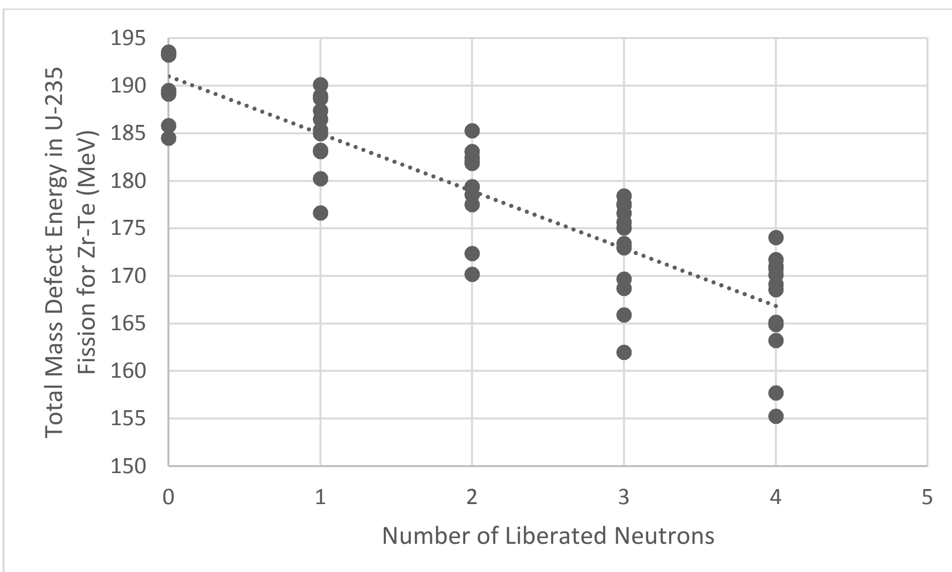


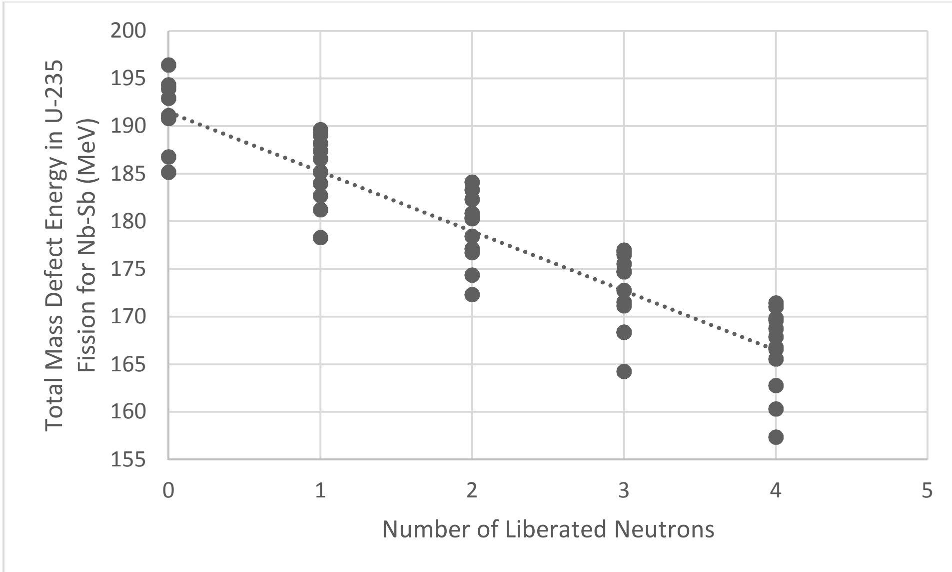
Total Mass Defect Energy in U-235 Fission for Kr-Ba
185
180
175
170
165
160
155
150
145
0
1
2
3
4
5
Number of Liberated Neutrons



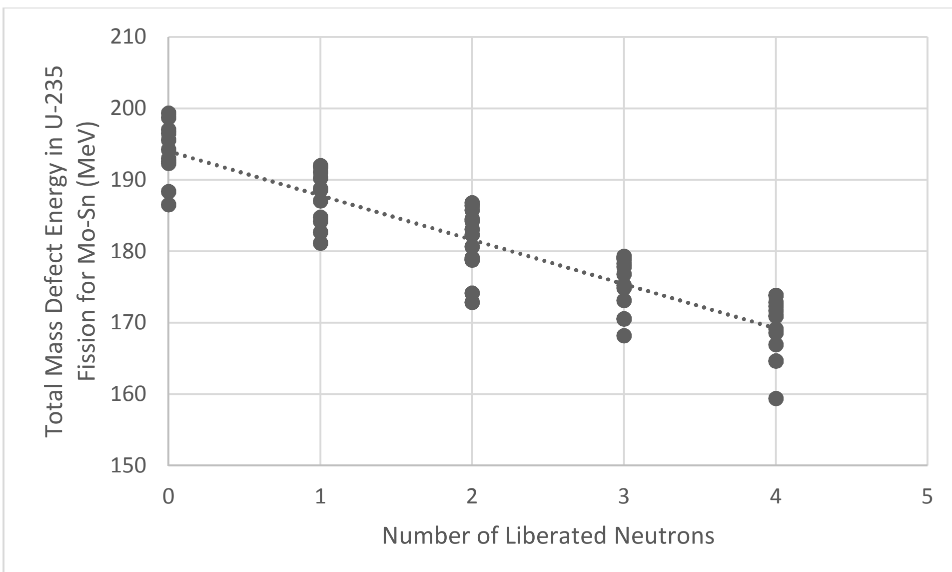
Total Mass Defect Energy in U-235 Fission for Sr-Xe (MeV)
190
185
180
175
170
165
160
155
0
1
2
3
4
5
Number of Liberated Neutrons


Total Mass Defect Energy in U-235 Fission for Y-I (MeV)
195
190
185
180
175
170
165
160
155
150
0
1
2
3
4
5
Number of Liberated Neutrons

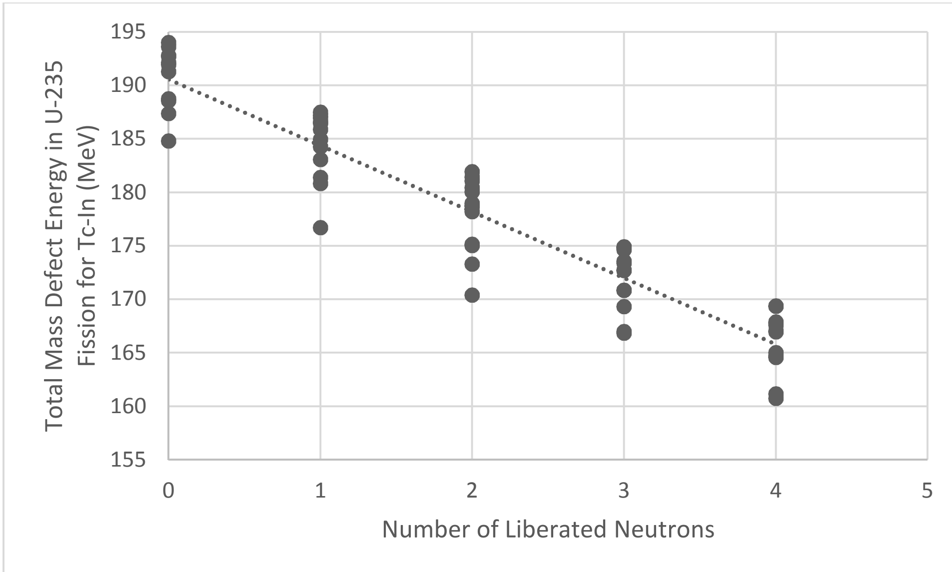

Total Mass Defect Energy in U-235 Fission for Zr-Te (MeV)
195
190
185
180
175
170
165
160
155
150
0
1
2
3
4
5
Number of Liberated Neutrons

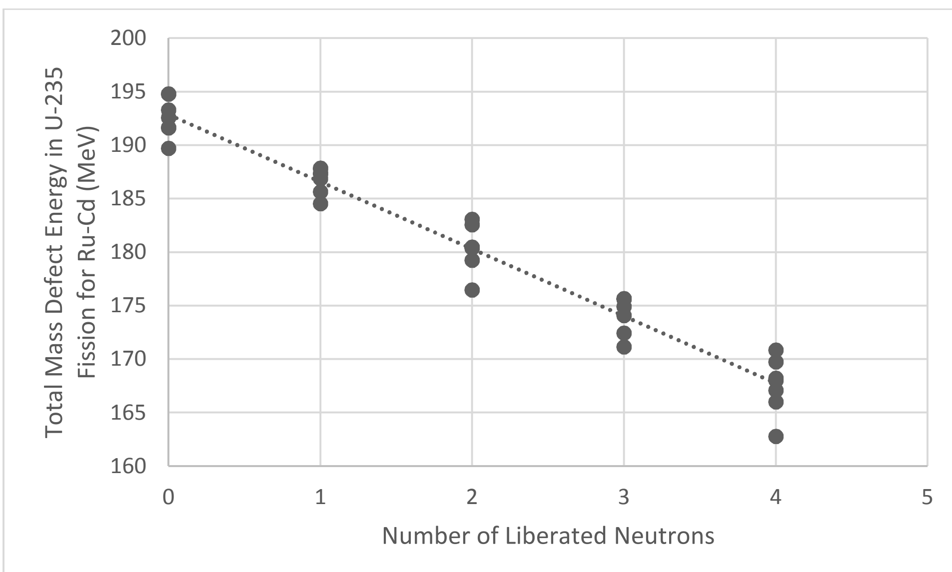


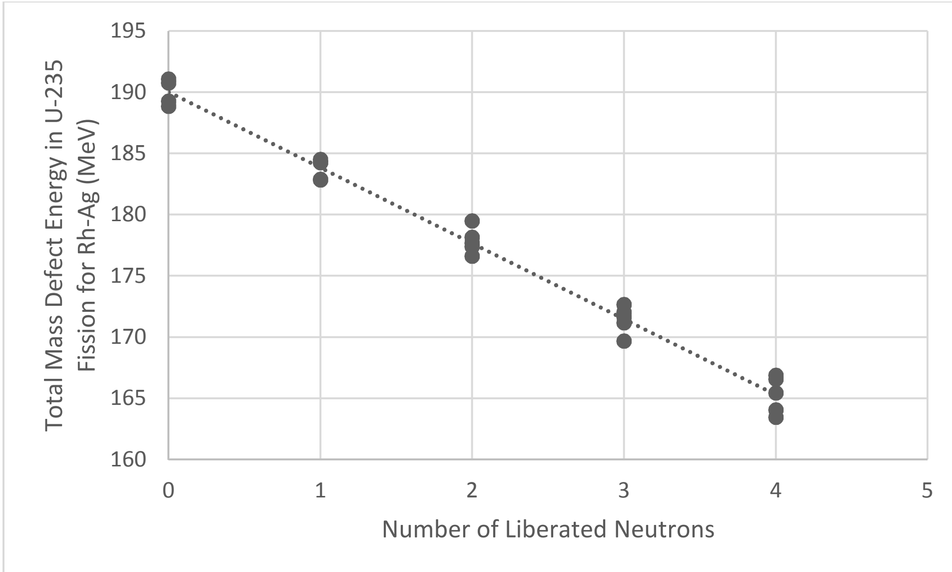
200
195
190
185
180
175
170
165
160
155
0
1
2
3
4
5
Total Mass Defect Energy in U-235 Fission for Nb-Sb (MeV)
Number of Liberated Neutrons



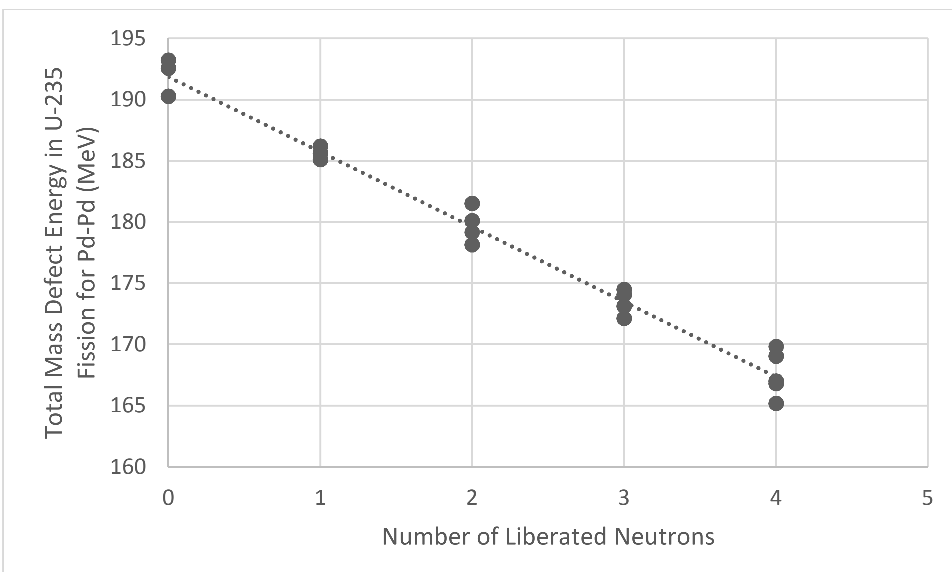
210
200
190
180
170
160
150
0
1
2
3
4
5
Total Mass Defect Energy in U-235 Fission for Mo-Sn (MeV)
Number of Liberated Neutrons


Total Mass Defect Energy in U-235 Fission for Tc-In (MeV)
195
190
185
180
175
170
165
160
155
0
1
2
3
4
5
Number of Liberated Neutrons


Total Mass Defect Energy in U-235 Fission for Ru-Cd (MeV)
200
195
190
185
180
175
170
165
160
0
1
2
3
4
5
Number of Liberated Neutrons



Total Mass Defect Energy in U-235 Fission for Rh-Ag (MeV)
195
190
185
180
175
170
165
160
0
1
2
3
4
5
Number of Liberated Neutrons



Total Mass Defect Energy in U-235 Fission for Pd-Pd (MeV)
195
190
185
180
175
170
165
160
0
1
2
3
4
5
Number of Liberated Neutrons

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