CHART OF THE NUCLIDES

The Chart of the Nuclides, like the Periodic Table, is a convenient format for presenting a large amount of scientific information in an organized manner.

EO 1.6 DEFINE the following terms:

- **a. Enriched uranium**
- **b. Depleted uranium**

Chart of the Nuclides

A tabulated chart called the *Chart of the Nuclides* lists the stable and unstable nuclides in addition to pertinent information about each one. Figure 3 shows a small portion of a typical chart. This chart plots a box for each individual nuclide, with the number of protons (Z) on the vertical axis and the number of neutrons (N = A - Z) on the horizontal axis.

The completely gray squares indicate stable isotopes. Those in white squares are *artificially radioactive*, meaning that they are produced by artificial techniques and do not occur naturally. By consulting a complete chart, other types of isotopes can be found, such as naturally occurring radioactive types (but none are found in the region of the chart that is illustrated in Figure 3).

Located in the box on the far left of each horizontal row is general information about the element. The box contains the chemical symbol of the element in addition to the average atomic weight of the naturally occurring substance and the average thermal neutron absorption cross section, which will be discussed in a later module. The known isotopes (elements with the same atomic number Z but different mass number A) of each element are listed to the right.

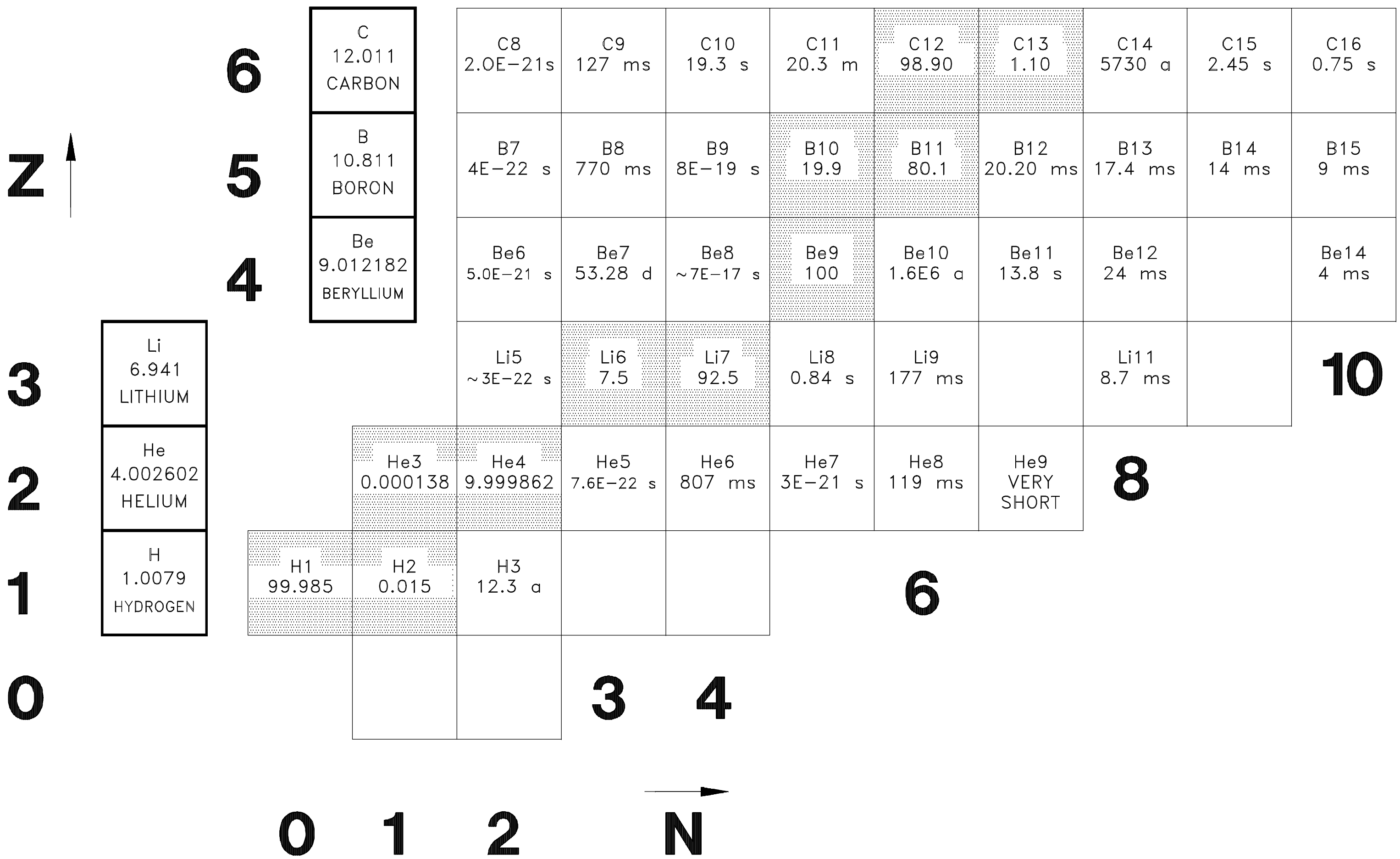

Figure 3 Nuclide Chart for Atomic Numbers 1 to 6

Information for Stable Nuclides

For the stable isotopes, in addition to the symbol and the atomic mass number, the number percentage of each isotope in the naturally occurring element is listed, as well as the thermal neutron activation cross section and the mass in atomic mass units (amu). A typical block for a stable nuclide from the Chart of the Nuclides is shown in Figure 4.

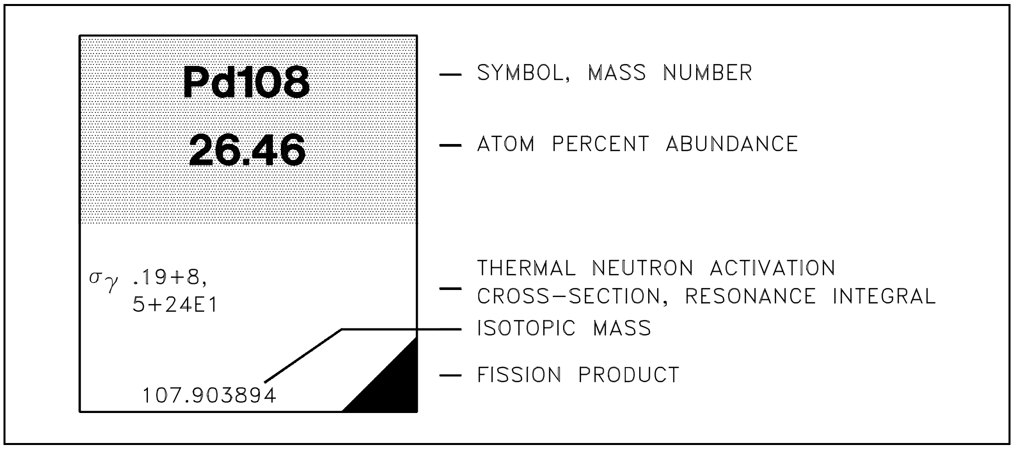

Figure 4 Stable Nuclides

Information for Unstable Nuclides

For unstable isotopes the additional information includes the half life, the mode of decay (for example, β^-, α), the total disintegration energy in MeV (million electron volts), and the mass in amu when available. A typical block for an unstable nuclide from the Chart of the Nuclides is shown in Figure 5.

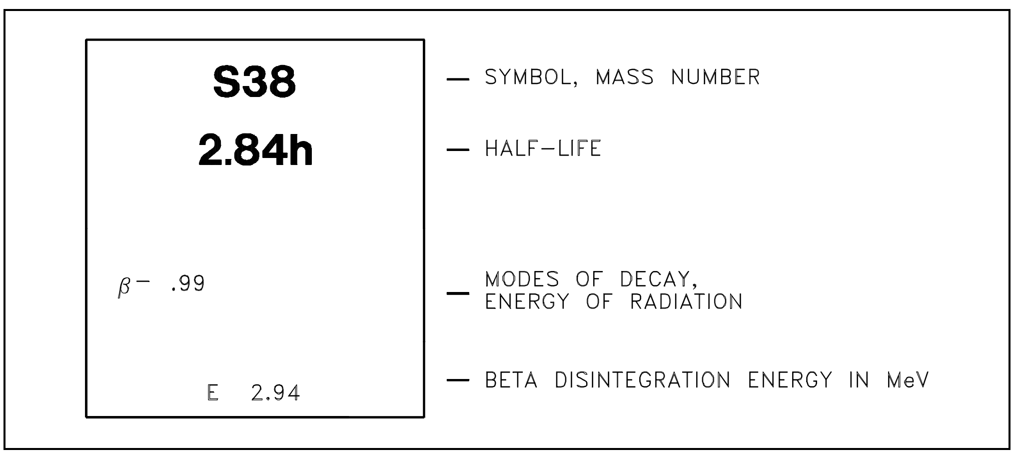

Figure 5 Unstable Nuclides

Neutron - Proton Ratios

Figure 6 shows the distribution of the stable nuclides plotted on the same axes as the Chart of the Nuclides. As the mass numbers become higher, the ratio of neutrons to protons in the nucleus becomes larger. For helium-4 (2 protons and 2 neutrons) and oxygen-16 (8 protons and 8 neutrons) this ratio is unity. For indium-115 (49 protons and 66 neutrons) the ratio of neutrons to protons has increased to 1.35, and for uranium-238 (92 protons and 146 neutrons) the neutron-to-proton ratio is 1.59.

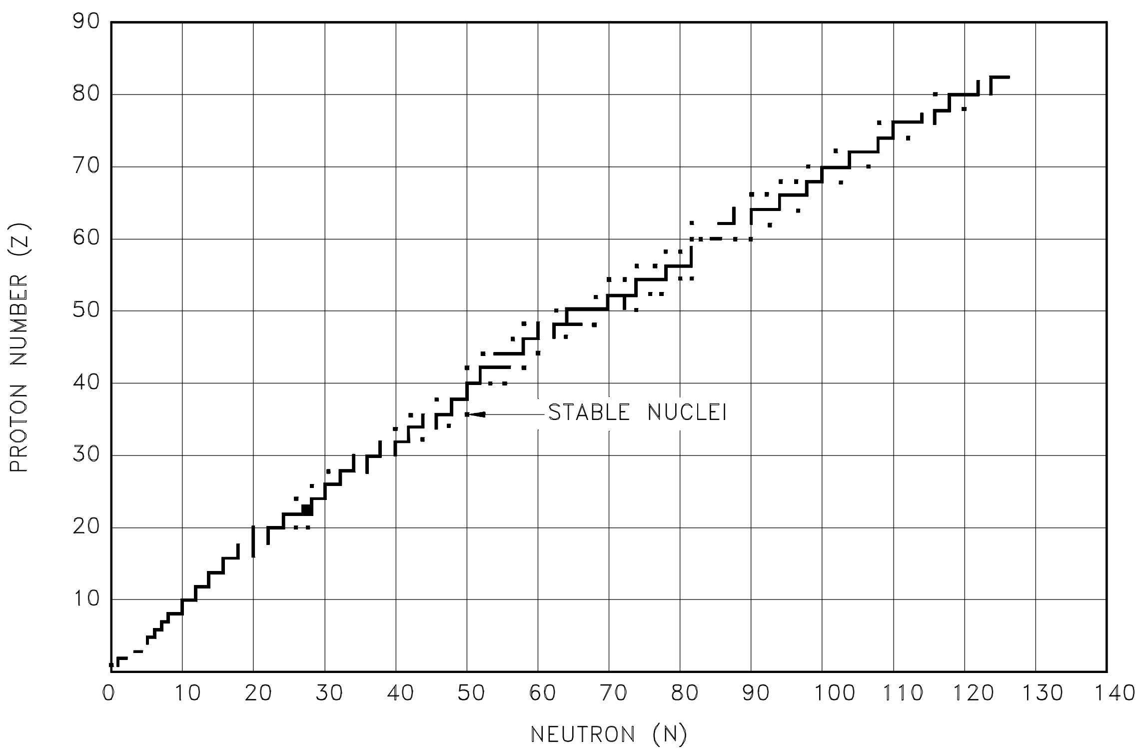

Figure 6 Neutron - Proton Plot of the Stable Nuclides

If a heavy nucleus were to split into two fragments, each fragment would form a nucleus that would have approximately the same neutron-to-proton ratio as the heavy nucleus. This high neutron-to-proton ratio places the fragments below and to the right of the stability curve displayed by Figure 6. The instability caused by this excess of neutrons is generally rectified by successive beta emissions, each of which converts a neutron to a proton and moves the nucleus toward a more stable neutron-to-proton ratio.

Natural Abundance of Isotopes

The relative abundance of an isotope in nature compared to other isotopes of the same element is relatively constant. The Chart of the Nuclides presents the relative abundance of the naturally occurring isotopes of an element in units of atom percent. Atom percent is the percentage of the atoms of an element that are of a particular isotope. Atom percent is abbreviated as a/o. For example, if a cup of water contains 8.23×10^{24} atoms of oxygen, and the isotopic abundance of oxygen-18 is 0.20%, then there are 1.65×10^{22} atoms of oxygen-18 in the cup.

The atomic weight for an element is defined as the average atomic weight of the isotopes of the element. The atomic weight for an element can be calculated by summing the products of the isotopic abundance of the isotope with the atomic mass of the isotope.

Example:

Calculate the atomic weight for the element lithium. Lithium-6 has an atom percent abundance of 7.5% and an atomic mass of 6.015122 amu. Lithium-7 has an atomic abundance of 92.5% and an atomic mass of 7.016003 amu.

Solution:

$$\text{Atomic Mass Lithium} = (0.075)\ (6.015122\ \text{amu}) + (0.925)\ (7.016003\ \text{amu})$$
$$= 6.9409\ \text{amu}$$

The other common measurement of isotopic abundance is weight percent (w/o). Weight percent is the percent weight of an element that is a particular isotope. For example, if a sample of material contained 100 kg of uranium that was 28 w/o uranium-235, then 28 kg of uranium-235 was present in the sample.

Enriched and Depleted Uranium

Natural uranium mined from the earth contains the isotopes uranium-238, uranium-235 and uranium-234. The majority (99.2745%) of all the atoms in natural uranium are uranium-238. Most of the remaining atoms (0.72%) are uranium-235, and a slight trace (0.0055%) are uranium-234. Although all isotopes of uranium have similar chemical properties, each of the isotopes has significantly different nuclear properties. For reasons that will be discussed in later modules, the isotope uranium-235 is usually the desired material for use in reactors.

A vast amount of equipment and energy are expended in processes that separate the isotopes of uranium (and other elements). The details of these processes are beyond the scope of this module. These processes are called enrichment processes because they selectively increase the proportion of a particular isotope. The enrichment process typically starts with feed material that has the proportion of isotopes that occur naturally. The process results in two types of

In the case of uranium, the natural uranium ore is 0.72 a/o uranium-235. The desired outcome of the enrichment process is to produce enriched uranium. *Enriched uranium* is defined as uranium in which the isotope uranium-235 has a concentration greater than its natural value. The enrichment process will also result in the byproduct of depleted uranium. *Depleted uranium* is defined as uranium in which the isotope uranium-235 has a concentration less than its natural value. Although depleted uranium is referred to as a by-product of the enrichment process, it does have uses in the nuclear field and in commercial and defense industries.

Summary

The important information in this chapter is summarized below.

Chart of the Nuclides Summary

- Enriched uranium is uranium in which the isotope uranium-235 has a concentration greater than its natural value of 0.7%.
- Depleted uranium is uranium in which the isotope uranium-235 has a concentration less than its natural value of 0.7%.