A quick guide to amateur neutron activation techniques

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What is neutron activation?

When neutrons enter an isotope of an element and are "captured" within the nucleus, they can change its isotopic characteristics in such a way that the normal inert isotope is left radioactive due to the creation of a new radioactive isotope within the element.

Why even bother doing neutron activation?

The prime reason for amateur fusioneers is to prove that they have done nuclear fusion. Another reason is for the sake of simple amateur experimentation once a fusor is up and running. It is an easy way to show improved fusion in fusors already doing well, (More fusion, more neutrons, more easily measured activation).

How do you activate, (make radioactive) an element with neutrons?

This is a very involved question to answer.

1. **You need special neutrons**
2. **You need a certain amount of them**
3. **You need to select a special element that is easy to activate**
4. **The element must usually be in the form of a foil or a chemical compound**
5. **You must have a Geiger counter connected to a digital counter and or a scintillation counter**

Let's beat these 5 terms to death in what follows to expand on some complex issues within each.

You need special neutrons??

A neutron is a neutron is a neutron. It is a single particle that is never emitted from any natural radioactive elemental isotope below Uranium. Thus, you cannot get neutrons, directly, from any radioactive material normally obtainable.

Neutron sources can be made up, but not normally by the amateur in a safe or legal way….At least to a level of neutron emission that can do detectable activation.

This is where the fusor comes in. Using the resultant D-D fusion, we produce fusion reactions where about 50% of its nuclear ash are neutrons of about 2.5 meV, (million electron volts). This term is the kinetic energy of the neutron. The equation, ($Ke=1/2MV^2$) informs us that as the neutron has a fixed mass, the velocity, alone, determines its kinetic energy. Here is where the special neutrons come into play.

In general, only "slow neutrons" will successfully activate an element. Another more common term for slow neutrons is "thermal neutrons". Slow is typically taken to mean the neutrons have a kinetic energy

of .02 eV. This means they are traveling about as fast as a high power rifle bullet and are in thermal equilibrium with surrounding molecules at room temperature. More on this later.

How do we get our 2.5meV neutrons slowed to .02eV? We shoot them into a hydrogen rich substance like water, paraffin, or high density polyethylene. This is called a "moderator". The neutrons slam into the hydrogen nuclei and send them flying and in doing so, each impact robs the neutron of some of its energy. Both the hydrogen nuclei (protons) and the neutrons ricochet all around in the "moderator". It turns out that .02eV is the average energy of molecules in a substance at room temperature. These molecules just bump against one another at rifle bullet velocities bouncing and shuffling around in the mass. The neutrons at .02eV join in with the molecules of the moderator, aimlessly moving in the "Brownian motion" of room temperature. Not one single neutron has a specific direction, moment to moment. Thus, they are getting slower and slower over time in a large moderator. In short, they are all tangled up in the moderator. They are going slow enough now to perform activation.

Why do we need a certain amount of neutrons?

The more neutrons we have trapped and wandering around in the moderator, the more intense will be the activation and increased radiation produced by the element that is placed in the middle of the moderator. Thus, the easier it is to detect that we have neutron activated the element when it is pulled out of the moderator after a specific time period. We will use a Geiger counter or a scintillation counter to see that the element is no longer at background radiation level, but is actually radioactive now.

A fusor must be doing a decent amount of fusion to kick out enough neutrons per second that enter the moderator to do activation work. D-D fusion sends the neutrons out over a full isotropic spherical blanket. There is no beaming or favored direction in D-D fusion, not even in a linear accelerator with a beam of deuterons bombarding a deuterium target! The neutrons produced still move out in a big neutron sphere.

The bigger the moderator is in size, and nearer it is to the fusor, the more neutrons at any level of fusion will enter the moderator and be ready to activate. So, at a fixed level of fusion in our fusor, with a fixed moderator size, we will be capable of doing only a fixed level of activation. More fusion means more activation per unit time of exposure. A bigger moderator also means more activation at any level of fusion.

You are now "in the know" on how we get the very special neutrons needed to do the job of activation.

Why do I need a "special element" to do activation?

There is a table of what are termed "capture cross sections" or, more simply put, "cross sections". Before I go into cross sections, we must understand the term isotope.

Stable elements often contain more than one isotope in them. As the proton number in an atom determines the element's type or name. The nucleus of some elemental atoms may contain varying numbers of neutrons in different atoms of the same element! This, coupled with binding energies, which present themselves as mass in the nucleus, is why atomic weights are often uneven numbers.

This is due to there being more or less neutrons in the element's many isotopic nuclei. The element Tin has ten totally stable isotopes within it! It is one of the elements with the most number of such isotopes. Bismuth only has one stable isotope! To be truthful, bismuth is radioactive, but decays so slowly that its half-life is many millions of times longer than the entire age of the universe! Therefore, you nor I and most all scientists are totally unable to detect any radiation from bismuth. The upshot is that there is an isotopic abundance that is known for each isotope of each and every element and is expressed as an "atomic percentage" of each isotope contained within that element.

As an example, Potassium has 3 isotopes. K39 is the most abundant at 93.22%, K40 is the rarest at only 0.118%, K41 makes up only 6.77%. K40 is radioactive, but has a half- life of 1.2 billion years! Thus, all potassium on earth is radioactive and it can easily be detected in the compound KCl using a common Geiger counter. Potassium chloride is in the product "No salt" that some folks eat who are on a low sodium diet. K40 throws out a nasty ~1 meV beta particle and an energetic' 1.4meV gamma ray.

Now, we get back to the term "capture cross section". This and other factors, to be discussed, are what constitute a "special activation element", for our fusor based activation.

The term capture cross section represents a specific area in space. This area is 10e-24 square centimeters. This is a tiny area, indeed, and is an area of nuclear size. This unit area is called a "barn", abbreviated by the small letter (b). The cross section, in barns, is a number assigned to each isotope of each element. It is experimentally determined based on the probability that a neutron will interact or be captured by a nucleus and alter a specific isotope of an element. In effect, we are saying, the more barns in a given cross section, the bigger is the target bulls-eye for that isotope and the bigger the target, the more likely will be the probability that a wandering neutron in the moderator will interact and alter that isotope's nucleus. A large number of barns will mean a lot of activation due to thermal neutron interactions.

Any isotope of any element can capture a neutron. This always increases the atomic weight by about 1. However, once in the nucleus it never changes the identity of the element at that instant in time. Capturing a neutron may or may not make the resultant nucleus radioactive. The introduction of a neutron into a nucleus can often create an unstable nucleus. This is a radioactive nucleus. In time, in order to become stable again, the nucleus will emit whatever particle will form a stable nucleus, once again. It will **never** re-emit the disturbing neutron. All nuclei cherish and tightly hold their neutrons. The foregoing is a lot more nuclear physics than this paper pretends to teach.

Note: . The capture cross section value for a specific isotope is represented by the Greek letter, sigma,sub c, (σ_c). In the "***Table of Isotopes***", sixth edition, 1967, Leander, Hollander and Perlman, all capture cross section values are based only on slow or "thermal neutrons", (.02eV). The table referred to earlier lists every thermal capture cross section for every isotope of all elements.

From all of this, we need to plow through these tables and find elements with isotopes that have huge cross sections. Huge cross sections mean far more probability that our limited thermal neutron count in the moderator will make that isotope of the element radioactive to a greater degree than one of a lower cross section. That sounds easy enough.

There are flies in this ointment, however. So we find an isotope with a huge cross section. What is its atomic percent of the element? If it is 1% or even 5%, there is not that much in our element to activate. OK, now we dig deeper and find an isotope with a large cross section and an atomic percent of 86%! That fly is killed off, happy days are here.

Wait! I said flies, plural. What does this wonder isotope turn into with a captured neutron? Go to the next higher atomic weight above our lovely bombarded isotope and see what we have. Those pesky flies did it to us again….#@$%&*… The new isotope is stable! It happens often and stability means it is not radioactive.

Well, let's say the gods favor us and the new isotope is, indeed, radioactive! Yeah! Another fly is dead and down. Sadly, we are not done yet as another fly is still buzzing around. What is the half-life of our newly created radioactive isotope? We find it is 75.6 days! We are killed by this last fly carrying the disease of long half-life.

Why, after the wonderment of filtering through the table and finding a huge cross section, a large isotopic percent of our isotope and a great radioactive new baby isotope that we created, would a long half-life kill us and our baby child radioactive isotope?

Think about it. We start with a stable isotope in great abundance in our element with a huge cross section that we will be turning into a radioactive new isotope. The key word is we start with a non-radioactive "stable" isotope. The new isotope has a 75.6 day half-life. We know from radioactive decay that half of the radioactive element will be gone in 75.6 days and it generally takes 5 half-lives to reduce the radiation to where only a percent or two of the original radiation remains. It works in reverse when activating an element as well!

To activate our lovely choice isotope in any given slow "neutron flux", (The number of neutrons per square center, per second entering our element), we would have to run our fusors continuously at full bore for 75.6 days just to reach the 50% radiation level of activation based on our normally pitiable neutron flux in our moderator. It would take more than a year of continuous fusor operation to fully activate and maximize the radiation from the new isotope.

What are the ideal characteristics for a great element and isotope of it that we seek for fusor activation?

Large cross section (20 barns or more)

Large atomic abundance (20% or more)

A radioactive final product

A very short half-life of the final activated product for easy activation and detection

(This means less than a 1 hour half-life, preferably only a few minutes!)

Why do we desire a foil for activation?

Think again. Let us say we have a perfect elemental specimen, but it is a large lump. Let us also say that it is a beta emitter with a 560keV average particle emission. In a suitable moderator, due to its large cross section the neutrons are going to interact within a few millimeters of the surface, for the most part. The betas from activated metals might only penetrate 0.5mm of metal and they would be grossly weakened and perhaps not detectable in some GM tube detectors. Thus, you are only really reading the surface emission.

Using a thin foil in the moderator of a favorable geometry for the area of your GM detection tube would mean you would be counting activation betas coming at the tube from front and rear of the foil.

When would I use a GM counter versus a scintillation system?

In the "***Table of Isotopes***", sixth edition, 1967, Leander, Hollander and Perlman, you will find the type and relative percentages of radiations emitted from your chosen activated isotope. If you have a preponderance of betas in the activated product, you would use a GM counter. If the betas are of low energy a mica windowed counter tube would be demanded. However, all betas from activation are best counted with a 2" pancake detector probe. Note it is important to have a digital counter connected to the GM counter. You must first record a statistically valid background count rate inside your lab or environment as a base line. Subtract this from the timed count of your activated element to find out how much radiation you have due to activation.

If you are getting a preponderance of gamma rays, due to activation, a scintillation counter connected, again, to a digital counter is needed. Those fortunate enough to possess a gamma ray spectrometer can double verify activation by detecting the precise energy of the gamma rays listed in the "***Table of Isotopes***". Gamma detection of more massive or thick items is easily accomplished. Hard gammas can penetrate to the full depth of activation in thick sections. For those doing gamma spec. work, this will broaden the peaks as attenuation will be present on really thick or large specimens irradiated.

The above book is a must have for anyone serious about activation, gamma spectroscopy or curious about the vast number of elemental isotopes. You will pay big bucks if you want a genuine, original, hard back copy. $100 or so is about right in fine condition. A soft cover original can easily be $50.00.

I have seen reprints or PDF's offered on ABE for $40.00. For us real book lovers, the touch and feel of a hard back copy is the only real book solution. I have three hardbacks and one softback in my collection. I use the worst of the hard backs in my lab.

Doing the hard work for you based on the above book and experience.

There are only four great easy elements to activate with a fusor. I will touch on each in order of desirability from the major points listed.

1. **Rhodium103** - abundance 100%, cross-section 144b, product Rh104, T1/2 43 seconds
   Emission almost totally beta with a maximum energy of 2.24meV!
   This was Enrico Fermi's pride and joy. He used it extensively to calibrate neutron sources. Rhodium is terribly, expensive, but highly variable in its price over the years from $10,000/troy oz. to $750/troy oz. 1/10 ounce bars are thin and commercially available. As of this writing Rhodium is about $2,000 per ounce to purchase from kitco.com.

2. **Silver107 and 109** – abundance Ag107 51.35% Ag109 48.65%, cross section Ag107 35b, Ag109 89b, products Ag108, T1/2 = 2.42min, all beta 1.64meV max and Ag110, T1/2 = 24.4 seconds, almost all beta 2.87 meV
   This is a favorite with all fusioneers due to its price, availability and hot betas from two different activation product isotopes.
3. **Indium115** - Note it is radioactive T1/2 = 600 trillion years, abundance 95.7%, cross section,45b to In116 and 154b to In116m1, In116 T1/2= 14 seconds almost all beta 3.3meV max!, In116m T1/2 = 154 minutes, beta to 1meVmax and a great big load of gammas for spectroscopy ranging from 417keV to over 2.0meV! Indium is not hard to find and is only slightly more expensive than silver.

4. **Manganese53** – abundance 100%, cross section 13.3b, product Mn56, T1/2 = 2.5 hours, beta to 2.85meV max and a number of good gammas. .857keV is predominant. Cool, but requires long activation periods. Not a great cross section, but 100% abundance wins. Another great thing is that Manganese sulfate is water soluble and a saturated solution in a gallon jug will act as the moderator!

Interesting also rans….

Gold197 – abundance 100%, cross section 99b, product Au198, T1/2 = 2.6 days! Beta to 962keV max a gamma predominant at 412keV. Large cross section and 100% abundance wins if you can run for just 24 hours.

Dysprosium164 – abundance 28.2%, cross section 800b to Dy165 and 2000b to Dy165m!!! Wow! Dy165, T1/2 = 139 minutes, product is mainly beta 1.3meV max. Dy165m1, T1/2 = 1.26minutes, Dy165m2,T1/2 = 32seconds. Note both 165m isotopes decay preferentially by isomeric transitions. Both have gammas, but it is recorded that DY165m2 has a very complex gamma spectrum. Dy165m1 has limited beta and gamma emissions betas are ~1meV. One I have never heard of, but with the monstrous cross section and a decent atomic percent, this might be a real sleeper. Figure out what compound is water soluble, moderate in a gallon jug and try for the gamma spec. The best among us can push a good fusor for 2 hours. You may not need to push it that long with a good gamma spec .

That is it! Try your luck at finding stuff to activate, but you will need the book on the isotopes.