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Summary of Alpha-Neutron Sources in GADRAS

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Abstract

A common source of neutrons for calibration and testing is alpha-neutron material, named for the alpha-neutron nuclear reaction that occurs within. This material contains a long-lived alpha-emitter and a lighter target element. When the alpha particle from the emitter is absorbed by the target, neutrons and gamma rays are released. Gamma Detector Response and Analysis Software (GADRAS) includes built-in alpha-neutron source definitions for AcC, AmB, AmBe, AmF, AmLi, CmC, and PuC. In addition, GADRAS users may create their own alpha-neutron sources by placing valid alpha-emitters and target elements in materials within their one-dimensional models (1DModel).

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Nomenclature

GADRAS Gamma Detector Response and Analysis Software

1. Background

Alpha-neutron materials are a common source of neutrons for calibration and testing. Americium-beryllium (AmBe) and plutonium-carbon (PuC) are examples of such materials. These sources always contain an alpha emitter and a target. The emitter is usually a high-Z radionuclide and the target a lighter element. When the emitter material and target material are either chemically mixed or placed adjacent to one another, alpha particles from the emitter bombard the target. If the alpha particle has sufficient kinetic energy to overcome the Coulomb barrier of the target, it may be absorbed by the target, transmuting the target into a different nuclide. This nuclide is usually in an excited state, and, by design, one of the primary decay modes is neutron emission. The neutrons may be accompanied by gamma emission as well. For example, consider a PuC source containing Pu-238 as the emitter and C-13 as the target. Upon absorption of an alpha from the plutonium, the carbon is transformed into an excited state of O-17,

$$ {}^{13}_{6}C + \alpha \rightarrow {}^{17}_{8}O^{*}. $$

The O-17 nuclide immediately decays by neutron emission into O-16, potentially leaving it in an excited state as well (depending on the energy of the alpha particle),

$$ {}^{17}_{8}O^{*} \rightarrow {}^{16}_{8}O^{*} + n. $$

If the alpha particle energy exceeds 5120 keV, the O-16 nuclide is left in an excited state after the neutron emission from the binding energy of the last two protons and neutron. It de-excites by emitting a 6129 keV gamma,

$$ {}^{16}_{8}O^{*} \rightarrow {}^{16}_{8}O + \gamma. $$

The 17 ps lifetime of this excited state is long enough for the recoiling O-16 nucleus to come to rest, minimizing any Doppler broadening of the 6129 keV gamma. The yield of this gamma is determined by the probability of entering different excitation levels of the O-16 nuclide, which is dependent on the energy of the incident alpha particle. Most alpha emitters emit a range of energies. Therefore, the relative yield of the 6129 keV gamma to each neutron is different for sources with the same target but different alpha emitters (e.g. PuC and CmC) because the alpha particle energies differ.

2. Implementation in GADRAS

There are three methods for accessing gamma yields in Gamma Detector Response and Analysis Software (GADRAS): 1) utilize built-in sources; 2) create sources using the 1D Model tool; or 3) use a combination of these two methods.

2.1 Built-In Sources

The built-in sources may be plotted at any time on the plot page by typing in the name of the source in the *Computed Spectrum* box. Figure 1 shows the source alias and strength input into the *Computed Spectrum* box as “PuC,1mC” (read as 1 milliCurie of Pu-238 in a PuC source) and the resulting estimate response from a HPGe detector. The 6129 keV gamma is apparent in the spectrum. The built-in alpha-neutron sources include **AmB**, **AmBe**, **AmF**, **AmLi**, and **PuC**. The definition for these sources can be found as *.gam* files in the GADRAS\Source\Neutron directory. For all built-in alpha-neutron sources, the activity is normalized to the activity of the alpha-emitter.

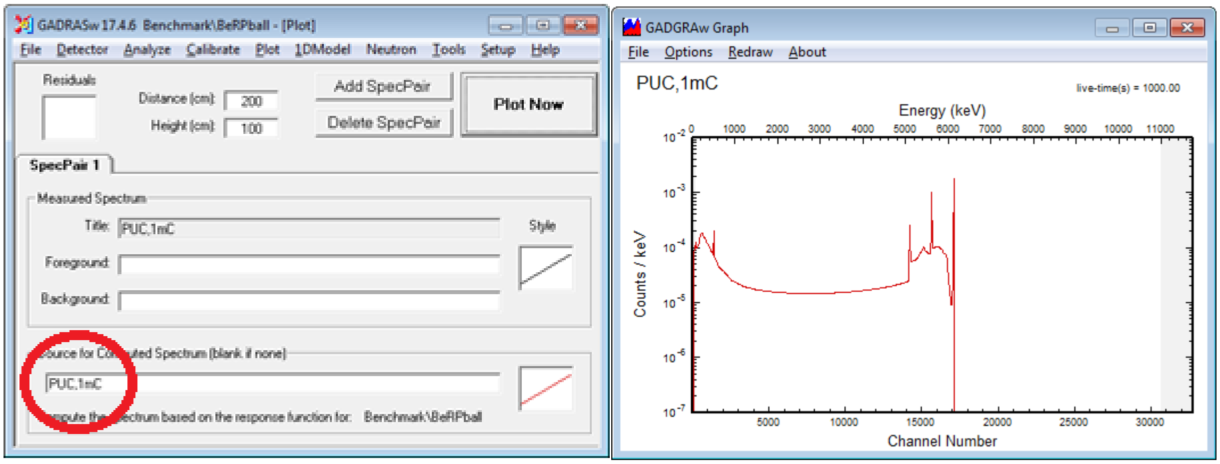

Figure 1. Specifying a Built-in Alpha-Neutron Source on the Plot Page

2.2 1D Model

Like all built-in sources, the alpha-neutron sources listed above are also available to be placed as a trace source in any 1D model shell. In addition, the 1D model can generate neutron and gamma emissions from alpha-neutron materials.

In the GADRAS root folder (typically *C:\GADRAS* on a Windows machine), there is the *Material.lib* file. Upon loading the program, GADRAS populates the material drop-down box in the 1D Model page with the material definition given in this file. When the 1D Model is saved or the radiation transport is simulated, GADRAS searches the material for alpha emitters and valid targets. If a material contains *valid* alpha emitters and *valid* targets, it will automatically generate the neutron and gamma emissions. Details regarding which emitters and targets create alpha-neutron sources are discussed in the following section.

Common materials known to contain valid emitter and target nuclides are distributed with GADRAS and appear in the dropdown materials list prepended with “AlphaN-” as shown in Figure 2. This list includes **AcC**, **AmB**, **AmBe**, **AmF**, **AmLi**, **CmC**, and **PuC** source materials. The “AlphaN-” prefix is used to group the alpha-neutron sources together in the menu, similar in nature to the grouping of high explosive materials prepended with “HE-”.

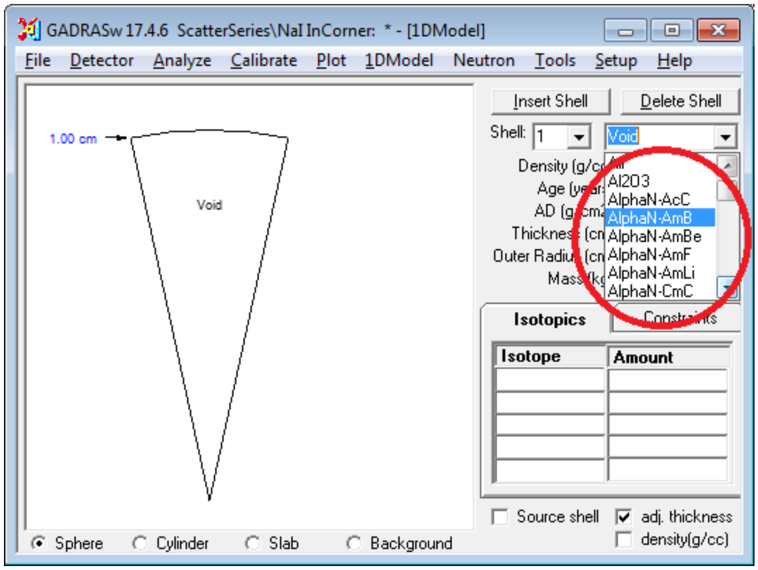

Figure 2. Specifying a Built-in Alpha-Neutron Material on the 1D Model Page

Users may add new material definitions by editing (or creating) the *Material.user* file (see *Material.user.example* for example material definitions). Materials created in this file will also be added to the drop-down box.

2.3 Neutron

GADRAS uses the code Sources4C [1] to compute the neutron yield from materials or interfaces containing both alpha emitters and targets. The list of valid emitters is shown below in Table 1. The list of valid targets is shown in Table 2.

Table 1. List of Valid Alpha Emitters [1]

Ce-142	At-219	U-230	Cm-240	Po-210	Th-226
Nd-144	Rn-217	U-231	Cm-241	Po-211	Th-227
Sm-146	Rn-218	U-232	Cm-242	Po-212	Th-228
Sm-147	Rn-219	U-233	Cm-243	Po-213	Th-229
Sm-148	Rn-220	U-234	Cm-244	Po-214	Th-230
Sm-149	Rn-222	U-235	Cm-245	Po-215	Th-232
Gd-152	Fr-221	U-236	Cm-246	Po-216	Pa-230
Pb-210	Fr-222	U-238	Cm-247	Po-218	Pa-231
Bi-210	Fr-223	Np-235	Cm-248	Es-253	Am-240
Bi-211	Ra-222	Np-237	Cf-248	Es-254	Am-241
Bi-212	Ra-223	Pu-235	Cf-249	Es-254m	Am-242m
Bi-213	Ra-224	Pu-236	Cf-250	Es-255	Am-243
Bi-214	Ra-226	Pu-237	Cf-251	Fm-254	Pu-241
At-215	Ac-225	Pu-238	Cf-252	Fm-255	Pu-242
At-217	Ac-226	Pu-239	Cf-253	Fm-256	Pu-244
At-218	Ac-227	Pu-240	Cf-254	Fm-257	Bk-249

Table 2. List of Valid Alpha Targets [1]

Li-7	Be-9	B-10
B-11	C-13	N-14
O-17	O-18	F-19
Ne-21	Ne-22	Na-23
Mg-25	Mg-26	Al-27
Si-29	Si-30	P-31
Cl-37		

2.4 Gamma

The gamma emission from alpha-neutron sources is not provided through Sources4C. Some literature is available on the measured relative yield of gammas compared to neutrons. While the gamma energies are well known for many sources, data on the relative yield of these gammas to neutrons is somewhat limited. A small database of gamma yields included in GADRAS is compiled from literature which is used to determine the gamma emission from alpha-neutron sources. It is a combination of emitter-dependent and approximate emitter-independent yields. There are emitter-independent gamma yields for **Li-7**, **Be-9**, **B-10**, **B-11**, **C-13**, **N-14**, **O-17**, **O-18**, and **F-19** targets. In addition, there are specific emitter yields for **Am-241/Li-7**, **Am-241/Be-9**, **Am-241/B10**, **Am-241/B11**, **Pu-238/C-13**, **Cm-244/C-13**, **Am-241/F-19**, and **Pu-238/F-19** combinations. These yields are contained in the *Program\gadras.exe.config* file. An excerpt of this file is shown below. Yields may be modified or emitter/targets added by editing this file.

```
<setting name="AlphaGammaLineSpectra" serializeAs="Xml">
      <value>
            <ArrayOfString>
                  <string>Default Be9 4438 1</string>
                  <string>Default C13 6129.89 0.01843</string>
                  <string>Pu238 C13 6129.89 0.01843</string>
                  ...
            </ArrayOfString>
      </value>
</setting>
```

Each <string> tag contains a single line of information describing the gamma lines from an alpha-neutron source. The first word is the emitter nuclide (or “Default” if it is to be emitter-independent). The second word is the target nuclide (must be specified; no “Default” is allowed). The following numbers are gamma energy/yield pairs. The energy is in units of keV and the yield is a fractional yield relative to the number of neutrons created by the source. The program will always use the emitter-specific yields if available and only the emitter-independent yields if not.

3. Summary

GADRAS has the ability to use pre-built alpha-neutron sources for plotting or as trace-sources in 1D models. In addition, if any material (existing or user-defined) specified in a 1D model contains both an alpha emitter in conjunction with a target nuclide, or there is an interface between such materials, then the appropriate neutron-emission rate from the alpha-neutron reaction will be computed. The gamma-emissions from these sources are also computed, but are limited to a subset of nine target nuclides. If a user has experimental data to contribute to the alpha-neutron gamma emission database, it may be added directly or submitted to the GADRAS developers for inclusion. The *gadras.exe.config* file will be replaced when GADRAS updates are installed, so sending the information to the GADRAS developers is the preferred method for updating the database. This is also preferable because it enables other users to benefit from your efforts.

References

[1] *SOURCES-4C: Code System For Calculating a,n; Spontaneous Fission; and Delayed Neutron Sources and Spectra.* Los Alamos National Laboratory, 2002, LA-UR-02-1839.

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