Gadolinium as a converter foil

What is it used for?

* Neutron moderation

One of the many ways neutrons can interact with matter is through neutron absorption. Neutron absorption occurs

Natural gadolinium consists of 6 stabel isotopes and one unstable isotope. The two isotopes which contribute the most to it’s neutron absorption cros-section are Gd-155 and Gd-157 with cross-section 60900 and 254000, respectively. This is quite a significant difference compared to the cross section og B and Li absorber. When a neutron beam traverses a volume of natural gadolinium and its isotopes undergo neutron capture it result in daughter isotopes, gamams, conversion electrons, characteristic X-rays and ACK electrons. The neutron capture reaction equation of Gd-155 and Gd-157 are

A close up of a logo

Description automatically generated

When an isotope absorbs an incoming neutron it enters an excited state. Deexitation of the isotope occurs in the for om either gamma or conversion electron emission, two competing processes. The Q-value (characteristic decay energy?) of the reaction determines the energy of the gamma ray, energy spectrum is continuos with Q-value being the limit. In other words, gammas emittet from Gd-155 and Gd-157 have energies 7.9MeV and 8.5 MeV, respectively, or less. The most common energies. Characteristic energy peaks? Competing with gamma is the emission of conversion electrons, which in contrast to gamma emission, has a descrete energy spectrum. Primary electron sfrom internal conversion vary a fixed part of the characteristic decay energy, thus resulting in a descrete energy spectrum.

Once a conversion electron

range maksimum being the Q-value and he energy of an emittet gamma ray is dependent on the Q-value of the reactions, it’s maximum being Q value

Emission of a gamma and an conversion electron are competing processes, either

Gadolinium

* Used as a neutron converter
* Has a high neutron absorption cross section
* Cost? Density?

Natural gadolinium

* 6 stable isotopes 1 unstable isotope
* Gd-155 and Gd-157 contribute to high neutron absorption cross-section.
* Reaction equation of the isotopes are : …
* Characteristic decay energies are 7.9 and 8.5 MeV, respectively
* Products of the reaction is a daughter fissile nuclei (a nuclei that has underwent fission with a thermal neutron), gamma rays, internal conversion (IC) electrons, X-rays and Auger and Coster-Kroning (ACK) electrons.
  + After capture the fissile nuclei is in an exicted state.
  + To deexcite it either emits high/low(?) energy gamma rays or internal conversion electrons, two competing processes.
    - Gamma
      * Continuous energy spectrum
      * Maksimum energy is the characteristic decay energy of the neutron capture reaction.
    - Conversion electrons
      * *A radioactive decay process (def.?)*
      * Possible when gamma-decay is possible, except when atom is fully ionized (why?)
      * The fissile nucleus interacts electromagnetically with one of the orbital electrons of the atom. As a result
        + An electron is ejected from the atom, known as the IC electron.

Not to be confused with B-decay, electron emission from the nuclei.

Atomic number unchanged, since electron emitted from shell and not nuclei.

* + - * + Electrons from a higher energy level descend and fill the hole left in place of the ejected (IC) electron.

Descending electrons emit characteristic X-rays, auger electrons, or both.

Filling of an inner shell vacancy can be accompanied by an electron from the same atom, these are called Auger electrons. Coster-Kroning electrons are a special case of the auger process in which a vacancy is filled by an electron from a higher subshell of the same shell.

The secondary electrons, those produced by IC electrons, are refered to, in this thesis, as Auger and Coster-Kroning (ACK) electrons.

* + - * IC electrons have a descrete energy spectrum. Characteristic energies of
        + Gd-155: 0.089 MeV and 0.199MeV
        + Gd-157: 0.079 MeV and 0.182 MeV

Anything else?

* Reaction products are gammas and conversion electrons, competing processes.

The capture of thermal neutrons by gadolinium produces electrons with characteristic energies, which depend on the type of gadolinium isotope. The isotopes with the greatest neutron absorption cross-section are Gd-155 and Gd-157, 60900 and 254000 barns, respectively. The electron energy is dependent on the isotope of gadolinium. In natural gadolinium the mo

4/24/20

Thoughts

* Converterfoils in general?
  + What is their purpose, why do we need them
  + Alpides are unaware/blind of/to neutrons
* Keep it short and simple
  + Probably need several paragraphs on Gd distributed over different sections
* List key benefactors
* Argue for why you have chosen to use Gd

Why are we using gadolinium

**What is gadolinium?**

Gadolinium (subject of the paragraph)

* Is a chemical element
* Was discovered in 1880
* Is a metal
* Has atomic number 67
* Appears as a solid under standard pressure and room temperature.
* Naturally occurs as a composition of seven isotopes; six stable Gd-154, Gd-155, Gd-156, Gd-157, Gd-158, Gd-160; and one radioisotope, Gd-152.
  + The most abundant being Gd-158 (24.84%), followed by Gd-160 (21.86%), Gd-156 (20.47%), Gd-157 (15.67%) and Gd-157 (14.80%).
* First used as a particle converter?
* [https://en.wikipedia.org/wiki/Gadolinium - Isotopes](https://en.wikipedia.org/wiki/Gadolinium#Isotopes)

**Why use gadolinium as a particle converter?**

Gadolinium

* Attributes high neutron capture cross section due to isotopes Gd-157 and Gd-157, … and …., respectively.
  + The 157Gd isotope has the highest thermal neutron capture cross-section of any known stable element.
  + Used in neutron capture therapy (GdNCT). Why? Widely? Reference?
* In an excited state decays by emitting internal conversion (IC) electrons and gamma-rays.
  + IC electrons (changing the subject?) have characteristic kinetic energies resulting in a descrete energy spectrum.
    - Possible to detect neutron activity,
    - E.g. fields, science, weapons,, dosimetry, ?
  + Gamma-rays continuous energy spectrum …

Attributes of Gadolinium?

Gadolinium

* Attributes high neutron absorption cross section
* Neutron penetration depth, reference?
* Electron

**Layout**

In general as a converter

* Intro: what is Gd
* What are some characteristics
* What is it good for?
* In comparison to other converters, how does it score?
* Has it been used before?
  + What fields?

Neutron capture in gadolinium

**4/24/20**

**Introduction to Gd**

Gadolinium (Gd) is a chemical element with atomic number 64. It is a metal and appears as a solid under standard pressure and room temperature. In nature Gd occurs as a composition of seven isotopes; the most abundant being Gd-158 (24.84%), followed by Gd-160 (21.86%), Gd-156 (20.47%), Gd-157 (15.67%) and Gd-157 (14.80%).

**Gd Cross section and its use**

Gd has many favorable characteristics allowing an eclectic range of use; for instance in alloys to make magnets, electronics and data storage disks( [\*](https://www.rsc.org/periodic-table/element/64/gadolinium)); and as a contrast agent in MRI, to diagnose cancerous tumors([\*](https://www.chemicool.com/elements/gadolinium.html)).

Of particular interest is its high *neutron absorption cross section*, high probability of neutron capture. Of all known natural occurring nuclei, Gd-157 has the highest neutron absorption cross section having resonance at thermal-neutron energies ([\*](https://ebookcentral-proquest-com.pva.uib.no/lib/bergen-ebooks/reader.action?docID=404842&ppg=536)). As efficient neutron absorbers, Gd plays an important role in neutron shielding alloys for nuclear reactor safety and storage ([\*](https://digital.library.unt.edu/ark:/67531/metadc898814/)). An additional use of great Gd neutron capture is as Gd-based neutron poison, for instance Gd(III) nitrate in moderator systems for regulating power generation and shut-down of Heavy Water Nuclear Reactors ([\*](https://web.archive.org/web/20080423194722/http:/www.hss.energy.gov/NuclearSafety/techstds/standard/hdbk1019/h1019v2.pdf) page 31).

Not limited to the field of nuclear physics, Gd neutron absorption capability also benefit(s?) neutron capture therapy for cancer treatment and **neutron detection**, due to reaction products following neutron capture. *In gadolinium neutron capture therapy (GdNCT) a cancer patient is injected with Gd endused tracer followed by exposure to a neutron beam. Neutron absorbed by the Gd tracer produce secondary particles such as photons and electrons. While traversing tissue, the particles deposits dose and The particles travels the tissue exposed to a neutron beam, once Gd absorbs neutrons, decays and release product particles the particles is injected to the cancer patient product particles deposits dose locally to*

Introduction to neutron detection???

**Neutron capture in gadolinium**

Neutron capture cross section of natural Gd is given by the weighted sum of isotopic cross sections. Relative abundance of Gd isotopes in natural Gd and their neutron capture cross section are listed in table 1. Isotopes Gd-157 and Gd-155 collectively contribute 99.99% of the cross section, resulting in . Natural Gd interaction with thermal neutrons may therefore be simplified as a *“two-absorbing isotope system*” consisting of the isotopes Gd155 and Gd157 [Dumazert, 2018].

**Nuclear reaction equation**

Since natural Gd interaction with neutrons can be ascribed to isotopes Gd-157 and Gd-155, it is worth studying their corresponding nuclear reaction equation.

Once a Gd nuclei has absorbed a neutron it exists in an excited energy state from which it decays by *gamma-transition, resulting primarily in (*means of) gamma-ray () emission and internal conversion (IC) electrons. Byproducts of the decay are ACK electrons and X-rays, prompted by vacancies left by the IC electrons, *for further explanation of gamma-transition see section ??. The Q-value () is defines as the difference in mass before and after a nuclear reaction and the net energy released during the decay. This energy is distributed as kinetic energy among product particles. Due to the Gd nuclei’s large mass, compared to a photon (massless) and an electron, the recoil energy is neglectable ( Modern Nuclear Chemistry, page 219*[*\**](https://ebookcentral-proquest-com.pva.uib.no/lib/bergen-ebooks/reader.action?docID=4830611&ppg=238)*). I.e. most of the Q-value is distributed among gamma-rays and IC electrons.*

The Q-value () represents the net energy released during the decay … and the energy sum of gammas and electrons

What determines te energy of a gamma-ray?

Promt gamma energy spectrum is continuous, the gamma-rays may take any energy ranging from … to the Q-value. Peaks from more common transitions? The use of gammas in neutron detection.

In co

Both primary products, promt gammas and IC electrons, are used in neutron detection. May

More here

* Gamma-decay
  + Continuous spectrum
* IC electrons
  + Descrete spectrum
  + ACK elecrtons, X-rays (contribution? Noise)
* Both particles are used in neutron detection. Some detectors construction take advantage of the promt gamma-rays, with reccocnizable energy peaks (fig?). The number of gammas reviel neutron activity(?) and can …. The use of gamma counters? Which type of detectors….
* When were conversion electrons first utilized or studied? Benefits? The use of conversion electrons

Use of gamma

Use of electrons

FORTSETT HER

Read: http://www.nucleide.org/DDEP\_WG/introduction.pdf

Decay by gamma

* Reference:
  + Gd157: [https://arxiv.org/pdf/1809.02664.pdf page 13/27](https://arxiv.org/pdf/1809.02664.pdf%20page%2013/27)
  + Gamma decay: http://oregonstate.edu/instruct/ch374/ch418518/CHAPTER%209%20GAMMA%20RAY%20DECAY-rev.pdfGd155: ?
* Continuous energy spectrum
* Cascade?
* Decay scheme?

Conversion electrons

* Reference: <http://www.nucleide.org/DDEP_WG/introduction.pdf> (23)
* Discrete kinetic energy
* AKG electrons
* X-rays

Conversion coefficient?

First gamma then electrons. Reference??

Main contributors to neutron capture in natural gadolinium are the isotopes Gd-158 (24.84%) and Gd-157 (14.80%) with neutron capture cross section …. and …, respectively.

* Gd-155 and Gd-157
  + Cross section
  + Reaction equation
    - Q-value (reference?)
    - Reaction products: isotope\* (nuclear rearrangements) and secondary particles (decay of excited isotope)
      * New isotope, nuclei in an excited energy state, decays by gamma and electrons.
      * Following conversion electrons are auger-ck electrons and X-rays.

Cross section

Why?

Compare to other capture elements, B and LI

* Neutron capture therapy with B and Gd, <https://link.springer.com/article/10.1007/s11172-005-0045-6>
* detector

High neutron absorption cross section

* Efficient neutron absorber
* Powerful/great neutron absorber
* The presence of gadolinium
* Large capture cross section for thermal neutrons

Use

* Utilization
* Employmed
* Deploy?
* Make use of
* Exploit

Absorber

* capture

Undetected

* unimpeded

Nulcear reaction equation

* capture reaction

Reaction products

*All isotopes of natural gadolinium and their attributes are listed in table ?.*

Nuclear reactor safety and storage

[29] J.-S. Choi, J.C. Farmer, C. Lee, L. Fischer, M. Boussoufi, B. Liu, H. Egbert, Neutron- Absorbing Coatings for Safe Storage of Fissile Materials with Enhanced Shielding and Criticality Safety, Materials Science & Technology Conference and Exhibition, Detroit, Michigan, United States of America (2007)