Delayed Neutrons

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Introduction

An essential problem when designing a nuclear reactor is to be able to control the rate of production of neutrons. In most reactors control rods composed of materials with high neutron capture such as Cd-113 or B-10 are inserted into the reactor to reduce the number of available neutrons. [1] Since the number of neutrons grows exponentially, it is necessary that the e-folding time be on the order of the time associated with mechanical process of moving the rods. Therefore the e-folding time (or time constant) should be at least tenths of seconds. Unfortunately, most neutrons (designated prompt neutrons) have a time constant of milliseconds. This is where delayed neutrons come into play. Delayed neutrons have a time constant of about 0.1 seconds, and they constitute 0.65% of the fission neutrons. [1] These neutrons allow control rods to regulate the number of neutrons in the reactor.

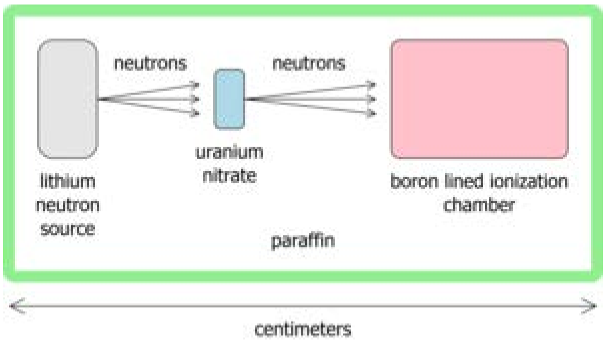

Fig. 1: Shown is a schematic of the experiment performed by Roberts et al. to first observe delayed neutrons. [3,4]

Discovery

Delayed neutrons were first discovered by Roberts et al. in 1939. [2] The experiment was conducted as follows. First a piece of lithium, used as a neutron source, was positioned a few centimeters from a boron lined ionization chamber. To generate neutrons, the lithium was bombarded by a pulse of deuterons. When there was nothing in between the lithium and the ionization chamber, neutrons were only detected at the chamber when the deuteron pulses were on. However, when a sample of uranium nitrate was placed between the two pieces of equipment such that fission could occur, neutrons were detected up to 90 seconds later. [3,4]

Origin

Further experiments would reveal that delayed neutrons are accompanied by prompt neutrons and beta radiation. [5-7] It was therefore determined that delayed neutrons are emitted from neutron-rich products of prompt radiation after a beta-decay. [8] This additional neutron radiation is possible because the fragment generated from prompt fission has yet to reach beta-decay stability. Specifically, a nuclear fission process results in what is called a "precursor." The precursor then beta-decays and some of the resultant products become delayed neutron emitters. [2]

Further Study

More recent experiments have studied the spectra of the delayed neutrons. The spectra show structure that is directly related to the delayed neutron emitter and resultant grandchild nuclei. By using a technique such that spectra is only measured for specific precursors, it is possible to study the properties of the precursors, such as the shape of the excited nucleus. In general, research in this area has allowed for a better understanding of delayed neutrons and hence forms the basis for nuclear reactor control. [2]

References

[1] W. D. Loveland, D. J. Morrissey and G. T. Seaborg, *Modern Nuclear Chemistry, 1st Ed.* (Wiley-Interscience, 20061.

[2] C. Wagemans, *The Nuclear Fission Process* (CRC Press, 1991).

[3] R. B. Roberts, R. C. Meyer, and P. Wang, "Further Observations on the Splitting of Thorium and Uranium," Phys. Rev. **55,** 510 (1939).

[4] R. B. Roberts, L. R. Hafstad, R. C. Meyer, and P. Wang, "The Delayed Neutron Emission Which Accompanies Fission of Uranium and Thorium," Phys. Rev. **55,** 664 (1939).

[5] L. Szilard and W. H. Zinn, "Instantaneous Emission of Fast Neutrons in the Interaction of Slow Neutrons With Uranium," Phys. Rev. **55,** 799 (1939).

[6] H. L. Anderson, E. Fermi, and H. B. Hanstein, "Production of Neutrons in Uranium Bombarded by Neutrons," Phys. Rev. **55,** 797 (1939).

[7] E. T. Booth, J. R. Dunning, and F. G. Slack, "Delayed Neutron Emission from Uranium," Phys. Rev. **55**, 876 (1939)

[8] N. Bohr and J. A. Wheeler, "The Mechanism of Nuclear Fission," Phys. Rev. **56,** 426 (1939).