Improved Scintillator Materials for Compact Electron Antineutrino Detectors*

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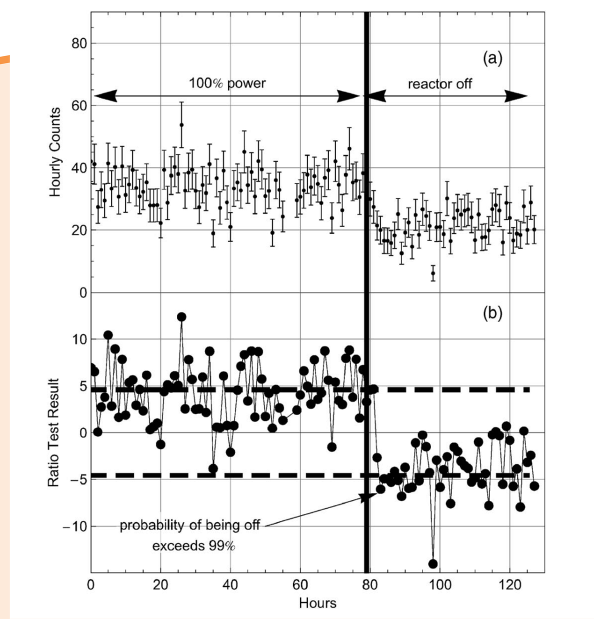
Introduction

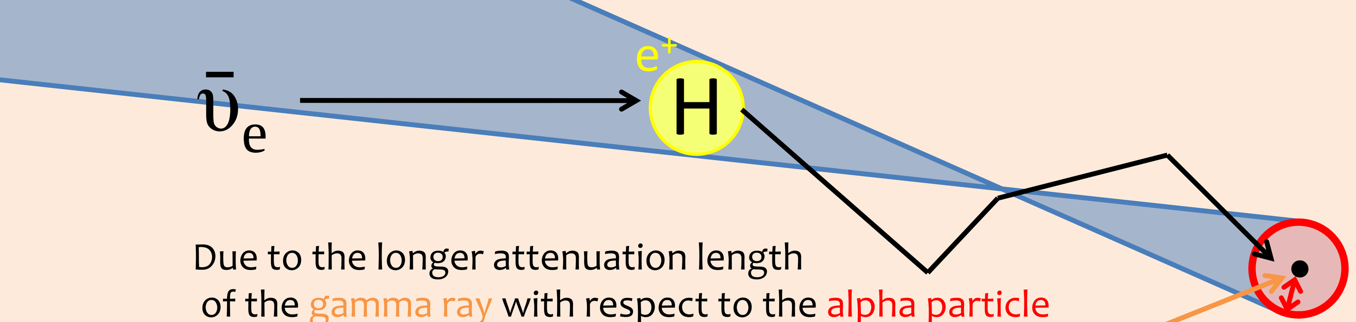
Analyse of the electron antineutrino spectrum emitted by nuclear reactors provides a means to estimate the operational status and thermal power output of that reactor.[1,2] Furthermore it has been demonstrated that it is possible to estimate the direction of the incoming neutrino.[3] This means that an antineutrino detector can be used for the monitoring of processes inside nuclear reactors for both operational purposes and the reactor safeguards regime setup by the International Atomic Energy Agency.[4,5]



Hourly neutrino rate, distinction can be made between on and off (taken from [1]).

Reverse beta decay

An antineutrino reacts with a proton to form a positron and neutron. The positron is annihilated almost instantly while the neutron undergoes thermalisation over several centimeters till it encounters a neutron capture agent.[3]

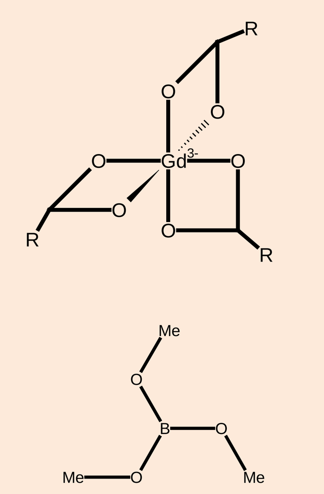


Due to the longer attenuation length of the gamma ray with respect to the alpha particle directional information is lost with gamma rays. From the position of the alpha pulse and the positron pulse the direction of the neutrino can be estimated.

Neutron capture agent

Until recently neutron capture agents that were used employed unstable compounds.[9] These systems needed constant purification and checking. Recently it was shown that beta-diketone gadolinium coordination compounds improved the overall stability of the system.[7] However current Gd systems are not stable in polymers.[10]

The unstable compound trimethylborate has in small scale tests successfully been used as an neutron capture agent variant.[11] By improving the design of the coordinating ligands surrounding the boron atom, compounds with improved attenuation lengths, improved stability and solubility should be obtainable.



Gadolinium beta-diketone (R is an alkyl group) and Trimethylborate

Objectives / Signal processing

The reverse beta decay process produces two time differentiated signals due to positron annihilation and the energy deposition of a gamma-ray or alpha particle. Due to the specific timing and spatial distance between these two signals it is possible to differentiate between real and random events.[12] With the use of boron as neutron capture agent and pulse shape discrimination it is possible to screen for the distinct finger print of an alpha particle signal and reject the signals coming from gamma rays.[13]

Current status

Existing antineutrino detectors have overall efficiencies ranging from 10 to 78% for the detection of antineutrinos, this range stems a.o. from their different sizes.[2,6,7] With small detectors (1 m³) a significant amount of the gamma radiation travels outside the detection area and is lost for measurements.[1] To enable higher efficiencies with small detectors a system where almost all of the deposited energy is preserved inside the area of detection is essential.

Detector size	Hazardous chemicals	Directional sensitive	Easily deployable	Dead volume
Large	Yes	Yes	No	Almost none
Small	Yes	No	Some	significant

Gamma versus Alpha

A neutron produced by reverse beta decay will undergo thermalisation via collisions with other atoms till it can be captured by a nucleus.[8] Depending on the specific nucleus a gamma ray or alpha particle is emitted.

Emitted ray or particle	γ	α	
Attenuation length	300	10	mm
Energy	2.2	0,06	MeVee
Signal also present in background signals	Mainly	minor	
Directional sensitive	No	Yes	

Fluorescent compounds

Presently used fluorescent compounds and wavelength shifters have been in use since the beginning of scintillation counting.[8] In recent years new technologies including solar cells, OLEDS and Q-dots have provided new fluorescent materials which may also be of interest for scintillation purposes.[14,15,16]

These compounds which have recently been developed are synthesized with cost, durability and quantum efficiency in mind. These substances are easy to tune to specific wavelengths and are chemically stable.

Fluorescent Q-dots emitting different colors upon irradiation with UV light

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* INCAS³ is made possible by the support of: The Northern Netherlands Provinces (SNN). This project is co-financed by the European Union, European Fund for Regional Development and the Ministry of Economic Affairs, Peaks in the Delta.