Determination of background sources in BOREXINO

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Abstract

Background originating from radioactive decays is an important aspect of detectors which are dedicated to the search of rare events in the field of astro and particle physics. In the following some problems related to the background in liquid scintillation detectors are illustrated and two independent methods for the determination are presented.

1 Introduction

BOREXINO one of the forthcoming generation of solar neutrino experiments will detect solar ^{7}Be neutrinos via $\nu_e - e^- -$ scattering in a liquid scintillator [2]. The energy threshold of 250keV and the capability of a real time measurement of the 662keV ^{7}Be neutrinos are unique features of this detector. Assuming standard solar model predictions the count rate for ^{7}Be neutrinos will be in the region of 50 events per day which shows the importance of radiopurity of all detector components, especially the demands put on the scintillator [1]. The spatial resolution allows to define a fiducal volume of 100t and to make use of the self shielding of the ultrapure scintillator. Due to its low energy threshold all types of kinds of radioactive decay can contribute to the background in BOREXINO even if the released energy is below the threshold due to pile up effects and the limited energy resolution.

Possible isotopes were investigated from two sides. One approach is to measure the deposed energy directly in the liquid scintillator and to use specific signatures to identify certain isotopes, the other approach is to use ultrasensitive trace analysis. The latter was carried out by means of neutron activation analysis giving access to the determination naturally occurring quasistable isotopes. An overview on the applied analytical methods will be given in the following and some examples will be presented.

2 Sources of background in BOREXINO

2.1 Anthropogenic background

Although the absolute mass of a radioactive contamination with a half life of typically 10 years may be very low it could contribute to the background in BOREXINO due to its high specific activity. The activity can originate from artificially made sources, radioactive fall out or fission products. Typical representatives for these sources are ^{60}Co, ^{137}Cs and ^{85}Kr which is worth to be highlighted due to its ubiquity. ^{85}Kr is released as a fission product from nuclear fuel reprocessing plants into the atmosphere were an activity of $1.1 Bq/m^3$ can be found [4].

In the BOREXINO prototype (CTF=Counting Test Facility) we were able to determine the activity of dissolved ^{85}Kr in the liquid scintillator prior to a cleaning step which removed the observed noble gas completely. The determination was done by evaluating coincidences within the range of 5μs analyzing the energy of the consecutively emitted β and γ.

2.2 Cosmogenic and muon induced background

The exposition of organic liquid scintillators to the cosmic radiation leads to an activation of the matrix by the muonic component. These reactions produce unstable isotopes which have a half life ranging from some ms to 53.3 days in the case of ^{7}Be. The produced nuclei are summarized in tab. 1. It suggests itself to identify the short living isotopes by searching for coincidences in the ms or s range with muons passing BOREXINO. A rough estimation of the ^{7}Be activity leads activity of 0.2 decays/day/100t in the Gran Sasso underground laboratory after the decay of the ^{7}Be produced on the surface. In the case of ^{11}C this activity will be in the range of 2 decays/day/100t.

Another critical background source is ^{14}C which is usually produced by the hadronic component of the cosmic radiation in the upper atmosphere or neutron induced reactions underground. ^{14}C can be dangerous for detectors with low threshold as BOREXINO because not all decays of ^{14}C can be rejected if the activity exceeds a certain rate although the β-endpoint of ^{14}C is at 156keV due to pile up effects and the limited energy resolution. Despite the fact that the scintillator is made out of crude oil components some ^{14}C can be carried in by the production or by the contact with atmospheric CO_2. For the investigated liquid scintillator the CTF determined the ratio of $^{14}C/^{12}C$ to be $(1.85 \pm 0.13) \cdot 10^{-18}$ which fulfills the Borexino requirements.

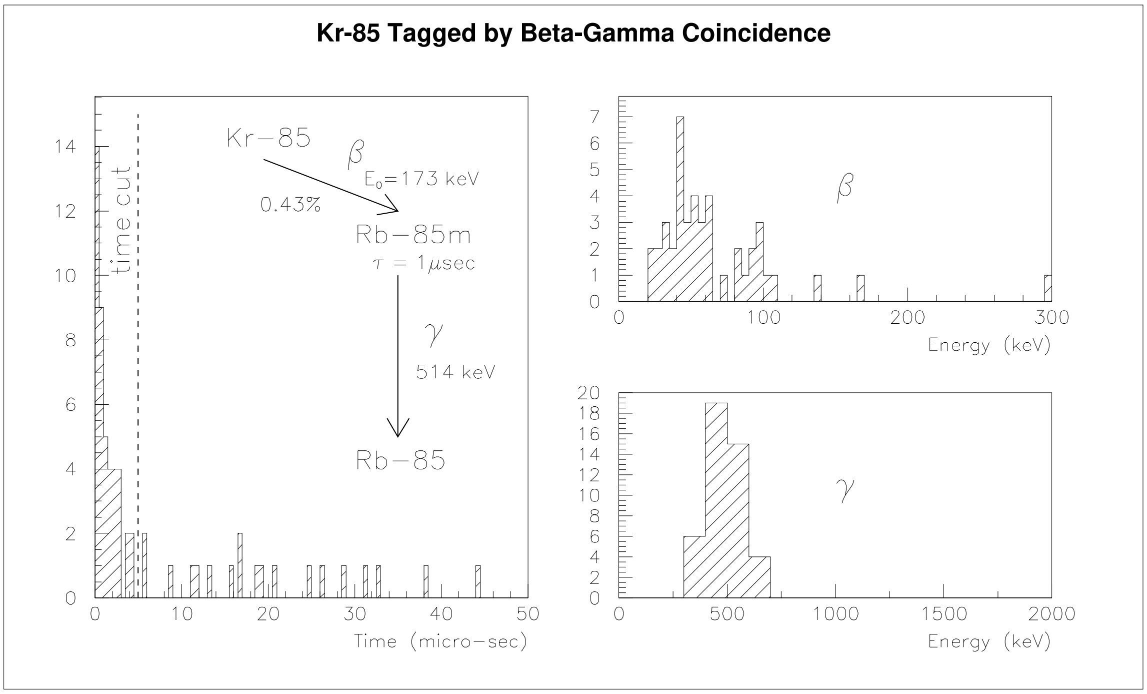

Figure 1: ^{85}*Kr β-decay is tagged by a delayed coincidence. In the right part the adjacent spectra are shown.*

2.3 Naturally occurring quasistable isotopes

The class of quasistable isotopes of primordial origin are another source of background for BOREXINO. In the energy window between 250kev and 800keV there are some isotopes of relevance which are compiled in tab.2. The most stringed demands on radiopurity are set on the concentration of ^{238}U and ^{232}Th and their progenies. For both elements the accepted concentrations have to be in the order of 10^{-16}g/g for the scintillator, the innermost part of the detector. ^{40}K and ^{87}Rb contribute with concentrations of 10^{-14}g/g with 10 events per day to the background with ^{40}K being potentially harmful due to it's high concentration in dust or microparticles coming in

Nuclide	Production via	Decay mode	$T_{1/2}$	Q-Value [MeV]
^{12}B	^{12}C(μ)	β^-	20ms	13.4
^{8}Li	^{12}C(μ, α)	β^-	0.84s	16
^{11}Be	^{12}C(μ, p)	β^-	13.8s	11.5
^{11}C	^{12}C(μ, n)	β^+	20.4m	0.96
^{7}Be	^{12}C(μ, α n)	$\beta^- + \gamma$	53.3d	0.478

Table 1: *Muon produced radioactive nuclei.*

contact with the scintillator.

Nuclide	Abundance	Decay mode	$T_{1/2}$	Limit [g/g]
^{238}U	99.3%	$\alpha + \beta^- + \gamma$	$4.5 \cdot 10^{9}$ a	$9.4 \cdot 10^{-17}$
^{232}Th	100%	$\alpha + \beta^- + \gamma$	$1.4 \cdot 10^{10}$ a	$2.4 \cdot 10^{-15}$
^{40}K	0.0117%	EC+$\beta^- + \gamma$	$1.3 \cdot 10^{9}$ a	$7.8 \cdot 10^{-14}$
^{87}Rb	27.835%	β^-	$4.7 \cdot 10^{10}$ a	$1.6 \cdot 10^{-14}$
^{113}Cd	12.22%	β^-	$9.3 \cdot 10^{15}$ a	$1.4 \cdot 10^{-8}$
^{115}In	95.8%	β^-	$4.4 \cdot 10^{14}$ a	$1.2 \cdot 10^{-11}$
^{138}La	0.09%	EC+$\beta^- + \gamma$	$1.1 \cdot 10^{11}$ a	$5.9 \cdot 10^{-11}$
^{176}Lu	2.59%	$\beta^- + \gamma$	$3.8 \cdot 10^{10}$ a	$1.8 \cdot 10^{-14}$

Table 2: *Limits for some important naturally occurring radioisotopes assuming 10 events detected in the energy range 250keV - 800keV in 100t of liquid scintillator. The limits are given under the assumption of natural isotopic composition.*

3 Methods of determination

3.1 BOREXINO prototype

Element	Concentration [g/g]
U	$< 2 \cdot 10^{-16}$
Th	$< 5 \cdot 10^{-15}$
K	$< 4 \cdot 10^{-12}$
Rb	$< 7 \cdot 10^{-13}$
Cd	$< 1 \cdot 10^{-12}$
In	$< 2 \cdot 10^{-12}$
La	$2 \cdot 10^{-14}$
Lu	$< 8 \cdot 10^{-16}$

Table 3: *Limits of naturally occurring radioisotopes in a liquid scintillator based on 1,2,4-Trimethylbenzene determined by means of NAA.*

One approach to the determination of radioisotopes is the observation of the radioactive decay of the isotope being investigated. For the identification of the decay the energy of the decay products can be used as a signature. Particle discrimination capabilities and the good timing resolution provide further information in the case of the BOREXINO prototype. This makes the CTF an ideal detector for the search of coincidences as they can be observed in the ^{238}U chain, the ^{232}Th chain and in the

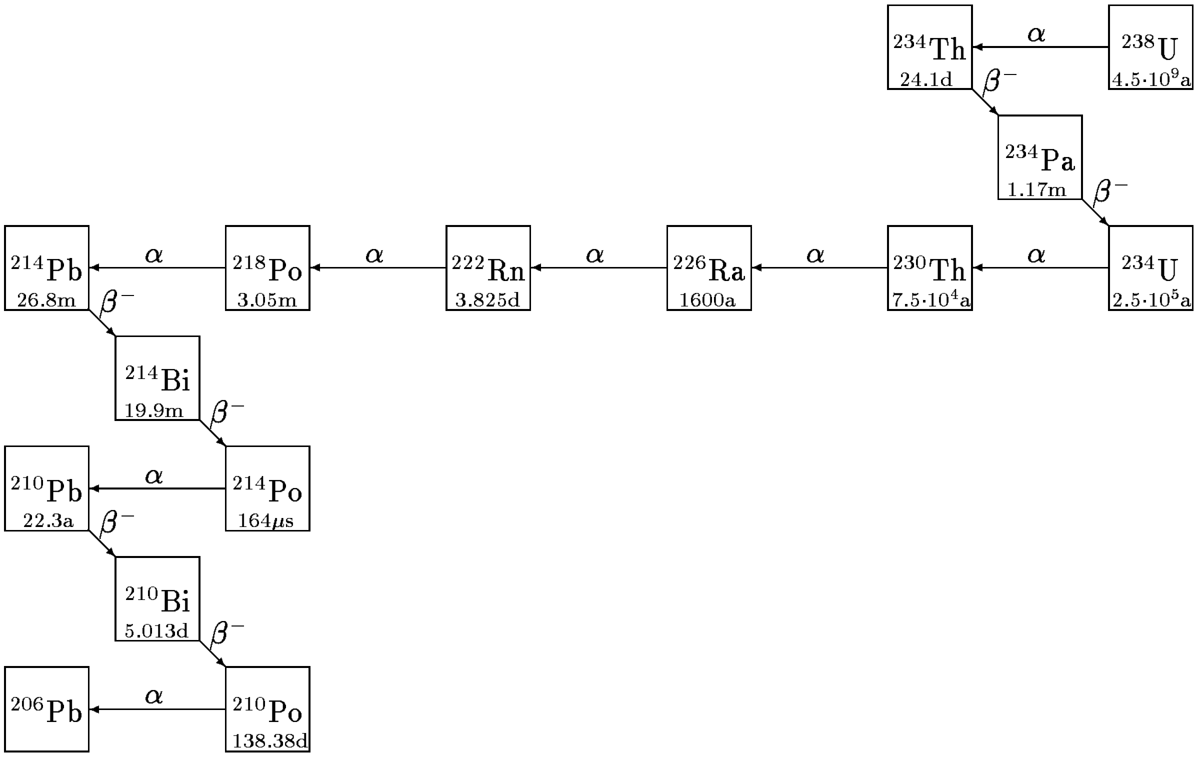

Figure 2: *Decay chain of ^{238}U with the delayed coincidence of $^{214}Bi \rightarrow {}^{214}Po \rightarrow {}^{210}Pb$*

decay of ^{85}Kr described above. For the determination of ^{226}Ra we used the $\beta - \alpha$ coincidence in the decay of $^{214}\mathrm{Bi} \rightarrow {}^{214}\mathrm{Po} \rightarrow {}^{210}\mathrm{Pb}$ were the emitted β is followed by the α of the ^{214}Po decay with a half life of 162μs. This coincidence rate directly leads to the activity of ^{226}Ra which can be expressed in units of ^{238}U content under the assumption of equilibrium in the decay chain. This decay chain is presented in fig. 2 to give an overview to the reactions. The detected rate in the investigated liquid scintillator 1,2,4-Trimethylbenzene corresponded to a concentration of $4.2 \pm 2.0 \cdot 10^{-16}$g/g for the ^{238}U chain and $< 3.3 \cdot 10^{-16}$g/g for the ^{232}Th chain[1] at a confidence level of 85%.

3.2 Neutron activation analysis

Another way to measure the activity of quasistable isotopes are methods of trace analysis which have to be capable to measure traces in organic matrices in the region between 10^{-12}g/g to 10^{-17}g/g. The irradiation with thermal neutrons can transform quasistable nuclei to nuclei with shorter half lifes by the caption of a neutron and thereby increase the detection power of radioanalytical methods. We have de-

[1]Details are given in these proceedings by E. Resconi

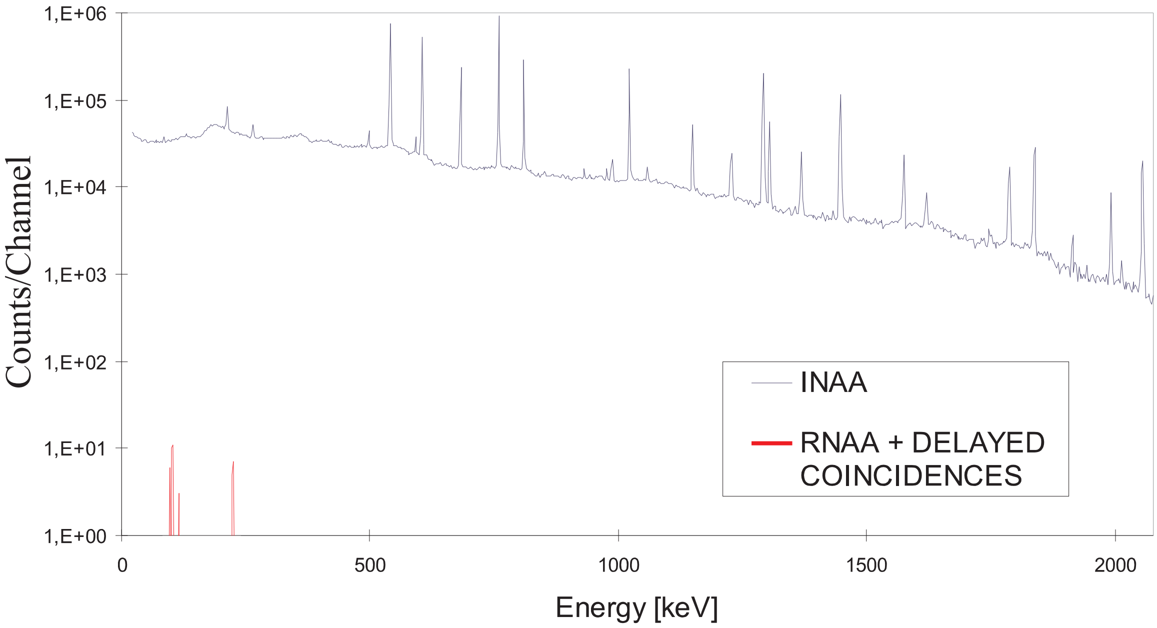

Figure 3: *NAA spectra prior and after radiochemical treatment with the lower spectrum being acquired in a counting mode making use of a signature in the decay of* ^{239}Np.

veloped radiochemical neutron activation analysis to determine traces of quasistable and stable isotopes with ultimate sensitivity. Therefore we have combined long time irradiation (100h), radiochemical processing of the irradiated 250g samples and instrumental methods to increase detection power. The γ spectra of the irradiated samples fig. 3 show the necessity to apply radiochemical methods for the separation of interfering activity. The spectra were recorded before and after the processing step. The latter is counted in the delayed $\beta - \gamma - e^-$ mode making use of a specific signature in the decay of ^{239}Np which is the indicator radio nuclide for ^{238}U [3]. This application of a specific signature leads to a further increase in the signal/noise ratio revealing detection limits of $2 \cdot 10^{-16}$g/g for Uranium and $5 \cdot 10^{-15}$g/g for Thorium in the investigated liquid scintillator. The limits and values measured for some relevant elements are presented in tab. 3.

4 Summary

Comparing the results of different analytical methods it appears that the methods applied reveal consistent results to characterize the background in the BOREXINO experiment. The data on the activity of ^{226}Ra, ^{228}Th and ^{238}U, ^{232}Th allow a reliable determination for the contribution of both decay chains to the measured signal even if the equilibrium in the chains may be broken. Cd, In, La and Lu can be ruled out as major background sources by means of NAA while the limits that can be set on the concentration on K and Rb are to be improved. The low concentration of ^{14}C in the scintillator and the effectivity of different cleaning procedures of the scintillator as gas sparging, liquid-liquid extraction with ultrapure water and distillation showed the possibility to achieve the limits requested by BOREXINO.

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