Radon induced surface contaminations in low background experiments

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Abstract. In neutrinoless double-beta decay and dark matter searches, one of the main issues is to increase the experimental sensitivity through careful material selection and production, minimizing the background contributions. In order to achieve the required, extremely low, counting rates, very stringent requirements must be fulfilled in terms of bulk material radiopurity. As the experimental sensitivity increases, the bulk impurities in the detector components decrease, and surface contaminations start to play an increasingly significant role In fully active detectors, like cryogenic particle detectors, surface contaminations are a critical issue (as shown by the CUORICINO experiment). ^{222}Rn is by far the most intense source of airborne radioactivity, and if a radio-pure material is exposed to environment where the Radon concentration is not minimized, ^{210}Pb and ^{210}Po contaminations can occur. The mechanisms and the dynamics of Radon-induced surface contaminations are reviewed, and specific solutions to prevent and to reject the induced background are presented.

Keywords: Bolometer, surface contamination, double-beta decay, dark matter
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INTRODUCTION

In experiments looking for rare events, like neutrinoless double beta decay (DBD) and dark matter (DM), one of the main issue is to increase the experimental sensitivity through the material selection, minimizing the background contribution coming from the materials used for the detector realization. Moreover the net reduction of the background produced by the bulk part of the apparatus has raised concerns about the background contribution coming from the surfaces.

Materials for detector sensitive parts are now realized with very low radioactive contents and a great effort was also put into the selection of all the passive materials used to realize the support structures of the detector. At the same time it is clear that all the surface treatments need to be performed under really strict constraints. A non-well defined surface treatment can induce a higher increase of the radioactive contamination on the surfaces compare to the bulk one. Many procedures and techniques were developed during the last years in order to remove and to minimize the presence of possible contaminants on detector surfaces. To succeed in this strategy a big effort was put in defining: all possible mechanisms that lead to surface contaminations, specific cleaning procedures which are able to reduce and to control the surface radioactivity [1] [2].

All the possible precautions that are taken during the detector assembly could be completely useless if a great attention is not paid to the environment in which the detector will be assembled. The presence in air and in gases of possible radioactive elements that can stick on the detector surfaces leading to recontaminations, that will vanish all the applied cleaning procedures.

It is well known that in air is normally detectable a net contamination of ^{222}Rn, an isotope that is produced by the ^{238}U chain. Radon is a noble gas, it can emanate from materials that are normally contaminated in ^{238}U and it will diffuse in the air. Depending on the building infrastructures, ventilation, material condition and material properties, the concentration of ^{222}Rn can change strongly from one configuration to another. To avoid, or better minimize, the recontamination process of the detector a specific design of the detector storage and assembly line must be defined. In particular all components must be stored in a clean environment where the presence of ^{222}Rn must be reduced as much as possible to avoid the possible sticking of radioactive nuclei on detector material surfaces. A more complex task is the control of the radioactive contaminants in air during the detector assembly phase. Given these constraints the realization of a controlled environment is really tricky and it implies very strong efforts into the isolation of the air

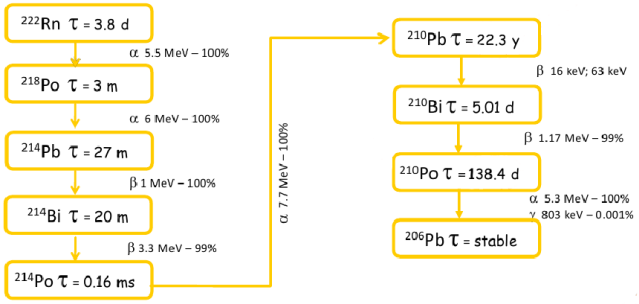

FIGURE 1. Radon decay chain

volume in which all the assembly procedures will be carried out. To evaluate the real requests of such effort a sizing of the contamination produced by such radioactive mechanisms must be carried out. The contamination induced by ^{222}Rn is very unsafe mainly because of one of its ^{210}Pb daughter, which has a long half-life time. This isotope has an half-life time of about 22 years and if it is deposited on the detector components, the induced background contribution will remain almost unchanged for all the data taking of the experiments. It is also very crucial to understand the mechanism through which the ^{210}Pb isotope will remain trapped on the material surfaces. It must be taken into account that the net contamination due to this isotope in air can be much higher with respect to the one given by ^{222}Rn. There are two ways in which this contamination is produced: one is linked to the continuous production of ^{210}Pb from the upper part of the decay chain (namely ^{222}Rn, see Fig.1). The other mechanism is due to the usual presence of ^{210}Pb in the environment.

SURFACE CONTAMINATIONS IN BOLOMETERS

Cryogenic particle detectors that are employed for DBD [3] and DM [4] experiments are very sensitive to surface contaminations. These detectors are sensitive in the whole volume without a superficial dead layer that is commonly present in other types of detectors. This implies that such detectors are fully sensitive also on the detector surfaces and in this way they are affected by the contamination of surfaces which are directly facing the sensitive parts of the detector [5]. In this configuration it is mandatory to control and to reduce all the possible radioactive contaminations on the detector surfaces.

To obtain the best background level a detailed analysis and research of the real surface contamination sources must be carried out. In the specific the background induced by the presence of ^{222}Rn, and its progeny, in air can be caused directly by the Rn itself. The understanding of the mechanisms will show us the best way to minimize the Rn contribution to background. An important approach that was adopted to study the real contribution of Rn to surface contaminations is the realization of a Rn chamber where the concentration of the gas is artificially increased at a very high level. In this condition the exposure of materials to the contaminated environment will stress all the mechanisms of particle sticking, giving us the possibility to better analyze the main channels that will contribute to surface contaminations. At the same time in the chamber are placed materials of different kinds and with different surface roughness helping us to better understand what characteristics of the exposed material will dominate in the contamination process. By identifying the correlation between the induced surface contamination and the Rn concentration, we will be able to scale the obtained data to the expected contamination induced on the detector during the assembly procedures. Moreover it is possible to define a threshold of Rn concentration that must not be exceeded in order to prevent a net excess in the final background of the experiment.

THE STICKING FACTOR

The evaluation of the sticking probability of nuclei on sensitive surfaces of low background experiment components allows to estimate the contribution that an exposure to radioactive contaminants will have on the expected sensitivity of the experiment. The values of the sticking factor will allow also to give the minimum requirements that

TABLE 1. List of detector materials exposed inside the Rn-box

Material	Exposure [d]
Copper	1076
PTFE	1140
Si	1080
TeO_2	1183
ZnSe	in progress

must be fulfilled in order to have a safe environment in which the experiment components can be stored and assembled.

We define the Sticking Factor (Σ) for Rn as the ratio between the number of radon nuclei that stick on a sample and the total number of nuclei which have a probability (dP) different from 0 to stick on it:

$$\Sigma_{Rn} = \frac{N(dP = 1)}{N(dP = 0)} \tag{1}$$

Obvioysly Σ_{Rn} is a function of the Rn concentration, of the time exposure and of the material features. During the development of this work all these dependences have been taken into account. When a sample is exposed to an atmosphere enriched in some radioactive element (e.g. Rn), there will be different mechanisms that will bring to the contamination of the sample. Mainly there are three processes: the first is the deposition of the particulate that have bound to the radioactive elements of the atmosphere (e.g. aerosols); the second mechanism is the diffusion of Rn through the material and finally the third is the nucleus recoil implantation as a consequence of the nuclear decay.

The experiment

In order to evaluate the sticking factor, it is necessary to expressly expose radio-pure detector components to an atmosphere enriched in ^{222}Rn. In order to do that a plexiglass box (Rn-box) with hermetic enclosure was build, inside which three ^{238}U rocks, degasing ^{222}Rn, were placed. The atmosphere inside the box was monitored during the entire experiment. At the saturation level, reached after two weeks, the concentration inside the Rn-box was about 320 kBq/m^3.

Various detector materials were stored inside the Rn-box for different periods of time. In Table 1 are listed the samples and their exposure time. The analysis of the contamination of the samples was performed extracting the samples from the box and measuring the surface activity with a Silicon barrier detector in a vacuum chamber (about 7 μm Hg). The active surface of the detector is 1200 mm^2 and the dead layer is 50 nm thick. The analyzed samples have a surface of 2500 mm^2 and during the measurement they were placed right in front of the detector in order to maximize the geometric efficiency of the measurements, which is evaluated with Monte Carlo simulation to be 10%.

Results

The samples were measured one at the time, in Fig. 2 is shown a typical acquired energy spectrum. By looking at the histogram and the time evolution of the spectrum we can make some important remarks:

- just Po isotopes stick on the surface;
- ^{218}Po shows a gaussian peak, while the other two isotopes have a long tail that extends to low energy;
- there is no evidence of a direct ^{222}Rn contamination (no peak at ^{222}Rn Q-value);
- the ^{210}Po contamination is proportional to the time exposure;
- ^{210}Po is increasing with time.

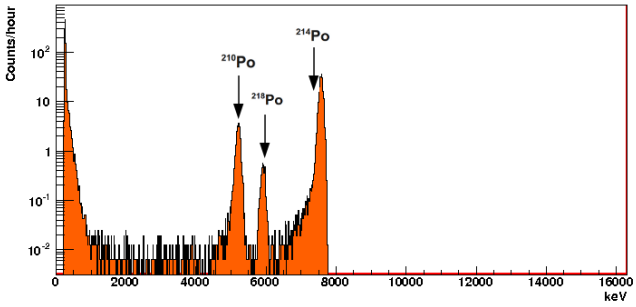

FIGURE 2. Energy spectrum of a copper sample exposed to ^{222}Rn for 63 d.

TABLE 2. Evaluated sticking factor for various materials.

Material	Σ_{Rn}
Copper	$(1.86\pm0.10)\cdot10^{-9}$
PTFE	$(3.06\pm0.22)\cdot10^{-10}$
Si	$(3.97\pm0.54)\cdot10^{-10}$
TeO_2	$(3.75\pm0.21)\cdot10^{-10}$
ZnSe	in progress

We understand that Po is the source of surface contamination, and ^{222}Rn is not directly responsible. All Po isotopes stick to the surface and diffuse into the surface, the nuclear recoil of ^{218}Po is not enough to explain the long tail of ^{214}Po and ^{210}Po. By means of Monte Carlo simulation we estimate that a recoiling nucleus of ^{218}Po in copper can only travel for 15 nm, while the observed profiles need a deeper (of the order of hundreds of μm) contamination for the entire tail reconstruction. The diffusion mechanism remains still unclear.

Using the same model proposed in [6], we are able to estimate the Σ_{Rn} for the discussed materials. The final results are reported in Table 2.

CONCLUSIONS

In this work we demonstrated how surface contaminations induced by Rn exposure of radio-pure material is a serious limitation to the sensitivity of bolometric low background experiments looking for DBD and DM. We have also evaluated the probability that a ^{222}Rn nucleus sticks on the surface of various materials. All the studied materials are detector components of bolometric experiments.

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