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To cite this article: L Di Noto *et al* 2016 *J. Phys.: Conf. Ser.* **675** 012035

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The high precision measurement of the ^{144}Ce activity in the SOX experiment

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Abstract. In order to perform a resolute measurement to clarify the neutrino anomalies and to observe possible short distance neutrino oscillations, the SOX (Short distance neutrino Oscillations with BoreXino) experiment is under construction. In the first phase, a 100 kCi ^{144}Ce - ^{144}Pr antineutrino source will be placed under the Borexino detector at the Laboratori Nazionali del Gran Sasso (LNGS), in center of Italy, and the rate measurement of the antineutrino events, observed by the very low radioactive background Borexino detector, will be compared with the high precision ($< 1\%$) activity measurement performed by two calorimeters. The source will be embedded in a 19 mm thick tungsten alloy shield and both the calorimeters have been conceived for measuring the thermal heat absorbed by a water flow. In this report the design of the calorimeters will be described in detail and very preliminary results will be also shown.

1. Introduction

Since the neutrino anomalies leave room to the existence of sterile neutrino and to the short distance neutrino oscillations [1–3], the SOX experiment was proposed [4] with the goal of observing the neutrino events emitted by a high activity ^{144}Ce - ^{144}Pr artificial source. The source will be placed in a tunnel, 8 m far from the center of Borexino detector and thanks to the very low radioactive background and to the detector properties [5,6], short distance oscillations of eV mass sterile neutrino might be observed and at the same time a disappearance experiment can be performed, if the source activity is also measured with less than 1% precision [4,7].

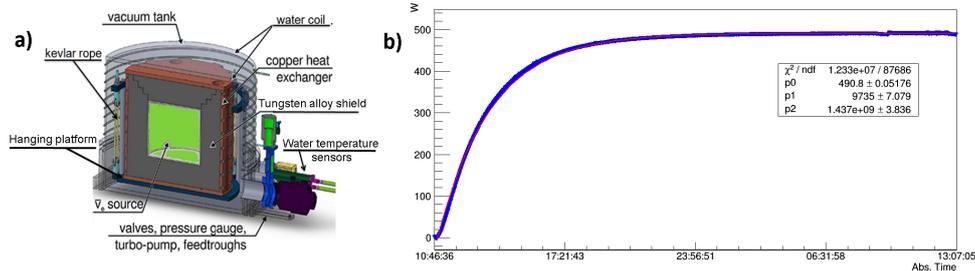


Figure 1. a) Section of the source with the tungsten alloy shield embedded inside the INFN-TUM calorimeter. The main parts of the apparatus are clearly visible. b) Preliminary power measurement performed by using a mock-up electrical source. In the picture the parameter as resulted by fitting the data with the exponential function of equation 2, are reported as well.

As the size of the source embedded in the shield is really close to the available room in the tunnel, the project will be developed in two different phases: the calorimetric measurement of the activity, just before the insertion of the source inside the pit under Borexino (1 week duration) and the second phase, when the source will be installed inside the tunnel and the Borexino data taking will occur (1.5 year duration). Other calorimetric measurements in the between or at the end of the data taking might be also performed in order to increase the accuracy of the final results.

2. Description of the calorimetric measurement

The ^{144}Ce - ^{144}Pr artificial source will be produced with around 100 kCi activity at the reactor of the Mayak Production Association in Russia after a chemical extraction of the $^{144}\text{CeO}_2$ from exhausted nuclear fuel. The radioactive powder will be sealed inside a double stainless steel container and then embedded in a 19 mm thick safety shield made of a tungsten alloy (see figure 1a). After the production and the transportation to the LNGS, the calorimetric measurement will occur thanks to two different calorimeters, that are under construction and testing by the INFN-TUM and the CEA groups within the SOX collaboration. Both the calorimeters have been conceived to measure the source activity with high precision by knowing the power released by the radiation in the tungsten shield and absorbed by a water flow.

In the INFN-TUM calorimeter the water flows inside a copper heat exchanger, in contact with the tungsten shield (see figure 1a), while in the CEA calorimeter the source with the tungsten is directly immersed in the water inside the calorimeter chamber. In both the systems, neglecting the heat losses P_{lost} , the power P is achieved by measuring with high accuracy the mass flow \dot{m} and the temperatures T_{out} and T_{in} of the water outgoing and entering in the copper heat exchanger, according to the relation:

$$P = \dot{m}c(T_{out} - T_{in}) \quad (1)$$

where c is the specific heat of the water averaged in the T_{in} - T_{out} temperature range. As it will be shown in the following, the calorimeters have been designed in order to minimize P_{lost} that will be estimated during the calibration and testing phase and reduced as much as possible.

In particular in the INFN-TUM calorimeter, for reducing the convection, the copper heat exchanger is kept in vacuum at a pressure lower than $5 \cdot 10^{-5}$ mbar, while the source inside the tungsten, separated through a vacuum flange, is at atmospheric pressure. Secondly for minimizing irradiation, two stages of 10 layers each one of super insulators are placed between the copper and the vacuum tank and at the same time hot water flows inside a pipe built directly on the tank itself (see figure 1a) in order to thermalize the chamber close to the copper

temperature. Finally for reducing the conduction, the source inside the copper heat exchanger is placed on an hanging platform, suspended by three kevlar ropes with low heat conductivity. In both the systems a closed water loop is foreseen and in the INFN-TUM calorimeter the water loop was designed in order to accurately control the massflow and the temperature of the water just before the entrance in the vacuum tank. Thanks to a proportional valve controlled by a feedback loop, the water flow, coming from the chiller, can be tunable in the range of 2-15 g/s and stabilized at 0.3% of the nominal value, heavily reducing the oscillations due to the chiller pump. At the same time also the temperature of the water entering inside the calorimeter can be stabilized within 0.1 K in the 13-17 °C range, compensating any environmental temperature fluctuation or chiller instability during all the phases of the measurement. In particular during the calorimetric measurement a massflow of 10 g/s was chosen, giving a difference of temperature of $T_{out} - T_{in} \sim 28$ °C, for a source power of 1200 W correspondent to 100 kCi activity.

On the contrary, during the second phase, since the source will be inserted in the pit inside the copper heat exchanger of the INFN-TUM calorimeter, the water loop will be necessary to cool down the apparatus and the controls feedback will be aimed to stabilize the temperature in the tunnel in order to prevent turbulence effect in the scintillator liquid of the Borexino detector.

3. Preliminary results and conclusions

In the calibration phase, before the source delivery, the set up can be tested with a mock-up source made by a copper cylinder with the same dimensions of the source container, embedded in an Aluminum body that replaces the tungsten shield. Inside the copper cylinder six electrical heaters are placed and they can be turned on with a total maximum power of 1200 W (the same power dissipated by a 100 kCi Ce source), measured very precisely by an amperometer and a voltmeter directly connected with the heaters. The temperature of the copper and of the aluminum part (on the top, on the side and on the bottom) can be monitored and the temperatures of many critical points inside the vacuum chamber (as the platform, the copper jacket and the internal chamber) are acquired as well.

As first test a rough measurement performed with a simple copper coil directly at contact with the aluminum was done at atmospheric pressure with a set power of 497 W. The plot of the measured power calculated by the relation 1 as a function of the time is shown in figure 1b. The data were acquired after the heaters switching on and the fit was done with the exponential function:

$$P(t) = p_0 \left(1 - e^{-\frac{t-p_2}{p_1}} \right) \quad (2)$$

where the time scale is in UNIX time date format. From the fit the measured power at the equilibrium was found around 491 W, less than the set value since the heat losses due to the convection can not be neglected and a first estimation of the time constant $p_1 \simeq 9735$ s = 2,7 hours was achieved for the first time.

In conclusion two calorimeters have been built for measuring the source activity with a precision < 1% and now they are under testing. In the next months many calibrations will be performed with the mock-up source, while the final measurement with the Ce source and the starting of the Borexino data taking is fixed in the autumn 2016.

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