



A high precision calorimeter for the SOX experiment



L. Papp^{a,*}, M. Agostini^a, K. Altenmüller^a, S. Appel^a, A. Caminata^b, R. Cereseto^b, L. Di Noto^b,
S. Farinon^b, R. Musenich^b, B. Neumair^a, L. Oberauer^a, M. Pallavicini^b, S. Schönert^a,
G. Testera^b, S. Zavatarelli^b

^a Physik-Department und Excellence Cluster Universe, Technische Universität München, Germany

^b Dipartimento di Fisica, Università degli Studi e INFN Genova, Italy

ARTICLE INFO

Available online 27 November 2015

Keywords:

Calorimetry

eV-scale sterile neutrinos

ABSTRACT

The SOX (Short distance neutrino Oscillations with Borexino) experiment is being built to discover or reject eV-scale sterile neutrinos by observing short baseline oscillations of active-to-sterile neutrinos [1]. For this purpose, a 100 kCi ¹⁴⁴Ce–¹⁴⁴Pr antineutrino generator (CeSOX) will be placed under the BOREXINO detector at the Laboratori Nazionali del Gran Sasso. Thanks to its large size and very low background, BOREXINO is an ideal detector to discover or reject eV-scale sterile neutrinos. To reach the maximal sensitivity, we aim at determining the neutrino flux emitted by the antineutrino generator with a < 1% accuracy. With this goal, TU München and INFN Genova are developing a vacuum calorimeter, which is designed to measure the source-generated heat with high accuracy.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

The calorimeter for the SOX experiment is designed to determine the source-generated heat released into a water coil by measuring the flow and the temperature difference between the input and output lines with high accuracy. The 100 kCi ¹⁴⁴Ce–¹⁴⁴Pr antineutrino generator requires a biological shield, which is made of massive 19 cm thick tungsten-alloy, to prevent its surrounding from undesirable radiation (see Fig. 1).

After a precision measurement of the activity, the antineutrino generator will be placed in a rectangular tunnel under the Borexino detector at 8.5 m distance from its center. Respecting the tight dimensions of the tunnel, the calorimeter (or at least a minimum setup with the heat exchanger) must be built in a compact form that fits under the detector. The dimensional limitation, the weight (appr. 3 t with the tungsten-alloy shield), the required safety measure and the less than 1% error limit demands a high technology design for the hardware and instrumentation (Fig. 2).

2. Calorimeter construction

Safety on the SOX experiment has the highest measures because of the use of radioactive material, therefore the construction and

handling must be designed failproof (Fig. 3). The heat exchanger is embedded in a stainless steel vacuum tank, consisting of two parts, separated by a 924 mm diameter flange. The closure is guaranteed by the weight of the top lid with an elastic O-ring without clamps or bolts to avoid any overpressure in the tank in case of water leakage from the heat exchanger. The high accuracy calorimetric measurement requires 10^{−4} mbar or lower (Fig. 4).

To minimize the radiation heat loss, the outer side of the vacuum tank is surrounded by a pipe serpentine to circulate the coolant liquid; in that way, the inner and outer temperatures of the vacuum tank are close to be the same. Between the heat exchanger and the vacuum tank, two radiation shields are placed, made of multi-layer insulator. The heat exchanger is made of 20 mm thick copper with embedded water pipes to provide a homogenous heat distribution. Radiative heat loss is lower than 30 mW [3]:

$$P = \frac{A_1 \cdot \sigma(T_1^4 - T_2^4)}{\frac{\epsilon_1}{\epsilon_s} - 1 + \sum_{n=1}^{N-1} \frac{A_1}{A_{SN}} \left(\frac{2}{\epsilon_s} - 1 \right) + \frac{A_1}{A_{SN}} \left(\frac{1}{\epsilon_s} + \frac{1}{\epsilon_2} - 1 \right)}, \quad (1)$$

where ϵ is the emissivity, A the surface area and N the number of radiation shield layers. T is the temperature and σ the Stefan–Boltzmann constant. The index s refers to the radiation shields, 1 to the innermost surface, i.e. the copper heat exchanger. Index 2 denotes the outermost surface, the stainless steel shell of the vacuum tank.

To prevent conductive heat loss, the heat exchanger is located on a stainless steel plate held by three doubled Kevlar ropes (breaking test 7t/each), taking into account the heavy load and the risk of seismic activity. Conduction of the Kevlar ropes with $\lambda = 0.04$ W/m,

* Corresponding author.

E-mail address: laszlo.papp@tum.de (L. Papp).

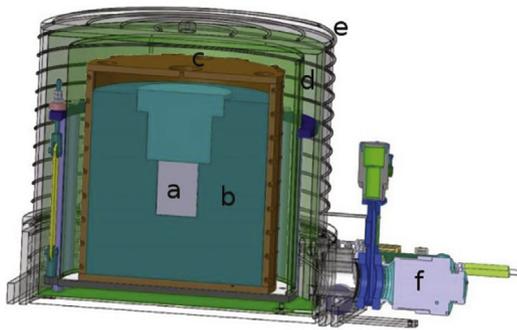


Fig. 1. Cross-section of SOX calorimeter: (a) antineutrino generator; (b) tungsten-alloy biological shield; (c) copper heat exchanger; (d) heat radiation shield; (e) vacuum tank; (f) turbo pump.

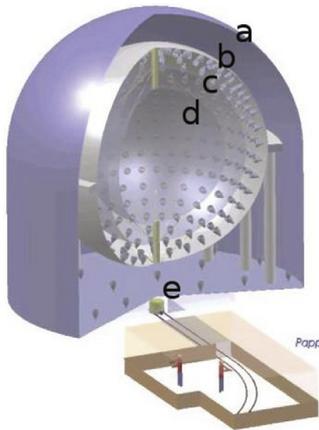


Fig. 2. Borexino detector: (a) water tank \varnothing 18 m, 2700 t pure water; (b) stainless steel sphere \varnothing 13.7 m; (c) outer vessel \varnothing 11 m; (d) inner vessel \varnothing 8.5 m 278 t liquid scintillator PC+PPO; (e) SOX antineutrino generator and calorimeter [2].



Fig. 3. The copper heat exchanger and its support.

$$A = 6 \cdot 2 \text{ cm}^2, d = 0.3 \text{ m};$$

$$\dot{Q} = \lambda \cdot \frac{A}{d} \cdot \Delta T < 0.4 \text{ mW} \quad (2)$$

3. Heat power measurement

The SOX calorimeter measures power P with precision mass flow \dot{m} (0.1% stability) of a cooling liquid (high purity water) and ΔT :

$$P = \dot{m} \cdot c \cdot \Delta T, \quad (3)$$

where c is the specific heat capacity of the cooling liquid. The flow rate has an upper constraint to ensure a big enough ΔT (to keep

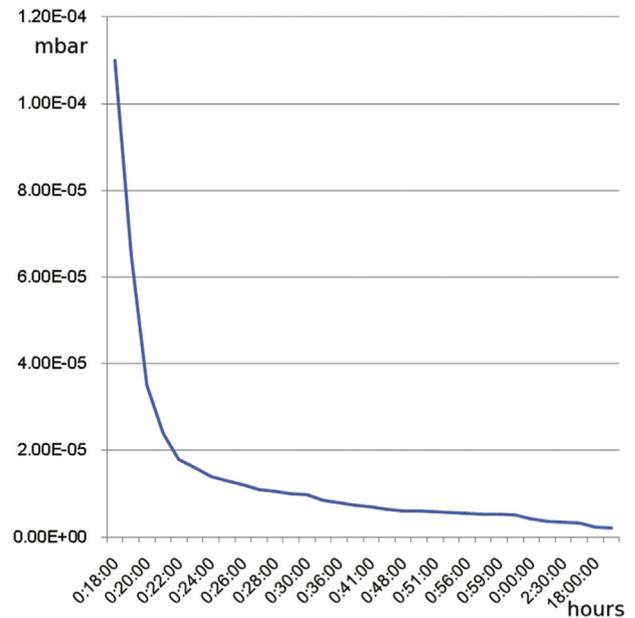


Fig. 4. Pressure measurement of the SOX calorimeter.

the relative error low) and a lower constraint to provide a turbulent flow. Ideal $\dot{m} \approx 10 \text{ g/s}$ at 1 kW power, $\Delta T = 25^\circ \text{ C}$ and 5 mm pipe diameter. Stable flow rate is guaranteed by a fixed height water reservoir and a high precision flow regulating valve (accuracy 0.05%). The redundant flow measurement with Coriolis flow meters has an accuracy of 0.05%. The temperature sensors have 5 mK accuracy. The systematic error for one heat power measurement

$$\sigma_p^2 = \sqrt{35 [\text{W}^2] + 0.02 [\text{W}^2/\text{K}^2] \cdot \Delta T^2} \quad (4)$$

is between 1 and 3 W ($\sim 0.4\%$). The final calibration will be performed with an electric heater. Additional temperature, pressure and strain gauges measure any changes on the normal conditions.

4. Conclusion

Preliminary tests and measurements have been done and are in accordance with simulations. In fall 2015 the mechanical integration and calibration measurements with an electric heater will be completed. In 2016 the ^{144}Ce – ^{144}Pr antineutrino generator will arrive and data acquisition is started. The calorimeter is designed to meet the requirements for a possible second phase of the SOX experiment with a neutrino ^{51}Cr source (CrSOX).

Acknowledgments

This research was supported by the DFG cluster of excellence ‘Origin and Structure of the Universe’ (EXC153) (<http://www.universe-cluster.de>) and the ERC Advanced Grant ERC-2012-ADG_20120216 N. 320873.

References

- [1] G. Bellini, et al., *The Journal of High Energy Physics* 38 (2013).
- [2] G. Bellini, et al., *Physical Review D* 89 (2014).
- [3] R. Siegel, J.R. Howell, *Thermal Radiation Heat Transfer*, Hemisphere Publishing Corporation, Washington DC, 1992.