

Short-Term Quality Control and Assurance for Borexino

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Introduction

The Borexino experiment is a differential energy, real-time, neutrino detector constructed at the Laboratori Nazionali del Gran Sasso, Italy. Borexino is in its final stage of completion and will be the first detector to directly measure the flux of ⁷Be neutrinos and perhaps the pep + CNO fluxes and geoneutrino antineutrinos. The detector is composed of a graded shield composed of different media and increasing levels of purity from the outside to the inner core of 300 t high purity Pseudocumene (PC) + 1.5 g/l PPO (fluor) liquid scintillator.

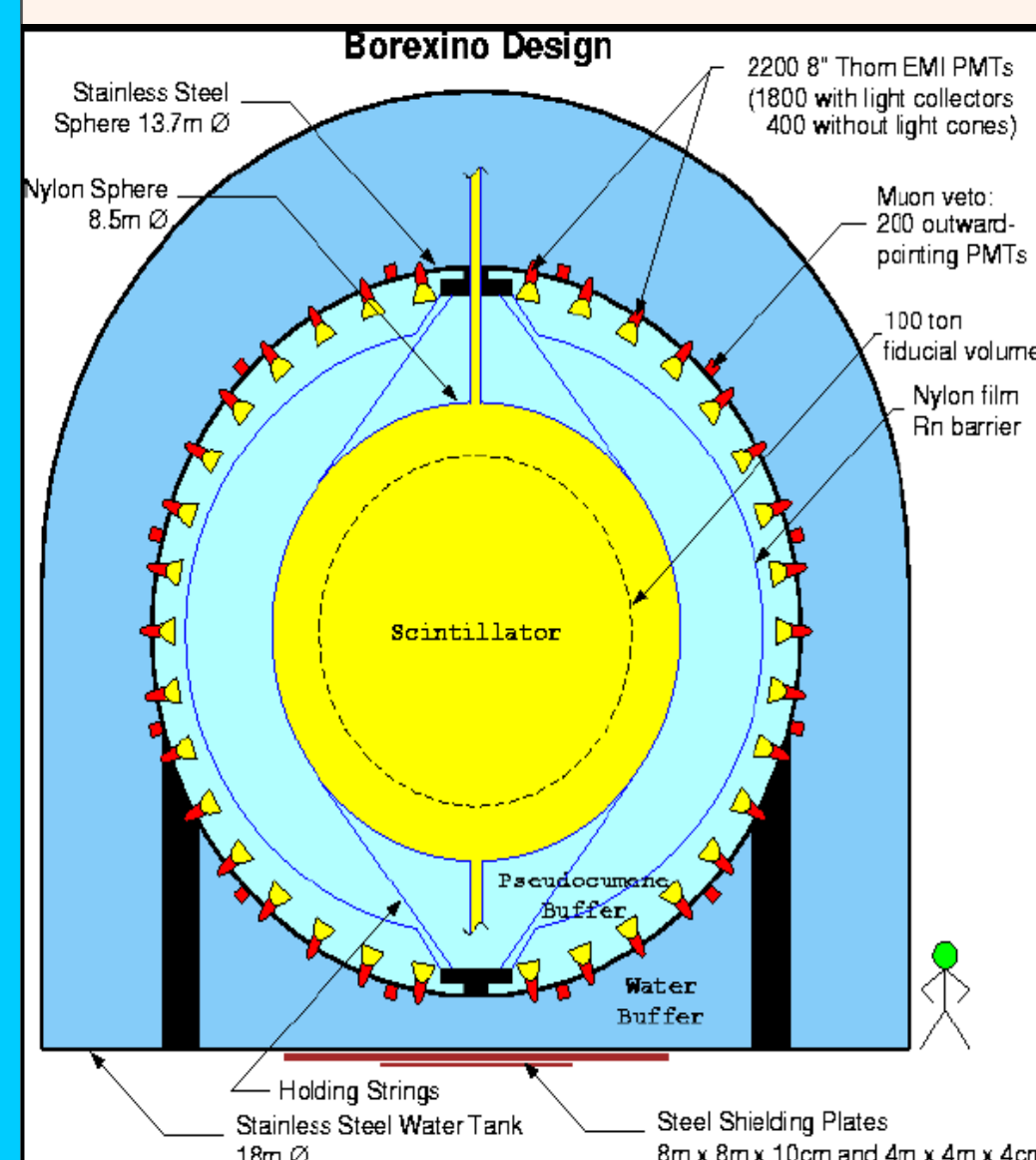


Fig. 1: The Borexino differential energy, sub-MeV neutrino detector. The inner 300 tonne liquid scintillator is shielded by graded shells of PC, Nylon and Ultra-pure Water from cosmic rays and natural contaminants

Sub-MeV ⁷Be neutrinos are detected at a rate of approximately 30 events per day. In order to have a reasonable signal-to-noise ratio the background rate from natural, cosmic and anthropogenic radiation must be significantly less than the signal. Muon induced radiation is greatly suppressed by the rock overburden (3800 m.w.e.) or by tagging muon events with an outer ultra-pure water (UPW) Čerenkov veto. γ 's from the rock and the PMT support structure are attenuated by a DMP (quencher) PC buffer surrounding the PC scintillator. The central 300 t PC and PC buffer are housed in two thin Nylon balloons providing an active Radon barrier and a highly radiopure medium in which to hold the liquid scintillator and buffer.

The Need for Quality Control:

To reach a background level of decay-per-day (dpd)/100 tonne requires extremely high radiopurity of the PC and surrounding detector components. For example, assuming equilibrium $X=^{232}\text{Th}/^{238}\text{U}$ must be $<10^{-16}$ gX/gPC and $<10^{-14}$ gK_{nat}/gPC (see Table 1) Knat= Natural Potassium

	²³⁸ U		²³² Th		K _{nat}	
	(g/g)	Bq/kg	(g/g)	Bq/kg	(g/g)	Bq/kg
UPW	1.e-10	1.2 m	1.e-10	0.4 m	1.e-7	3.e-3
PC Buffer	1.e-15	12 n	1.e-15	4 n	5.e-12	0.16 μ
Nylon	5.e-12	62 μ	2.e-11	81 μ	1.e-8	0.31m
PC Scint	5.e-16	6.1e-3	2.e-16	0.8 n	1.e-14	0.3 n

Table 1: Required radiopurities of various detector components. The postfix m, μ ,n stand for 10⁻³, 10⁻⁶, and 10⁻⁹ respectively.

All of the components have been measured in the past with ultra-low background high purity Ge detectors, Inductively Coupled Plasma Mass Spectroscopy (ICPMS) and Neutron Activation Analysis, and all material selection requirements have been met [1]. However, these media are continuously being used for routine maintenance operations, so that there is always a risk of contaminating detector media such as the liquid scintillator or the UPW used as external shielding. For example, air contains radioactive noble gases as well as dust loaded with natural radioactive contaminants so that an effort must be made to keep air and dust from entering the purification plants especially during filling of the detector. In fact, air contains ~ 1.4 Bq/m³ $\sim 121,000$ dpd/m³ ⁸⁵Kr so that we can't tolerate more than 9 mL of air in the inner core. In addition, dust in the air can introduce radioactivity in the detector components. LNGS Hall "C" rock, a main source of high radioactivity dust, has been measured to have 0.66 ± 0.14 ppm (part per million) ²³⁸U and 0.066 ± 0.025 ppm ²³²Th [2]. For this reason, it is critical to prevent, and to determine the level of dust in the various liquid components.

Consequently, there is an active program for Quality Control (QC) and Assurance (QA) within the Borexino operational structure to ensure that the radiopurity requirements that were met in the past are maintained during operations and the filling of the detector.

Quality Control in General:

ISO 9000 defines Quality Control as a set of activities or techniques whose purpose is to ensure that all quality requirements are being met. In order to achieve this purpose, processes are monitored and performance problems are solved.

In the context of Borexino the simplest way to interpret the "quality requirements" is the "radiopurity requirements" for the success of the physics program of the detector. Similarly, "processes monitored" are the monitoring of any activities /procedures using the detector components which may compromise their radio-purity. From this perspective, it is clear that there must be a two-streamed approach to quality implementation, a QA scheme where the process is reviewed at the managerial level, and a QC program where the process is independently tested to *gain confidence* that radio-purity is not breached in the particular process. *Gain confidence* because at the level of nBq/kg it is clearly not possible to measure the radiopurity of any substance on a short time-scale. However, we can indirectly ascertain whether quality has been compromised using various techniques to be discussed in panels in this poster.

Quality Implementation at Managerial Level: QA and Planning

Quality Assurance is an important part of the way Borexino is being managed. For example, within the Borexino management structure the "Technical and Safety Management Board" plans the day-to-day activities involving the interaction/movement of detector components which may pose risk of contamination. At this stage of the management structure there is active input from members on the committee who are directly involved in QC & QA. The short-term plan is reviewed in the interest of quality, safety and to determine the efficacy of the procedure itself. If there is risk of compromising the quality requirements the procedure necessity is balanced with the risks. A plan is drawn which details the particular tasks and the process is independently reviewed in the interest of quality, safety and necessity. The operational group, which is the group directly responsible for operating the plants, and carrying out the processes is briefed on the risks involved, and the plan for carrying out the process is implemented. The next stage of Quality Implementation is the monitoring of the procedures to build confidence that the process has been carried out properly and with the expected quality. For example, a task involving the installation of a new component or line of the in-line purification plant requires a detailed plan for installation, cleanliness protocol including quality testing, and finally He leak checking to $<10^{-9}$ mBar l/s to verify that the part has been properly installed and will not introduce contamination present in air.

Quality Implementation in the Field: Monitoring Quality Requirements

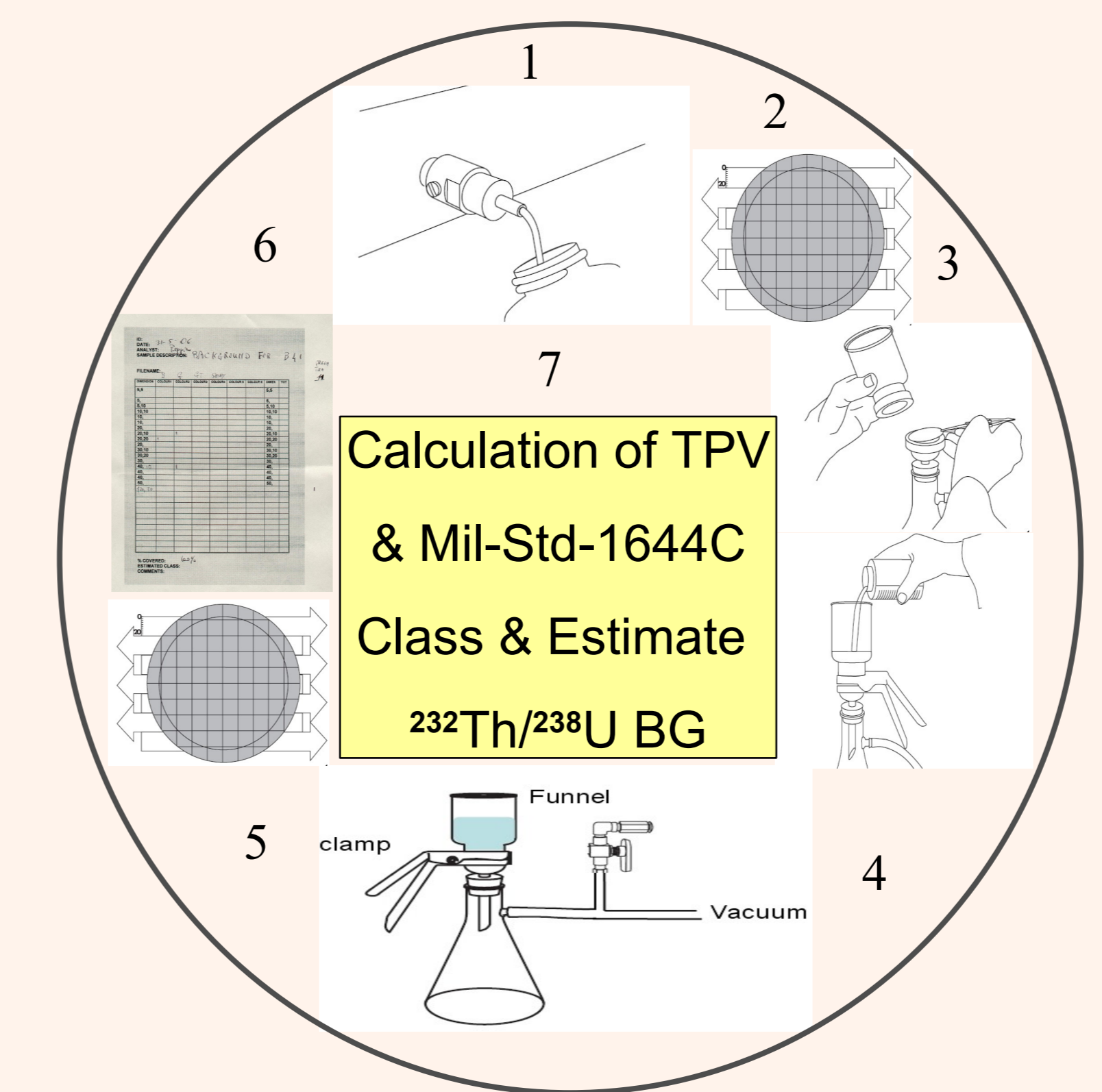
The Borexino radio-purity for various detector components is shown in Table 1. It is clear that determination of the radio-purity at the level of nBq/kg is simply not possible on a short time scale needed to monitor activities involving detector components and procedures. For this reason techniques are developed in order to *gain confidence* that a particular process was done successfully and that radio-purity has not been compromised.

Techniques implemented are particle counting (measuring the *undissolved* contaminants) in the various liquid detector components, ICPMS measurements as well as other monitoring techniques. High resolution ICPMS allow us to measure the *dissolved* $X=^{232}\text{Th}/^{238}\text{U}$ and all other metals to be measured at $<$ ppt (part-per-trillion) or $\sim 10^{-12}$ gX per g liquid. Liquid Particle Analysis (LPA) is an indirect measure of the Xg/g liquid but allows us to set an upper limit of the contamination at a level of $\sim 10^{-15}$ gX per g liquid based on knowledge of the X contamination in LNGS Hall "C" rock. All of these measurements can be done over a period of several hours.

Quality Monitoring: Liquid Particle Analysis

Dust comes from many different sources and is composed of many different elements including natural radioactive elements such as ²³²Th/²³⁸U/²³⁵U/²³²Th. Therefore, it is important to determine the amount of dust in the various liquid detector components. It is known that the cumulative dust concentration as a function of the diameter of the particle follows a power law: D^α , where $\alpha \sim -2$ to -3 .

In Borexino, the Mil-STD-1246C [3] is used to evaluate the level of cleanliness and it assumes a similar power law distribution. The particle analysis technique (see diagram describing the technique below) consists of estimating the total volume of the particulates in a particular sample (TPV) above a certain particle diameter to estimate the particle class. The TPV also allows us (assuming a reasonable estimate for $X=\text{Th}/\text{U}$ in rock) to make an estimate of the total amount of contamination Xg/g liquid.



Quality Monitoring: Scanning Electron Microscope (SEM) -Particle ID

SEM analysis coupled with Energy Dispersive X-Ray Fluorescence has helped us determine the nature of the particles that we see in various liquid samples. The technique is to use custom-made filters constructed by APC GmbH (*Analytische-Produktions-Steuerungs-und -Controll-geräte*). These are polycarbonate 0.4 micron filters sandwiched between a 40 nm layer of Au and a 20 nm layer of Au. A portion of the filter is cut-out and placed into the SEM vacuum chamber to be analyzed.

The technique enabled us to determine the fraction of rock-like (particles consisting mostly of Ca, Mg) particles we see in a sample. The types of particles seen with the SEM fall broadly in two classes, particles which are *rock or concrete-like* and particles which are *stainless-steel-like* (Fe, Ni, Cr present). It is natural for us to expect stainless-steel-like particles because all of the piping in the Borexino plant is stainless steel. We have found that statistically $\sim 1/2$ of the particles are rock-like and the other half stainless steel like.



Figure 2: Images with optical microscope of a) and b) LNGS concrete powder (5X mag), and c) LNGS rock powder (20X mag) created by tumbling rock and concrete in the presence of UPW. Note the multiple colours of rock and concrete powder making these difficult to identify.

Analyzing rock and concrete dust allows us to classify particles we see, however, in the final analysis of the TPV all particles are included except fibres longer than 300 microns which microscopically do not appear naturally in LNGS rock.

Quality Monitoring: Liquid Particle Counting (1-30 microns)

We have also used the HIAC 9703 optical liquid particle counter for analyzing the liquid detector components. These detectors allow particles to be sized in bins of 2 microns starting at 1 micron. From the expected power law distribution for ultra-pure chemicals [4] it is clear that most of the particles are in the smaller size bins. The HIAC 9703 measures the particle diameter by measuring the extinction of light as particles pass through a capillary. The instrument draws 5 mL at a time and extracts the number of particles in each sample and averages the result from 8 samples. So that the total sample size is 40 mL which is a small amount compared to ~ 700 mL sample analyzed in optical microscopy counting. In this sense, this instrument measures the high statistics, small diameter region of the particle size distribution, whereas, the optical microscopy technique measures the low statistics, large particles, and is an analysis over the full volume of a sample.

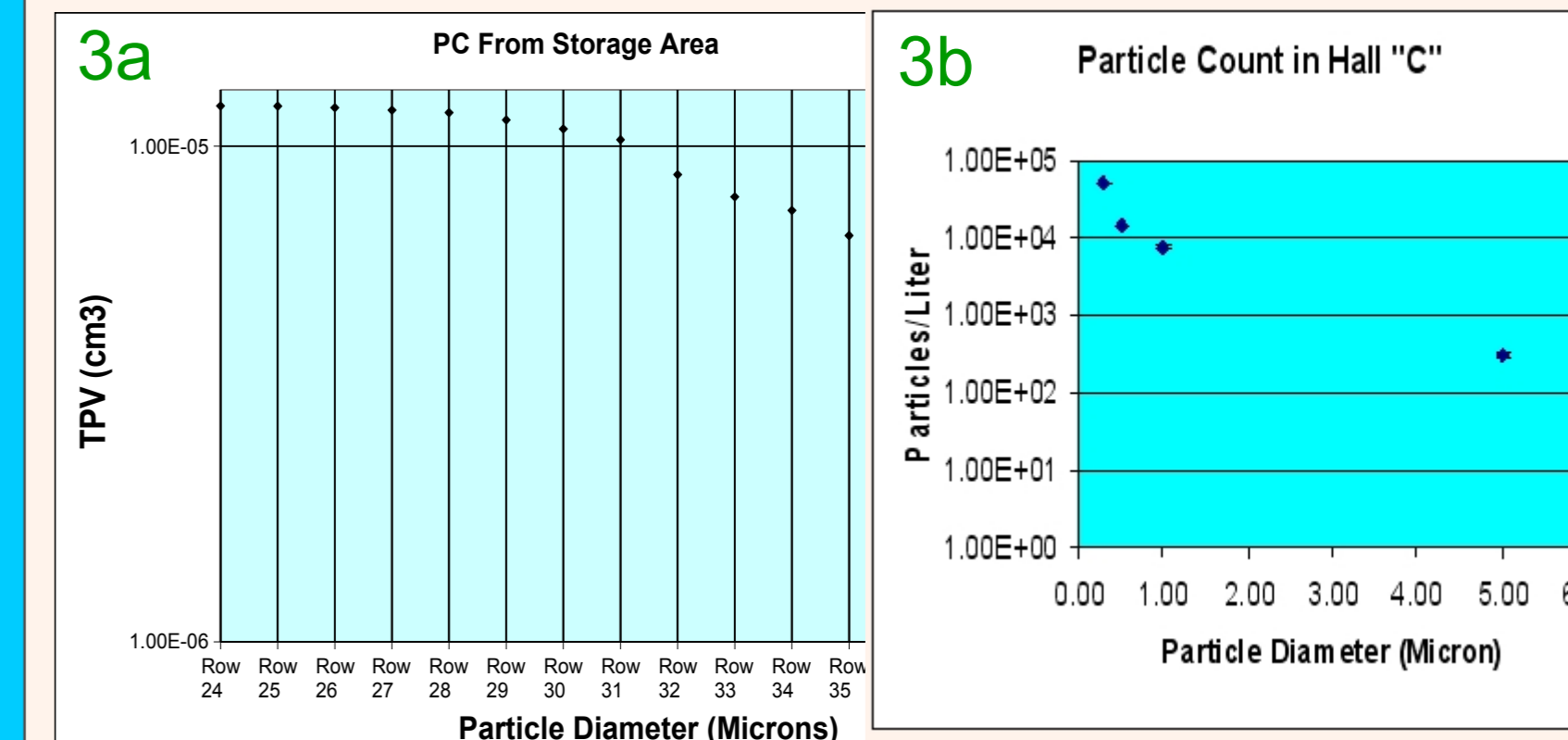


Figure 3a: Example of total particle volume in sample as a function of particle diameter as taken with HIAC 9703 Liquid Particle Counter. The sample is unpurified PC. Figure 3b: Particle Distr'n in LNGS air

Quality Monitoring: ICPMS

At LNGS many experiments require ultra-low background conditions and radioactive contaminants (e.g. lead, uranium, potassium, etc.) at ultra trace levels need to be determined for material selection, testing cleaning procedures and for general quality assurance for low background experiments. Consequently, LNGS purchased a 7500 series Agilent Technologies Inductively Coupled Plasma Mass Spectrometer (ICPMS) to support various experimental endeavours. The instrument can measure trace elements as low as one ppt or quickly scan (several hours) more than 70 elements to determine the composition of an unknown sample. In the standard configuration it allows moreover isotopic analysis with accuracy better than 1%.

In the context of Borexino, ²³⁸U and ²³²Th could be determined at the level of < 1 ppt of dissolved content in various liquid components. This is extremely useful for verifying there is no unexpected contaminants in the system. The contaminants might themselves not be a significant problem but their presence maybe the symptom of a bigger problem that may need to be investigated.

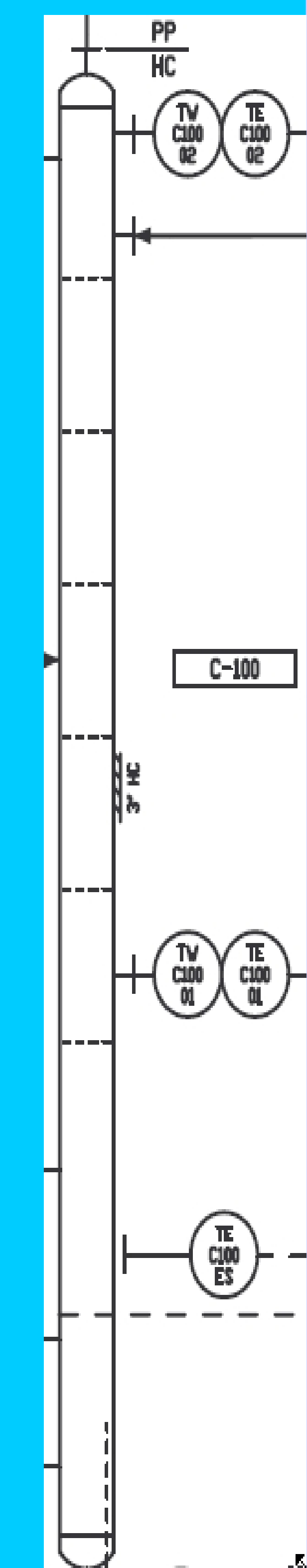
ICPMS requires careful sample preparation. Each vial used in the analysis requires many weeks of leaching periods in ultra-pure Nitric acid under carefully controlled conditions. Once the vial is properly cleaned (as verified by ICPMS) it can be used in the field. In the case of PC, sample preparation is more complicated because the ICPMS instrument in its current configuration cannot work properly in the presence of an organic matrix. For this reason, the metallic ions are back extracted with acidified UPW. This technique was useful for estimating the performance of water extraction.

Acknowledgements

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Literature Cited:

- 1) Borexino collaboration, G. Alimonti et al., *Astropart. Phys.* 8 (1998) 141
- 2) P.G. Catalano, *Mem. Soc. Geol. It.* 35(1986)647, E. Belloti et al., LNGS Preprint, 2006
- 3) Military Standard 1246C, Dept of Defense, (USA)
- 4) Mitchell, J., *Proc. 44th Annual Meeting, Institute of Environmental Sciences.*



Several 1000 litres of vessels

The challenge of QC+QA: Maintain a level of cleanliness at the level of nBq/kg Th/U and ingress of air at the level of mL's

Several km of piping