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Development of an environmental monitoring station for HPGe detectors

Melo [a] G. R., Zahn [b] G. S., Genezini [b] F. A., Moreira [b] E. G.

[a] *Instituto Federal de Educação Ciência e Tecnologia de Rondônia - Campus Vilhena*
BR 174 km 3, nº 4334- 76982-270, Vilhena, RO
gleiser.melo@ifro.edu.br

[b] *Centro do Reator de Pesquisas, IPEN-CNEN/SP*
P.O Box 11049 - 05422-970 São Paulo, SP, Brazil

ABSTRACT

Neutron Activation Analysis (NAA) is a well-established nondestructive analytic technique where the gamma radiation emitted by an irradiated sample is analyzed using an HPGe detector. The Neutron Activation Laboratory (LAN) of IPEN-CNEN/SP has been performing NAA analyses for over 30 years, and has plans of implementing quality control protocols to their analyses. In this sense, the environmental monitoring of the laboratories where the detectors are used has been performed for many years, in a manual way with no more than 2 measurements per day. In this work, an automated monitoring station based on a microcontroller ArduinoUNO board has been developed which comprises four thermo hygrometer sensors for monitoring different parts of the environment, plus a thermocouple for monitoring the inside of the liquid nitrogen dewar. The results obtained allow for a discussion on the performance and adequacy of the sensors.

Keywords: **Arduino, HPGe, environmental monitoring.**

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1. INTRODUCTION

High resolution gamma spectrometry and neutron activation analysis (NAA) are closely related, as NAA is based in the gamma spectroscopy of neutron-irradiated samples. The application of gamma spectroscopy relies on some conditions, one of which is that the detector system and the associated electronics are stable in time.

The signal detection in high resolution spectroscopy is performed by the detector, which is comprised by the medium that will interact with radiation – frequently a semiconductor crystal – and a signal pre-amplification device where charge induced by radiation will be integrated and amplified. The most widely used detector in high resolution spectroscopy is HPGe (high purity germanium), that may present some limitations related to the efficiency, that is usually lower than that of a NaI(Tl) detector, and the need to be kept in environments with controlled temperature and humidity, in addition to being more stable has a much higher energy resolution than its peers[1]. On the other hand, the detector crystal itself must be kept at low temperature (usually -196ºC) to avoid currents and fluctuations caused by thermal effects [2].

In order to avoid high capacitance, the preamplifier is mounted as close as possible to the detector. One part of the preamplifier is kept cooled and in vacuum, together with the crystal, but most of it is placed outside vacuum, where it is subjected to variations in the environmental temperature and humidity – this is made even worse by the fact that the liquid nitrogen dewar vent is placed close to the preamplifier, thus subjecting it to large temperature oscillations and intense water condensation while the dewar is filled.

The influence of environmental variables will cause operating anomalies, either of high or low importance, and were studied by Sutton in a study on the impact of environmental variables in "in situ" HPGe data collection [3] – for a lab detector the environment is much more stable, but some of Sutton's discussions are relevant. It was also observed by Mei-Wo *et al.* that those variations may affect the resolution of the detectors, affecting the stability of its electronic components [4].

Taking into consideration all of the facts explained above, the continuous verification of the detector's environment should provide a helpful tool to warrant its stable operation, as well as to help in the assessment of possible variations. For this purpose, an environmental monitoring station was developed that aims to be low-cost, unobtrusive and easy to use.

2. STATION COMPONENTS

2.1. Arduino Microcontroller

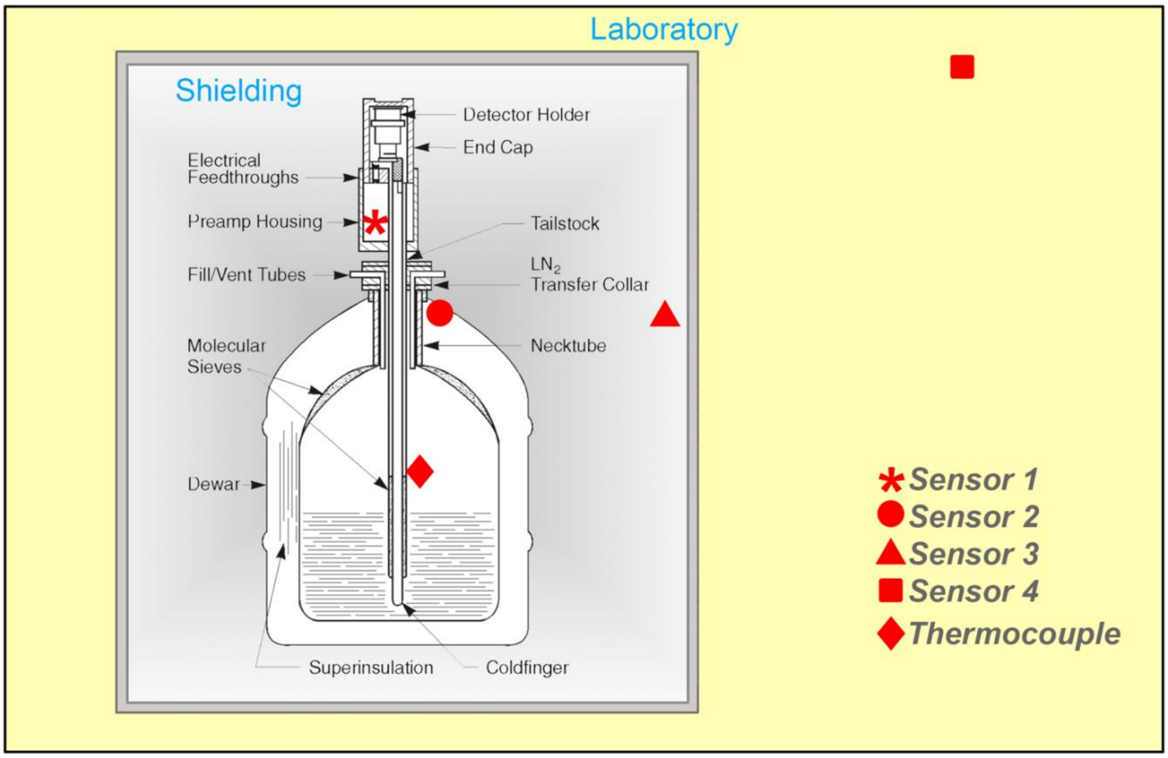
The Arduino board is available in several models, each with a different number of I/O pins. In this project, the board chosen was the Arduino UNO, equipped with an ATmega328 microcontroller with 32 kB of flash memory and an ATmega 8U2, programmed for Universal Serial Bus (USB) to serial communication conversion. As described by Evans, this board is the best choice for basic and intermediate projects, with autoswitching power and an integrated 3,3V [5].

2.2. DHT Sensor

For temperature and humidity sensing, the DHT22 sensor from Aosong Electronics Co., Ltd was chosen. It can operate from 0 to 99.9% relative humidity with 2% accuracy, and from-40-80º C. Results can be displayed with one decimal digit, and the response time is approximately 2 seconds, according to the sensor data [6]. This sensor has accuracy for humidity ±2% RH (Relative Humidity) and for temperature ±0.5ºC, resolution for humidity 0.1% RH and for temperature 0.1ºC, repeatability for humidity ±1% RH and for temperature ±0.2ºC and long-term stability of humidity measurement of ±0.5% RH/year [6].

Four sensors were distributed in distinct locations around the detector: one close to the preamplifier (S1), one close to the dewar vent (S2), one inside the detector radiation shielding (S3), and one (S4) outside the shielding, in the laboratory – this can be seen in Figure 1.

Figure 1: *Placement of the sensors in relation to the detector*



2.3. Type K Thermocouple

Thermocouples come in several configurations and have to be chosen according to the expected use. In this work, the most important specification was related to the alloy used in each thermoelement material. Type K thermocouple was introduced early in the 20th century by Hoskins Manufacturing, and has Chromel (Ni/Cr) as the positive thermoelement and Alumel (Ni/Al) as the negative one; it can operate from -200ºC to 1372ºC, with ±0,1ºC resolution, 0.03 % accuracy and long term stability ≤ 0.05 %/year [7].

Based on the Seebeck effect, a thermocouple is a device that couples two distinct thermoelements on one end (called junction end, which is the sensitive part); the other end (reference end) must be in a distinct, known temperature – the difference in temperature then creates an electric potential between the distinct materials [8].

The type K thermocouple was placed inside the liquid nitrogen dewar in such a way that its junction end seated halfway through the dewar, so it could be sensible to low liquid nitrogen situations (Figure 1).

2.4. MAX31855K

To calculate the temperature at the joint end, a procedure known as cold joint compensation is necessary, in order to eliminate the contribution of other joints. According to the datasheet of the MAX31855K module [9], before converting the thermoelectric voltage in an equivalent temperature, it is necessary to compensate for the difference between the ambient temperature and the reference temperature of 0ºC, so this module linearizes the thermocouple output voltage, using the reference K-type thermocouple value of 41.276 µV/ºC (eq.1):

$$T_{OUT} = (41.276\ \mu V/{}^{o}C) \times (T_R{}^{o}C - T_{AMB}{}^{o}C) \tag{1}$$

where T_{OUT} is the output voltage of the thermocouple, T_R the junction end temperature and T_{AMB} the ambient temperature. The accuracy guaranteed by the factory is ~~of~~ 2ºC for temperatures in the range -200ºC to 700ºC.

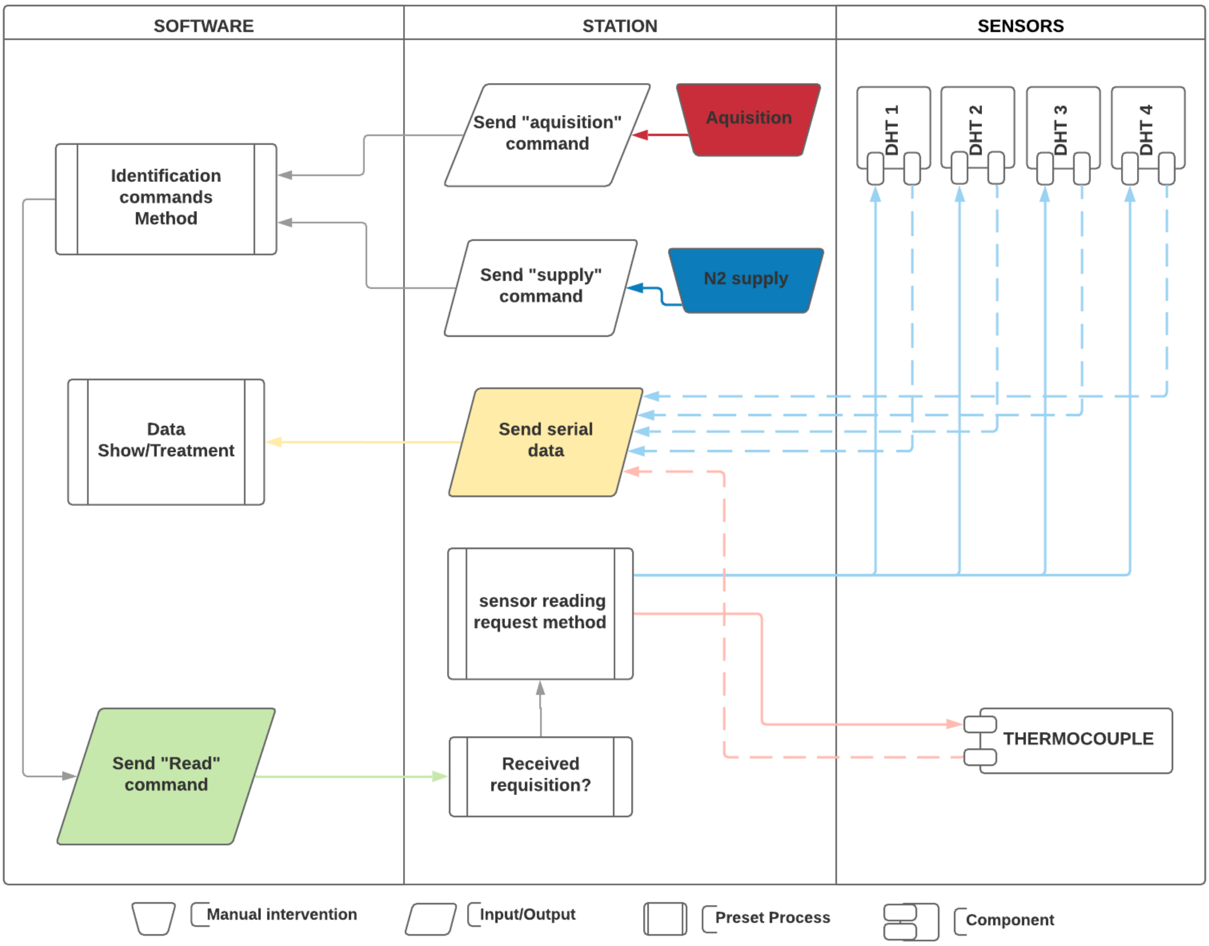
3. PROGRAMMING

3.1. Controller Software/Arduino Microcontroller

The station software was developed using the C# programming language and the Microsoft Visual Studio environment [10].

The HPGe Detector Monitoring System, called HPGe-DeMoSI, was developed to work in a user-friendly and intuitive screen. The purpose of the HPGe-DeMoSI is to allow the user to record the environmental conditions around the detector, not only during the measurement process but also when the detector is idle, essentially creating a detector log. Those registers will be stored in a database so that custom reports can be created filtered, for example, by a specific date, or by the user's name, etc.

Figure 2: *Workflow between software, station and sensors*

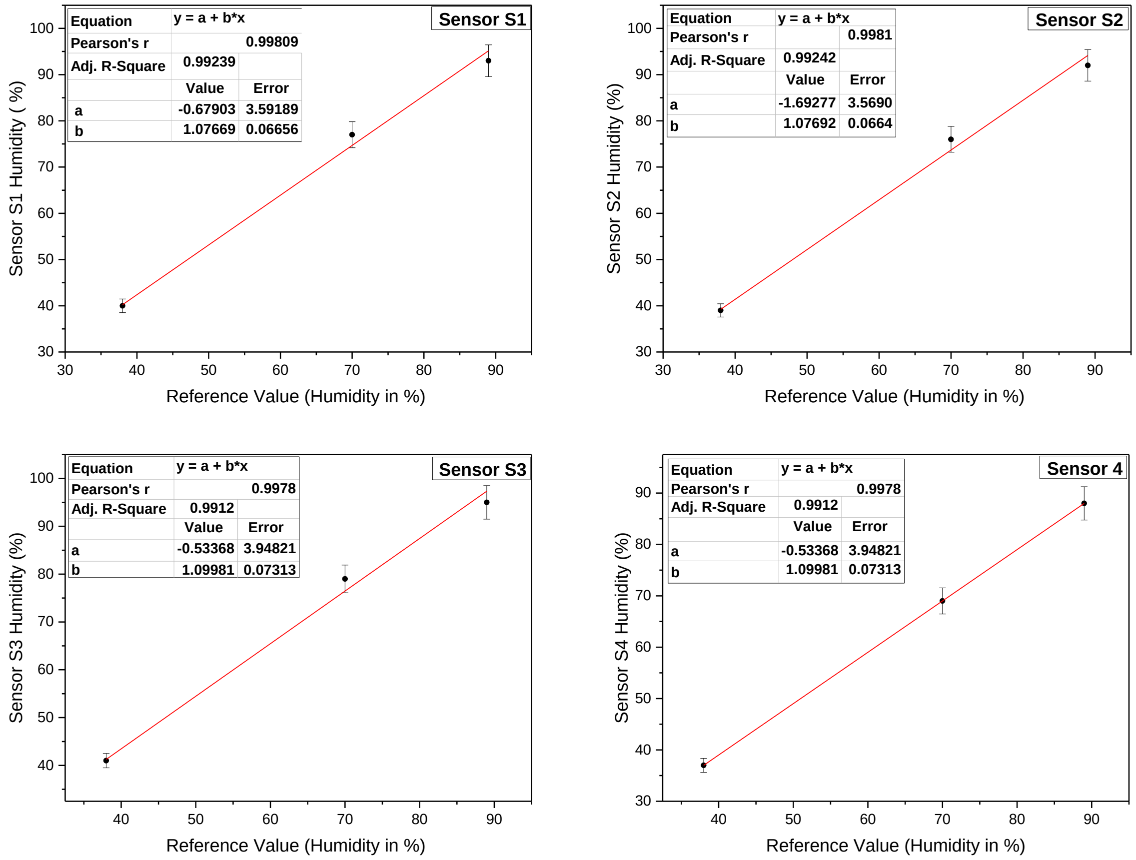


The integration of all sensors and modules to the Arduino board, as well as its required C++ programming, resulted in a multiparameter station with USB-based serial communication which shall passively work on attending computer-sent requisitions. Thus, a simplified protocol was created for the communication between station and computer software, basically by sending reserved characters for each type of job the station is expected to perform. The communication flow is presented in Figure 2, where one should notice that the station only performs the readings and sends the data when the computer instructs it to do so; the computer software sends a request each second, in order to keep the display updated, but only sends the readings to the database in the user-selected intervals.

4. RESULTS

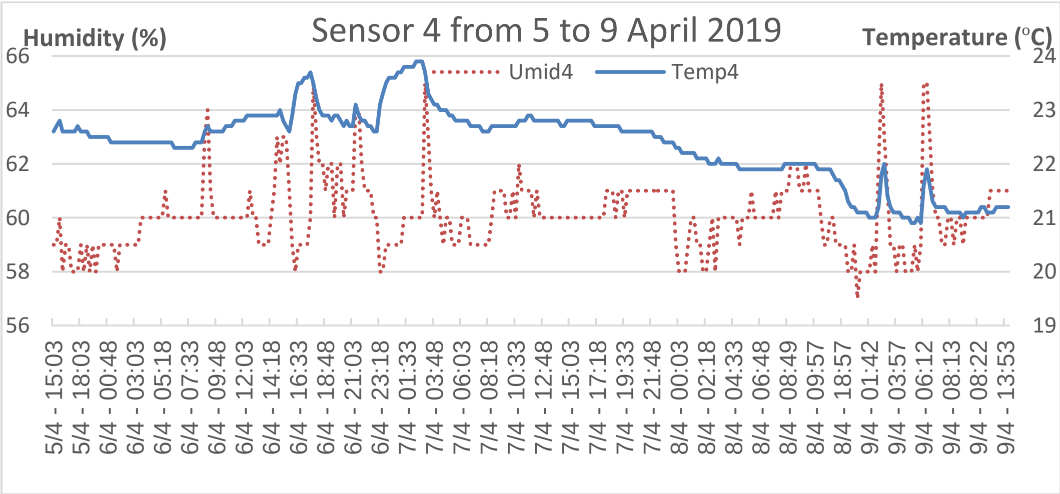
In order to assure the measurement reliability, the DHT22 sensors went through a calibration verification process using a certified Maxiterm 7666.02.0.00 thermo hygrometer [11] as reference value. This process was performed on all sensors at the same time, with the exception of S4, which went through a more complete process – Figure 3 shows the results for the humidity calibrations.

Figure 3: *Humidity calibration curves for sensors S1-S4.*



With the station properly programmed, a continuous measurement data collection was performed. Figure 4 shows the records from sensor S4 for the period from 5/4/2019 to 9/4/2019. The humidity peaks seen in the graph seem to correlate with ambient humidity records from CETESB (the state environmental agency) measurement station in Pinheiros, near to IPEN. On 6/4at18h the relative air humidity was 92%, and the temperature was 22.2ºC; on 7/4, at 02h, humidity reached 94%, with a temperature of 22.3ºC; on 9/4 from 03h to 06h humidity and temperature were 96% and 19.2ºC, respectively. As the laboratory where the system is installed has dehumidifiers installed, the humidity peak values are always below the ambient ones.

Figure 4: *Temperature (Temp) and humidity (Umid) in S4 for the period from 5-9 April/2019.*



In Figure 5 it can be seen that sensor S2, (being close to the dewar vent) registered higher humidity levels. It can also be noticed that there is a strong temperature drop, coupled with a peak in humidity, around 8h20 on 9/4/2019 – this is due to the dewar filling process, that took place at 8h10 that day; on sensors S3 (Figure 6) and S1 (Figure 7) there is also a noticeable drop in temperature during the dewar filling process, but it is much less pronounced due to their location.

Figure 5: *Temperature (Temp) and humidity (Umid) in S2 for the period from 5-9 April/2019.*

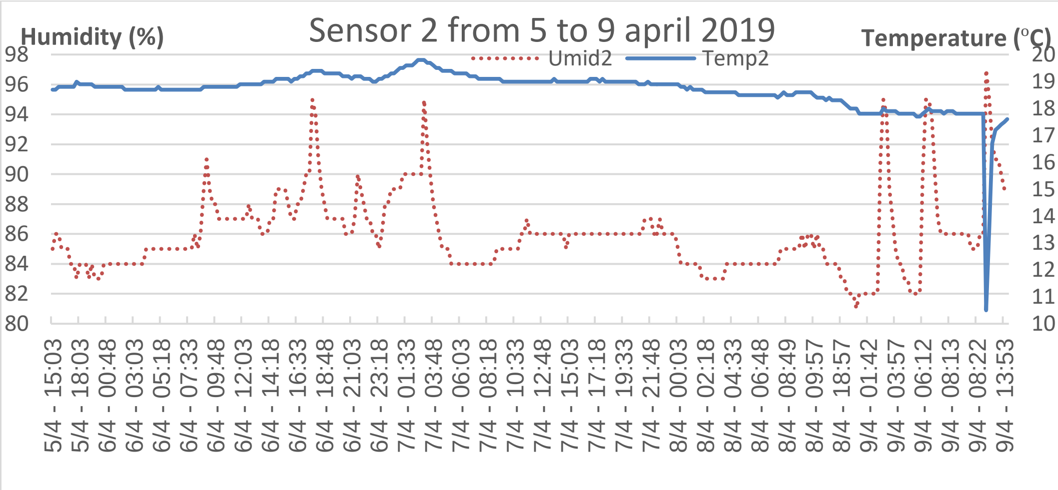


Figure 6: *Temperature (Temp) and humidity (Umid) in S3 for the period from 5-9 April/2019.*

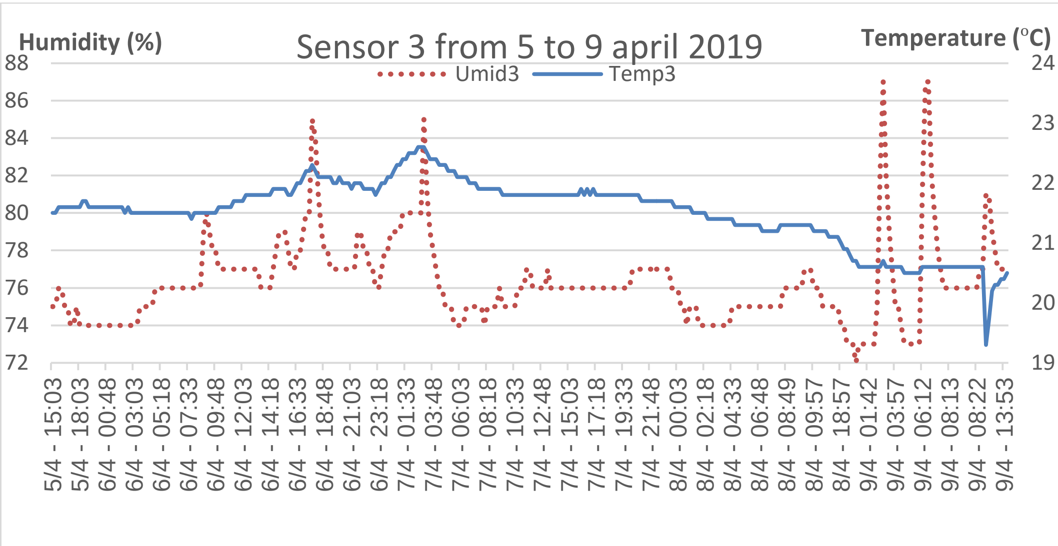
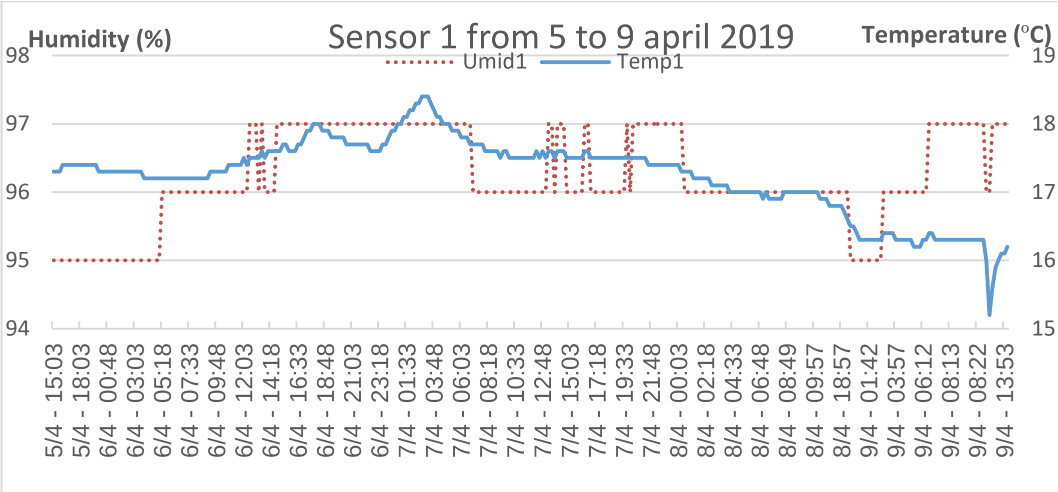


Figure 7: *Temperature (Temp) and humidity (Umid) in S1 for the period from 5-9 April/2019.*



These results seem to indicate that the location of sensor S2 close to the dewar vent is unnecessary, once sensor S3 is already installed in a position that reliably represents the microenvironment in which the detector is inserted, while being less stressed by extreme humidity from the condensation during dewar filling - sensor S2 could be put to better use if installed at some other point in the experimental room, in order to check for possible temperature gradients. The placement of sensor S1 inside the preamplifier casing also led to questions whether submitting it constantly to a high humidity environment could lead to sensor degradation, as described in its datasheet, so this sensor could also be relocated.

The thermocouple inserted into the dewar was placed in such a way that its sensitive tip is placed midway through the length of the detector's cold finger, so as to alert for low liquid nitrogen situations. During the test period, the liquid nitrogen was always above half the dewar's capacity, so no temperature variation was observed and a constant value of -196ºC was measured. In the future a test shall be performed by letting the dewar run emptier and checking if the thermocouple's readings present noticeable variations in that case; if this is the case, a visible alarm could be added to the software to alert for the necessity of urgent refilling, avoiding possible issues.

5. CONCLUSION

In this work, an environmental monitoring station for an HPGe detector was developed. Based on the results obtained in one week of tests, the system seems to be viable and reliable, but a definitive assessment shall require a longer measurement time. Moreover, the results indicate that sensor S1 may not be the most appropriate for its location, due to the constant high humidity, and that sensor S2 could be used elsewhere, as it is somewhat redundant with sensor S3. Also, an alarm triggered by thermocouple placed inside the liquid nitrogen dewar should be useful to indicate the necessity of refilling – the small variations observed in the other sensors didn't seem to indicate the need for other alarms, though, and simply recording the values in a detector log database should be enough.

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