SuperNEMO Progress Report 2018-2020

Introduction

The SuperNEMO collaboration is currently in the final phase of the commissioning of the SuperNEMO Demonstrator, the first SuperNEMO Module. It will demonstrate the efficiency of the developed tracko-calorimetric method and the possibility of fulfilling the requirements of the SuperNEMO experiment in terms of the background, energy resolution of the calorimeter, and, ultimately, sensitivity. The Demonstrator Module by itself will have an important physics programme, including an expected 0νββ- decay half-life sensitivity $T(0\nu)_{1/2} > 6{\cdot}10^{24}$ yr with 6.3 kg of Se-82 in 2.5 years of data taking as well as unique studies of the 2νββ decay mode.

During the last three years the SuperNEMO project has been focused on the integration of the different components of the detector at the Laboratoire Souterrain de Modane. Despite significant difficulties in the last two years, including the Covid-19 pandemic having a considerable impact on activities in LSM during 2020, major progress has been made. The detector is fully installed. The calorimeter is fully commissioned and the tracker commissioning is under progress. This report presents the main results obtained in 2018-2020.

Year 2018

The most important result is the completion of the basic assembly of the SuperNEMO Demonstrator in November 2018 (see Fig.1). The creation, assembly and installation of all the main internal elements of the module: calorimeter, tracker, VETO system, Se-82 foils and calibration system was completed, after which the Demonstrator module was closed.

Figure 1. SuperNEMO Demosntrator (first module), mounted under the clean tent in the main hall of the LSM laboratory (Modane, France).

The achievement of this goal was made possible by solving a set of tasks.

1. The Demonstrator calorimeter has been assembled (see Fig.2). There are two walls consisting of 520 optical modules (blocks of plastic scintillators 256x256x194 mm in combination with low-background PMT 8" R 5912-03, developed by HAMAMATSU together with the SuperNEMO collaboration). All modules have been pre-tested. A record energy resolution of FWHM= 8.0-8.2% and a time resolution of 400 ps for 1 MeV of electrons were obtained for plastic scintillators of this type (based on polystyrene) and size [1].

Figure 2. Assembled calorimeter wall (upper left), back view (upper right) and calorimeter construction in LSM (below).

Figure 3. Left: clean room created at the JINR DLNP for radiochemical purification of isotopes (Se-82). Right: Se-82 source foils installed inside SuperNEMO Demonstrator.

2. All Se-82 source foils are installed in the Demonstrator (see Fig. 3, right). The source foils are produced from purified selenium enriched in Se-82. The 2.5 kg of enriched selenium for the production of SuperNEMO source foils have been purified in Dubna. A full range of work on the radiochemical purification of Se-82 have been carried out at JINR. A clean room for radiochemical purification has been created (see Fig. 3, left). The method of radiochemical purification of Se-82 in kilogram quantities has been developed and tuned. Before installation of foils in the Demonstrator their radioactive purity was checked using the BiPo-3 ultra-low-background detector [2] (see Fig. 4, left). Some difficulty was encountered in foil installation, that has been successfully solved, but caused a delay in the closure of the Demonstrator module.

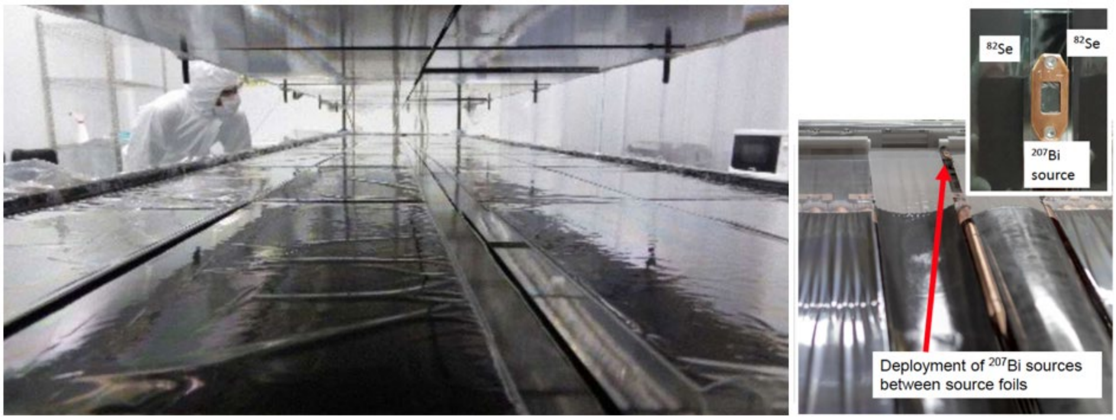

Figure 4. Left: Measurement of radioactive contamination of Se-82 source foils for the SuperNEMO Demonstrator using the BiPo-3 ultra-low-background detector (installed in the underground low-background laboratory of Canfranc, Spain). Right: the automatic calibration system.

3. A calibration system with automatic deployment of radioactive sources Co-60, Bi-207 for time and energy calibrations was installed in the Demonstrator and tested (see Fig. 4, right). A delay due to necessity to redesign the source deployment system without guide wires caused some delay in the detector integration, but the system is now working well and is fully operational.

4. The cabling of tracker and calorimeter and installation of electronics has been started. The high-voltage and signal cables for the Demonstrator's tracking detector manufactured by JINR were used.

5. Software for simulation, data acquisition and analysis has been developed. A test run of half of the detector (tracking chamber + calorimeter) has been performed (see Fig. 5), the data acquisition is regularly exercised during calorimeter commissioning runs.

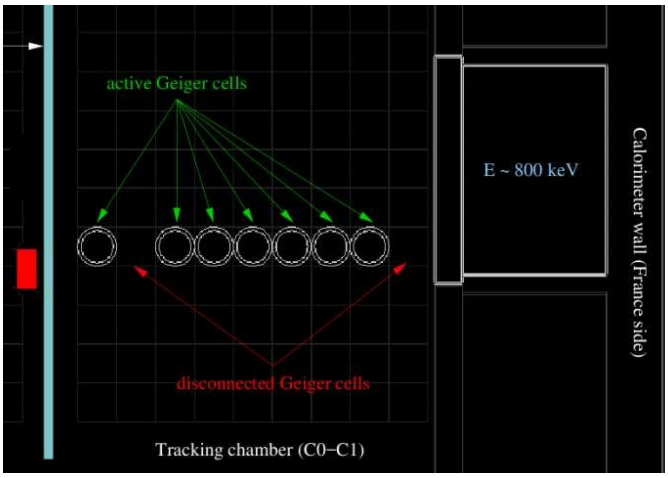

Figure 5. One of the first events recorded in the SuperNEMO Demonstrator in a test run.

6. A complex series of low-background measurements was carried out: selection of structural materials of the module using low-background germanium HPGe detectors, validation of radon protection techniques using radon detectors, etc.

Year 2019

In 2019 futher work was carried out to equip the detector. Important elements were assembled: gas system, magnetic shields for the PMTs, electronics, light injection and monitoring system. The cables were connected to the majority of the Demonstrator Module detector channels (the full calorimeter and part of the tracker). Physical data taking with a portion of a detector was carried out, the collected data were used to debug software and data processing algorithms. A passive shielding design was developed (iron + borated polyethylene, BP). BP-shielding delivered to the laboratory, the production of iron shielding was delayed due to twice higher price asked by the manufacturer and the need to find additional funding resources.

Unfortunately, due to problems with the tracker (discussed in detail below) the realization of the project has been delayed.

1. The gas system (inlet and recirculation) was delivered and installed in the underground laboratory LSM (Fig. 5, left). Integration into a unified facility control system was carried out. A number of tests and elimination of leaks were carried out.

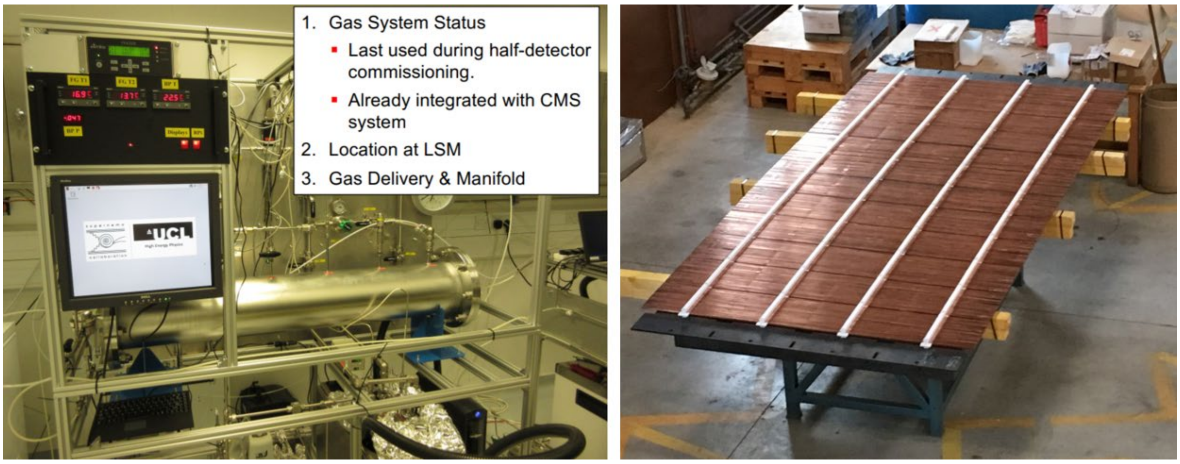

Figure 5. Left: SuperNEMO Demonstrator gas system mounted in LSM. Right: Coil pre-mounting.

Figure 6. Cabling up of the tracking detector of the SuperNEMO Demonstrator.

2. All elements of the setup for creating a magnetic field are manufactured and delivered to the LSM (see Fig.5, right). The final installation of the magnetic coil system is postponed until the completion of work on the tracking detector. In parallel, the final calculations for optimizing the magnetic field for the purposes and tasks of the SuperNEMO demonstrator were carried out.

3. Electronics and related equipment are manufactured, delivered and tested at LSM. Cable equipment: the connection of the calorimeter is fully completed, it is fully functional. The tracker is equipped on 2/3 (Fig. 6), the completion of the equipment is suspended due to the tracker problem discussed below.

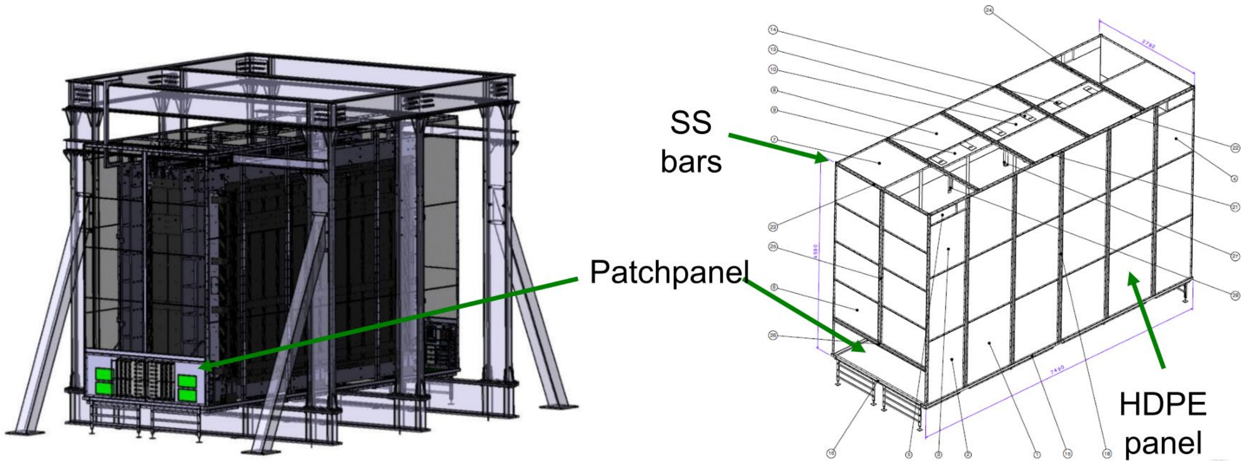

Figure 7. Final design of the anti-radon tent.

4. Calculations were carried out and a detailed design of the final version of the tent made of HDPE (high-pressure polyethylene) panels selected for excellent radiation purity was developed (Fig. 7). Most of the components were manufactured and purchased. The final version of the anti-radon tent will be installed after finalising the detector gas tightness.

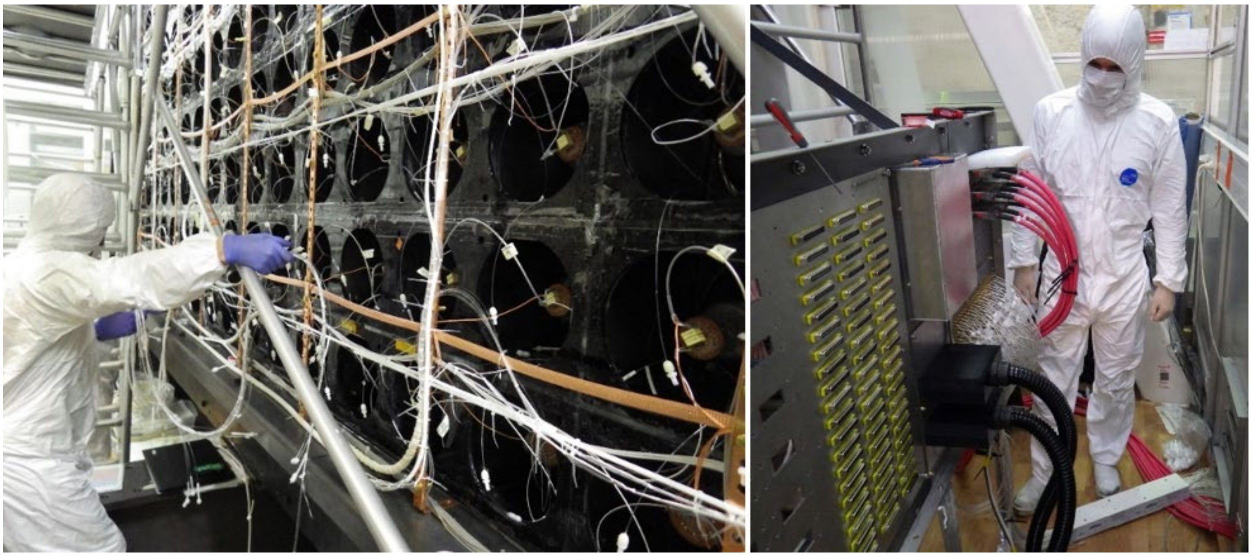

Figure 8. Installation of fibers (left) and light injection system (right).

5. Commissioning and testing of the light injection and monitoring system has been performed. All fibers have been routed and connected to optical modules (Fig.8). Fibers at radon patch panel have been sealed. Reference optical modules and reference sources have been installed. Reference optical modules are being commissioned.

6. The equipment for the data acquisition system (DAQ) is delivered and installed in the LSM. A prototype DAQ was developed and debugged, on which tests and a series of measurements were carried out. The system was debugged, the data format was optimized, and data processing systems were tested.

7. The final design of passive shielding (iron + borated polyethylene, BP), its integration into the laboratory space was developed (Fig. 9). All elements of the BP shielding are purchased, manufactured and delivered to LSM, the shielding is fully ready for assembly. There is a delay with the iron shielding because of explosive rise in prices for shielding material. Initially, the lowest possible price was almost $2M USA for the production of ultra-pure iron passive shielding. After lengthy negotiations, several redesigns of shielding in order to optimize the price (adjusting the sizes to the production technology), finding our own reserves (stocks), we managed to reduce the price of iron shield down to $ 600,000 USA, which turned out still to be twice as much as the amount foreseen in the project, which required a search for additional resources.

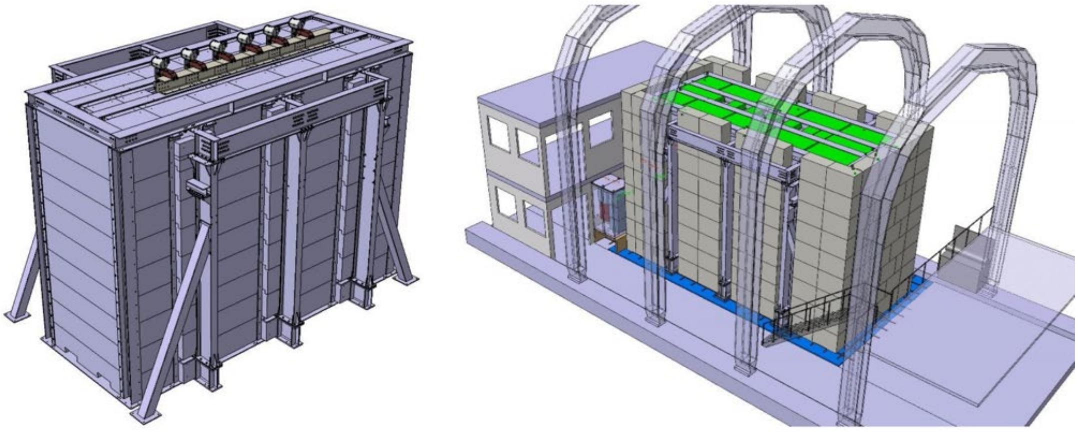

Figure 9. The structure of iron shielding (left) and its integration with neutron shielding (borated polyethylene) in the underground laboratory.

8. Calorimeter commissioning data was collected with different conditions (with or without Bi-207 source, single- vs multi-PMT trigger, light injection runs). The data collected was used for reflectometry, PMT trigger rates, cross talk, baseline-&-waveform studies.

Figure 9. Top: the nature of the sagging of the track chamber. Bottom: methodological studies (measurements) of the sagging at the LSM.

The main problem discovered during the first tracker commissioning. In the process of testing the electrical properties of the Geiger cells of the track detector, it was found that a significant part of the tracker cells are inoperable due to a short circuit of the wires. Studies and tests have shown that cell failure is associated with sagging of the tracker frame in the middle part (see Fig. 9). Accordingly, the sagging of the frame caused the wires of part of the Geiger cells to sag, causing them to short-circuit to closely located elements (cathode rings).

This problem was actively studied. Measurements of the tracker frame sagging were carried out, calculations of the beam loading were checked. The tracker volume consists of two C-shaped sections connected together. Before the connection, the functionality of the sections in the vertical position was checked, no problems were revealed. Therefore the distortions occurred when connecting sections together and / or connecting tracker with calorimeter and with source frame was recognized as the main cause of the problem.
As a result, the collaboration developed and approved two scenarios for solving this problem:

A. Installation of additional supports (beams) above the tracker volume with a system of lifting bolts, with the help of which the main frame of the tracker will be straightened, that will allow to restore the correct geometry, eliminating the sagging of Geiger cell wires. This option is faster in terms of execution time, however, it is associated with the risk of damage to the source foils, which are installed in tension and connected to the tracker volume through a hard contact.

B. Reopening of the Demonstrator tracker volume, fixing docking problems and closing it back. The second option is associated with additional time and efforts.

To decide between the two options it was planned to inspect the condition of the wires and source foils with a special camera mounted on an articulated probe (Optimax Borescope), introduced into the inner volume of the tracker through the technical holes for the deployment of calibration sources.

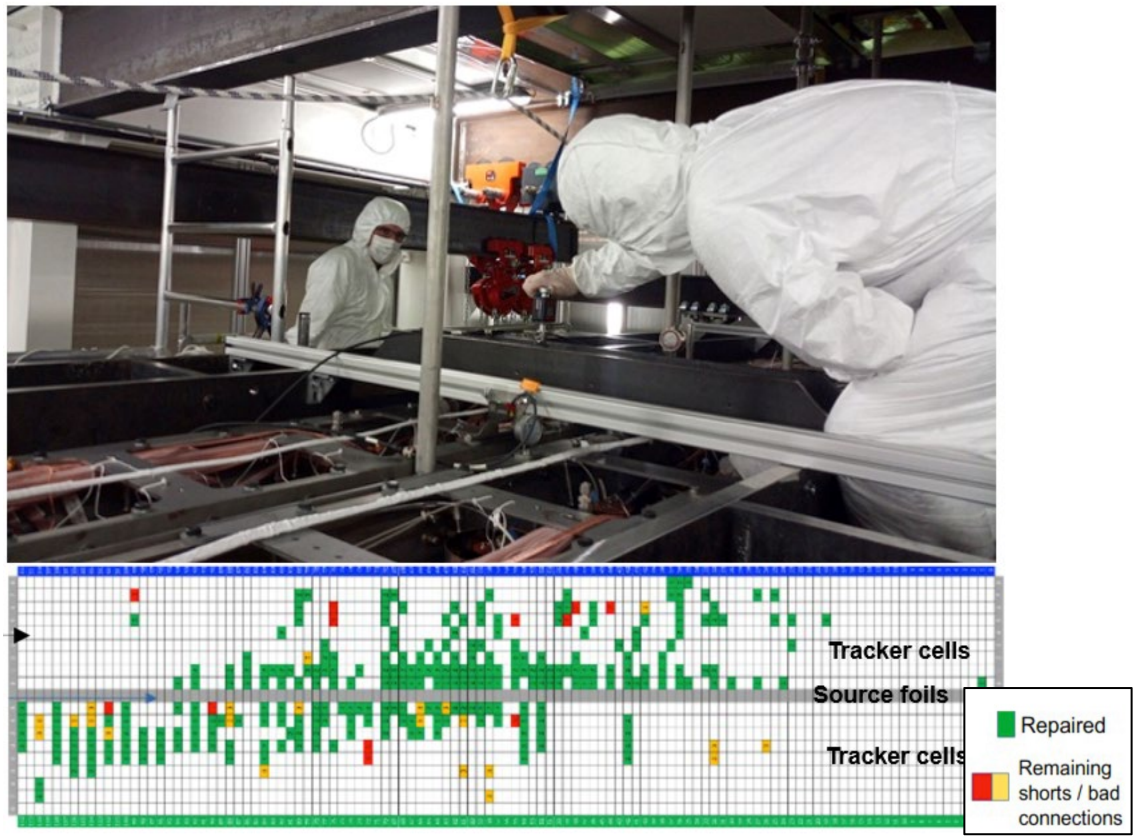

Figure 10. Top: lifting of the top of the tracker. Bottom: map of the restored Geiger cells.

Year 2020

A mechanical deformation of the tracker frame discovered in 2019 which, although only 4-6 mm over 6 m length, led to an unacceptably high rate of tracker short-circuits. Despite these difficulties, decisive progress has recently been made. A special mission to the LSM in September 2020 restored the detector geometry to nominal, and reduced the rate of short-circuits to an acceptable level below 2%.

1. After the careful investigation of inner tracker volume the hypothesis about the wire sagging was confirmed and the option A was finally approved to restore the detector geometry. Very delicate but essential operation was performed in September 2020 lifting the tracker frame in various points by 0.5mm up to 4 mm. The nominal geometry was successfully restored. This allowed to reduce the number of Geiger cell shorts from 20% to less than 2% (see Fig.10). Structure is mechanically stable (monitored with laser gauges). Foils (observable with the borescope) are intact.

2. Big improvements are reached in the gas tightness of the detector volume. The main calorimeter walls are gas tight after sealing. The first overpressure was obtained during the gas sealing operations. The leak scan is performed when demonstrator is filled with Helium to investigate the TOP and with Argon to investigate the BOTTOM. A set of leaks has been identified, and the sealing operations are in progress.

3. The calorimeter was fully commissioned with the timing and energy calibration of each optical module. The calorimeter is made of 721 optical modules and 99% of them are running properly. The data acquisition runs are routinely taken with the whole calorimeter with and without radioactive sources. First enviromental background studies (without shielding) have been performed (see Fig.18).

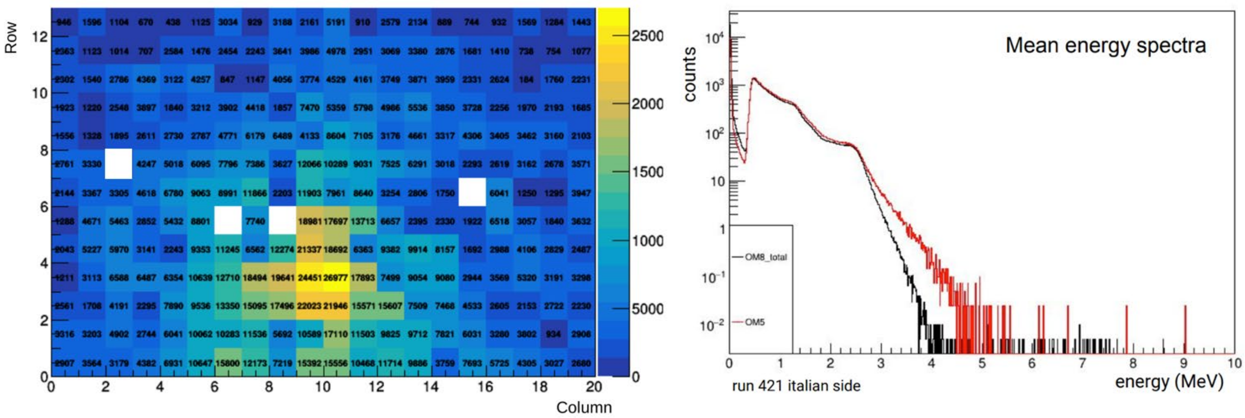

Figure 11. Counting rate of optical modules in a run with Co-60 source for one of the calorimeter walls (left). Energy spectra of all 5-inches and 8-inches optical modules (right).

All 2018 – 2020 period

Alongside the hardware work, a huge amount of work has been undertaken on the software and simulations and, in addition, collaboration members have continued to work on the analysis of NEMO-3 datasets. In the 2018-2020 period the collaboration has published 6 papers that are listed below[3]-[8]. The Dubna group played an active role in all of them.

The JINR Dubna is also strongly involved in a collaboration with “ISOTOP” company (Russia) to enrich ^{150}Nd and ^{96}Zr in large quantities by centrifugation. JINR is also working on the possible way to apply reverse method purification to theses isotopes.

Reasons for the delay

The project was delayed due to a number of objective circumstances.

1. Detected sagging of the track detector wires (since 2019). This is the main cause of the problems that took a long time to resolve. Confirming the existence of the problem, identifying the causes, developing a plan to correct the situation and implementing it required more than a year of collaboration efforts (including delays due to Covid). Fortunately, a solution to the problem was eventually found and implemented, so currently the work plan for launching the Demonstrator is successfully moving towards the final stage.

2. Additional delays in 2018 were associated with the need to redesign the automatic calibration system and complications in the production of foil sources. We emphasize that the Demonstrator is a complex facility, the assembly of which is carried out under the most stringent requirements for the radiation purity of all materials and equipment. Because of this, all production processes take a long time to complete. Due to the complexities of logistics, it is almost impossible to prevent time losses.

3. Large rise in prices for shielding material. Initially, the lowest possible price was almost $ 2M USA for the production of ultra-pure iron passive shielding. After lengthy negotiations, several redesigns of shielding in order to optimize the price (adjusting the sizes to the production technology), finding our own material reserves (stocks), we managed to reduce the price of iron shield down to $ 600,000 USA, which turned out still to be twice as much as the amount foreseen in the project, which required a search for additional resources. In the face of the budget deficit experienced by most of the project countries, finding resources was a real challenge. As a result, we note that by joint efforts of the parties, at the moment we have a real plan for financing this part of the project, but with significant delays in relation to the original plans.

4. Limitations due to the Covid pandemic are slowing down the progress activity. The access to the underground laboratory was stopped during several months and current international restrictions prevent many SuperNEMO collaborators (Russian, UK, US) for travelling.

The delays in the implementation of the SuperNEMO Demonstrator work plan associated with points 2-4 amounted to up to more than one year. Detailed plans exist for the remaining integration steps, including the installation of the anti-radon tent and the magnetic field coil. The tracker commissioning will start in early 2021 after the completion of the gas tightness; this will launch the data-taking phase with the full detector. A detailed design for the SuperNEMO shielding has been developed, along with a preliminary funding plan.

References

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