CUPP – CENTRE for UNDERGROUND PHYSICS in PYHÄSALMI

T. Enqvist[†], T. Jämsen[‡], M. Lehtola, M. Mutanen, J. Narkilahti,
S. Nurmenniemi, J. Peltoniemi, T. Räihä, J. Sarkamo, and C. Shen

CUPP, *P.O. Box 3000, FIN-90014 University of Oulu, Finland*
[†]CUPP, *P.O. Box 22, FIN-86801 Pyhäsalmi, Finland*
email: timo.enqvist@oulu.fi
[‡] Sodankylä Geophysical Observatory, University of Oulu

Abstract

The Pyhäsalmi mine in Pyhäjärvi, Finland, is the deepest operational base-metal mine in Europe. It provides excellent opportunities for the research of underground physics by having very stable bedrock, low background radiation level, modern infrastructure, and good traffic conditions all around a year. The mine extends at the moment down to 1440 metres, corresponding to about 4000 m.w.e.

The aim of the CUPP-project is to construct a large underground laboratory in the Pyhäsalmi mine. It is particularly attractive for future long-baseline neutrino experiments, since the distance to major accelerator centres is very intersting (Pyhäsalmi – CERN 2288 km) and it is technically possible to construct the halls required to host very large-volume detectors, at depths 1000 – 1500 m undergound.

An experiment measuring multiple muon events is starting at the shallow depths during the summer 2004. The single-muon flux will be measured also during the summer down to the 1440-level. The flux has already been measured for a long time at the shallow depths, also the neutron fluxes have been monitored.

1. INTRODUCTION

The Pyhäsalmi mine is the oldest operational base-metal mine in Finland. It is run by the Pyhäsalmi Mine Ltd (owned by the Inmet Mining Corporation, Canada), and it produces zinc, copper and pyrite. The mining operation after the excavation of the new mine was started again in 2001 and continues probably until 2017 at least.

The activity to host an underground laboratory in the old part of the mine was started in 1993, and the Centre for Underground Physics in Pyhäsalmi (CUPP-project) was formally established 1997 by the University of Oulu.

Figure 1. Pyhäjärvi is located in the middle of Finland along the main highway 4 (E75) between Jyväskylä and Oulu. The distances are: 165 km to Oulu, 180 km to Jyväskylä and 475 km to Helsinki.

Pre-feasibility studies, including background measurements [1], rock analysis and preliminary plan [2], safety analysis [3], and reactor-neutrino background analysis [4] have been made.

2. LOCATION OF THE MINE

The Pyhäsalmi mine is located in Pyhäjärvi which is a small town in the central Finland (see Fig. 1) between the areal centres and university towns Oulu and Jyväskylä, both of which have an international airport. The driving time to either of these towns is about 2 hours, and there are also regular train and bus connections, and to Helsinki as well. The roads are kept clear all the year round, and the railway line extends to the mine.

The municipality of Pyhäjärvi has about 6500 inhabitants. It has the usual services, including a hotel, banks, a post office, supermarkets, pharmacy, medical centre, bookstore and some restaurants. The distance from the centre of the town to the mine is about five kilometres.

3. INFRASTRUCTURE

The Pyhäsalmi mine with its existing and modern infrastructure offers unique possibilities to carry out sensitive and low-counting-rate experiments

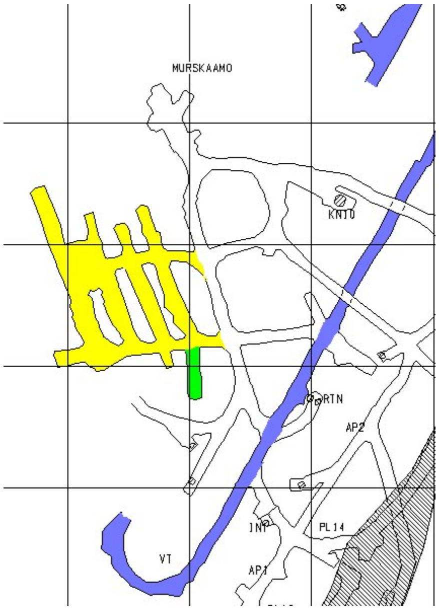

Figure 2. Schematic view of the caverns at 660 metres underground. The yellow-coloured areas (at the left) can be used for the scientific purposes. These include an old lunch room (green), and many service and storage rooms, largest of them is of the size of 30 m × 10 m × 8 m. The blue-coloured area in the middle is the spiral-shaped decline, and the shadowed area in the right-lower corner shows the mining zone.

as all the experiments to detect neutrinos, for example. The mine can be divided into two parts; the old mine and the new mine. *The new mine* extends down to 1440 metres where the mining operation is going. The existing caverns of *the old mine*, situating in the top of the new mine at depths 95 – 1080 m, can be used for scientific purposes at the moment.

3.1. The old mine

The old part of the mine extends down to the depth of 1080 m (3000 mwe). The mining in the old mine was stopped in the autumn 2001, and many of the caverns are now available for scientific use, though the mining company may still need some caverns for service purposes. In Fig. 2 the caverns available at the depth of 660 metres are shown as an example.

The caverns at the old mine can be accessed by car or by truck via the spiral-shaped decline (1:7) going all the way down into 1440 metres. The tunnel will no more be used for transporting ore. The official load size is 2.6 × 2.8 × 8 m^3. Larger equipments may be transported only to specific sections.

At the upper levels water leakage through rock is possible, also gases may escape through rock if in direct contact. This problem disappears mostly at the depth of several hundreds of metres where the rock is tighter.

The temperature of the rock at the 100-m level is about 6°C and at the 1000-m level it might be about 16°C. The humidity is high at the upper levels, while the deeper levels are very dry. The ventilation is kept operative.

All caverns used for scientific measurements will be provided, at least, with electricity and data connection. It will be possible to arrange a remote control via internet. Clean air and water can be supplied. There will be plenty of free space to host experiments in the old mine, as well as for storage, service and manufacturing at different levels. Also new caverns can be easily excavated if necessary.

The level of background radiation of radioactive isotopes of the rock in the mine was measured at several depths underground [1]. The activity concentrations of ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K isotopes were measured as follows: ^{238}U: 27.8–44.5 Bq/m^3, ^{232}Th: 4.0-18.7 Bq/m^3, ^{226}Ra: 9.9–26.0 Bq/m^3 and ^{40}K: 267–625 Bq/m^3. The results indicate the low background-isotope concentrations in the mine. The measured radon concentrations in the mine were also low, varying typically between 10 and 150 Bq/m^3, depending on ventilation.

3.2. The new mine

The maximum depth of the new mine reaches 1440 metres, corresponding to 4000 m.w.e. Construction of large experimental halls and caverns to 1440 – 1500 metres level is technically possible, as shown in the preliminary-design report of the deep underground laboratory [2].

The new mine started to operate in 2001, and it can be really referred to as a new mine, although it is connected to the old mine. It can be accessed via a fast lift which can transport both people and heavy equipments. Also the same truckway that goes to the old mine can be taken all the way down. The largest objects must be transported by trucks or special vehicles via the decline.

The temperature at the 1440 m level is about 23 °C. The humidity depends on the ventilation and outside-air temperature. The rock is very tight, so there is very little water leakage through the walls. On the other hand, the water has a high concentration of metal ions and sulphur which prevents the growth of harmful organisms.

There are no free caverns for research purposes in the new mine at the moment. Hence everything needed for the scientific work must be excavated. The excavation cost will be 70 – 100 euros/m^3, depending on the depth, the size and the shape of the cavern. The largest cavern that could be easily constructed is 100 m × 15 m × 20 m. Larger caverns require careful planning and more expensive support structures, because of a high stress-field in the deep mine.

4. PERFORMED, RUNNING, AND NEAR-FUTURE EXPERIMENTS

4.1. Muon flux measurements

The two main experiments in Pyhäsalmi mine at the moment are the *MUG*-experiment which measures single-muon flux and the *multimuon experiment* starting to measure the flux of multiple muons in summer 2004.

The MUG-experiment has been running from year 2000 and it is the pilot experiment in the mine measuring the single-muon flux at the shallow depths at 90- and 210-metres level. It uses several $50 \times 50 \times 5$ cm^3 plastic scintillators. This is mainly meant for educational purposes, but it was able to record beautifully the effects of recent changes of solar activity.

The multimuon experiment [5] is the first larger-scale experiment. The purpose of this experiment is to measure multiple simultaneous hits of muons at depths between 90 and 400 metres underground. This data is used to obtain information on the composition of high-energy cosmic rays at the knee region (10^{15}–10^{16} eV), with the purpose to clarify their origin and possibly to find an explanation to the change in the spectrum.

The experimental setup of the multimuon experiment consists of drift chambers previously used at LEP in the DELPHI-detector as Barrel Muon chambers (MUBs). The prototype is built using about 8 planks, and later on will be expanded with the rest of the available Muon Barrel detectors (about 100 planks). Additionally plastic scintillators may be added around the drift chambers to gain more data. Some detectors will be located at other depth levels to gain information on the energy spectrum.

During summer 2004, the single-muon fluxes will also be measured in deeper levels down to the main level of 1440 metres underground. The fluxes will be measured with plastic scintillators (similar to MUG-detectors).

4.2. Near-future neutrino experiments

The facility is suitable for neutrino experiments, and could host for example solar neutrino experiments. Also supernova neutrino experiments are under consideration. A modern low-cost supernova neutrino detector could be constructed and operated by the local staff. Several different detector options will be considered. One example is an OMNIS-type detector [6] consisting of heavy-elements (iron or lead) as a target material. Another possibility is a detector based on carbon [7]. There exist suitable caverns at 660 (see Fig. 2) metres underground for such detectors.

These detectors are ment not only for supernova neutrino detection, since they happen rarely, but will be planned to be versatile. For example, they might monitor the muon or neutron fluxes.

Simulation, planning and design works of different detector types has already been started.

5. FUTURE EXPERIMENTS

The ability to excavate large experimentals halls makes it possible to host several large-scale neutrino experiments in the Pyhäsalmi mine in the future. It is technically possible and economically feasible to construct new large-volume underground laboratory rooms at the depth of about 1500 metres, corresponding about 4200 m.w.e. [2].

These new laboratory rooms could host, for example, far-distance detectors of the future long-baseline neutrino oscillation experiments, if the neutrino factory will be built in CERN. The distance between Pyhäsalmi and CERN is 2288 km, which is very interesting for neutrino studies. The baseline and its density profile have been modelled very accurately [8], and simulations for the neutrino factory are going on.

The Pyhäsalmi site provides also an interesting option for observing neutrinos from a multi-MW machine as there is no technical obstacle for excavating the caverns for the large-volume detectors, up to one-million cubic metres like UNO, if their shape can be optimised.

Another significant proposal [9] by Technical University of Munich, Germany, is the construction of a large-volume liquid scintillation detector. The purpose is to observe low-energy solar neutrinos, supernova and supernova relic neutrinos, geoneutrinos, and proton decay. The volume of the detector would be about 30 000 m^3. This detector requires extremely low background of reactor neutrinos. It has been calculated [4] that in the Pyhäsalmi site the flux of reactor neutrinos is the smallest among the European underground laboratories.

REFERENCES

[1] N. Wang, *The characteristics of uranium and radon migration underground*, CUPP-07/2000;
J.N. Abrurashitov, V.N. Gavrin, V.L. Matushko, and A.A. Shikhin, *Measurement of the fast neutron background in the Pyhäsalmi mine* CUPP-11/2003.

[2] *The preliminary plan for the deep laboratory*, Kalliosuunnittelu Oy (Rockplan ltd) (2001).

[3] H-D. Schneider, D. Wagner, and A. Studeny , *Risk Analysis - CUPP project*, DMT-Montan Consulting GmbH, Germany (2003).

[4] K. Loo, J. Peltoniemi, J. Sarkamo, and T. Enqvist, *Calculated Reactor Neutrino Flux in the Pyhäsalmi Mine*, CUPP-05/2004, in preparation.

[5] T. Enqvist, M. Lehtola, M. Mutanen, S. Nurmenniemi, J. Peltoniemi, C. Shen, T. Jämsén, A.-M. Elo, K. Mursula, L. Ding, Q. Zhu, K. Eggert, F. Vissani, P. Keränen, M. Pearce, *A Proposal to Study Underground Multimuon Events* CUPP-04/2003.

[6] D.B. Cline, G.M. Fuller, W.P. Hong, B. Meyer, J. Wilson, Phys. Rev. D**50** (1994) 720;
P.F. Smith, Astropart. Phys. **8** (1997) 27; Astropart. Phys. **16** (2001) 75;
J.J. Zach, A St J. Murphy, D. Marriott, R.N. Boyd, Nucl. Instrum. Methods A **484** (2002) 194.

[7] L. Cadonati, F.P. Calaprice, M.C. Chen, Astropart. Phys. **16** (2002) 361.

[8] E. Kozlovskaya, J. Peltoniemi, and J. Sarkamo, *The density distribution in the Earth along the CERN-Pyhäsalmi baseline and its effect on neutrino oscillations*, CUPP-07/2003.

[9] L. Oberauer, hep-ph/0402162 (2004).