Geo-neutrino Program
at Baksan Neutrino Observatory

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Construction of a large volume scintillator detector has been discussed for a long time. The works aimed to its preparation has been resumed recently.

We will discuss:

- Benefits of its location at Baksan Neutrino Observatory
- Its potential for geo-neutrino studies
- Current progress
Baksan Valley

Mountain Andyrchy

Baksan valley

Baksan Neutrino Observatory and Neutrino village
BNO Facilities and Neutrino village

- Andyrchy EAS array
- Carpet-3 EAS array
- BUST
- Tunnel entrance
- Neutrino village
Underground labs of BNO

- **Low Bkg Lab1**
- **Low Bkg Lab2** + Laser Interferom. 620 m – 1000 m w.e.
- **Low Bkg Lab3** «DULB-4900»
- **GeoPhys Lab1**
- **GeoPhys Lab2**
- **GeoPhys Lab3** «НИКА»
- **4000 m**
- **1500 m**
- **1320 m**
- **3400 m**
- **3700 m**
- **4300 m**
- **BUST’s hall**
- **OGRAN’s hall**
- **GGNT’s hall**
- **BLVST**

Entrance
Muon shielding

Muon flux (cm$^{-2}$ s$^{-1}$)

A - Baksan underground scintillation telescope (BUST)

G - EAS “Andyrchi” installation

B - Low background laboratory

C - Gallium-Germanium neutrino telescope (GGNT)

D - Neutrino Detectors (for further projects)

Mt. Andyrchi

Entrance

Distance from the entrance, m

Baksan river

(3.0±0.15) · 10$^{-9}$ μ/cm$^2$/s
The future neutrino detector at Baksan will have a standard layout, similar to KamLAND and Borexino, but with larger mass and deeper underground.

Neutrino interaction channel:
\[ \bar{\nu}_e + e^- \rightarrow e^+ + n \]

Signal signature:
- prompt \((e^+)\) +
- delayed \((n\) capture\)

Deposited energy is converted to visible light and then detected by photo-sensors.
BLVST Scientific Program

Probing Earth’s interior:
- Geo-neutrino flux
- Th/U ratio
- 40K abundance
- Georeactor

Probing solar interior:
- Solar neutrino
- Neutrinos from CNO cycle

Monitoring Nuclear Power Plants

Testing Supernova Explosion Models:
- Neutrinos right from SN explosions
- Relic SN flux
## Signal / Background flux

<table>
<thead>
<tr>
<th>Location</th>
<th>Total reactor neutrino $R$ (TNU)</th>
<th>Reactor neutrino within geo-neutrino window $R_G$ (TNU)</th>
<th>Geo-neutrino $G$ (TNU)</th>
<th>$R_G/G$</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baksan</td>
<td>38.24</td>
<td>14.37</td>
<td>52.6</td>
<td>0.3</td>
<td>[1]</td>
</tr>
<tr>
<td>Gran Sasso</td>
<td>94.15</td>
<td>35.35</td>
<td>39.8</td>
<td>0.9</td>
<td>[1]</td>
</tr>
<tr>
<td>Sudbury</td>
<td>190.74</td>
<td>72.85</td>
<td>49.9</td>
<td>1.4</td>
<td>[1]</td>
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<tr>
<td>Pyhasalmi</td>
<td>72.97</td>
<td>27.61</td>
<td>52.9</td>
<td>0.5</td>
<td>[1]</td>
</tr>
<tr>
<td>Hawaiï</td>
<td>3.44</td>
<td>1.29</td>
<td>15.3</td>
<td>0.1</td>
<td>[1]</td>
</tr>
<tr>
<td>Kamioka</td>
<td>27.79</td>
<td>10.30</td>
<td>31.7</td>
<td>0.3</td>
<td>[1]</td>
</tr>
<tr>
<td>Jinping</td>
<td>27.8</td>
<td>6.8</td>
<td>59.4</td>
<td>0.1</td>
<td>[2]</td>
</tr>
</tbody>
</table>


More on geo-neutrino studies

1a. Determination of $^{238}\text{U} + ^{232}\text{Th}$ flux at a mountainous location (larger contribution from the crust) - to complement world-wide measurements.

1b. Measurement of Th/U ratio. The precision is expected to be ~10%.

Channel: $\bar{\nu}_e + p \rightarrow e^+ + n$

Requirements: low reactor flux, low radioactive background

2. Detection of $^{40}\text{K}$ neutrinos - to determine its contribution to the radiogenic heat production. May vary depending on whether it is present in mantle or not.

Channel: $\bar{\nu}_e + e \rightarrow \bar{\nu}_e' + e'$

Requirements: low $^{14}\text{C}$ contamination


[Sinev et al., Phys.Part.Nucl. 46(2), 2015]
Georeactor

- hypothetical chain reaction taking place in the Earth’s centre. It explains the (unknown) changing force sustaining the magnetic field of Earth.

**EXPECTED RATES** (events/year):
for 3-10 TW georeactor, no oscillations, 10 kton target, 100% efficiency

Georeactor: \(\sim(300 - 1000)\)
Power reactors: \(\sim700\)
Intrinsic background: \(\sim10\)

Georeactor fuel composition can be determined by the spectrum shape.

LAB (linear alkyl benzene) is the standard choice:
- low-cost
- high light yield (~$10^4$ photons/MeV)
- high transparency
- compatible with structure materials
- flash point ~140°C
Liquid Scintillator Studies

Samples from KINEF (Kirishi, Russia) are currently under examinations using chromato-mass-spectroscopy analysis:

### Transparency

<table>
<thead>
<tr>
<th></th>
<th>$L_{440}$, m</th>
<th>$L_{430}$, m</th>
<th>$L_{420}$, m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude LAB</td>
<td>25.6</td>
<td>18.1</td>
<td>14.0</td>
</tr>
<tr>
<td>Refined LAB</td>
<td>72.5</td>
<td>48.3</td>
<td>39.5</td>
</tr>
<tr>
<td>Refined LAB after 1 year</td>
<td>25.6</td>
<td>18.1</td>
<td>14.5</td>
</tr>
</tbody>
</table>

The decrease of light attenuation length is the result of interaction of hydrocarbons with oxygen and the formation of primary oxidation products.

→ Possible solution: blowdown of the LAB storage tank with an inert gas or introduce antioxidants.


### Natural radioactivity

For LAB-based liquid organic scintillator containing 2 g/l of BPO scintillation addition:

- $^{232}$Th : $6.2 \cdot 10^{-12}$ g/g
- $^{238}$U : $1.8 \cdot 10^{-11}$ g/g

Low concentration of $^{14}$C is also of great importance for lowering detection threshold:

(e.g. for measuring solar CNO neutrinos in the elastic electron scattering).

$^{14}$C/$^{12}$C : $(3.3 \pm 0.5) \cdot 10^{-17}$

Prototyping first

2019
(fully funded)

0.5 t

2020-...
(funding is under negotiation)

5 t

10 kt
First prototype

0.5 ton of liquid scintillator (LAB)
20 PMTs (10-inch Hamamatsu R7081-100)
Modeling of First Prototype

The shape of light concentrators has been optimized via detector modeling with LSMC package.

Light concentrators ~optimal

Summary

• Baksan is a good location for geo-neutrino studies:
  – Far from power reactors
  – Low muon flux
  – Well studied backgrounds
  – At mountainous region (thick crust) – complementary to other experiments

• The work has started:
  – Examination of liquid scintillator
  – Assembling of the first prototype
Neutrino detection

Geo-neutrinos can be detected via inverse beta-decay (IBD) reaction:

\[ \bar{\nu}_e + e^- \rightarrow e^+ + n \]

**prompt signal** – brings the information about the neutrino energy:

\[ E_\nu \approx E_{e^+} + 1.3 \text{ MeV} \]

**delayed signal** – neutron capture provides a coincidence marker.

On H: 2.2 MeV after ~200 μsec.
On Gd: 8.1 MeV after 30-50 μsec.

Calculated geo-neutrino energy spectrum (from Th and U).


IBD cross section is given by:

\[ \sigma_{\text{IBD}} = 9.55 \cdot 10^{-44} pE(1 + \delta) \]

where \( p \) and \( E \) are the positron momentum and energy, and \( \delta \) is a correction for nuclear recoil and weak magnetism.