Upgrade of Apatity Neutron Monitor

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Abstract. The neutron monitor (NM) in Apatity has been deeply upgraded in the end of 2013. We developed and installed new amplifier-discriminators. The detecting tubes of NM were tested and calibrated with additionally using of a pulse-amplitude analyzer. Due to this operation electric noise and interfering pulses are reduced. The NM was equipped with a new rapid data acquisition system. The system registers each NM pulse with time accuracy of 1 microsecond. This gives a possibility to investigate such fast phenomena as, for example, multiplicities in NM. Moreover, using these detailed data, it is possible to produce not only a standard NM count rate (number of pulses per minute) but (if necessary) a count rate with any high time resolution. Based on the detailed data we implemented the software calculation of so called "large dead time" data, which previously was done by hardware.

1. Hardware modernization
The neutron monitor (NM) in Apatity is a conventional 18-NM-64 instrument with SNM-15 tubes filled with BF3. Here we omit well-known facts about SNM-15 (BP-28 analogue). Using of SNM-15 discharged tube is not deviated from producer recommendations: negative high voltage supply, low input impedance of an amplifier.

In the end of 2013 the NM has been upgraded. As a first step of the modernization, new amplifiers were made in order to replace the outdated ones. New amplifiers are designed using modern electronic components. Because of this, the performance and noise immunity of the amplifier has increased significantly.

The second step was a calibration of all counters/amplifiers. The usual method of NM calibration is to obtain the “voltage – count rate” characteristics, like the one shown in Fig.1. The operating high voltage must be set at the middle of the characteristics plateau (around 2300 V in this case).

![Figure 1](image_url)  

Figure 1. The “high voltage – count rate” characteristics of a NM counter (tube).
We developed a new calibration methodics. Measurement and analysis of an amplitude spectrum of output pulses were included. The spectrum was obtained by a pulse-amplitude analyzer. The sample of the amplitude spectrum is shown in Fig.2. A NM amplifier-discriminator has a cutoff level of pulse amplitude to reduce noise. When the gain factor is optimal, the cutoff level (it is shown red line) falls on the gap between noise and real pulses. Higher gain factor expands the blue graph to the right, and some noise pulses pass through the discriminator because their amplitudes become above 1 V. Lower gain factor presses the blue graph to the left, and some real NM pulses become less then cut off level. Such mismatch between the gain factor and the cutoff level can be a source of latent long-term NM instability. A small variation of any parameter (gain factor, cutoff level, low voltage supply etc.) causes unexplained NM data floating. The cutoff level of a conventional NM is 1 V (red line in Fig.2), while the gain factor is set uniformly ~10^3. Usually these two values are not consistent with individual tube parameters. So for any amplifier an individual adjustment of the gain is necessary. Only after pulse-amplitude spectrum measurement on each tube the gain factor can be set exactly into the gap, as it shown in Fig.2.

![Figure 2](image_url)

**Figure 2.** The amplitude-spectral characteristics of a NM counter. The discriminator cutoff threshold is set to 1 V (red vertical line). When the cut off level and gain factor are consistent, the discriminator cutoff threshold is on the gap on the pulse-amplitude spectrum.

The two above mentioned characteristics allow us to set the high voltage and gain factor exactly to stable operating point.

2. **Advanced data acquisition system**

The traditional way to gather NM data is to register a count rate, i.e. a total number of pulses per time unit (typically one minute). These standard data do not contain information on pulse sequences and distribution within a time unit interval. We call this way 'integral way' or standard.

The second way is to register exact time of each pulse coming. We equipped our registration computer with a multichannel high-speed digital input card Adlink PCI-7348, and
our data collecting program registers each NM pulse: in which tube it occurred and how many microseconds elapsed since the previous pulse. The time resolution is 1 µs. These detailed data give much more information about cosmic rays and processes in a neutron monitor. We call this way 'differential way' or detailed. Schematic it is shown in Fig.3.

Figure.3. Two ways of NM data registration: integral and differential. The integral way produces minimum information – just a count rate. The differential way gives full information on NM pulses.

The NM in Apatity now registers both standard and detailed data. At the present moment the same registration system is set also in Baksan (Northern Caucasus) and Barentsburg (Spitsbergen) stations. The system has several advantages.

1) The 'integral way' doesn't allow to obtain NM data with time resolution less than standard registration interval (typically 1 min). Original data of the 'differential way' can be processed (anytime later) and count rate with any time resolution down to 1 second or less, if necessary, can be derived. For example, GLE69, 20 Jan 2005, was so huge and sudden (increase was up to thousands percents within some minutes, for example [1]) that time resolution less than 1 minute could be useful.

2) The detailed data are useful for study of multiplicity events (multiple productions of neutrons in NM). A multiplicity event in NM data is a cluster of pulses with short intervals between them. Number of pulses in each multiplicity event, distribution of pulses in time and space (distribution on NM tubes) can be investigated [2, 3]. Now such study is conducted on three equipped stations only. It would be good to setup our system on some stations in other places: low latitude, high mountain etc.

3) Most other NMs register data with a small dead time (SDT) 10 µs. Apatity station from the its very beginning, since 1969, registers also large dead time (LDT) data. Large dead time is 1200 µs. The LDT data more correctly represent the primary cosmic ray flux. Earlier LDT data were produced by hardware. But this hardware is difficult to adjusting and not used on other stations. We decided not to interrupt this long data series. Now it is automatically calculated by software using detailed data. Our system is setup on three stations and LDT processing may be done on their data.

4) Examining detailed data we can reveal some specific false NM pulses. For example, a sequence of pulses with equal time interval between them – periodic interference. Such false pulses give a negligible impact on the total count rate, so they cannot be seen in the standard data. But they are serious obstacle for the multiplicity study when a series of pulses
(multiplicity event) is searched. Due to the detailed data the periodic interference can be easily recognized and rejected.

5) It is easy to integrate any additional measuring unit to our system and join other data with accuracy 1 µs. For example, on the Baksan station a NM and Extended Air Shower (EAS) detector are set in one building. Pulses of these two units are registered by our system and can be compared with high accuracy. Pulses from EAS detector are used as a marker of EAS among NM pulses. In this data flow a hadronic core of EAS falling down to NM can be separated and studied [4].

3. Conclusion
The data acquisition system of the NM in Apatity is significantly upgraded. All electronic equipment from the tube-detector to the registering computer was replaced. The modern high-speed amplifiers, the new circuit design and the high-speed digital I/O cards were used. The software was upgraded too. The main goal of the modernization is to register 'detailed' information about pulses. The registration of the 'standard' NM information is not changed. With a new high-speed system registering the detailed information the capabilities of our neutron monitor as a cosmic ray detector are significantly expanded.

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References
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