DREAMS AND REALITY OF USING NAKED Ge DETECTORS IN LIQUID NITROGEN, STATUS (LONG-TERM STABILITY) OF GENIUS-TF

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GENIUS-TF-II is a setup of *six* naked high purity Ge detectors (15 kg) in liquid nitrogen in Gran Sasso. It has been installed in October, 2004 - after the first four naked Ge detectors had been installed on May 5, 2003 (GENIUS-TF-I). The GENIUS-Test-Facility (GENIUS-TF) is **the first** and up to now **only** setup ever testing the novel technique aiming at extreme background reduction in search for rare decays in particular underground. The goal of GENIUS-TF was to test some key operational parameters of the full GENIUS project in 1997.[1–6] Simultaneous physical goal was to search for the annual modulation of the Dark Matter signal.[12,25]

After operation of GENIUS-TF over three years with finally six naked Ge detectors (15 kg) in liquid nitrogen in Gran Sasso we realize serious problems for realization of a full-size GENIUS-like experiment: 1. Background from ^{222}Rn diffusing into the setup, on a level far beyond the expectation. 2. Limited long-term stability of naked detectors in liquid nitrogen as result of increasing leakage current. None of the six detectors is running after three years with the nominal leakage current. Three of the six detectors do not work any more at all.

The results of our three years of investigation of the long-term stability casts serious doubt on the possibility to perform a full GENIUS project - or its copies GERDA or CAMEO/GEM.

Keywords: High purity Ge detectors; HEIDELBERG-MOSCOW experiment.

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1. Introduction

Some years ago, the status of cold dark matter search, of investigation of neutrinoless double beta decay and of low-energy solar neutrinos all required new techniques of *drastic* reduction of background in the experiments. For this purpose we proposed the GENIUS (GErmanium in liquid NItrogen Underground Setup) project in 1997.[1–6] The idea of GENIUS (and GENIUS-TF) is to operate 'naked' Ge detectors in liquid nitrogen (as applied routinely already for more than 20 years by the CANBERRA Company for short term technical functions tests,[8] and later 'rediscovered'[24]), and thus, by removing all materials from the immediate vicinity of the Ge crystals, to reduce the background considerably with respect to conventionally operated detectors. The liquid nitrogen acts both as a cooling medium and as a shield against external radiactivity.

After the success of the HEIDELBERG-MOSCOW experiment in $0\nu\beta\beta$ decay,[17–21] GENIUS is no more needed for $\beta\beta$ decay experiments with ^{76}Ge, but may still be required for dark matter and solar neutrino experiments using Ge as target.[16] Therefore, we continued the research on the GENIUS Test Facility. *Monte Carlo simulations* for the GENIUS project, (and for GENIUS-TF) and investigation of the *new physics potential* of the project have been performed in great detail, and have been published elsewhere.[1,2,6,7,12,15] We were **the first** to show (in our HEIDELBERG low-level facility already **in 1997**) that such device can be used for *spectroscopy*[1,3,5] at least over short measuring times.

The small scale version of GENIUS, the GENIUS-Test-Facility has as main goal to test the long-term stability of the detectors under liquid nitrogen conditions, and also other operational parameters. A detailed description of the GENIUS-TF project is given in.[12,14]

The GENIUS-Test-Facility has been approved by the Gran Sasso Scientific Committee in March 2001.

Additionally to investigation of some key operational parameters of GENIUS, the GENIUS-TF was planned to extend our work on WIMP-nucleon cross sections with the HEIDELBERG-MOSCOW and HDMS experiments,[32–34] and aims at testing of the claimed evidence for WIMP dark matter from the DAMA experiment.[?,35] The relatively large mass of Ge in the full scale GENIUS-TF compared to existing experiments would permit to search directly for a WIMP signature in form of the predicted seasonal modulation of the event rate.[25]

GENIUS-TF which has been operated over three years in Gran Sasso (see Fig.1) is the only up to now existing test facility underground for a project operating naked Ge detectors in liquid nitrogen such as GENIUS[2] and its copies (Cameo, Gerda).

The first four naked detectors (in total 10 kg) were installed on May 5, 2003 (GENIUS-TF-I). This has been reported in CERN Courier[13] and in.[14] In[14] first energy calibration spectra are shown which demonstrate the (initial) good energy resolution obtained.

Fig. 1. Upper part: Left: Location of GENIUS-TF-I was the building on the right (car in front), opposite to the HEIDELBERG-MOSCOW experiment building (left side). Location of GENIUS-TF-II is the building of the HEIDELBERG-MOSCOW experiment (left). Right: from the right to the left - Irina Krivosheina, S. Karpov, H. Strecker (December 2006). Lower part: Left: The first four contacted naked Ge detectors in the vacuum box during transportation from the previous GENIUS-TF-I localization. Right: Hans V. Klapdor-Kleingrothaus (second from the right) together with his colleagues - Sergey Karpov (right), Herbert Strecker (on front from the left) and Theo Apfel.

2. The GENIUS-TF-II and III Setups

In October 2004 we have installed a new setup GENIUS-TF-II (see Figs. 1,2,3), containing now **six naked** Ge detectors (in total 15 kg), and, as technical improvement **a second copper vessel**, for further shielding of the Radon. That ^{222}Ra diffusing into the setup has been a problem for

GENIUS-TF-I, has been described by analysis of the measured spectra in detail in.[11] The inner shielding by bricks of (5-10) cm super-clean poly-cristalline Germanium (∼300 kg) was used also in this setup forming the inner highly efficient shield of the Ge detectors (see Fig. 3).

Fig. 2. Left - View from the top on the GENIUS-TF-II setup during installation in October 2004. Right - The six contacted naked Ge detectors.

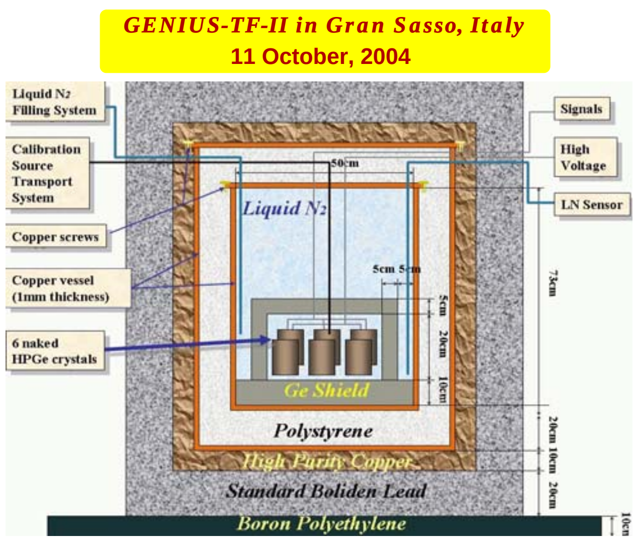

Fig. 3. Schematical view of the TF-II setup.

The thin wall (1 mm) inner copper box containing the liquid nitrogen is made of high-purity electrolytic copper and is thermally shielded by 20 cm of special low-level styropor, the outer copper box (also made of electrolytic copper) is followed by a shield of 10 cm of electrolytic copper (15 tons) and 20 cm of low-level (Boliden) lead (>35 tons).

The high-purity liquid nitrogen used, is produced by the BOREXINO nitrogen plant, which has been extended for increase of the production capacity to be able to provide enough nitrogen also for GENIUS-TF (see[11,14]).

GENIUS-TF-III started operation in beginning of March 2005 after the inner shield of polycrystalline Ge bricks had to be removed according to contract with Kurchatov institute.

3. Development of Operational Parameters

3.1. *Background from ^{222}Rn:*

The unexpected (according to our Monte Carlo simulations[12]) high background from ^{222}Rn in GENIUS-TF-I (see[11]) has been reduced in GENIUS-TF-II by about a factor 2. This ^{222}Rn background is still compatible with the goal of GENIUS-TF to search for dark matter,[25] but will be a *serious problem* for any full GENIUS-like experiments looking for neutrinoless double beta decay, because the ^{222}Rn leads to the 'famous' background lines from ^{214}Bi near the Q-value for double beta decay of ^{76}Ge.[18,23]

Table 1. The high voltages applied to the detectors after installation in GENIUS-TF I, II and III as function of time, and the nominal voltages.

Det-s	D1	D2	D3	D4	D5	D6
	GENIUS-TF-I, from 10.12.2003, till 25.09.2004					
10.12.03	2404	2603	2879	2301	n. inst.	n. inst.
06.04.04	2600	2220	2879	2301	-	-
04.05.04	2600	2220	3200	2500		
	GENIUS-TF-II, from 18.11.2004, till 28.02.2005					
08.10.04	250	1296	261	954	1253	502
18.11.04	364	2200	347	2298	3501	1015
20.01.05	"	"	"	"	"	1000
	GENIUS-TF-III, from 15.03.2005					
15.03.05	80	1802	20	2153	3501	980
03.05.05	0	1700	0	1500	3501	980
09.03.06	-	1700	-	-	3500	911
19.05.06	-	1600	-	-	2100	850
Nom.	**3000**	**2600**	**3200**	**2500**	**3500**	**2000**

3.2. *Long-Term Stability:*

The most dramatic result is obtained for the long-term stability of the detector operation in liquid nitrogen. It is shown in Table 1. As a result of increasing leakage currents, finally from initially six detectors only three were still working in 2006 and *not one of them* with the nominal high voltage (see Table 1). The reasons for the deterioration of the surface purity with time which lead to the increasing leakage currents need further investigation.

There might, however, be also other reasons. For some detector experts a surface–purity problem may not come very surprising.[26–30] From their experience, partly in detector producing companies, they expect this for a naked detector, having no shield of its surface against an open surrounding (the liquid nitrogen) other than a coating by some passivant of some sort, as used[29] by most manufacturers including the company having produced the GENIUS-TF detectors (ORTEC). In fact it would not be surprising that the high voltage of several thousand volts lying at the detector surface would attract ions from the surrounding liquid nitrogen. It is further well known that recently crushed germanium pieces have a highly active surface and are a very active getter They have been used as such in deionized water to further improve the purity of the water, and will be an active getter for impurities also in liquid nitrogen.[29,30] Perhaps this suspicion might be checked by mass spectroscopic investigation of detector surface material. The energy resolution on long terms also decreases systematically[31] (see[9,10]).

4. Perspectives

An important task is to improve further the presently used method of pulse shape analysis. In particular the efficiency of the method at low energies has to be carefully determined. The inner polycrystalline Ge shield which had to be removed according to contract with Kurchatov institute, at beginning of March 2005 should be replaced by a shield of monocrystalline Si, of which a sufficient amount is available.

For the purpose of testing the modulation signal measured by DAMA the amount of detectors has to be increased to about 40 kg to reach a comfortable time scale of measurement of a few years.

5. Conclusions

GENIUS-TF is the *only setup with naked Ge detectors worldwide running underground and over a longer time period*. It has lead to important insight into the conditions of technical operation of naked Ge detectors in liquid nitrogen. The relatively large background from ^{222}Ra diffusion is a problem unsolved up to now. The main problem realized, is, however, the increase of leakage current after long running of the detectors, caused by increasing surface impurity of the crystals. This led to serious restrictions of the high voltages applicable and finally to destruction of the detectors. *The information GENIUS-TF delivered after almost three years of operation on the possibility of long-term operation of such experiments, may cast some doubts on the possibility of such experiments on larger scale in general.*[9,22]

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