Available online at www.sciencedirect.com

ScienceDirect

Nuclear Instruments and Methods in Physics Research A 566 (2006) 472–476

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

Status of GENIUS-TF-II and TF-III—The long-term stability of naked detectors in liquid nitrogen

H.V. Klapdor-Kleingrothaus*,[1], I.V. Krivosheina[2]

Max-Planck-Institut für Kernphysik, P.O. Box 10 39 80, D-69029 Heidelberg, Germany

Received 12 June 2006; received in revised form 11 July 2006; accepted 19 July 2006
Available online 4 August 2006

Abstract

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 proposal in 1997 [H.V. Klapdor-Kleingrothaus, Int. J. Mod. Phys. A 13 (1998) 3953; H.V. Klapdor-Kleingrothaus, J. Hellmig, M. Hirsch, GENIUS-Proposal, 20 November 1997; J. Hellmig and H.V. Klapdor-Kleingrothaus, Z. Phys. A 359 (1997) 351 and nucl-ex/9801004; H.V. Klapdor-Kleingrothaus, M. Hirsch, Z. Phys. A 359 (1997) 361; H.V. Klapdor-Kleingrothaus, J. Hellmig, M. Hirsch, J. Phys. G 24 (1998) 483; H.V. Klapdor-Kleingrothaus, CERN Courier, November 1997, pp. 16–18]. Simultaneous physical goal is to search for the annual modulation of the Dark Matter signal [H.V. Klapdor-Kleingrothaus, et al., Nucl. Instr. and Meth. A 481 (2002) 149; C. Tomei, A. Dietz, I. Krivosheina, H.V. Klapdor-Kleingrothaus, Nucl. Instr. and Meth. 508 (2003) 343].

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 may cast doubt on the possibility to perform full GENIUS-like projects.

PACS: 95.55.Vj; 14.60.Pq; 23.40.−s; 29.40.−n

Keywords: High purity Ge detectors; Dark matter; Majorana neutrino; Double beta decay; GENIUS-like experiments; Naked Ge detectors

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 [7], and later 'rediscovered' [8]), 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 radioactivity.

*Corresponding author. Tel.: +49 6221 516 262; fax: +49 6221 516 540.
E-mail address: H.Klapdor@mpi-hd.mpg.de (H.V. Klapdor-Kleingrothaus).
URL: http://www.mpi-hd.mpg.de.non_acc/.
[1]Spokesman of HEIDELBERG-MOSCOW, GENIUS-TF and HDMS Collaborations.
[2]On leave from Radiophysical-Research Institute, Nishnii-Novgorod, Russia.

0168-9002/$ - see front matter
doi:10.1016/j.nima.2006.07.048

After the success of the HEIDELBERG-MOSCOW experiment in $0\nu\beta\beta$ decay [9–12] 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 [13]. 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 [1,2,6,14–16]. 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 Refs. [15,17].

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

Additionally to the 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 [18,19], and aims at testing of the claimed evidence for WIMP dark matter from the DAMA experiment [20,21]. 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 [22].

GENIUS-TF which is now operating over three years in Gran Sasso 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 [23]. In Ref. [17] first energy calibration spectra are shown which demonstrate the (initial) good energy resolution obtained.

2. The GENIUS-TF-II and III setups

In October 2004 we have installed a new setup GENIUS-TF-II (see Figs. 1–5), containing now *six naked* Ge detectors (in total 15 kg). Fig. 3 gives a schematic view of a detector with its *extremely* low amount of material used for the mechanical holder system. Fig. 4 shows the construction of the signal contact, which is a gold foil pressed to the bottom of the bore of the crystal by a spring made from a special steel wire.

As technical improvement in GENIUS-TF-II *a second copper vessel*, for further shielding of the Radon, has been additionally installed. That ^{222}Rn diffusing into the setup has been a problem for GENIUS-TF-I, has been described by analysis of the measured spectra in detail in Ref. [24].

Fig. 1. 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).

The inner shielding by bricks of (5–10) cm super-clean polycrystalline Germanium (~300 kg) was used also in this setup forming the inner highly efficient shield of the Ge detectors (see Fig. 5).

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 ton) and 20 cm of low-level (Boliden) lead (>35 ton).

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 Refs. [15,17,24]).

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 [15]) high background from ^{222}Rn in GENIUS-TF-I has been reduced in GENIUS-TF-II by about a factor of 5 [25]. It has been shown in Ref. [24], that the Rn background originates from diffusion of ^{222}Rn into the liquid nitrogen. The observed count rate corresponded to a ^{222}Rn activity of 1.2 mBq/m^3 [24] for GENIUS-TF-I (this concentration refers to the nitrogen in the gaseous phase). With the improvement of a factor of five in GENIUS-TF-II, the count rate in the energy interval 0–50 keV

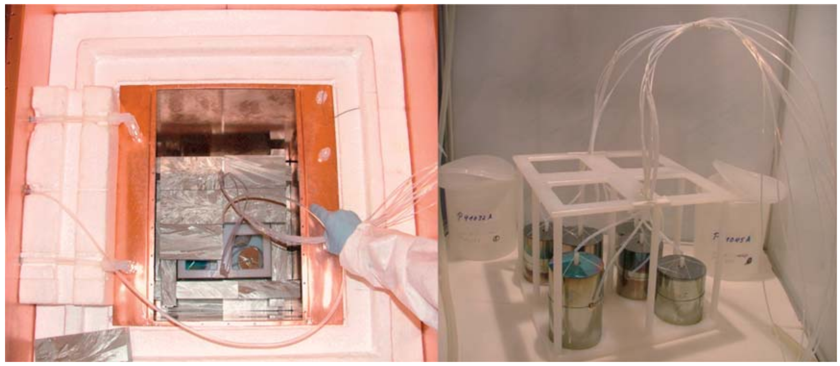

Fig. 2. Left—view from the top on the GENIUS-TF-II setup during installation in October 2004. Right—the six contacted naked Ge detectors.

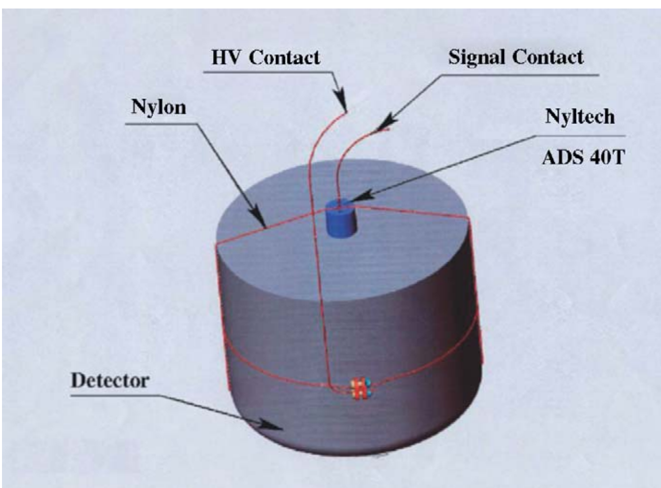

Fig. 3. Schematic view of a naked Ge detector for the GENIUS-TF experiment and its holder construction.

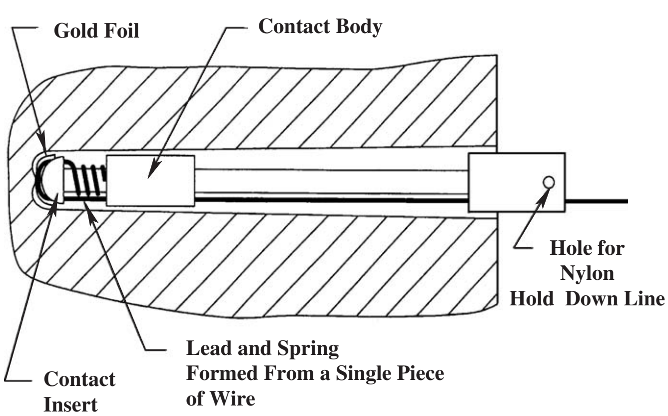

Fig. 4. The construction of the signal contact of a naked Ge detector for the GENIUS-TF experiment (courtesy Ortec company).

originating from ^{222}Rn is about 2 counts/kg yr keV. This value is about a factor of 400 higher than expected in the GENIUS-TF proposal [15] from Monte Carlo calculations and the measured ^{222}Rn contents in the liquid nitrogen after purification by the BOREXINO-GENIUS-TF Low Temperature Adsorber (LTA) [17,24]. A background of

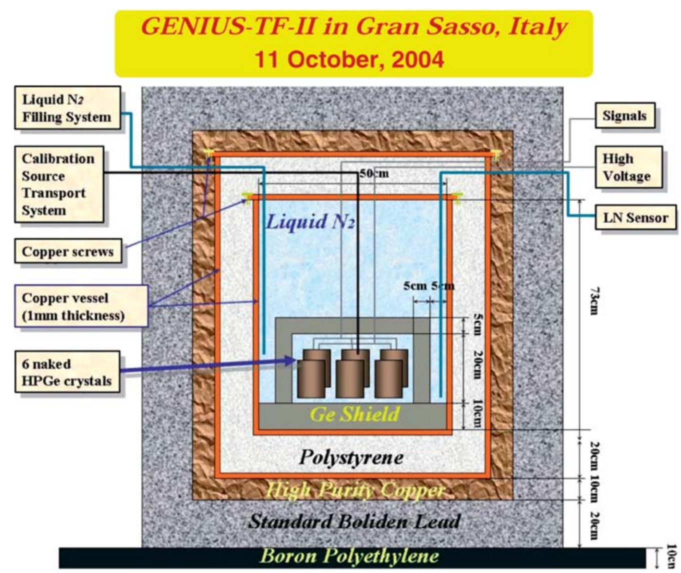

Fig. 5. Schematic view of the GENIUS-TF-II setup.

this order of magnitude would be still compatible with the goal of GENIUS-TF to search for dark matter [22], but will be a *serious problem for any full* GENIUS-like experiments, because the ^{222}Rn leads to the 'famous' background from ^{214}Bi lines near the Q-value for double beta decay of ^{76}Ge[9,26,27].

Some reduction of the ^{222}Rn background might be obtained by an improved transport system for the liquid nitrogen from the LTA to the GTF setup (see Ref. [24]). But the above result shows that it is probably unavoidable to install permanent cleaning procedures of the liquid nitrogen from ^{222}Rn in full GENIUS-like experiments. We suggested already in Ref. [14] to install a liquid nitrogen recycling device (through condensation) inside the tank.

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 at present only three are still working and *not one of them* with the nominal

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

Detectors	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	364	2200	347	2298	3501	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

Table 2
Resolution (in keV) for all detectors of GENIUS-TF for the lines 356 keV of ^{133}Ba, 344 keV from ^{152}Eu and 1173 keV from ^{60}Co, respectively

Detectors	D1	D2	D3	D4	D5	D6
GENIUS-TF-I, data taking from 10.12.2003, till 25.09.2004						
For line 356 keV ^{133}Ba						
07.03.04	2.98	1.87	1.86	1.86	not inst.	not inst.
For line 1173 keV ^{60}Co						
15.04.04	4.2	4.17	5.82	3.06	not inst.	not inst.
GENIUS-TF-II, data taking from 18.11.2004, till 28.02.2005						
For line 356 keV ^{133}Ba						
08.10.04	11	8.2	–	8	11	9
10.10.04	13	10.4	–	9.2	8.7	8.31
26.10.04	–	5.4	–	4.96	5.68	5.27
30.10.04	–	3.94	–	2.86	3.06	3.08
22.11.04	–	3.46	–	3.39	3.55	3.59
06.12.04	–	3.37	–	3.19	3.53	3.85
31.01.05	–	3.31	–	3.1	3.4	3.9
07.02.05	–	3.3	–	2.56	3.18	3.76
GENIUS-TF-III, data taking from 15.03.2005						
15.03.05	–	5.34	–	2.9	7.37	6.14
For line 344 keV ^{152}Eu						
15.03.05	–	5.08	–	2.83	7.24	4.26
15.12.05	–	5.85	–	–	7.65	5.75
27.05.06	–	6.08	–	–	9.98	4.3

high voltage (see Table 1). The reasons for a deterioration of the surface purity with time which could lead to the increasing leakage currents, need further investigation. There might, however, be also other reasons. However, for some detector experts a surface purity problem may not come very surprising [28–30,32,33]. 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 [32] 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 [32,33]. 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 also Table 2).

4. Conclusions

GENIUS-TF is the *only setup with naked Ge detectors world-wide 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}Rn 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, which, among others, could be 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.

Acknowledgements

The authors would like to thank their colleagues from MPI Heidelberg: Herrn, H. Strecker,T. Apfel, M. Reissfelder, M. Saueressig for their help during installation of GENIUS-TF-II. The authors would like to thank the technical staff of the Max–Planck Institut für Kernphysik and of the Gran Sasso Underground Laboratory. HVKK also gives his thanks to Dr. Tom Raudorf from the ORTEC Company (USA) for very useful discussions. We acknowledge the invaluable support from BMBF and DFG (project 436RUS 113/670/0-2), and LNGS of this project.

References

[1] H.V. Klapdor-Kleingrothaus, Int. J. Mod. Phys. A 13 (1998) 3953.
[2] H.V. Klapdor-Kleingrothaus, J. Hellmig, M. Hirsch, GENIUS-Proposal, 20 November 1997.
[3] J. Hellmig, H.V. Klapdor-Kleingrothaus, Z. Phys. A 359 (1997) 351 and nucl-ex/9801004.
[4] H.V. Klapdor-Kleingrothaus, M. Hirsch, Z. Phys. A 359 (1997) 361.
[5] H.V. Klapdor-Kleingrothaus, J. Hellmig, M. Hirsch, J. Phys. G 24 (1998) 483.
[6] H.V. Klapdor-Kleingrothaus, CERN Courier, November 1997, pp. 16–18.
[7] J. Verplancke, CANBERRA Company, private communication 5.03.2004.
[8] G. Heusser, Ann. Rev. Nucl. Part. Sci. 45 (1995) 543.
[9] H.V. Klapdor-Kleingrothaus, I.V. Krivosheina, A. Dietz, et al., Phys. Lett. B 586 (2004) 198.
[10] H.V. Klapdor-Kleingrothaus, I.V. Krivosheina, A. Dietz, et al., Nucl. Instr. and Meth. A 522 (2004) 371.
[11] H.V. Klapdor-Kleingrothaus et al., hep-ph/0201231, Mod. Phys. Lett. A 16 (2001) 2409.
[12] H.V. Klapdor-Kleingrothaus, I.V. Krivosheina, in: Proceedings of Second Scandinavian Neutrino Workshop, SNOW2006, May 2–6, 2006, Stockholm, Sweden, Physica Scripta (2006).
[13] H.V. Klapdor-Kleingrothaus, in: Proceedings of the Second International Workshop on Low Energy Solar Neutrino Detection, Tokyo, Japan, 4–5 December 2000, World Scientific, Singapore, 2001, p. 116.
[14] H.V. Klapdor-Kleingrothaus et al. MPI-Report MPI-H-V26-1999; Preprint: hep-ph/9910205, and in: H.V. Klapdor-Kleingrothaus, I.V. Krivosheina (Eds.), Proceedings of the Second International Conference on Particle Physics Beyond the Standard Model BEYOND'99, Castle Ringberg, Germany, 6–12 June 1999, IOP Bristol, 2000, pp. 915–1014.
[15] H.V. Klapdor-Kleingrothaus, et al., Nucl. Instr. and Meth. A 481 (2002) 149.
[16] H.V. Klapdor-Kleingrothaus, 60 Years of Double Beta Decay—From Nuclear Physics to Beyond the Standard Model, World Scientific, Singapore (2001) 1-1281p.
[17] H.V. Klapdor-Kleingrothaus, et al., Nucl. Instr. and Meth. A 511 (2003) 341;
H.V. Klapdor-Kleingrothaus et al., in: H.V. Klapdor-Kleingrothaus (Ed.), Proceedings of the Third International Conference on Particle Physics Beyond the Standard Model, BEYOND02, Castle Ringberg, Germany, 2002, IOP 2003, 499.
[18] HEIDELBERG-MOSCOW collab., Phys. Rev. D 59 (1998) 022001.
[19] H.V. Klapdor-Kleingrothaus, I.V. Krivosheina, C. Tomei, Phys. Lett. B 609 (2005) 226.
[20] R. Bernabei, et al., Phys. Lett. B 424 (1998) 195;
R. Bernabei, et al., Phys. Lett. B 450 (1999) 448;
R. Bernabei, et al., Phys. Lett. B 480 (2000) 23.
[21] R. Bernabei, et al., Riv. Nuovo Cimento. 26 (2003) 1;
R. Bernabei, et al., Phys. Lett. B 424 (1998) 195;
R. Bernabei, et al., Riv. Nuovo Cimento. 450 (1999) 448;
R. Bernabei, et al., Riv. Nuovo Cimento. 480 (2000) 23.
[22] C. Tomei, A. Dietz, I. Krivosheina, H.V. Klapdor-Kleingrothaus, Nucl. Instr. and Meth. A 508 (2003) 343.
[23] H.V. Klapdor-Kleingrothaus, CERN Courier 43 (6) (2003) 9.
[24] H.V. Klapdor-Kleingrothaus, et al., Nucl. Instr. and Meth. A 530 (2004) 410.
[25] H.V. Klapdor-Kleingrothaus et al., to be published.
[26] H.V. Klapdor-Kleingrothaus, et al., Phys. Lett. B 578 (2004) 54.
[27] K.Ya. Gromov, et al., J. Part. Nucl. Lett. 3 (2006) 30.
[28] G.F. Knoll, Radiation Detection and Measurement, second ed., Wiley, New York, 1989.
[29] E. Flyckt, Philips Photonics Components, Brave, France, private communication, May 2006.
[30] A.B. McDonald (SNO collaboration), Queen University, Canada, private communication, May 2006.
[31] H.V. Klapdor-Kleingrothaus, I.V. Krivosheina et al., Gran Sasso Annual Report 2005, pp. 125–133.
[32] T. Raudorf, ORTEC Company, private communications 07.08.2006.
[33] W.L. Hansen et al., IEEE Trans. on Nucl. Sci. NS-27, No. 1, (1980);
W.H. Brattain, P.J. Boddy, J. Electrochemical Soc. 109 (1062) 574;
D. Frankl, Electrical Properties of Semiconductor Surfaces, Pergamon Press (1967).