# THE GALLEX PROJECT

T.KIRSTEN
*Max-Planck-Institut für Kernphysik*
*P.O.Box 103980*
*6900 Heidelberg*

GALLEX COLLABORATION:
M.Breitenbach, W.Hampel, G.Heusser, J.Kiko, T.Kirsten, H.Lalla, A.Lenzing, E.Pernicka, R.Plaga, B.Povh, C.Schlosser, H.Völk, R.Wink, K.Zuber
*Max-Planck-Institut für Kernphysik,Heidelberg*

R.v.Ammon, K.Ebert, E.Henrich, L.Stieglitz
*Kernforschungszentrum Karlsruhe-KFK*

E.Bellotti
*Dip.di Fisica dell'Università,Milano and*
*Laboratori Nazionali del Gran Sasso-INFN*
O.Cremonesi, E.Fiorini, C.Liguori, S.Ragazzi, L.Zanotti
*Dip.di Fisica dell'Università, Milano*

R.Mössbauer,A.Urban
*Physik Dept. E15 , Technische Universität München*

G.Berthomieu, E.Schatzman
*Université de Nice-Observatoire*

S.d'Angelo, C.Bacci, P.Belli, R.Bernabei, L.Paoluzi, R.Santonico
*II-Universita di Roma -INFN*

M.Cribier, G.Dupont, B.Pichard, J.Rich, M.Spiro, T.Stolarczyk, C.Tao, D.Vignaud
*Centre d'Etudes Nucléaires de Saclay, Gif-sur Yvette*

I.Dostrovsky
*Weizmann Institute of Sciences,Rehovot*

G.Friedlander,R.L.Hahn,J.K.Rowley,R.W.Stoenner,J.Weneser
*Brookhaven National Laboratory, Upton,N.Y.*

ABSTRACT. The **GALLEX** collaboration aims at the detection of solar neutrinos in a radiochemical experiment employing 30 tons of Gallium in form of concentrated aqueous Gallium-chloride solution.The detector is primarily sensitive to the otherwise inaccessible pp-neutrinos. Details of the experiment have been repeatedly described before [1-7]. Here we report the present status of implementation in the *Laboratori Nazionali del Gran Sasso* (Italy). So far, 12.2 tons of Gallium are at hand.The present status of development allows to start the first full scale run at the time when 30 tons of Gallium become available.This date is expected to be january,1990.



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## 1.Introduction

The measurement of solar neutrinos allows to probe the state of the sun's interior in the most direct way.Contrary to helioseismological investigations,the solar neutrino spectrum can provide detailed information on the ongoing fusion reactions,and,together with solar model calculations,on temperature and chemical composition[8,5]. This potential is partially lost if the neutrino fluxes leaving the solar core are modified by neutrino flavor oscillations($\nu_e,\nu_\mu,\nu_\tau$) on their way to the detector,yet the payoff could then be the confirmation of non-zero neutrino masses[9,10,11].

Should non-vanishing neutrino masses apply at all,then there is a very large probability that they can be unraveled through solar neutrino measurements.This is due to the MSW-effect [9] which effectively enlarges even initially small mixing angles once neutrinos pass through matter with high electron densities as in the case of the sun.This opens the possibility to probe neutrino masses $\sqrt{\Delta m_i^2}$ down to $\approx 10^{-6}$ev/$c^2$, a mass range highly interesting in Grand Unification schemes.

Measurements of $^8$B-neutrinos with the radiochemical Homestake Chlorine detector[12] and with the Kamiokande Cerenkov detector[13] have firmly established a severe deficite relative to the standard solar model expectation.Whether this is due to neutrino oscillations or to deviations of the solar structure from the canonical model could be decided if the flux of the pp-neutrinos is measured,since the latter is directly tied to the solar luminosity and therefore hardly affected by not too unreasonable stellar structure modifications.

Apart from this principal decision,it could then also be possible to estimate from the pp-and $^8$B-neutrino fluxes actual values for neutrino mass differences and/or mixing angles.This comes about since the reduction factors of the measurable $\nu_e$-fluxes display distinct spectral response in the MSW-mechanism.

Experimentally,the low energy of pp-neutrinos ($E_{max}$=420keV) provides formidable problems.For many years to come,the only realistic possibility is a radiochemical Gallium-experiment,based on the inverse Beta-decay reaction

$$^{71}\text{Ga}\ (\nu_e, e^-)\ ^{71}\text{Ge}\ .$$

With an energy threshold of 233 keV,the neutrino capture rate on Ga is dominated by pp-neutrinos.The standard solar model prediction for Gallium has the highest reliability and the smallest error among all radiochemical neutrino detection schemes. The $^{71}$Ge production rate is (132 + 20, -17) SNU[x)] ($3\sigma$) [8],including 74 SNU from pp-and pep-neutrinos.

During 1979-1984, a pilot experiment employing 1.26 tons of Gallium has been carried out in collaboration between MPI Heidelberg and Brookhaven National Laboratory [14].The overall result was that the experiment is feasible if at least 30 tons of Gallium could be made available.This was not possible in the MPI/BNL-collaboration,but the GALLEX collaboration assembled in 1985 succeeded in assuring the required funds.Since that time work is beeing performed towards the implementation of the GALLEX-experiment at the INFN Gran Sasso underground laboratory L.N.G.S. (Laboratori Nazionali del Gran Sasso) and respective reports have been published[1-6].In this communication we do not intent to repeat previous reports but rather concentrate on a description of the actual implementation status,supported by numerous illustrations. As originally proposed,the starting date for data taking is planned for january,1990.

x) *SNU = solar neutrino unit,$10^{-36}$ captures per atom and second.*

## 2.Status of the Experiment

The principal features of the experiment are summarized in Figure 1.In the following we describe the status of the various aspects of the experiment.

**TARGET**

30 t Ga as $GaCl_3$ in 1 tank

**PRODUCTION RATE**

1.09 capt./d (SSM)

.84 capt./d (Cons.model)

**PRODUCTION BACKGROUND**

muons: < 2% of signal

fast neutrons:< 1% of signal

target impurities: < 1% of signal

**EXTRACTION**

air purge → $GeCl_4$ → $GeH_4$ → purification (GC) → counter

as tested in 1.3 t BNL/MPI Pilot experiment

**SEQUENCE**

exposure~14 d ,extraction 1 d

:repeat:: 50 runs in 2 yrs

**CALIBRATION**

>800 kCi $Cr^{51}$ source

**Figure 1.** Concept of the GALLEX experiment.

### 2.1. PROVISION OF GALLIUMCHLORIDE

We use an 8-normal aqueous Galliumchloride solution to facilitate Ge-extraction as volatile $GeCl_4$ by nitrogen purge of the target. 30 tons of Ga are contained in 100 t of solution.The solution is produced by Rhone Poulenc in Southern France and conditioned to a Cl/Ga-ratio of 3.25,the optimum for Ge-extractions according to our extraction test experiments.So far we have received,in three partial deliveries, 40.15 t of Galliumchloride solution.The Ga-content is 30.17 %,corresponding to 12.1 t of Ga. Legal contracts with our supplier call for the provision of the full 30 t of Ga till end of 1989.

All purity specifications are easily met by the product delivered so far (Table1).This was checked by neutron activation analysis (U,Th,Fe,As,Se,Ba) and by Radon-determinations using proportional counting.Additional Ge-extraction tests with spiked product solutions also gave satisfactory results. It is particularly remarkable that the critical $^{226}$Ra-concentration is more than one order of magnitude below specification,making background-$^{71}$Ge production through actinide impurities completely negligible.We consider this to be a result of our intense guidance of the producer and our continuous analytical production control.

Altogether 14 teflon lined 1200-l tanks are available for the transport of the solution from the producer to the LNGS (one "six-pack" in a 20" standard container per transport,containing ca. 4 t of gallium).The solution is received in a

**Table 1.** Key properties of the target solution.

| | measured | specification |
|---|---|---|
| Ga (g/l) | 567.5 | 565 ± 10 |
| Cl (g/l) | 938.5 | |
| Cl/Ga (mol/mol) | 3.25 | 3.25 |
| density (g/ml) | 1.8889 | |
| $^{226}$Ra (pCi/kg) | 0.03 | < 0.50 x) |
| U (ppb) | <0.05 | < 25 x) |
| Th (ppb) | <0.1 | < 2 x) |
| Zn (ppb) | ≈ 20 | |
| As (ppb) | < 1 | |
| Ba (ppb) | ≈ 20 | |

x) These specifications would lead to a 1%-contribution to the standard solar model production rate for each individual background source.

**Figure 2.** Technical Outside Facility (TOF) for $GaCl_3$-target conditioning.

**Figure 3.** Interior of the TOF. Bridge balance(front), $10m^3$-tank(rear), storage tanks (large, side) and transport tanks (small, side).

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Technical Outside Facility ("TOF") erected 1km from the tunnel entrance (Figure 2). Here it is transfered into storage tanks for later preparation in a 10 $m^3$-mixing and transport tank equipped for fast truck transport into the tunnel (Figure 3). This allows to minimize the cosmic ray exposure time after the end of preextractions of cosmogenic $^{68,69,71}Ge$ in the 10 $m^3$-tank within TOF. A bridge balance in the TOF serves to check the total quantities of solution during handling.

## 2.2. GALLEX UNDERGROUND LABORATORY FACILITIES

The Gallex facilities are located in the eastern wing of hall A in the Gran Sasso Underground Laboratory [15].Access is by 6.3 km highway from the tunnel entrance.The LNGS infrastructure includes a 40 t -hall crane, a number of auxiliary cranes as well as phone- and computer links to the outside institute.

The 3-story process building ("PB";Figure 4) accomodates the tank room (Figure 6) and the Ge-extraction facilities, such as absorber columns and control room. In smaller labs it houses the Ge-synthesis- and counter filling stations,the atomic absorption lab and the facilities for the Calciumnitrate neutron monitor.Plastic spill trays with the capacity to take up all the target solution plus diluting water in case of an emergency such as e.g. caused by an earthquake are installed below the side access road next to the tank room.

The 2-story counting building ("CB",Figure 5) contains the counting station in a Faraday cage (Ground Floor Lab,"GFL") and - connected via optical fiber- the First Floor Lab ("FFL"). The latter houses the electronics beyond digitalization, the computer facilities and a small auxiliary counting station.

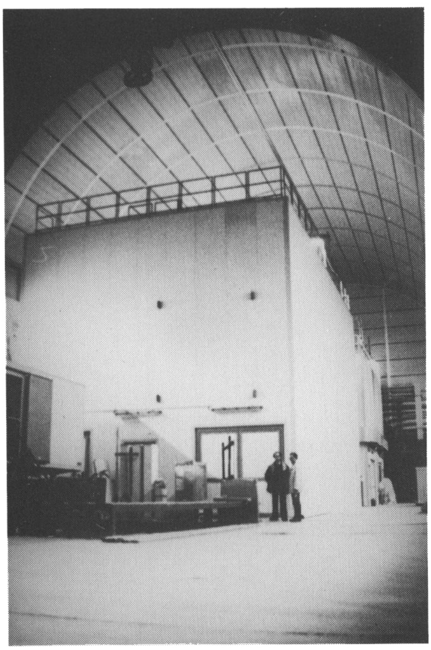

**Figure 4.** Gallex target building.The counting building (Fig.5) is visible in the back.

**Figure 5.** Gallex counting building.

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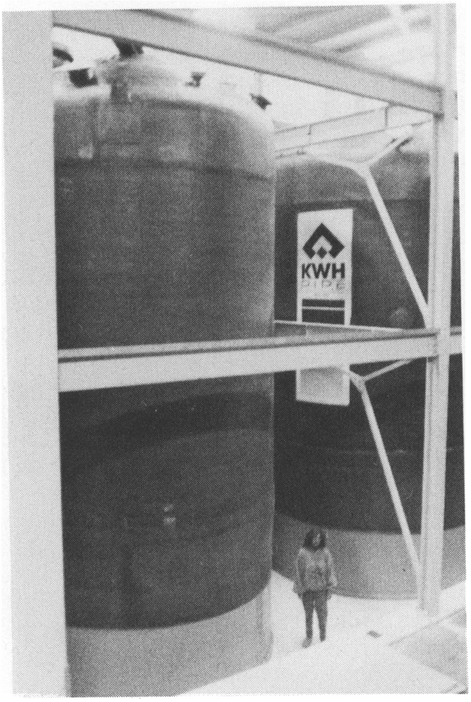


Figure 6. The two target tanks in their final position.Meanwhile the building is closed with panels.

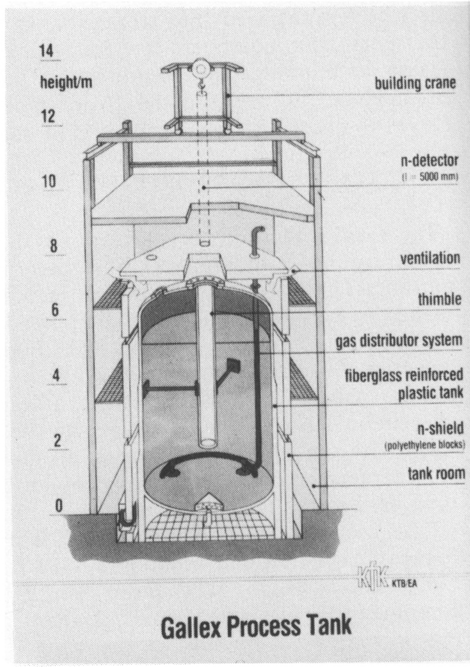


Figure 7. Schematic cross section of the target tank.The neutron shield is an option only,at present it is not considered to be necessary.

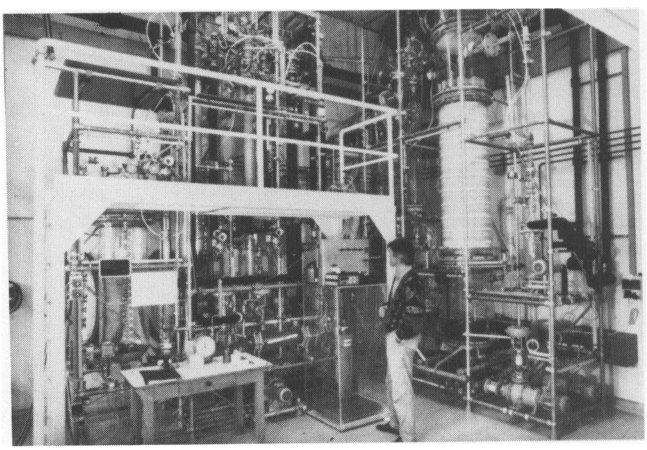

Figure 8. The Karlsruhe pilot facility for testing Ge-absorption and defining the design of the actual Ge-extraction system.

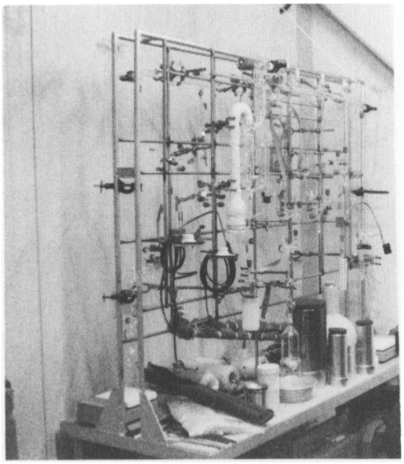

Figure 9. Line for conversion of $GeCl_4$ in $GeH_4$

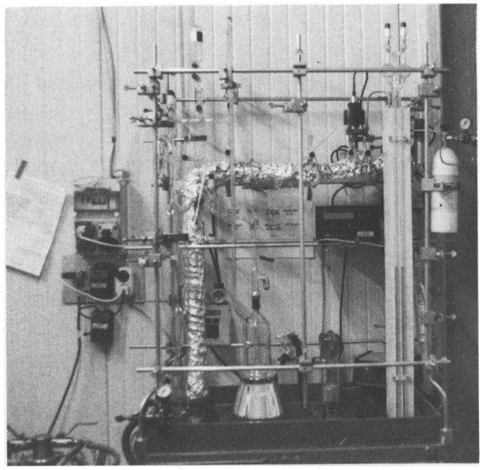

Figure 10. Counter filling station.

2.3 TARGET TANKS AND GERMANIUM EXTRACTION

The 54 $m^3$ of 8.2 molar Galliumchloride solution will be exposed in one single $70m^3$ -tank.This facilitates extraction and a later artificial neutrino exposure with a $^{51}Cr$ - Megacurie neutrino source inserted into a central thimble. The latter can also take up the $Ca(NO_3)_2$-vessel for internal neutron monitoring (see 2.4.).

We have installed two equal tanks (Figure 6) for redundancy,safety,and eventual later tank inspections; yet only one tank is used at a time. The tanks are made by Plastilon Ltd (Finland) from PALATAL (brand name) unsaturated polyester reinforced by special low - U/Th- (Corning "S2") glass fiber.They are lined with PVDF. The same material is also used for the sparging system within the tanks (Figure 7).

Operating conditions and equippment design have been defined and optimized with the help of a pilot facility, scaled 1:9 , which is operative at Karlsruhe since 2 years (Figure 8).

The extraction will be performed by use of 3000 $m^3$ of nitrogen during 16 - 20 hours in the "once-through"-mode. Instead of unconvenient and noise generating compressors,we use evaporated liquid nitrogen. The volatile Germaniumchloride taken over by the sparging nitrogen is absorbed in 3 large absorber columns,(3.1m length, 25 cm diameter) filled with pyrex helices.

The $GeH_4$ preparation line (Figure 9) and counter filling line (Figure 10) are newly build from scratch for the Gran Sasso Lab as duplication of respective lines which have been operating at MPI since many years .

In preparing $GeH_4$ from $GeCl_4$ we use tritium free reagents and gaschromatographic purification. Conversion yields are 97+ %,for yield determinations we use an atomic absorption spectrophotometer installed on site. Extraction yields are,in addition, monitored by isotope dilution technique using off-site thermion mass-spectrometry at Karlsruhe. This implies spiking with separated Germanium isotopes.

## 2.4. CALCIUM NITRATE EXPERIMENT AND SIDE REACTIONS

Unwanted $^{71}Ge$ production is largely dominated by $^{71}Ga(p,n)^{71}Ge$ whereby the protons are secondaries from either natural radioactivity in the target or from the residual cosmic ray muon flux at the underground site($\approx 15/m^2$,d). A redetermination of the relevant $^{71}Ge$-production rate in $GaCl_3$-solution at the CERN muon beam led to an estimate of the cosmic ray induced $^{71}Ge$ production rate in the target geometry of the experiment equivalent to 2.1 ± .7 SNU (1.6 % of the SSM production rate).

Contributions from the target impurities are completely negligible (see Table 1). The environemental fast neutron flux at the experiment site is low:
($\Phi_n$(>2.5 MeV)= .23 x $10^{-6}/cm^2$,s [16]).
In order also to account for the neutrons originating from the tank walls and for the actual moderation conditions, in-situ measurements of the $^{71}Ge$ production rate via fast neutrons will be performed with the help of an elongated 470 l vessel containing $Ca(NO_3)_2$ solution. It is inserted into the thimble of the target tank. From the $^{37}Ar$ produced via $^{40}Ca(n,\alpha)^{37}Ar$ in the $Ca(NO_3)_2$ solution,the $^{71}Ge$ production rate can be scaled . Figure 11 shows the $Ca(NO_3)_2$ vessel. The auxiliary equippment for purging the liquid, as well as for conditioning and counting the $^{37}Ar$ is fully operational, the $^{37}Ar$ recovery yield is 95 ± 2%. Experiments will be performed with as well as without target solution inside the tank.

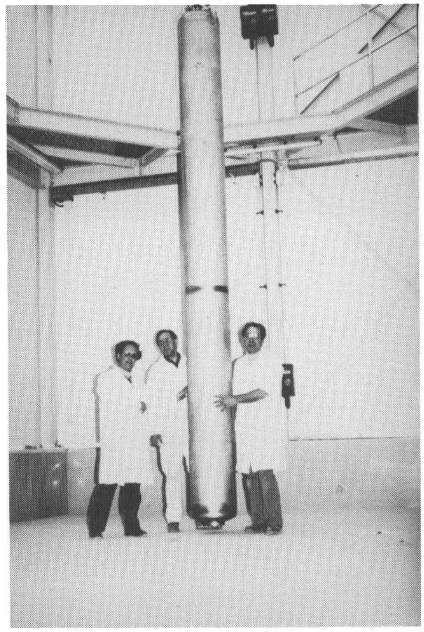

**Figure 11.** $Ca(NO_3)_2$-vessel to monitor n-induced $^{71}Ge$-production via $^{37}Ar$ from Ca.

## 2.5. LOW LEVEL COUNTING

After conversion of the extracted germanium into gaseous $GeH_4$ (German), low-level detection of $^{71}Ge$ is performed using miniaturized gas proportional counters located in a detector tank consisting of coincidence/anticoincidence devices (well-type NaI crystal pair and plastic scintillator) and passive shields (lead,copper,iron). $^{71}Ge$ (electron capture) decays result in ionizing events at ≈10.4 keV (K-peak) and ≈1.2 keV (L-peak) due to Auger electrons and/or stopped X-rays. Using a fast transient digitizer,the fully registered pulse shape serves to discriminate against backgrounds (especially Compton-electrons) .The fast wave form analyzer together with the superior properties of a newly developed preamplifier has led to a remarkable resolution power,up to the identification of individual features within a single primary ionization event (Figure 16).

*2.5.1. Counters.*

In five years of counter development we have continosly refined and optimized the counter performance with respect to efficency and background. Our final design (counter type "HD2-Fe", Figure 12) is made from hyperpure Suprasil, has a solid Fe-cathode,and a directly sealed 13 $\mu$m - tungsten anode wire. Its key features are minimal dead volume (volume efficiency >90% ), low capacity (< 1pF) , hence high signal/noise ratio, and low background rates (see below). 17 identical counters of this type alone are available. Using special quartz technology,their dimensions have been standardized,so any counter is alike the other.

*2.5.2. Counter Environment.*

Counters are supported in specially taylored Cu/low-activity-Pb housings, the preamplifier is also integrated (Figure 12). Their positioning within the NaI - well is shown in Figure 13.

The shield tank features:

- 8 counter positions within the pair spectrometer with the option to detect also $^{68}$Ge (positron emitter) in the coincidence mode.
- 24 positions within a low radioactivity copper block (opposite end).
- high purity Cu-shield next to the NaI.
- outer steel vessel filled with low radioactivity lead.
- two sliding end-doors also filled with lead.
- air lock design with glove boxes to enable counter change without venting the low radon atmosphere inside.

The device is installed inside the Faraday cage in the GFL of the Gallex counting building (Figure 14). The analog part of the electronics installed in the GFL (Figure 15) is electrically decoupled from the MicroVax and its periphery installed above in the FFL via an optical fibre link. The data are supplied by the Camac oriented electronics to condensed disk with shared on-line access and permanent tape storage . Software for on-and off-line -data analysis is ready for use.The full system is presently being used for background measurements.

*2.5.3. Counting Conditions.*

Systematic studies of the counting properties of potential gas mixtures have revealed the general suitability of $GeH_4$-Xe mixtures for Xe-proportions from 0 - 95 % at pressures up to 2 atmospheres. These studies also gave guidance for optimizing the trade off among individual parameters such as slow drift velocity (low Xe, good rejection efficency), good energy resolution (high Xe,low gas pressure ), K/L peak efficiency ratio ,amount of Ge- carrier which can be accomodated (order of 1mg), convenience of energy and rise time calibration, and overall background performance. Favored gas compositions are pure $GeH_4$ or 30 % $GeH_4$ / 70 % Xe - mixtures.

The neutrino exposure time of an individual run is planned to be ~20 days. Counting will be performed for periods of > 90 days, hence normally 5 or more multiplexed counters operate simultaneously.

*2.5.4. Counter Backgrounds.*

Counter background measurements on the various counter types under development had been performed before at the Heidelberg Low-Level Counting Laboratory,with full veto power to reject the frequent cosmic ray related events at shallow depth.Nevertheless, a reduction of the integral background rate (by a factor 2-3) was obtained after moving into the Gran Sasso tunnel. Measurements performed first in a

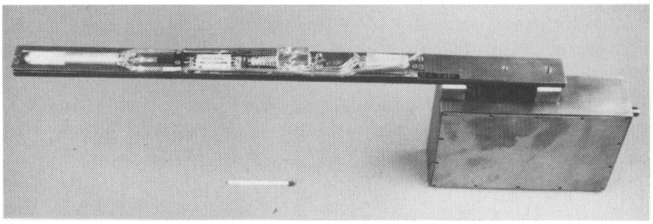

**Figure 12.** HD2(Fe)-proportional counter in its housing.Empty air space (Radon!) is minimized by a form fitted low activity-lead mould.A copper tube is slided over the counter (removed for this foto).The active volume is at the left end.

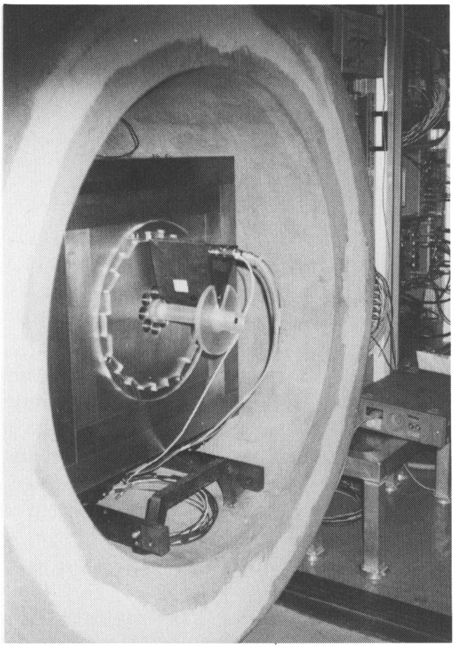

**Figure 13.** One counter box inserted for demonstration into one of eight counter positions within the well of the NaI-crystal.It is surrounded by ultra-pure copper.The outer shield is lead-filled steel.A fitting counterpiece (door),also lead in steel,is not seen in this opened position.At the opposite end of the tank,a low radioactivity copper block with 24 counter positions is mounted in an analagous manner.

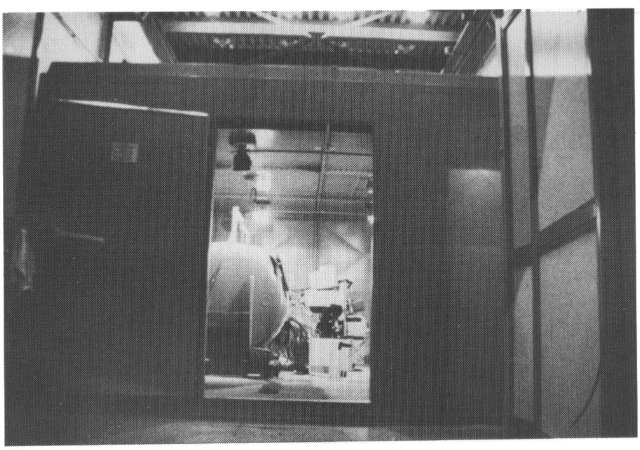

**Figure 14.** The Faraday cage with the door opened to allow the view of the tank shield inside.

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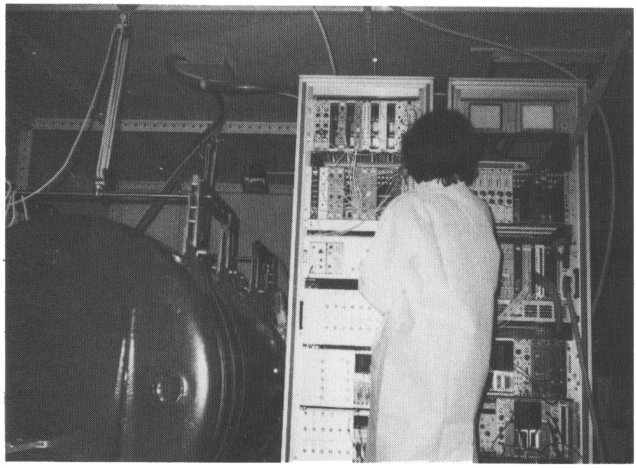

**Figure 15.** Electronics for pulse registration and pulse shape analysis, next to the tank shield.It also handles the signals from the peripheral detectors (NaI, Radon - detector). The computer, terminals and the rough periphery are decoupled from the Faraday cage via fiber optics leading to the electronics lab on top (FFL).

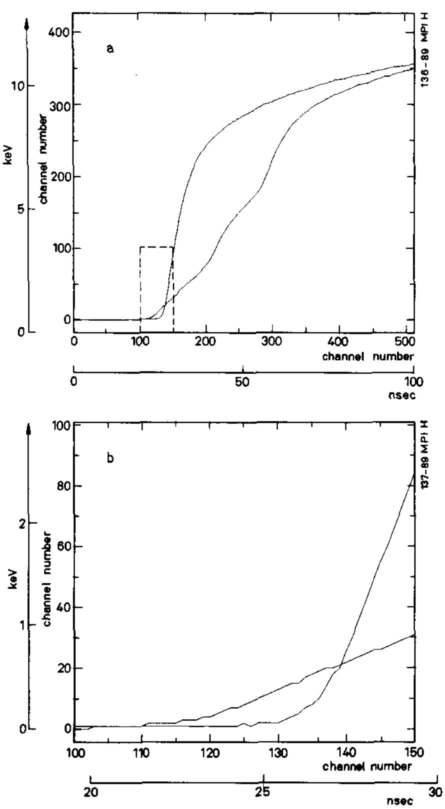


**Figure 16.** A (steep) genuine $^{71}$Ge decay pulse and a background pulse of the same energy. The lower part of the figure magnifies the box insert in the upper part.
It demonstrates the power to resolve microscopic processes occuring within the counter for a given primary event.

preliminary ("Bypass") station and later in the FFL gave good results. Employing pulse shape discrimination using a fast Tektronix transient digitizer (Figure 16) the results obtained for these counters are shown in Figure 17. The mean background rates are .15 cpd (L-peak) and .01 cpd (K-peak). These values allow to measure a 90 SNU - production rate of $^{71}$Ge in a 4-year experiment with a relative error of 8 %. A further reduction might be expected from the operation of the Radon control system which so far was not in operation.

Background measured with counter type HDII–Fe
at the Gran Sasso

**Figure 17.** Background rates measured in the Gran Sasso.

| Counter # | Location | Counting time [d] | Bkg count rate [counts/d] | | | | |
|---|---|---|---|---|---|---|---|
| | | | >0.5 keV | L peak | | K peak | |
| | | | | Total | Fast | Total | Fast |
| 37 | Bypass | 22.5 | 1.78 | 0.27 | 0.09 | 0.09 | <0.04 |
| 59 | FFL | 56.3 | 0.94 | 0.21 | 0.12 | 0.12 | 0.02 |
| 70 | FFL | 90.7 | 1.06 | 0.41 | 0.20 | 0.09 | 0.01 |
| All | | 179.5 | 1.05 | 0.31 | 0.15 | 0.09 | 0.01 |

## 2.6. ARTIFICIAL $^{51}$Cr-NEUTRINO SOURCE

All technical provisions for inserting an artificial calibration source [17]into the target tank have been installed (thimble, source crane, mechanical structure adaption of the roof above the tank). The source experiment is presently planned in 1992, after about 18 months of observing solar neutrinos.

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**References**

[1] Kirsten,T. (1986) The Gallex Project of Solar Neutrino Detection. Adv.Nucl.Astrophys. (Edition Frontieres), 85 -96.
[2] Kirsten,T. (1986) Progress Report on the "GALLEX" Solar Neutrino Project. 12th Int.Conf. Neutrino Physics and Astrophysics, World Scient. Publ. 317-329.
[3] Kirsten,T. (1987) Das GALLEX Sonnenneutrino-Experiment. Mitt. Astron.Ges. **68**, 59 - 70.
[4] Hampel,W. (1988) The present status of the Gallium solar neutrino detector GALLEX in: Neutrino Physics, Proc. Heidelberg Conf. Springer Publ. 230 - 238.
[5] Kirsten,T. (1988) Status of the solar neutrino problem. Proc.9th Workshop on Grand Unification, Aix-les-Bains, World Scientific. Publ. 221 - 241.
[6] Hampel,W. The Status of Gallex. Neutrino 88, Boston, World Scientific Publ. 311-316.
[7] Kirsten,T. (1989) Upcoming experiments and plans in low energy neutrino physics. Neutrino 88, Boston, World Scientific Publ.742-764.

[8] Bahcall,J. and Ulrich,R. (1988) Solar models, neutrino experiments and helioseismology. Rev.Mod.Phys. **60**, 297 - 372.

[9] Mikheyev,S. and Smirnov A. (1986) Resonance enhancement of oscillations in matter and solar neutrino spectroscopy. Sov.J.Nucl.Phys. **42**, 913-917.

[10] Bouchez,J.,Cribier,M.,Hampel,W.,Rich,J.,Spiro,M.,and Vignaud.D. (1986) Matter effects for solar neutrino oscillations. Z.Physik **C32**, 499 - 511.

[11] Hampel,W. (1986) The signal from the Gallium Solar Neutrino Detector:Implications for neutrino oscillations and solar models. Proc.Symp.Weak and Electromagnetic Interactions in Nuclei.Heidelberg,Springer Publ. 718 - 722.

[12] Davis,R. (1988) Solar Neutrinos. Neutrino 88, Boston, World Scientif.Publ. 518 - 525.

[13] Hirata,K. et al. Observation of $^{8}$B solar neutrinos in the Kamiokande II detector. Phys.Rev.Letters **63** , 16 - 19.

[14] Kirsten,T. (1984) The Gallium Solar Neutrino Experiment. Inst.Phys.Conf.Series 71, 251 - 261.

[15] Paoluzi,L. (1989) The Gran Sasso National Laboratory. **A279**, 133 - 136.

[16] Belli,P., Bernabei,R., d'Angelo,S., dePascale,M., Paoluzi,L., Santonico,R., Taborgna,N., Iucci,N., and Villoresi,G. (1989) Deep underground neutron flux mesurements with large $BF_3$ counters. Report Rom2F/88/029, submitted to Nuovo Cimento.

[17]Cribier,M.,Pichard,B., Rich,J., Spiro,M., Vignaud,D., Besson,A., Bevilacqua,A., Caperan,F., Dupont,G., Sire,P., Gory,J., Hampel,W. and Kirsten,T. (1988) Study of a high intensity 746 keV neutrino source for the calibration of solar neutrino detectors. Nucl.Instr.Methods **A 265**, 574 - 586.