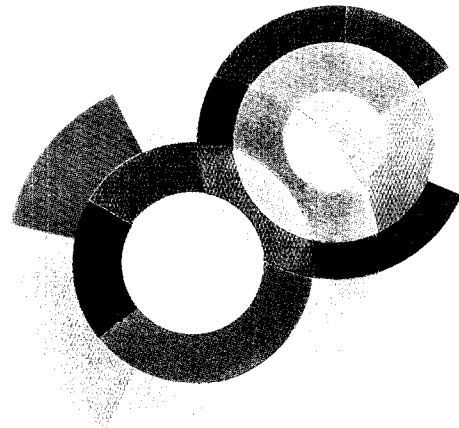
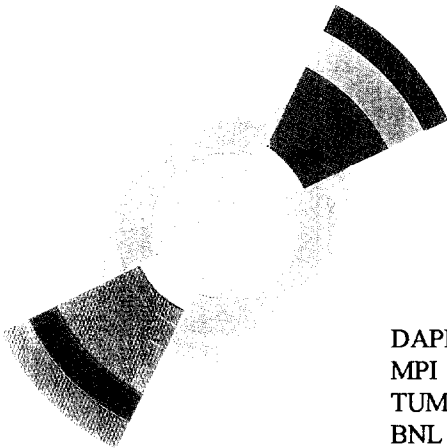


Swg835



DAPNIA/SPP 97-26  
MPI H-V41-1997  
TUM SFB-375/221  
BNL - 64864  
ROM2F /97/45

November 1997

## FINAL RESULTS OF THE $^{51}\text{Cr}$ NEUTRINO SOURCE EXPERIMENTS IN GALLEX

W. Hampel et al.,  
(GALLEX Collaboration)

Submitted to *Physics Letters B*

# DAPNIA

Le DAPNIA (Département d'Astrophysique, de physique des Particules, de physique Nucléaire et de l'Instrumentation Associée) regroupe les activités du Service d'Astrophysique (SAp), du Département de Physique des Particules Élémentaires (DPhPE) et du Département de Physique Nucléaire (DPhN).

Adresse :           DAPNIA, Bâtiment 141  
                          CEA Saclay  
                          F - 91191 Gif-sur-Yvette Cedex

# Final results of the $^{51}\text{Cr}$ neutrino source experiments in GALLEX

GALLEX collaboration <sup>1,2,3,4,5</sup>

W. Hampel, G. Heusser, J. Kiko, T. Kirsten, M. Laubenstein, E. Pernicka, W. Rau,  
U. Rönn, M. Wójcik<sup>6</sup>

*Max-Planck-Institut für Kernphysik (MPIK), Postfach 103980, D-69029 Heidelberg,  
Germany<sup>1</sup>*

R. v. Ammon, K. H. Ebert, T. Fritsch, D. Heidt, E. Henrich, L. Stieglitz, F. Weirich  
*Institut für Technische Chemie, Forschungszentrum Karlsruhe (FzK), Postfach 3640, D-  
76021 Karlsruhe, Germany*

M. Balata, F. X. Hartmann, M. Sann  
*INFN – Laboratori Nazionali del Gran Sasso (LNGS), S.S. 17/bis Km 18+910, I-67010  
L'Aquila, Italy<sup>2</sup>*

E. Bellotti, C. Cattadori, O. Cremonesi, N. Ferrari, E. Fiorini, L. Zanotti  
*Dipartimento di Fisica, Università di Milano e INFN – Sezione di Milano, Via Celoria  
16, I-20133 Milano, Italy<sup>2</sup>*

M. Altmann, F. v. Feilitzsch, R. Mößbauer  
*Physik Department E15, Technische Universität München (TUM), James-Franck Straße,  
D-85748 Garching b. München, Germany<sup>3</sup>*

G. Berthomieu, E. Schatzman<sup>7</sup>  
*Observatoire de la Côte d'Azur, Département Cassini, B.P. 229, 06004 Nice Cedex 4,  
France*

I. Carmi, I. Dostrovsky  
*Department of Environmental and Energy Research, The Weizmann Institute of Science  
(WI), P.O. Box 26, 76100 Rehovot, Israel*

C. Bacci<sup>8</sup>, P. Belli, R. Bernabei, S. d'Angelo, L. Paoluzi  
*Dipartimento di Fisica, II Università di Roma "Tor Vergata" e INFN – Sezione di Roma 2,  
Via della Ricerca Scientifica, I-00133 Roma, Italy<sup>2</sup>*

A. Bevilacqua<sup>9</sup>, M. Cribier, L. Gosset, J. Rich, M. Spiro, C. Tao<sup>10</sup>, D. Vignaud  
*DAPNIA, CEA Saclay, F-91191 Gif-sur-Yvette Cedex, France*<sup>4</sup>

J. Boger, R. L. Hahn, J. K. Rowley, R. W. Stoenner, J. Weneser  
*Chemistry Department, Brookhaven National Laboratory (BNL), Upton, NY 11973, USA*<sup>5</sup>

<sup>1</sup> This work has been supported by the German Federal Minister for Research and Technology (BMFT). This work has been generously supported by the ALFRIED KRUPP von BOHLEN und HALBACH-Foundation, Germany.

<sup>2</sup> This work has been supported by Istituto Nazionale di Fisica Nucleare (INFN), Italy.

<sup>3</sup> This work has been supported by the German Bundesministerium für Bildung und Forschung (BMBF).

<sup>4</sup> This work has been supported by the Commissariat à l'énergie atomique (CEA), France.

<sup>5</sup> This work has been supported by the Office of High Energy and Nuclear Physics of the U.S. Department of Energy, United States.

<sup>6</sup> Permanent address : Instytut Fizyki, Uniwersytet Jagiellonski, ul. Reymonta 4, PL-30059 Kraków, Poland.

<sup>7</sup> Permanent address : DASGAL, Bâtiment Copernic, Observatoire de Paris, 5 place Jules Janssen, F-92195 Meudon Principal, France.

<sup>8</sup> Permanent address : Dipartimento di Fisica, III Università di Roma, via C. Segre 2, I-00100, Roma, Italy.

<sup>9</sup> Permanent address : SRS/SAPR, CEN Grenoble, F-38041 Grenoble Cedex, France.

<sup>10</sup> Permanent address : LPCC du Collège de France, 11, Place Marcelin Berthelot, F-75231 Paris Cedex 05, France.

## Abstract

The radiochemical GALLEX experiment, which has been measuring the solar neutrino flux since May 1991, has performed an investigation with two intense  $^{51}\text{Cr}$  neutrino sources ( $> 60$  PBq) that were produced in the Siloé nuclear reactor and used at the Gran Sasso National Laboratory, one between June and October 1994, and the second between October 95 and February 96. The ratio,  $R$ , of the the neutrino source strength derived from the measured rate of  $^{71}\text{Ge}$  production, divided by the directly determined source strength is  $R = 1.01^{+0.12}_{-0.11}$  for the first source and  $R = 0.84^{+0.12}_{-0.11}$  for the second one. The combined value of  $R$  for the two source experiments is  $R = 0.93 \pm 0.08$ . It shows that the  $> 40\%$  deficit of solar neutrino flux observed by GALLEX cannot be attributed to experimental artifacts and demonstrates the absence of any significant unexpected systematic errors at the 10 % level.

## 1 Introduction

The results of the radiochemical GALLEX experiment [1] show a significant deficit of solar neutrinos :  $70 \pm 8$  SNU (one-sigma statistical and systematic errors added quadratically) compared to the predictions of standard solar models (SSM) [2, 3, 4] which range from  $115 \pm 6$  to  $137 \pm 7$  SNU (one-sigma error). The consequences of this deficit, together with the deficit observed in the other solar neutrino experiments [5, 6, 7], are crucial for particle physics and/or for astrophysics. Thus, it is very important to guarantee the trustworthiness of the experimental techniques. The most straightforward check is to expose the experiment to neutrino sources with known activity levels and appropriate energies, under conditions nearly identical to those used in solar exposures. After three years of data taking with the Sun, the GALLEX collaboration performed such a comprehensive test for the first time in the summer 1994, with a very intense ( $> 60$  PBq)  $^{51}\text{Cr}$  neutrino source [8, 9]. The result, quantified in terms of the ratio of the neutrino source strength derived from the measured rate of  $^{71}\text{Ge}$  production, divided by the directly determined source strength, was found to be  $0.97 \pm 0.11$  [9], showing a good agreement between measurement and expectation. From the beginning of this work, it was planned to reirradiate the same material and to perform a second source experiment in the GALLEX detector. This was done during the fall of 1995. Preliminary results of the second source experiment were presented in the summer of 1996 [1, 10]. Counting of all  $^{71}\text{Ge}$  samples from the second source was completed during the summer of 1996, and the determination of the directly measured source activity has been finalized. In this paper, we present the final results of the two source experiments.

Section 2 is devoted to the production of the  $^{51}\text{Cr}$  source itself, from 40 kg of chromium enriched in  $^{50}\text{Cr}$ , using the Siloé reactor in Grenoble. The determination of the directly measured source activity, based in large part on measurements of the 320-keV gamma-ray observed in 10 % of the  $^{51}\text{Cr}$  decays but including other methods

as well, is presented in section 3. Section 4 presents the results of the activity deduced from the  $^{71}\text{Ge}$  observed during the exposure of the GALLEX detector to the intense  $^{51}\text{Cr}$  neutrino source for 3-4 months. The significance and the implications of the result are discussed in section 5.

## 2 Production of the sources.

$^{51}\text{Cr}$  was chosen as the most convenient neutrino source. It is produced by neutron capture on  $^{50}\text{Cr}$  and decays by electron capture with a half-life of  $27.706 \pm 0.007$  days. 90 % of the decays involve the emission of a  $\approx 750$  keV neutrino, while in 10 % of the decays, a  $\approx 430$  keV neutrino and a 320 keV gamma are emitted. Two intense sources of  $^{51}\text{Cr}$  have been made, one in June 1994 and the other in September 1995.

The production of the first source has been largely described in reference [11]. In this section, we summarize this production process, accentuating the differences in the production of the second source.

36 kg of chromium enriched to 38.6 % in  $^{50}\text{Cr}$  were used in the form of small irregular chips ( $\approx 1 \text{ mm}^3$ ). They were irradiated for more than three weeks in the core of the Siloé reactor, in Grenoble. A dedicated core was specially assembled for our purpose (see figure 1).

After the irradiation, the irradiated chromium was placed in a sealed shield made of tungsten, with walls 8.5 cm thick. This integral assembly constituted the source, which was used at the GALLEX detector in the Gran Sasso Laboratory.

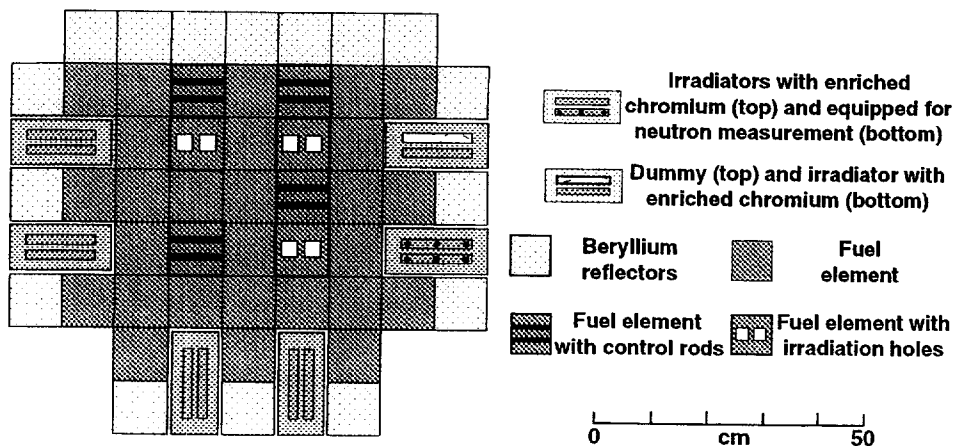


Figure 1: *Siloé core arrangement for the second chromium irradiation.*

After the completion of the first source experiment (see [11] for complete details), the chromium source, still in its tungsten shield, was returned to Grenoble. Shortly after, it was unloaded in a hot cell and stored in plexiglass containers; by this time,

the source had decayed to a low activity level, so that radiation damage of the plastic containers was not a problem. Prior to the second irradiation, the chromium was transferred back into the same zircalloy irradiators that had been used for the first irradiation.

Although the amount of chromium was the same, we chose to apportion the chromium chips among only 11 irradiators (instead of 12), just by filling each one more. Consequently, as seen in figure 1, the upper-right crenel has only one irradiator filled with chromium, the other being replaced by an aluminum mock-up (dummy) of the same size to minimize the perturbation on the neutron flux. This position was selected since it provided the least flux in the first irradiation. Taken together, the higher amount of chromium in each irradiator plus the one solid aluminum dummy increased the average neutron flux in the whole material.

Moreover, the beryllium reflectors were more efficient for the second source, due to a) a longer period of regeneration (irradiation with a low neutron flux to burn up the long-lived impurity,  $^{10}\text{B}$ , which has a large, 3800-b neutron-capture cross section) prior to the dedicated irradiation period, and b) the fact that, on average, the reactor fuel elements had less burn-up. Altogether the average flux was  $5.6 \times 10^{13} \text{ n/cm}^2 \cdot \text{sec}$  (7% more than for the first irradiation). Last but not least, based on the good operating experience we had had during the first irradiation, the safety authorities (French IPSN) gave us permission to irradiate for a slightly longer period. Irradiation started on September 5, 1995 at 11 am and stopped on October 2, at 0h00 (defined as end-of-bombardment, EOB) without any interruption. The evolution of the neutron flux during the second irradiation (see reference [10]) is similar to the first irradiation [11]. The irradiation lasted 26.5 days for the second source instead of 23.8 days for the first source. The characteristics of the production of the two sources are summarized in table 1.

After the irradiation ended, chromium unloading operations in a hot cell started after 6 h of cooling time. The chromium chips were then placed in a sealed stainless-steel container and inserted into the same tungsten shield that had been used for the first source. A drawing of the source configuration inside the shield can be found in reference [8].

### 3 Measurement of the source activity.

The total amount of irradiated chromium comprising the second neutrino source within the tungsten shield was  $35\,575 \pm 10 \text{ g}$ , after sampling (see subsection below) and after having subtracted the 25 g of vanadium produced from  $^{51}\text{Cr}$  decay after the first irradiation (the weight of the second source is slightly higher than for the first source due to better recovery of the chromium from the irradiators). Different independent methods have been used to measure the activity of the second source; details of these methods have been given in references [10, 11]. As is indicated below, the measurements of the 320-keV gamma ray of  $^{51}\text{Cr}$  consistently gave results with the smallest experimental uncertainties.

Table 1: Characteristics of the production of the two sources in the Siloé reactor.

	First source	Second source
Chromium weight (g)	$35\,530 \pm 10$	$35\,575 \pm 10$
Start of irradiation	May 27, 1994, 10 am	September 5, 1995, 11 am
End of irradiation (EOB)	June 20, 1994, 6 am	October 2, 1995, 0h00
Duration of the irradiation	23.8 d	26.5 d
Mean neutron flux (n/cm <sup>2</sup> .s)	$5.2 \times 10^{13}$	$5.6 \times 10^{13}$
Time between EOB and start of exposure of gallium	3.69 d	3.95 d

In the following, the quoted activities refer to the values at EOB.

### 3.1 Sampling and activity measurements based on the 320-keV line

The full amount of chromium chips was unloaded from the irradiators and mixed in the hot cell, as described in [11]. The sampling procedure was modified for the second source to collect more samples than for the first source. As in the first experiment, 30 samples were collected, each with an average weight of 0.56 g, and put into individual lead containers for activity measurements at Saclay by the ionization chamber technique. In addition, we performed 3 sampling operations to collect one large representative sample of 41.4 g.

In Saclay, the activity of the 320-keV gamma ray from each small sample was measured in the ionization chamber, which had been calibrated with a standard <sup>51</sup>Cr source. The dispersion of the distribution (see [9]) reflects true heterogeneities in the activities of the small samples. The precision of the method has been estimated as 2% (this value, slightly higher than our previous error estimate, has also been applied to the first source, resulting in a higher error than that quoted in [11]). The average specific activity of the samples is 1.895 TBq/g, and hence the total activity is  $(67.4 \pm 1.3)$  PBq.

At FzK, Karlsruhe, the large sample was split into 3 parts, each to be dissolved in 200 ml 3M H<sub>2</sub>SO<sub>4</sub>, and diluted to 1000 ml [12]. The sample thus obtained had a concentration of 19.19 mg Cr/ml. A dilution by a factor 10000 was followed by a chromium analysis (by ICP-AES, Inductively Coupled Plasma-Atomic Emission Spectroscopy) that showed with a precision of 2% that the dissolution was complete. The large dilution factor allowed us to measure the 320-keV line directly by high-resolution gamma-ray spectroscopy of aliquots of this solution. Such gamma-ray measurements were done by three groups in the collaboration, at Heidelberg, FzK and BNL.

At Heidelberg and FzK, solution aliquots were counted directly. At FzK, the



calibration of the gamma-ray spectrometer was done with a standard source in liquid form, containing a mixture of several radionuclides, obtained from Amersham. The resulting FzK value was  $(70.2 \pm 1.3)$  PBq [12]. At Heidelberg, the calibration was made with a standard  $^{51}\text{Cr}$  source in liquid form, obtained from PTB (German Office for Physical and Technical Standards and Measures). The result obtained was  $(68.3 \pm 1.3)$  PBq.

At BNL, counting samples were prepared by evaporating 25-microliter aliquots of the solution to dryness. The calibration was done with a solid, standard  $^{133}\text{Ba}$  source obtained from NIST (U.S. National Institute of Science and Technology). The measured result was  $(70.1 \pm 1.3)$  PBq.

The errors on all of these values are dominated by the systematic errors of the different calibration standards that were used, including the reproducibility of the detection geometry for sample and standard. Since the samples at each laboratory were aliquots of the same solution, sampling errors were small (and smaller than for the different solid samples that had been taken from the first source); the statistical errors due to counting were  $\leq 1\%$ .

### 3.2 Calorimetry

The calorimetric method has the advantage that, since it measures the activity of the total source, it does not depend on our ability to take representative samples. Immediately after insertion of the source into the tungsten shield, the total thermal power of the source was determined by placing the source-plus-shield configuration in a thermally shielded vacuum vessel and measuring the rate of the ensuing temperature increase. The source power is obtained by comparing the measured rate with that in similar measurements where known amounts of thermal power were supplied by a resistance heater.

In the period between the two source experiments, the thermal insulation of the cryostat had been improved. New calibrations of the calorimeter with a calibrated electric heat source were performed prior to the measurements with the new source. The calorimetric measurement started in Siloé 60 h after the end of bombardment (6 h later than for the first source). For 16 hours, immediately before the shipment to Gran Sasso, we recorded the increase of temperature of the tungsten shield due to the heat generated by the  $^{51}\text{Cr}$  in the calorimeter.

Combining these data with the calibrations done with electric heating, we deduce a total activity of  $(65.2 \pm 6.0)$  PBq. Despite the noted improvements in the calorimeter, the error is larger than for the first source, due to an unexplained nonlinear component in the temperature behaviour.

### 3.3 Vanadium content

As discussed in reference [13], there is a simple mathematical equation for the quantity of stable daughter,  $^{51}\text{V}$ , that has grown in from decay of the parent,  $^{51}\text{Cr}$ , during the irradiation; this equation depends only on the duration of the irradiation and

the  $^{51}\text{Cr}$  half-life. Thus, chemical analysis of the vanadium content after nearly complete decay of the source can be used to determine the strength of the  $^{51}\text{Cr}$  source at EOB. Such measurements were done at BNL, by NAA, neutron activation analysis, and at Karlsruhe, by two methods, ICP-AES and AAS, Atomic Absorption Spectroscopy.

At BNL, six replicate samples of the second source solution from FzK were irradiated in the Brookhaven Medical Research Reactor in December, 1996, 14 months after EOB. As in the NAA of the first source, each  $^{51}\text{Cr}$  sample was irradiated along with a known  $^{51}\text{V}$  standard. The  $^{51}\text{V}$  concentration in the  $^{51}\text{Cr}$  unknown was then obtained from the ratio of the  $^{52}\text{V}$   $\gamma$ -ray intensities in the chromium compared to that in the vanadium comparator. However, a spectrophotometric analysis of the vanadium standard solution showed that its concentration was  $10.5\mu\text{g}/\text{ml}$ , not the  $10.0\mu\text{g}/\text{ml}$  that was expected from the original preparation of a concentrated standard solution that had been diluted to prepare the NAA standard. So the previously reported  $^{51}\text{V}$  values for the first source [11] also had to be corrected for this 5% difference in concentration. The revised  $^{51}\text{V}$  concentration at EOB of the first source is  $(711.7 \pm 11.8 \text{ (stat.)})$  ppm. This quantity is quoted here because the measured  $^{51}\text{V}$  content of the second source is the total of the vanadium concentrations produced in the first and the second irradiations in Siloé. This total from the NAA is  $(1464.8 \pm 23.7 \text{ (stat.)})$  ppm, so that the net  $^{51}\text{V}$  for the second source is  $(753.1 \pm 26.5 \text{ (stat.)})$  ppm, a statistical error of 3.5%. The equivalent  $^{51}\text{Cr}$  source strengths at EOB derived from these vanadium values are  $(65.2 \pm 1.2)$  PBq for the first source, and  $(67.1 \pm 2.5)$  PBq for the second source, where the errors include the 1% systematic error in the concentration of the vanadium standard, combined in quadrature with the statistical errors.

In an analogous way, the vanadium content of the  $^{51}\text{Cr}$  samples was analyzed chemically at FzK, by ICP-AES and by AAS; details are given in reference [12]. For the first source, the mean vanadium concentration is  $(720.9 \pm 7.5 \text{ (stat.)})$  ppm. The total vanadium concentration in the second source, which is the sum produced in both irradiations, is  $(1521.5 \pm 25.9 \text{ (stat.)})$  ppm. The net concentration from the second source is  $(800.6 \pm 27.0 \text{ (stat.)})$  ppm, which is corrected to a value of  $(812.5 \pm 27.0 \text{ (stat.)})$  ppm to account for incomplete decay of the  $^{51}\text{Cr}$  to  $^{51}\text{V}$ .

The equivalent values of the  $^{51}\text{Cr}$  activity at EOB are  $(66.0 \pm 2.1)$  PBq for the first source, and  $(72.3 \pm 3.2)$  PBq for the second, where the errors include the 3% systematic errors in the ICP-AES and AAS analytical methods, combined in quadrature with the statistical errors.

### 3.4 Activity from neutron measurement during irradiation

The knowledge of the flux of neutrons and the relevant cross sections to produce  $^{51}\text{Cr}$  provides an independent method to evaluate the final activity of the source. The relative energy spectrum of the neutrons, as a function of the position in the median plane of the reactor, is found by solving numerically the transport equation in Siloé with the set-up described in figure 1. The on-line direct neutron measurement

by neutron flux monitors in one crenel gives the overall normalisation. The axial distribution is deduced from the profile measured in the first source experiment. From these inputs a total activity of  $(75.1 \pm 6.0)$  PBq is derived, a value  $(16 \pm 13)$  % higher than for the first source.

The gamma scanning method used for the first source experiment was not repeated for the second source.

### 3.5 Trace elements and ratio of activities

Impurities in the chromium are activated during the long irradiation period. Among them, there are several elements that are detectable at ppm levels via long-lived nuclides such as  $^{110m}\text{Ag}$  and  $^{124}\text{Sb}$ . Precise measurements have been performed outside the tungsten shield with Ge-crystals to detect energetic gamma rays that were emitted by the whole source, mainly for the purpose of obtaining external dose values. Results of these measurements [14] performed with the first source can be compared to the same measurements, performed at the same position with the second source, assuming that there were no changes in impurity concentrations between the first and second irradiations. The ratios of the impurity activities, corrected for the burn-up factor, can then be used to compare the activities of the two  $^{51}\text{Cr}$  sources. The second source is found to be  $(10 \pm 2)$  % more active than the first one. We note that this relative measurement is not used for the computation of the mean value of the source strength, but is in good agreement with it (see next subsection).

### 3.6 Mean value of the source activity

The mean values obtained by the different methods for both sources are summarized in table 2. Note that in the list of values for the first source (see [11] for comparison), some of the errors have been reevaluated, and an additional entry is given, based on measurements at FzK of the vanadium content.

Combining all these independent activity measurements by weighting them by their variances, we deduce the values of the source activity at EOB in Siloé of  $(63.4 \pm 0.5)$  PBq for the first source, and  $(69.1 \pm 0.6)$  PBq for the second source ( $1 \text{ PBq} = 10^{15} \nu/\text{s}$ ). To our knowledge, these are the strongest low-energy neutrino sources ever produced.

The weighted mean gives a standard error which looks small compared to the dispersion, mainly for the second source <sup>1</sup>. We consider this dispersion to be an estimate of unknown systematic errors. But, instead of taking 100 % of the full spread, we consider only the data points that are within one sigma, 68.3 %, of the weighted mean value. This procedure, which we think is reasonable, gives errors of

---

<sup>1</sup>The value of the  $\chi^2$  divided by  $n-1$  ( $n$  being the number of direct measurements) is 0.93 for the first source and 0.89 for the second source, close to 1, the value expected for a gaussian distribution. So, the use of the scale-factor prescription suggested by the Particle Data Group [15] ( $S = \sqrt{\chi^2/(n-1)}$ ) to improve the determination of the error is useless in the present case.

$^{+1.0}_{-1.5}$  PBq for the first source and  $^{+3.2}_{-2.0}$  PBq for the second source. Adding this error quadratically with the error obtained from the weighted mean, we obtain the values for the activities, which we call our best estimates:  $(63.4^{+1.1}_{-1.6})$  PBq for the first source and  $(69.1^{+3.3}_{-2.1})$  PBq for the second source.

Table 2: Direct measurements of the activity of the two sources with different methods.

Method (Laboratory)	Value (PBq)
First source	
Ionization chamber (Saclay)	$61.3 \pm 1.2$
Ge spectroscopy (Heidelberg)	$63.2 \pm 1.3$
Ge spectroscopy (Karlsruhe)	$63.1 \pm 1.3$
Ge spectroscopy (BNL)	$63.1 \pm 1.5$
Calorimetry (Grenoble/Saclay)	$61.9 \pm 3.0$
Neutronics (Grenoble)	$64.4 \pm 5.2$
Gamma scanning (Grenoble)	$64.0 \pm 5.2$
Vanadium content (BNL)	$65.2 \pm 1.2$
Vanadium content (Karlsruhe)	$66.0 \pm 2.1$
Weighted mean	$63.4 \pm 0.5$
Best estimate	$63.4^{+1.1}_{-1.6}$
Second source	
Ionization chamber (Saclay)	$67.4 \pm 1.3$
Ge spectroscopy (Heidelberg)	$68.3 \pm 1.3$
Ge spectroscopy (Karlsruhe)	$70.2 \pm 1.3$
Ge spectroscopy (BNL)	$70.1 \pm 1.3$
Calorimetry (Grenoble/Saclay)	$65.2 \pm 6.0$
Neutronics (Grenoble)	$75.1 \pm 6.0$
Vanadium content (BNL)	$67.1 \pm 2.5$
Vanadium content (Karlsruhe)	$72.3 \pm 3.2$
Weighted mean	$69.1 \pm 0.6$
Best estimate	$69.1^{+3.3}_{-2.1}$

Because of the operations at Grenoble and the transport to Gran Sasso, there was a delay of 3.95 days from EOB in Siloé until the second source was introduced into the reentrant tube in the GALLEX target tank, corresponding to a decrease of activity of 9.4 %.

## 4 The source experiments

The sources remained for 3-4 months in the reentrant tube in the center (of Tank A) of the GALLEX detector (see figure 4 in [8]).

The second source experiment started on October 5, 1995, at 22h47, when the  $^{51}\text{Cr}$  neutrino source was inserted in its final position, in the A-tank (at a position 32 cm lower than the position of the first source). As for the first source, a thermal shield, made of copper and cooled with tap water (60l/h) was placed between the source and the wall of the thimble in order to avoid any heat transfer to the gallium solution, which could change the kinetics of the desorption. It was equipped with thermocouples which recorded the decrease of heat emitted by the source during the experiment; see the illustration in reference [10].

The experimental conditions for the runs performed with the  $^{51}\text{Cr}$  source were kept as close as possible to those for the solar runs. The main difference between the two source experiments consists in the different lengths of time chosen for the exposures of the gallium target to the source. In the first one, the 11 exposure times were chosen to optimize the use of the source by producing about the same number of  $^{71}\text{Ge}$  atoms per exposure. So, we used rather short exposures, ranging from 3 days to 2 weeks, and only one 3-week exposure at the end of the experiment. For the second source, the exposure times were chosen to resemble more closely the durations of the solar exposures : after two short exposures (3.3 and 4 days), we switched to two 3-week exposures (as in GALLEX I), followed by three 4-week exposures (as in GALLEX II and III). In total, 7 exposures were performed in the second source experiment. During the last exposure (S144), the usual procedure was modified in that the target solution was slowly mixed every day by closed-loop gas circulation, the same procedure used for initial mixing after introduction of the Ge carrier.

The parameters of the 7 extractions that were performed in the second source experiment are given in table 3, together with those for the first source experiment (update of reference [8]). Since no blank runs were made between exposures, a correction has to be applied to take into account  $^{71}\text{Ge}$  production during extraction as well as carry-over of  $^{71}\text{Ge}$  atoms from one source exposure to the next [16].

Chemical analytical measurements of the concentrations of the different enriched Ge carriers (all approximately 1  $\mu\text{mol}/\text{gram}$ ) have been done on a regular periodic basis since the commissioning of GALLEX seven years ago. In the course of the recent experiments with the second  $^{51}\text{Cr}$  source, these data were reviewed in detail. Within statistics, the concentrations of the carrier solutions of the Ge isotopes enriched in masses 70, 73, and 76, had remained stable to better than 1 % over the years. However, the situation was different for the concentrations of the  $^{72}\text{Ge}$  and  $^{74}\text{Ge}$  carriers, which had increased gradually over time. To indicate the magnitude of these gradual changes, we note that the concentrations of the  $^{72}\text{Ge}$  and  $^{74}\text{Ge}$  carriers, in 1997 were respectively 4.1 % and 2.7 % greater than the values measured in November, 1991. The suspected cause of these increases in concentration was the slow loss of water by evaporation from the solutions over time.

The data for the source runs in which the  $^{72}\text{Ge}$  and  $^{74}\text{Ge}$  carriers were used have been corrected for these gradual changes; the runs affected are S107, S110, S111, S114 and S115 for the first source, S140, S141 and S144 for the second. Since the  $^{72}\text{Ge}$  and  $^{74}\text{Ge}$  concentrations have increased, these corrections caused a decrease in

Table 3: Characteristics of the exposures performed in the two source experiments. <sup>(a)</sup> 70, 72, 74, 76 indicate the use of carrier solutions enriched in <sup>70</sup>Ge, <sup>72</sup>Ge, <sup>74</sup>Ge, <sup>76</sup>Ge, respectively. <sup>(b)</sup> The yield values (integral tank-to-counter yield for Ge-carriers) are the corrected ones, after mass spectrometry measurements (see reference [8] for details). <sup>(c)</sup> Counters have either iron or silicon cathod; SC is for silicon counter with shaped cathod.

Run	Start of exposure	End of extraction	Days after EOB	Exp. length (days)	Carrier (a)	Yield (%) (b)	Counter type (c)	Counter efficiency			End of counting	Counting on-time (days)
								L	K	K		
First source (1994)												
S107	Jun. 23	Jun. 27	3.7	3.35	74	93.4	(SC)137	0.323	0.375	0.375	07.01.95	182.8
S108	Jun. 27	Jul. 1	7.0	4.0	70	96.9	(Si)106	0.299	0.320	0.320	07.01.95	181.0
S109	Jul. 1	Jul. 6	11.0	5.0	76	94.2	(SC)135	0.331	0.384	0.384	07.01.95	176.3
S110	Jul. 6	Jul. 13	16.0	7.0	72	95.6	(Fe)39	0.289	0.343	0.343	05.02.95	196.9
S111	Jul. 13	Jul. 20	23.0	7.0	74	94.4	(Si)114	0.292	0.313	0.313	05.02.95	192.1
S112	Jul. 20	Jul. 27	30.0	7.0	70	99.2	(Si)113	0.302	0.324	0.324	05.02.95	183.8
S113	Jul. 27	Aug. 9	37.0	13.0	76	95.2	(Fe)118	0.280	0.332	0.332	05.02.95	171.6
S114	Aug. 9	Aug. 24	50.0	15.0	72	96.1	(Fe)112	0.291	0.344	0.344	02.03.95	180.4
S115	Aug. 24	Sep. 7	65.0	14.0	74	93.5	(Fe)115	0.287	0.340	0.340	02.03.95	167.6
S116	Sep. 7	Sep. 28	79.0	21.0	70	98.5	(Si)108	0.302	0.323	0.323	25.03.95	168.5
S117	Sep. 28	Oct. 10	100.0	12.0	76	94.3	(Fe)103	0.291	0.344	0.344	02.05.95	192.5
Second source (1995)												
S138	Oct. 5	Oct. 9	3.95	3.3	70	98.5	(SC)130	0.330	0.383	0.383	13.04.96	177.9
S139	Oct. 9	Oct. 13	7.3	4.0	76	94.5	(Si)119	0.291	0.311	0.311	13.04.96	176.7
S140	Oct. 13	Nov. 1	11.3	19.0	72	95.4	(SC)135	0.331	0.384	0.384	04.05.96	177.1
S141	Nov. 1	Nov. 22	30.3	21.0	74	95.9	(Si)106	0.299	0.320	0.320	05.06.96	188.5
S142	Nov. 22	Dec. 20	51.3	28.0	70	99.3	(Si)113	0.302	0.324	0.324	27.06.96	165.2
S143	Dec. 20	Jan. 17	79.3	28.0	76	94.7	(Fe)39	0.289	0.343	0.343	30.07.96	169.8
S144	Jan. 17	Feb. 14	107.3	28.0	72	92.1	(SC)93	0.330	0.381	0.381	17.09.96	192.0

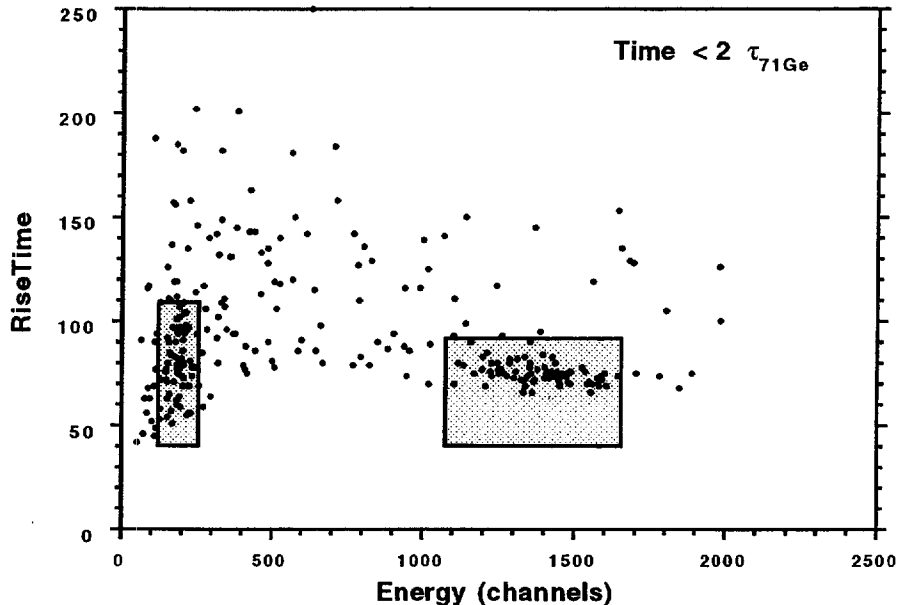


Figure 2: *Risetime vs energy for events in the first 33 days of counting for the second source experiment. The L- and K-windows for acceptable  $^{71}\text{Ge}$  pulses are the shaded boxes.*

the carrier yield and an increase in the production rate (SNU's) for each affected run.

An unusually large radon signal was observed for exposure S142, reducing the effective counting live-time for  $^{71}\text{Ge}$  to 72% (instead of 92 % for typical runs); this effect has been taken into account in the analysis. The standard analysis is performed with two components [8] : one that decays with the  $^{51}\text{Cr}$  lifetime and represents production of  $^{71}\text{Ge}$  by  $^{51}\text{Cr}$  neutrinos, and the second, a constant term that corresponds to the production of  $^{71}\text{Ge}$  by the Sun and by side reactions. The latter term has been taken equal to  $(0.67 \pm 0.11)$   $^{71}\text{Ge}$  atoms/day. The analysis program fits the value of the initial activity of the source at EOB at Siloé, taking into account the appropriate elapsed time (see [8] for details).

As seen in figure 2, a clear accumulation of events in the L and K regions for fast risetimes shows the dominant  $^{71}\text{Ge}$  signal above a very small background.

Table 4 shows the results for the two sources. We note that the capture cross section on gallium has been reevaluated recently by Bahcall [17]. For neutrinos coming from the decay of  $^{51}\text{Cr}$ , he now quotes  $58.1 (1_{-0.028}^{+0.036}) \times 10^{-46} \text{ cm}^2$  instead of  $(59.2 \pm 6.0) \times 10^{-46} \text{ cm}^2$  [18]. This new value (2 % smaller than the previous cross section) has been considered in the present data evaluation, for source 1 as well as source 2.

The individual results for the second source [10] are shown in figure 3b, together with the final individual results for the first source (figure 3a). We note the large

Table 4: Results of the exposures performed in the two source experiments. <sup>(a)</sup>The activity values are given at EOB. <sup>(b)</sup>The number of <sup>71</sup>Ge atoms produced per day by the source is stated at the beginning of each exposure period (statistical error only).

Run	Activity (PBq) (a)	<sup>71</sup> Ge produced per day (b)
First source (1994)		
S107	68.2 <sup>+19.6</sup> <sub>-17.2</sub>	11.5 <sup>+3.3</sup> <sub>-2.9</sub>
S108	78.8 <sup>+19.5</sup> <sub>-17.2</sub>	12.3 <sup>+3.0</sup> <sub>-2.7</sub>
S109	59.6 <sup>+17.1</sup> <sub>-15.2</sub>	8.4 <sup>+2.4</sup> <sub>-2.1</sub>
S110	63.9 <sup>+15.7</sup> <sub>-13.9</sub>	7.9 <sup>+2.0</sup> <sub>-1.7</sub>
S111	67.9 <sup>+19.8</sup> <sub>-17.3</sub>	7.1 <sup>+2.1</sup> <sub>-1.8</sub>
S112	47.5 <sup>+18.5</sup> <sub>-16.0</sub>	4.2 <sup>+1.6</sup> <sub>-1.4</sub>
S113	69.1 <sup>+19.5</sup> <sub>-17.0</sub>	5.1 <sup>+1.4</sup> <sub>-1.3</sub>
S114	49.2 <sup>+22.5</sup> <sub>-19.5</sub>	2.6 <sup>+1.2</sup> <sub>-1.0</sub>
S115	83.4 <sup>+31.9</sup> <sub>-27.3</sub>	3.0 <sup>+1.2</sup> <sub>-1.0</sub>
S116	15.3 <sup>+26.9</sup> <sub>-21.4</sub>	0.4 <sup>+0.7</sup> <sub>-0.6</sub>
S117	117.5 <sup>+62.0</sup> <sub>-50.9</sub>	1.8 <sup>+0.9</sup> <sub>-0.8</sub>
Second source (1995)		
S138	59.6 <sup>+17.8</sup> <sub>-15.5</sub>	10.1 <sup>+3.0</sup> <sub>-2.6</sub>
S139	65.0 <sup>+19.8</sup> <sub>-17.2</sub>	10.2 <sup>+3.1</sup> <sub>-2.7</sub>
S140	50.9 <sup>+9.7</sup> <sub>-8.8</sub>	7.1 <sup>+1.4</sup> <sub>-1.2</sub>
S141	69.0 <sup>+15.9</sup> <sub>-14.3</sub>	6.1 <sup>+1.4</sup> <sub>-1.3</sub>
S142	45.1 <sup>+24.0</sup> <sub>-20.4</sub>	2.4 <sup>+1.3</sup> <sub>-1.1</sub>
S143	59.4 <sup>+35.5</sup> <sub>-29.6</sub>	1.5 <sup>+0.9</sup> <sub>-0.8</sub>
S144	115.5 <sup>+69.2</sup> <sub>-58.2</sub>	1.5 <sup>+0.9</sup> <sub>-0.7</sub>



Table 5: Characteristics and results of the two source experiments. The combined value for the ratio of the activity deduced from the  $^{71}\text{Ge}$  measurement and of the activity directly measured, R, is given in the last column.

	First source	Second source	Two sources
Start of exposure	June 23, '94	Oct. 10, '95	
End of exposure	Oct. 5, '94	Feb. 14, '96	
No. of extractions	11	7	
End of counting	May 2, 95	Sept. 17, 96	
Activity directly measured (PBq)	$63.4^{+1.1}_{-1.6}$	$69.1^{+3.3}_{-2.1}$	
Activity deduced from $^{71}\text{Ge}$ (PBq)	$64.0^{+7.3}_{-6.9}$	$57.9^{+7.6}_{-7.2}$	
Ratio R	$1.01^{+0.12}_{-0.11}$	$0.84^{+0.12}_{-0.11}$	$0.93 \pm 0.08$

deviation of the third data point, run S140 (which is expected to contain about 30 % of the data), from the expected curve.

A global fit to all of the  $^{71}\text{Ge}$  data for the second source gives a value of the activity at EOB of  $(57.9^{+6.5}_{-6.2}(\text{stat.})^{+3.9}_{-3.7}(\text{syst.}))$  PBq, where the systematic error includes the uncertainty on the cross section [17], the error assigned to the energy and risetime cuts and the error coming the yield determination.

The ratio, R, between this activity deduced from  $^{71}\text{Ge}$  counting and the directly measured activity,  $(69.1^{+3.3}_{-2.1})$  PBq, is equal to  $0.84^{+0.12}_{-0.11}$ .

As quoted in [10], a reevaluation of the  $^{71}\text{Ge}$  activity for the first source experiment has been made, mainly due to updated determinations of the germanium recovery yields. The activity at EOB from  $^{71}\text{Ge}$  data for the first source is  $(64.0^{+6.1}_{-5.8}(\text{stat.})^{+3.9}_{-3.7}(\text{syst.}))$  PBq. The corresponding value of R is  $1.01^{+0.12}_{-0.11}$ , to be compared to the previously reported  $0.97 \pm 0.11$  [9]. We note that part of the increase in this R-value is due to the use in our analysis of the new cross-section value [17]; it induces a 2 % increase in the value of the  $^{51}\text{Cr}$  source activity as determined from  $^{71}\text{Ge}$  counting, and therefore a 2 % increase in R.

A combined analysis of the two source experiments has been performed, asking the program to fit directly a single number for the ratio R, using the value of the directly measured activity of each source as a normalization. This analysis gives  $R = 0.93 \pm 0.08$ <sup>2</sup>. A separate analysis of the events in the L- and in the K-region gives  $R = 0.84^{+0.10}_{-0.09}$  for the L- and  $R = 1.01 \pm 0.09$  for the K (statistical error only).

The main characteristics and the results of the two sources are summarized in table 5.

<sup>2</sup>The alternative pulse shape analysis method [19] also used in Ref. [1] gives  $R = 0.99 \pm 0.10$  for the first source,  $R = 0.85^{+0.11}_{-0.10}$  for the second source and  $R = 0.94 \pm 0.08$  for the two sources combined. These values are in good agreement with the values quoted above, obtained with the standard GALLEX analysis. We refer to Ref. [1] for a discussion on the two methods.

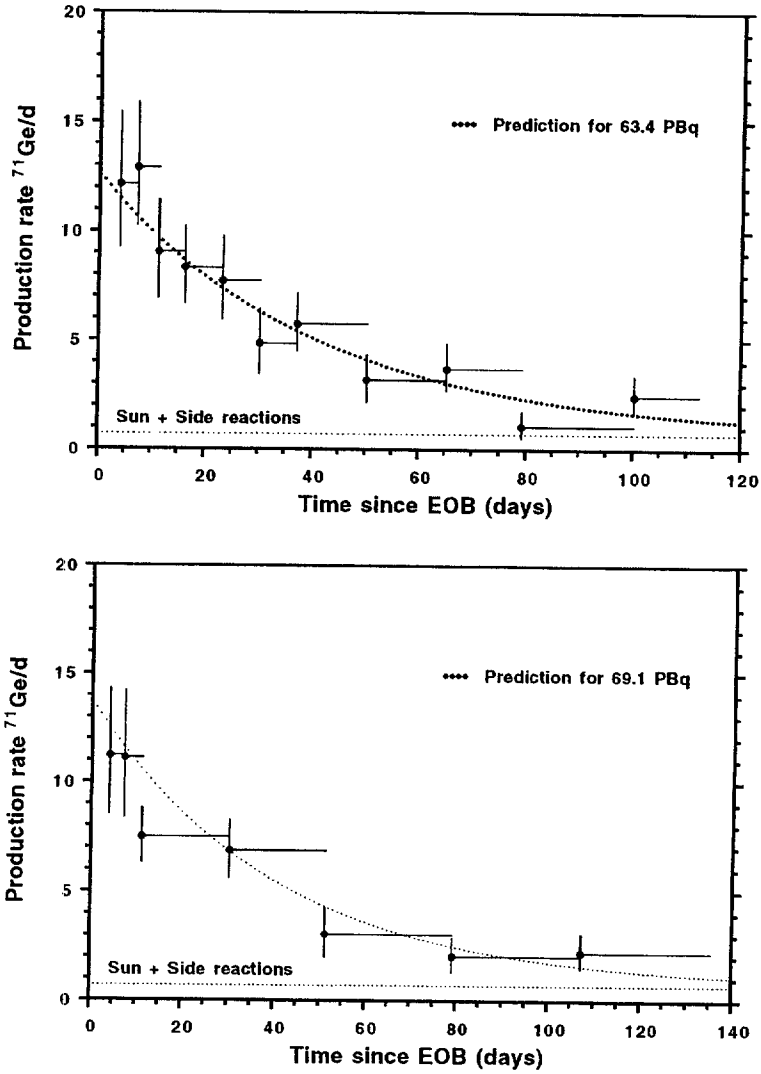


Figure 3: Number of  $^{71}\text{Ge}$  atoms produced per day a) during the first source experiment, b) during the second source experiment. The points for each run are plotted at the beginning of each exposure (the horizontal lines show the duration of the exposures). The predicted curve (dotted line) decreases with the known half-life of  $^{51}\text{Cr}$  and corresponds to the expected rate for a source activity of 63.4 PBq (first source) and 69.1 PBq (second source). Vertical bars are statistical errors. The horizontal line (small dots) corresponds to the constant 0.67 / day production rate due to solar neutrinos and side reactions.

## 5 Discussion of the results

The agreement between the predicted and the measured signal i.e., the ratio,  $R$ , is very satisfactory for the first source, but less so for the second source experiment, being  $1.6\sigma$  from the expected value of unity. The results of the two  $^{51}\text{Cr}$  source experiments are each within  $1\sigma$  of their combined mean value. We have considered a variety of possible systematic effects, but so far have found no indications of any experimental effects that might lower the results from the first source experiment to the second.

### 5.1 Tests of hot atom effects by in situ decay of $^{71}\text{As}$

In addition to the  $^{51}\text{Cr}$  source experiments reported here, in which some tens of  $^{71}\text{Ge}$  atoms were produced in the gallium detector in each run, another goal of the GALLEX collaboration has consistently been to produce much larger numbers of  $^{71}\text{Ge}$  atoms in the GALLEX target solution, on the order of  $10^5$  per run, by radioactive decay of  $^{71}\text{As}$  in situ. These  $^{71}\text{As}$  tests were finally begun in January, 1997, after the completion of the final series of GALLEX solar runs.

The point of these experiments is that the electron-capture decay of the  $^{71}\text{As}$  is a chemically disruptive process that mimics the conditions of the production of  $^{71}\text{Ge}$  by neutrino capture in the gallium solution. Such experiments test for radiochemical effects, such as hot-atom chemistry and the occurrence of trace impurities that can act as traps for  $^{71}\text{Ge}$ . Such tests with  $^{71}\text{As}$  had been previously done in benchtop experiments with hundred-ml volumes of GALLEX gallium solution, and in pilot-tank experiments with 1.3 tons of Ga in solution at BNL, but never before with the 30.3 tons of Ga in the 50,000-liter GALLEX target solution. Details of this work have been presented recently [20]. A brief summary is given here.

The  $^{71}\text{As}$  was produced at the Tandem accelerator at MPIK, purified, and transported to the Gran Sasso Laboratory. Three separate experiments were done; in each, a known number of  $^{71}\text{As}$  atoms in acidic aqueous solution was introduced into the GALLEX target solution.

The first two experiments compared different sets of experimental conditions: in the first, addition of carrier plus tracer, with rather strenuous mixing of the solution; in the second, carrier-free addition of tracer, with mild mixing. The last addition was designed to search for differences of  $^{71}\text{Ge}$  recovery, for short vs. long standing times in the solution. At the time of each addition of  $^{71}\text{As}$ , an equal aliquot of the  $^{71}\text{As}$  solution was set aside, to serve as a comparator.

Chemical extractions of the  $^{71}\text{Ge}$  were done in our usual manner. The recovery ratio was defined as the number of  $^{71}\text{Ge}$  atoms recovered from the tank relative to the number of  $^{71}\text{Ge}$  atoms that were in the comparator sample.

In all of the tests, the recovery was quantitative, with values ranging from 98 to 102%, all with  $\pm 3\%$  errors. We stress the importance of this result. These experiments demonstrated that there were no losses in the GALLEX target of  $^{71}\text{Ge}$  at carrier-free levels, nor were there losses that depended on standing time in the

gallium solution. Hot-atom chemistry had been definitively ruled out as a cause of  $^{71}\text{Ge}$  losses, verifying the results of our many earlier, small-scale tests.

## 5.2 Significance of the $^{51}\text{Cr}$ results

We can conclude that the  $^{51}\text{Cr}$  source experiments, supplemented by the new  $^{71}\text{As}$  data, have validated the methods used in the GALLEX radiochemical neutrino detector. The value  $R = 0.93 \pm 0.08$  shows that the  $> 40\%$  deficit of solar neutrino flux observed by GALLEX cannot be attributed to experimental artifacts and demonstrates the absence of any significant unexpected systematic errors at the  $10\%$  level. More details and discussion can be found in ref. [8].

The  $^{51}\text{Cr}$  experiments test our knowledge of two key aspects of the gallium neutrino detector ([8]): what we measure is essentially the product of the neutrino interaction cross-section and the chemical recovery yield of individual atoms of  $^{71}\text{Ge}$  from  $10^{29}$  target atoms in the GALLEX solution. Since the new  $^{71}\text{As}$  tests described above demonstrate that the chemistry is well understood, we now turn our attention to the question of the neutrino cross section.

The value of the neutrino cross section on  $^{71}\text{Ga}$  contains an excited state contribution. In discussing the results for exposure to the  $^{51}\text{Cr}$  source, we have used as a standard value of the cross section of  $^{51}\text{Cr}$  neutrinos the recently revised value of Bahcall [17],  $(58.1^{+2.1}_{-1.6}) \times 10^{-46} \text{ cm}^2$ ; this value includes estimated contributions of  $5\%$  attributable to excitation of those excited states of  $^{71}\text{Ge}$  that are energetically reachable. Unlike the very well determined ground state strength, these weak excited state cross-sections are estimated from (p,n) studies [21] that (a) have large experimental errors,  $50\%$ , and (b) are necessarily not as firmly connected to the weak interaction mechanism (see also the discussion by Hata and Haxton [22]). If we leave open the excited state contribution, the theoretical expectation for  $^{51}\text{Cr}$  is then  $R \geq 0.95$ .

In light of the quantitative results obtained with the  $^{71}\text{As}$  tests, we can draw a further conclusion, namely that our  $^{51}\text{Cr}$  experimental results limit the allowable range of values for the excited state contributions, to  $0.07 \pm 0.08$ , compared to the  $5\%$  estimate quoted above.

## 5.3 Update of the limit on $\nu_e \rightarrow \nu_x$ oscillation

Our result obtained with the  $^{51}\text{Cr}$  neutrinos can be used to put limits on  $\nu_e \rightarrow \nu_x$  oscillations. If the  $\nu_e$  emitted by the chromium source oscillate into  $\nu_x$  ( $\nu_\mu$ ,  $\nu_\tau$  or any sterile neutrino), they cannot transform  $^{71}\text{Ga}$  atoms into  $^{71}\text{Ge}$  atoms, and the observed  $^{71}\text{Ge}$  production rate will be reduced. The computation is performed using the exact geometry of the detector, with a mean path length in the gallium solution equal to  $1.9\text{ m}$ . Our result is displayed in figure 4. It updates the calculation made previously by Bahcall et al. [23] who used the preliminary value for the first source experiment ( $R = 1.04 \pm 0.12$ ).

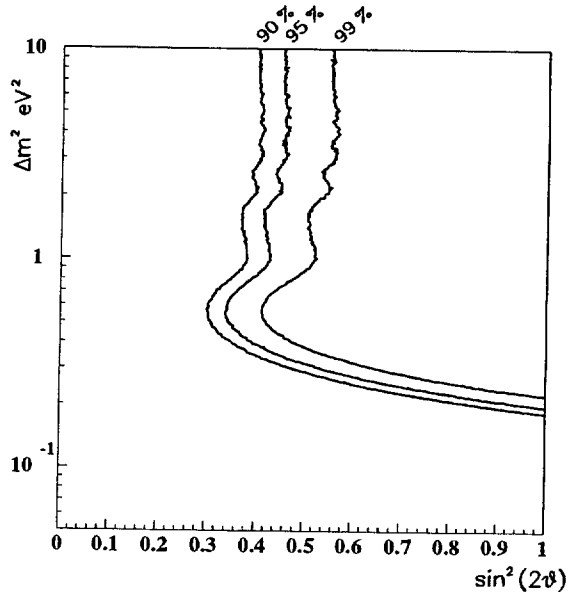


Figure 4:  $\Delta m^2$  vs.  $\sin^2 2\theta$  plot for  $\nu_e \rightarrow \nu_x$  oscillation. The region to the right of the curves is excluded at 90, 95 or 99 % confidence levels, respectively.

Interpreting our result in the framework of two-neutrino mixing, we find that it improves the existing limits for  $\nu_e \rightarrow \nu_\tau$  oscillations [24, 25] towards lower  $\Delta m^2$ , whereas in the case of  $\nu_e \rightarrow \nu_\mu$  oscillations our limit is comparable to those from accelerator experiments for large  $\sin^2 2\theta$  [26, 27].

If CP-invariance holds, our result is to be compared in addition to complementary searches in the antiparticle sector. Disappearance experiments  $\bar{\nu}_e \rightarrow \bar{\nu}_x$  performed at nuclear reactors give better limits, extending the area excluded in figure 4 down to  $\Delta m^2 = 7.5 \times 10^{-3}$  for maximal mixing and towards  $\sin^2 2\theta \approx 5 \times 10^{-2}$  for large  $\Delta m^2$  [28, 29].

## 6 Summary

In the fall of 1995, GALLEX performed a second experiment with a reactor-activated, intense neutrino source. It was done by re-irradiating in the Siloé reactor the same 35.6 kg of enriched chromium that had been used for the first source experiment <sup>3</sup>.

Optimized experimental conditions and a longer irradiation time brought the source to an activity of  $(69.1_{-2.1}^{+3.3})$  PBq as measured by various independent techniques, 10 % higher than that of the first source. Except for the two first short

<sup>3</sup> Scientific groups interested in subsequent use of this enriched chromium may contact M. Cribier at Saclay (cribier@hep.saclay.cea.fr).

exposures, the duration of the five following exposures was similar to the duration of solar exposures (3 to 4 weeks). The experiment started on October 5, 1995, when the source was introduced into the reentrant tube in the gallium target solution and ended on February 13, 1996, with the removal of the source.

The ratio of the activity deduced from  $^{71}\text{Ge}$  counting to the directly measured  $^{51}\text{Cr}$  activity is  $0.84^{+0.12}_{-0.11}$ . If we analyze the results of the two source experiments taken together, we obtain a value of the ratio  $0.93 \pm 0.08$ .

The separate tests involving the addition of  $^{71}\text{As}$  to the gallium target clearly showed that the recovery of the  $^{71}\text{Ge}$  resulting from the As decay was quantitative, i.e., we could rule out the possibility of any radiochemical trapping mechanisms in the GALLEX target. This conclusion, taken with the combined ratio from the  $^{51}\text{Cr}$  source experiments,  $0.93 \pm 0.08$ , allows us to estimate a value for the excited-state contribution to the neutrino capture cross-section on  $^{71}\text{Ga}$ . This value is  $0.07 \pm 0.08$ , to be compared with the  $\sim 0.05$  value obtained from (p,n) measurements.

### Acknowledgements

It is a pleasure to thank the technical staffs of Siloé (Grenoble), Saclay, the Brookhaven Medical Research Reactor and Gran Sasso for their very careful work. The generous help of L. Lembo during this experiment is appreciated. We thank M. Roos for discussions about how to express the errors. This work has been supported by the Commission of the European Communities, Grant G89200135 of the Large Scale Installations Plan given to LNGS.

### References

- [1] GALLEX Collaboration, W. Hampel et al., Phys. Lett. B388 (1996) 384.
- [2] J. N. Bahcall and M. H. Pinsonneault, Rev. Mod. Phys. 67 (1995) 781.
- [3] S. Turck-Chièze and I. Lopes, Ap. J. 408 (1993) 347; H. Dzitko et al., Ap. J. 447 (1995) 428
- [4] A. Dar and G. Shaviv, Ap. J. 468 (1996) 933.
- [5] B. T. Cleveland et al., submitted to Ap. J.; K. Lande, Proc. of the Neutrino'96 Conference, Helsinki, June 1996, ed. by K. Enqvist, K. Huitu, J. Maalampi, World Scientific, p. 25.
- [6] Y. Fukuda et al., Phys. Rev. Lett. 77 (1996) 1683.
- [7] J. N. Abdurashitov et al., Phys. Lett. B328 (1994) 234; V. N. Gavrin, SAGE Collaboration, Proc. of the Neutrino'96 Conference, Helsinki, June 1996, ed. by K. Enqvist, K. Huitu, J. Maalampi, World Scientific, p. 14.
- [8] GALLEX Collaboration, P. Anselmann et al., Phys. Lett. B342 (1995) 440

- [9] GALLEX Collaboration, P. Anselmann et al., "Update of the major results from the GALLEX Cr-source experiment", GALLEX internal note GX-79 <sup>4</sup>, July 1995.
- [10] GALLEX Collaboration, W. Hampel et al., "Preliminary results from the second <sup>51</sup>Cr neutrino source experiment in GALLEX", GALLEX internal note GX-90 <sup>4</sup>, July 1996.
- [11] M. Cribier et al., Nucl. Instr. and Methods A378 (1996) 233.
- [12] R. von Ammon, P. Dressler, H. Köhler, GALLEX internal note GX-95 <sup>4</sup>.
- [13] J. Boger, R. L. Hahn and Y. Y. Chu, "Determination of the <sup>51</sup>Cr source strength at BNL", GALLEX internal note GX-78 <sup>4</sup>, November 1995.
- [14] E. Bellotti et al., Nucl. Instr. and Methods B100 (1995) 199.
- [15] Particle Data Group, "Review of Particle Properties", Phys. Rev. D54 (1996) 1
- [16] M. Cribier, GALLEX internal note GX-89 <sup>4</sup>.
- [17] J. N. Bahcall, "Gallium Solar Neutrino Experiments: Absorption Cross Sections, Neutrino Spectra, and Predicted Event Rates", submitted to Phys. Rev. C, July 1997
- [18] J. N. Bahcall and R. K. Ulrich, Rev. Mod. Phys. 60 (1988) 297.
- [19] M. Altmann, F. v. Feilitzsch and U. Schanda, Nucl. Instr. and Methods A381 (1996) 398
- [20] T. Kirsten, talk given at the 4<sup>th</sup> Int. Conf. on Solar Neutrinos, Heidelberg, April 1997, to appear in the Proc.
- [21] D. Krofcheck et al., Phys. Rev. Lett. 55 (1985) 1051
- [22] N. Hata and W. Haxton, Phys. Lett. B353 (1995) 422.
- [23] J. N. Bahcall, P. I. Krastev and E. Lisi, Phys. Lett. B348 (1995) 121.
- [24] O. Erriquez et al., Phys. Lett. B102 (1981) 73.
- [25] N. Ushida et al., Phys. Rev. Lett. 57 (1986) 2897.
- [26] L. Borodovsky et al., Phys. Rev. Lett. 68 (1992) 274.
- [27] P. Vilain et al., Z. Phys. C64 (1994) 539.
- [28] G. Vidyakin et al., JETP Lett. 59 (1994) 390.
- [29] B. Achkar et al., Nucl. Phys. B434 (1995) 503.

---

<sup>4</sup>GALLEX internal notes are available on request by email at gallexcoord@vaxgs.lngs.infn.it.

