Perspectives on the Solar Neutrino experiments

Convener's report by
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1. The background problem

The perspective to achieve further steps in understanding the Solar Neutrino Problem is strictly connected to the ability of the experimentalists in developing new techniques, especially in the domain of the very low radioactivity levels. Very low levels of radioactivity are mandatory for real time experiments studying low energy solar neutrinos by means of the next generation detectors in this field. The real time detection of the events is needed in order to study the time variations of the neutrino signal, and in particular the day-night effect (the seasonal variations can be studied "in principle" also by radiochemical experiments, even if with lower resolution).
In addition the experimental situation as it appears from the data collected by the running experiments (Homestake, Kamiokande-Superkamiokande, Gallex-Sage-GNO) indicates that the puzzle is in the low energy neutrinos, and particularly in the ^{7}Be neutrinos. It is out of question that a low energy threshold in a solar neutrino experiment needs very low radioactivity levels for the detecting and construction materials. This condition can be achieved if we are able to select and purify the materials of the detector subsystems, but also if we can obtain reliable measurements of the radioactive contents as low as they have to be.
The sources of radioactivity particularly dangerous in the low energy region, stem from: i) widely prevalent primordial radioactivities, as ^{40}K, ^{238}U, ^{232}Th, and their decay products, as ^{226}Ra and the ^{210}Pb daughters; ii) ambient noble gas activities, and especially ^{222}Rn; iii) cosmogenic activities. The nuclides activated by cosmic rays vary with the composition of the detecting materials. In the case of organic compounds, ^{14}C, ^{7}Be, ^{2}H are among the most important sources of possible background. In addition cosmic muons crossing the detector may produce either unstable nuclides or neutrons, which decaying or interacting can simulate the signal events.

2. How to fight against the background

^{14}C, always present in the organic compounds, cannot be rejected via purification processes of the materials. As a consequence the only option is organic materials naturally "free" of ^{14}C, as it is the case of petrolchemical organics resident underground for millions of years. It is possible, in this case, that the ^{14}C contamination should be below 10^{-18} ^{14}C/^{12}C. The ^{14}C end point (156 KeV) obliges in any case to define a lower threshold over 200 KeV or so.
On the other hand, purification methods as: water extraction, distillation, Si and/or Al gel column, are effective in cleaning up liquid materials from primordial radioactivities. These methods have beeen succesfully tested in the detector Counting Test Facility (CTF) installed in the hall C of the Gran Sasso Laboratory. They seem able to reach purification limits up to 10^{-17} -10^{-16} (g of contaminants)/(g of materials) for ^{232}Th, ^{238} U, and daughters. A very important and crucial issue is also the ability to organize the transport and the handling of the detecting materials to avoid introduction of contaminants which could make fruitless to have very low levels of intrinsic radioactivity. The effort in this direction is heavy in terms of cost, time and manpower.

Another important problem is the ^{222}Rn, omnipresent in the environment at a concentration many orders of magnitude above what it can be tolerated in a low energy neutrino detector. A radiopurity level of $\sim 10^{-16}$ g/g needs that the ^{222}Rn does not exceed few μBq/m^3, to be compared to $\sim$ 20 Bq/m^3 of the free air and 40-100 Bq/m^3 or more of the underground laboratories. N_2 itself is very effective in stripping ^{222}Rn, provided that itself should be Rn free. In the Borexino preparation the use of cryogenic charcoal filters was succesful: the ultrapure N_2 line shows a Rn level < 1 μBq/m^3, which is a new record in this field.
Methods either for tagging the background events or for tagging the signal events with respect to the background can allow in certain cases, worse radiopurity levels. In the case of LENS, for example, which is an experiment still in RD phase, the signal detection can profit of the sequence ν_e+(A,Z)$\rightarrow$(A,Z+1)*+c$\rightarrow$(delay) γ+(A,Z+1) where (A,Z)could be either ^{176}Yb or ^{160}Gd; the delay, tens of ns; the γ energy in the 100 KeV range; the threshold energies, $\sim$244 KeV for Gd and $\sim$302 KeV for Yb.
In the case of other experiments, as f.i. Borexino, where the signal is the simple v-e elastic scattering, the identification of sequences of correlated decays, via delayed coincidences, can help in rejecting background events and in monitoring continuously the background level. The sequences Bi-Po (214,212), ^{224}Ra-^{220}Rn, ^{220}Rn-^{216}Po can be well exploited to this purpose.
The tagging of background events is needed to reject γ and neutrons, μ induced. In the CTF detector, as an example, a 2.2 KeV γ following a muon signal with a delay of about 240 μs was interpreted as the cosmogenic neutron capture on $^2_1$H and allowed the detection of the neutrons μ induced with very high efficiency.
The identification of the decay of unstable nuclides, muon produced, is more difficult because their lifetime can be long. Sometime it is difficult even to optain good previsions because the knowledge of the cross sections can be very poor. The variety of nuclides muon induced is very large and depends essentially on the composition of the material. In the region below 1 MeV and in presence of organic materials, ^{7}Be and ^{11}C play an important role. The first has a t(1/2)=53.3 days and emits a 0.478 MeV γ. The second emits an electron with an end point around 2 MeV, with t(1/2)=20.4 min.
In both cases, but especially in the case of ^{7}Be, a tagging based upon a delayed coincidence is practically impossible. As a consequence its suppression is the only tool against this background: the distillation is very effective in purifying the nuclides produced before the underground storage of the material, but during the running only a deep and adeguate rock shielding can really help.
Good taggings can be found also for other contaminants. Just an example: in CTF the presence of ^{85}Kr was identified through the decay ^{85}Kr-^{85m}Rb-^{85}Rb with the emission of a beta, with an end point at 175 KeV, followed by a gamma of 514 KeV. The half time is 1μs and the rate of this decay is only the 0.43% of the total ^{85}Kr decays. In this case the counting rate of the tagged events was 1.3$\pm$0.3 c/day corresponding to 300$\pm$70 decays of ^{85}Kr per day, which changed to 0.2$\pm$0.5 c/day after the N_2 stripping, corresponding to $\sim$50$\pm$35 decay/day.

3. How to measure the very low radioactivity levels

The R&*D* on the purification methods has to be accompanied by the development of systems having a sensitivity good enough to measure very low radioactivity levels. A variety of methods are already existing, but further systems have to be developed on purpose.
Ge detectors, underground installed, can reach 10^{-8}-10^{-9} g/g (sometime even more)for ^{238}U, ^{226}Ra, ^{232}Th, and 10^{-5}-10^{-6} g/g for ^{nat}K, provided that the experimental set up avoids Rn contamination.
The ICP MS (Inductively Coupled Plasma Mass Spectometer) can reach 10^{-14} g/g (Th, U equivalent), but its use is limited by the chemical decomposition (digestion)which is part of the measurement process. The digestion process is commonly known only for some materials, while for others it needs an R&D; it can limit not only the sensitivity of the spectrometer, but simply its use.

The ^{40}K measurements are even more delicate: the sensitivity range is very large depending on the material to be examined. We can go f.i. from $\sim 10^{-13}$-10^{-14} g/g for the water until few ppb for solid materials as f.i. nylon.
Other special systems are available (as the Atomic Absorption Spectroscopy), but it is evident that the common methods are not enough. In this frame the Borexino collaboration developed and constructed systems on purpose as: arrays to measure Rn ultratraces in gases and fluids, a Neutron Activation followed by an analysis making use of β-γ-e^{-} coincidences, a special detector called Counting Test Facility (CTF).
The Rn array procedures consist of absorption on a charcoal trap, a sample cleaning for chemical impurities, a counting process in a proportional gas counter. These systems reached record sensitivities:few mBq in liquids and few μBq in gases.
The NAA, as it is well known, is limited by matrix effects and by the activation parameters. An important improvement efficiency can be optained by looking for typical decay sequences of the nuclides under study, disentangling their activities from other interfering activated nuclei. For the study of ^{238}U the β-γ coincidence counting mode has been adopted, selecting the events by their γ-energy, β-energy, conversion electron energy, time difference between β decay and conversion electron emission. This method has been applied to determine the U, Th, Lu as well as the nuclides decaying by electron capture as ^{53}Cr, ^{64}Cu, ^{65}Zn, ^{75}Se, ^{85}Sr, ^{97}Rb, if the interfering activity is associated to the β-γ emission. In the case of ^{238}U a very well tagged decay of ^{239}Np can be identified, which decays through an isomeric state of ^{239}Pu. Record sensitivities were obtained with this NAA method: 10^{-17} g/g for ^{238}U, few 10^{-16} g/g for ^{232}Th, 10^{-16}-10^{-17} g/g for Au, La, Lu, Sc, and 10^{-13}-10^{-15}g/g for many other nuclides.
Finally the Counting Test Facility (CTF) is one of the more sensitive detectors in the world at ton scale. It was constructed just to determine the radioactivity of liquid scintillators, but it can be used also to measure the activity of solid materials. In preparation of Borexino, it was used to measure liquid scintillators based upon aromatic compounds and various materials as the Nylon strings of the Inner Vessel. Its sensitivity for the scintillators can reach 10^{-16} g/g for ^{232}Th and ^{238}U equivalent, better than 10^{-18} for the ratio ^{14}C/^{12}C. More in general it can vary in a substantial way depending if the nuclides under study decay via a well taggable sequence or not. An important improvement has been carried out recently by installing a Nylon barrier against the Rn emanated by the materials used to construct the detector. A gain in sensitivity of one order of magnitude, at least, is expected.

4. Perspectives in the near future

Two projects, in R&D phase, make use of ^{4}He, one of the noble gas (together with Neon and Xenon) which is not radioactive. With He as detecting material, some background problems are simplified, as the cosmogenic activation, but the absence of self-shielding can be a severe draw back. The main problems of this detector are the chemical purity of the detecting material and the γ flux coming from outside. Both the projects, Heron and Hellaz, are putting a major effort on a precise measurement of the paramenters of the interactions (localization in the space, recoil energy, recoil angle (Hellaz)).
Presently the R&D on Hellaz has been stopped, while the effort on Heron is going ahead and the researchers plan a revaluation of the project by 2002.
The project LENS, also in R&D phase, has abandoned now the ^{160}Gd option and is concentrating the effort to develop a liquid scintillator with 5-10% of ^{176}Yb loading. All the background problems discussed in the previous sections are present in this detector, a little attenuated by a good tagging of the signal, but more complicated by the use of a loaded scintillator. For the moment it is difficult to foresee when the R&D will be completed.
Finally Borexino, in construction phase, planes to start the data taking in 2002. Despite the successful tests done with the CTF, this experiment remains a challenging project.
All the experiments mentioned up to here are focussed on the pp and ^{7}Be Solar Neutrinos and are real time experiments. A radiochemical ex-

periment also for low energy neutrinos, GNO, is running now with the goal to extend in time the Gallex data, but with an upgrading of the subsystem concerning the decay measurements of the purged nuclei, which will improve the systematic errors.
Superkamiokande and SNO will continue their data taking in the ^{8}B Solar Neutrino region with a threshold in the range 5-6 MeV. Superkamiokande will improve the statistics, but we cannot expect major changes on their very important results in the next few years. On the other hand results from SNO are expected.
For more details on the various experiments see the contributions to this workshop of: N. Ferrari, H. de Kerret, E. Meroni, T. Noble, Y. Suzuki.