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^{37}Ar BASED NEUTRINO SOURCE FOR CALIBRATION OF THE IODINE SOLAR NEUTRINO DETECTOR

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The methodology of the creation of a compact neutrino source based on the ^{37}Ar isotope as well as the technique of calibration of an iodine detector of solar neutrinos is described. An important overall expected result is the creation of a prototype of the source with the intensity up to 400 kCi, delivery of this source to the Baksan neutrino observatory and the test calibration of the single module of the iodine detector. Simulation shows that at least 45–70 ^{127}Xe atoms will be detected in the irradiation of ~ 40 tons of methylene iodide by the source leading to $\sim 19\,\%$ of the error on the measured production rate. This result should be considered as a test of the developed technology and will verify overall technical readiness for the creation of a full scale neutrino source and the full scale calibration of the iodine detector.

Предлагаются методика изготовления компактного искусственного источника нейтрино на основе изотопа ^{37}Ar и техника калибровки йодного детектора солнечных нейтрино. Ожидаемые результаты планируемого эксперимента: изготовление прототипа источника активностью до 400 кКи, доставка его в Баксанскую нейтринную обсерваторию и проведение испытательной калибровки модуля йодного детектора. Расчеты показывают, что облучение примерно 40 тонн дииодида метилена прототипом источника приведет к образованию 45–70 атомов ^{127}Xe, что соответствует $\sim 19\,\%$ статистической неопределенности измерения скорости захвата электронных нейтрино на йоде. Этот результат следует рассматривать как испытание технологии и проверку готовности к проведению полномасштабной калибровки йодного детектора источником высокой интенсивности.

1. MOTIVATION

During the last few years, a new technology emerged — the artificial production of very intense neutrino sources. The first example, ^{51}Cr, was used in the very impressive calibration of the two gallium-germanium telescopes of solar neutrinos, SAGE and GALLEX. In addition to permitting the direct calibration of solar neutrino detectors, this new technology will also permit new experimental investigations of the fundamental properties of the neutrino, such as its magnetic moment, etc.

Our intention involves the production of a second such source, ^{37}Ar, which emits monoenergetic neutrinos with the energy of 814 keV. The source, when created, will eventually also permit a second independent calibration of the SAGE or GALLEX gallium detectors of solar neutrinos, as well as the BOREXINO solar neutrino detector. However, our immediate interest is the iodine detector.

The important result of four existing experiments detecting solar neutrino — the Homestake chlorine experiment, SUPERKAMIOKANDE, SAGE and GALLEX — is that there is an essential deficit of solar neutrino flux observed on the Earth. A combined fit to the results of these detectors produces two key differences between the predicted and observed spectra: first, the high energy part (> 5 MeV) of the spectrum is about a factor of two smaller than predicted and second, the 1 MeV region of the spectrum is an order of magnitude smaller than predicted, that is visible as an almost complete absence of neutrinos from ^{7}Be in the spectrum of solar neutrinos. These distortions of the solar neutrino spectrum have led to the suggestion that there may exist an energy dependent conversion of electron neutrinos to neutrinos of other flavors either due to matter-induced flavor transitions within the Sun or vacuum transitions during the neutrino flight between the Sun and the Earth.

Since the spectral distortion is the greatest in the 1 MeV region, it is most desirable to further explore the solar emission in this energy region. In order to fully explore the solar electron neutrino emission in a particular energy region it is necessary to detect it readily by the inverse of beta decay. The two types of electron neutrino specific detectors that have operated to date are ^{37}Cl, the Homestake chlorine detector and ^{71}Ga, the SAGE and GALLEX detectors. In 1988 Haxton [1] pointed out that the ^{127}I to ^{127}Xe transition may have much higher relative sensitivity to 1 MeV electron neutrinos than does ^{37}Cl. More detailed calculations of electron neutrino cross sections by Engel, Pittel, and Vogel [2] indicated that the ratio of the cross section at 1 MeV to that in the ^{8}B energy range for ^{127}I is four times the ratio for ^{37}Cl.

The technology of an iodine detector is quite similar to that of the chlorine detector; atoms of an inert gas, ^{127}Xe, are swept out of an iodine containing liquid, and detected by their decays in a small proportional counter. One reason that ^{127}I may have been overlooked in previous investigations of possible solar neutrino detectors is that unlike the ^{37}Cl and ^{71}Ga cases, transitions from the ground state of ^{127}I to the ground state of ^{127}Xe are forbidden by spin considerations. Thus, the lowest energy permitted neutrino induced transition from ^{127}I is to the first excited state in ^{127}Xe, 125 keV above the ^{127}Xe ground state and 789 keV above the ^{127}I ground state. This is the only transition that can be driven by the 862 keV neutrinos from ^{7}Be electron capture in the Sun. As in the ^{37}Cl case, the ^{8}B solar neutrinos can drive transitions to a large number of final excited states of ^{127}Xe, up to the particle emission threshold.

The large cross section of ^{8}B solar neutrinos on ^{37}Cl, is due to one transition, that to the isobaric analog of the ^{37}Cl ground state at 5.1 MeV above the ^{37}Ar ground state. This IAS transition accounts for 60 % of the ^{8}B rate in ^{37}Cl. For an ^{127}I detector, the IAS transition does not contribute to the production of ^{127}Xe since the IAS state is 13 MeV above the ^{127}Xe ground state or 5.8 MeV above the particle emission threshold. In order to experimentally verify the predicted energy dependence of the neutrino cross section for $^{127}\mathrm{I}(\nu_e, e^-)^{127}\mathrm{Xe}$ it is necessary to carry out a series of calibration experiments. The ^{7}Be sensitivity can be measured with an intense source of neutrinos from an electron capture decay process. For the ^{71}Ga detectors, SAGE and GALLEX, this was done with a ^{51}Cr source, which produces 750 keV neutrinos. Unfortunately, this source is not suitable for an ^{127}I detector since its neutrinos are 39 keV below the transition energy to the lowest accessible state in ^{127}Xe. Fortunately, a suitable source is available, ^{37}Ar, which emits 814 keV neutrinos. Development of the technology for the production of an ^{37}Ar neutrino source, its experimental check, development and test of technology of calibration of an iodine

detector of solar neutrinos are main purposes of our intention. The experience gained in the successful completion of the work will also permit the production of high-intensity ^{37}Ar sources for other future experiments.

2. METHODOLOGY

The desired isotope ^{37}Ar can be produced in two ways: 1) by activation of the isotope ^{36}Ar (natural abundance 0.34 %) in a thermal neutron flux after a preliminary enrichment of ^{36}Ar up to 90 %; or 2) in a flux of fast neutrons through $^{40}\mathrm{Ca}(n,\alpha)^{37}$Ar reaction. In 1988 Haxton [3] analyzed the first way in detail. Due to some problems such as a high «burning-up» of ^{37}Ar being produced by thermal neutrons and the necessity of confining a large amount of the target ($\sim$8 kg of argon) in a liquid form in the neutron trap of a high-flux reactor this way seems to be unrealizable. The second way was considered in 1992 by Gavrin [4] et al. There it was shown that ^{37}Ar should be obtained by neutron irradiation of the calcium-containing target in the power reactor BN-600, Zarechny, Russia. The most convenient targets are metallic Ca (1.54 $\mathrm{g\cdot cm^{-3}}$) and CaO (2.43 $\mathrm{g(Ca)\cdot cm^{-3}}$). There it was shown also that one needs to place approximately 200 kg of metallic Ca in 20 irradiating assemblies in the blanket of BN-600 to obtain 1 MCi of ^{37}Ar. As a response of natural calcium on neutron irradiation the isotopes of argon (mainly ^{37}Ar) and also other gaseous products such as helium and hydrogen are formed. After irradiation the gaseous phase must be extracted from the target by physical or chemical methods. It is planned to first investigate argon extraction by heating the target; if necessary, an alternative chemical method involving the dissolution of the target and the sweep of the ^{37}Ar out of the resulting solution. After extraction, the extracted argon must be reliably packed in a minimum volume in order to increase the efficiency of registration of neutrino flux from a source by an iodine detector. The activity of the prototype of a source should be reliably determined, for example, by calorimetric method.

The reactor BN-600 is a power reactor, that is, it's main goal is the production of electric power. Therefore it is necessary for us to clearly demonstrate that the irradiation of a calcium containing target in BN-600 is both safe and within required technological parameters. These considerations then determine the need to carry out a wide range of calculations: three-dimensional multigroup neutron-physical calculations of the reactor BN-600, thermohydraulic and strength predictions. The main predicted parameters will first be checked experimentally at the small research reactors BR-1 and BR-10, IPPE, Obninsk, and then during test irradiation of experimental irradiating assemblies in BN-600. The neutron fields during target irradiation will be determined by the technique of activation detectors, and the rate of generation of ^{37}Ar by the technique of proportional counters used in radiochemical solar neutrino experiments. The experimental compatibility tests of the material of the calcium-containing target with construction materials of the breeder reactor will be tested on the sodium stand at the same temperature regime as the target is expected to have in the industrial reactor.

A last stage of the work is the test calibration of an iodine detector module at Baksan neutrino observatory. To estimate what can be the most convenient iodine target and how much of it is needed for calibration one has to consider the following questions.

The reaction $^{127}\mathrm{I}(\nu_e, e^-)^{127}$Xe has a very low cross section at 1 MeV. Preliminary estimations, based on the IUCF (Indiana University Cyclotron Facility) measurements of G-T matrix

elements via (p, n) reaction, show that the cross section is $1.15 \cdot 10^{-45}$ cm^2. The most suitable iodine containing target is liquid methylene iodide CH_2I_2 with a density of 3.32 g $\cdot$ cm^{-3}, which implies 3.15 g(I) $\cdot$ cm^{-3}. Let us assume that the methylene iodide is placed between two spherical shells with the neutrino source inside the inner shell and the outer shell 100 cm distant from the inner shell. Then the ^{127}Xe production rate will be 5.5 atoms ^{127}Xe produced per day per MCi ^{37}Ar. For a compact neutrino source with ~ 50 cm of maximal dimension one should build a tank for irradiation which will contain ~ 40 tons of methylene iodide.

To estimate the error on the measured source production rate one can make some realistic assumptions for the exposure and counting conditions. Assume that a ^{37}Ar source prototype was made whose intensity was 0.4 MCi and that there was no delay before the start of the first irradiation. Then the ^{127}Xe production rate is 2.2 atoms/day. The source was left inside the target continuously and 8 extractions are made, each with an extraction efficiency of 98 %. The duration of the exposures is 4, 6, 8, 12, 18, 24, 28 and 28 days. The counting efficiency is 75 % and the background rate is zero. Each run is counted continuously from 2 to 300 days after extraction. Under these conditions, as our simulation shows, at least 6–9 ^{127}Xe atoms are detected in each run leading to $\sim 19\,\%$ of the error on the measured production rate. Thus, the results of such an experiment must be considered as a rough test irradiation.

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