CONF-8405193--28

BNL--34995

DE84 014567

REPORT ON SOLAR NEUTRINO EXPERIMENTS

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ABSTRACT

A summary is given of the status of solar neutrino research that includes results of the Brookhaven chlorine detector, a discussion of the development of the gallium, bromine, and lithium radiochemical detectors, and some proposals for direct counting detectors. The gallium and bromine radiochemical detectors are developed and are capable of giving critical information of interest about neutrino physics and the fusion reactions in the interior of the sun. A plan for building these detectors is outlined and a rough cost estimate is given. A review is given of the plans in the Soviet Union in solar neutrino research.

THE FUSION REACTIONS IN THE SUN

The sun's energy is generally believed to be a set of hydrogen fusion reactions that convert hydrogen into helium with the emission of positrons, gammas and neutrinos. The goal of solar neutrino research is to observe the neutrino spectrum from the sun in order to test this theory quantitatively, and thus provide essential information needed to understand the interior of the sun and the evolution of stars. In addition this research is of importance to the understanding of nuclear fusion processes and the physics of neutrinos.

The standard theory of the sun and the predicted solar neutrino spectrum was covered in W. Haxton's report to this conference and is described in earlier articles.[1,2] For the purposes of the discussion here it is convenient to summarize the solar neutrino spectrum in the form of the three branches of the proton-proton chain (PPI, PPII and PPIII) and the small contribution (2%) from the C-N cycle. These cycles are shown in Table I along with the neutrino fluxes calculated from the standard solar model.[2]

MASTER

RESULTS OF THE CHLORINE EXPERIMENT

A solar neutrino detector based upon the neutrino capture reaction $^{37}Cl(\nu,e^-)^{37}Ar$ was built in the period 1965-1967 and designed to observe the anticipated flux of neutrinos from the sun.[3] The results of this experiment are well known. The measurements show that the capture rate in ^{37}Cl is below that predicted by the standard solar model calculations. This experiment has been in operation continuously and during this time improvements have been made in counting techniques and analysis. There has been a reduction in counter background that has greatly improved our detection sensitivity and characterization of ^{37}Ar decay events. A maximum likelihood method of statistical analysis

Table I The proton-proton and carbon-nitrogen cycles

	Reaction	Neutrino Energy in MeV	Neutrino Flux cm^{-2} sec^{-1}
	$H + H \rightarrow D + e^{+} + \nu$ (99.75%)	0-0.42 spectrum	6.1×10^{10}
	or		
PPI	$H + H + e^{-} \rightarrow D + \nu$ (0.25%)	1.44 line	1.5×10^{8}
	$D + H \rightarrow {}^{3}He + \gamma$		
	${}^{3}He + {}^{3}He \rightarrow 2H + {}^{4}He$ (87%)		
	${}^{3}He + {}^{4}He \rightarrow {}^{7}Be + \gamma$ (13%)		
PPII	${}^{7}Be + e^{-} \rightarrow {}^{7}Li + \nu$	0.861 (90%) line 0.383 (10%) line	4.3×10^{9}
	${}^{7}Li + H \rightarrow \gamma + {}^{8}Be \rightarrow 2{}^{4}He$		
	${}^{7}Be + H \rightarrow {}^{8}B + \gamma$ (0.017%)		
PPIII	${}^{8}B \rightarrow {}^{8}Be^{*} + e^{+} + \nu$	0-14.1	5.6×10^{6}
	The Carbon-Nitrogen Cycle		
	$H + {}^{12}C \rightarrow {}^{13}N + \gamma$		
	${}^{13}N \rightarrow {}^{13}C + e^{+} + \nu$	0-1.20 spectrum	5.0×10^{8}
	$H + {}^{13}C \rightarrow {}^{14}N + \gamma$		
	$H + {}^{14}N \rightarrow {}^{15}O + \gamma$		
	${}^{15}O \rightarrow {}^{15}N + e^{+} + \nu$	0-1.73 spectrum	4.0×10^{8}
	$H + {}^{15}N \rightarrow {}^{12}C + {}^{4}He$		

was developed to analyze the time distribution of the recorded events. The combined result of 59 observations performed during the period 1970-1983 is shown in Figure 1. Also shown are the yearly average values. The results may be summarized as follows:

(1) The combined ${}^{37}Ar$ production rate over this period is 0.47 ± 0.04 ${}^{37}Ar$ atoms per day in 615 tons of C_2Cl_4. Allowing for a background ${}^{37}Ar$ production from cosmic ray muons and neutrinos of 0.08 ${}^{37}Ar$ per day,[4] the neutrino capture rate that may be ascribed to solar neutrinos is 2.1 ± 0.3 SNU (SNU = Solar Neutrino Unit = 10^{-36} captures/sec ${}^{37}Cl$ atom).

(2) There is an indication that the yearly average ${}^{37}Ar$ production rate is anti-correlated with the solar activity cycle. The two highest experimental runs correlate in time with large solar flares and high energy proton fluxes (>150 MeV) observed in the earth's atmosphere.[5]

The neutrino capture rate expected in ${}^{37}Cl$ derived from the standard solar model is in the range 6-8 SNU depending on the values chosen from the measured data and the opacity values that are used.[6]. Considerable effort in recent years has been devoted to remeasuring the nuclear reaction cross sections that lead to the production of ${}^{8}B$ in the sun,[7,8] ${}^{3}He(\alpha,\gamma){}^{7}Be$ and

$^{7}Be(p,\gamma)^{8}B$. There are many so-called non-standard solar models that predict neutrino capture rates in the range 1.5-2.5 SNU. These models are directed at reducing the internal temperatures in the sun by introducing continuous mixing, diffusion processes, low heavy element abundances, a helium core, a fast rotating core and internal magnetic fields. All of these models have features that either conflict with other observations or disagree with our present understanding of the physics of stellar structures.[9] It is important to recognize that the chlorine experiment is predominantly sensitive to the flux of ^{8}B neutrinos (PPIII branch) and the flux of these neutrinos is extremely sensitive to the internal temperatures in the sun.

Another explanation that has been advanced for the low solar neutrino capture rate in ^{37}Cl is that the electron neutrinos produced in the sun change to neutrinos of the muon, tauon, etc., flavors in the 8 minutes it takes them to traverse the sun and reach the earth.[10,11] According to the usual analysis of neutrino vacuum oscillations, the oscillation length depends upon

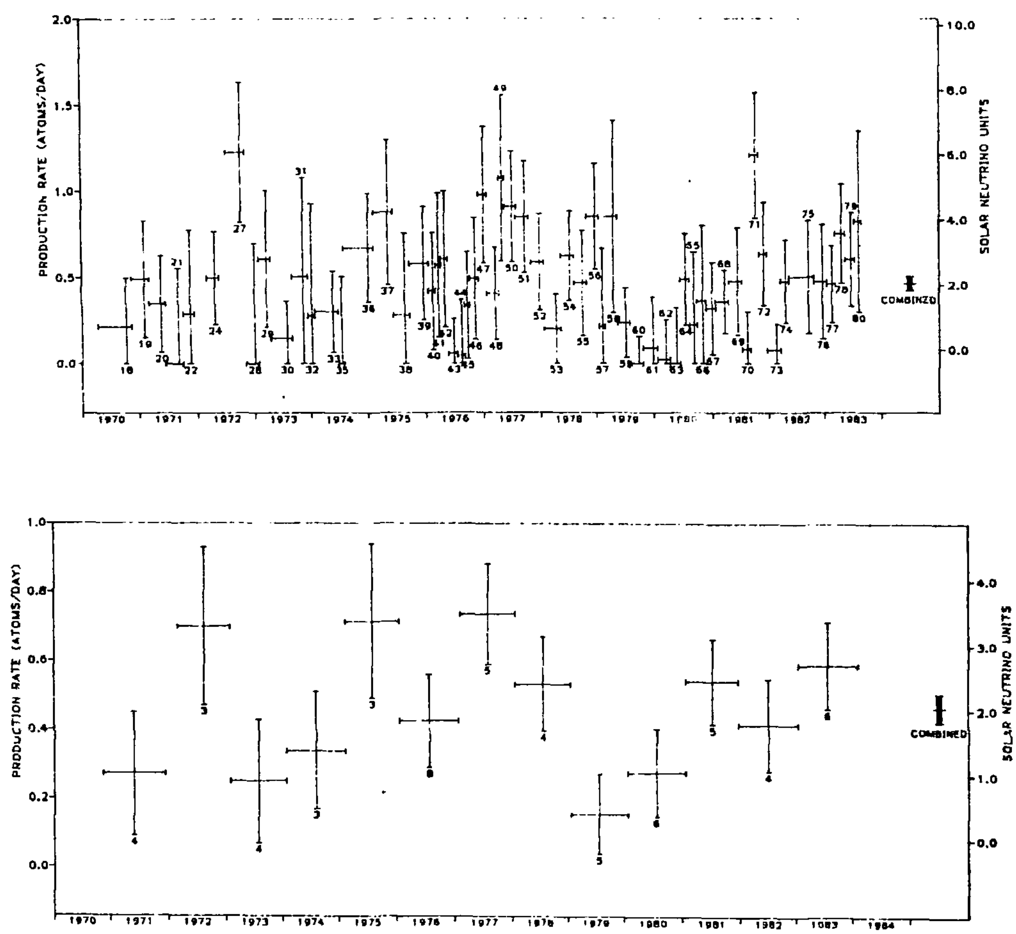

Fig. 1. Experimental results from the chlorine solar neutrino experiment: upper--individual measurements; lower--yearly averages.

the difference in the squared masses between the neutrinos (δm^2) and the mixing angle. There is little theoretical guidance for the magnitude of these parameters. Numerous experiments have been carried out at reactors and accelerators to search for the phenomena of neutrino oscillations and at the present time there is no clear evidence for neutrino oscillations at distances as great as the earth's radius. A solar neutrino detector capable of observing the low energy neutrinos from the H-H reaction (PPI branch) is the best and perhaps the only way of testing for neutrino oscillations at δm^2 as small as 10^{-8} $(eV)^2$.[12]

NEW SOLAR NEUTRINO EXPERIMENTS

It has been known since 1968 that the solar neutrino capture rate in ^{37}Cl was below theoretical expectation. A considerable effort has been devoted toward developing radiochemical detectors based upon using gallium, bromine and lithium as target elements. In addition a number of detectors based upon observing the neutrino capture or scattering event directly have been suggested. However, at the present time there are no plans in the United States for building a second experiment. A direct experimental proof that the sun is producing energy by hydrogen fusion is a problem of great fundamental interest. The cost of carrying out the next generation solar neutrino experiment is indeed very modest on the scale of the experiments and facilities discussed at this conference.

Table II summarizes the experiments that have been suggested and their relative sensitivity to the three branches of the proton-proton cycle, and the corresponding neutrino source in the sun.

Table II Summary of solar neutrino detectors

Branch	Neutrino Source	Information	Detector	
PPI	$H + H \rightarrow D + e^+ + \nu$ or $H + H + e^- \rightarrow D + \nu$	Primary H-fusion process, model independent	$^{71}Ga-^{71}Ge$ $^{7}Li-^{7}Be$ $^{205}Tl \rightarrow ^{205}Pb$ $^{115}In \rightarrow ^{115}Sn$	Radio-chemi-cal Direct
PPII	$^3He + ^4He \rightarrow ^7Be + \gamma$ $^7Be + e^- \rightarrow ^7Li + \nu$	^3He burning ^7Be decay rate Sensitive to model	$^{81}Br-^{81}Kr$ Radiochemical	
PPIII	$^7Be + H \rightarrow ^8B + \gamma$ $^8B \rightarrow ^8Be^* + e^+ + \nu$	^8B decay rate Very sensitive to solar model	$^{37}Cl-^{37}Ar$ $^{97}Mo-^{97}Tc$ $\nu-e^-$ scattering Kamioka P-decay expt. or Ar track projection chamber.	Radio-chemi-cal

The proton-proton chain is initiated with the H-H reaction, and the integrated rate of this reaction is essentially independent of the details of the solar model. Because of this presumed fact, astrophysicists have placed great confidence in the predicted rate of the H-H reaction in the sun (expected error around 3%). An experiment capable of observing the low energy neutrinos from this reaction would constitute a critical test of the theory. If a low rate for this reaction is observed, the most likely explanation would be that the electron neutrino oscillates, decays, or in some way is lost. In the context of the oscillation hypothesis an accurate experimental observation of this flux could give limits on values for the mixing angle and δm^2 not achievable by any other experiment.

Because of these concepts there has been an emphasis since 1978 to develop a neutrino detector capable of observing these low energy neutrinos.[13]. The ^{115}In experiment based upon the reaction $\nu + {}^{115}In \rightarrow e^- + {}^{115}Sn^* \rightarrow {}^{115}Sn + 2\gamma$ has the capability of observing the neutrino spectrum by detecting the emitted electron in coincidence with two successive low energy gammas. A neutrino detector based upon this principle that is capable of observing the solar flux is technically extremely difficult. Work on this approach will be reported at this conference by Martin Deutsch.[14] The ^{205}Tl experimental technique suggested by M. Freedman,[15] involves obtaining a well shielded geological deposit containing a thallium mineral since the product ^{205}Pb has a half life of 1.5×10^7 years. There is a deposit of the mineral Lorandite in Yugoslavia that appears to be satisfactory. However, work on the thallium radiochemical detector has been temporarily abandoned because of the lack of support. The major effort has been devoted to the gallium radiochemical system for observing the low energy neutrinos from the H-H reaction. The potential of this experiment will be discussed at the end of this report. The lithium experiment can observe the electron capture branch of the primary H-H reaction. This so-called PeP reaction occurs at a rate 380 times lower than the H-H reaction and the rate can be reliably calculated. Even with this very unfavorable factor the solar neutrino capture rate in ^7Li is relatively high and only a modest quantity of lithium is required. The main difficulty with the lithium experiment is the measurement of the product ^7Be. Although a ^7Li-^7Be neutrino detector has many features in its favor, work on this technique in this country was abandoned in 1978.[16]

The ^7Be decay neutrinos from the PPII branch have the second highest flux predicted by solar model calculations. A measurement of this flux would determine the rate of ^3He burning by the $^3He(\alpha,\gamma)^7Be$ reaction. Information on this rate would be of great value in understanding the solar model and the chlorine experimental results, and would be needed to interpret the results of a gallium experiment.[1] By virtue of the unique sensitivity of the three radiochemical detectors, gallium, bromine, and chlorine for the characteristic neutrino sources in the sun, one can in principle determine the solar neutrino spectrum by combining the rates observed by these three detectors. The status of the development of the bromine detector will be given later in this report.

It is of great interest to check the results of the chlorine experiment to assure that the low signal observed is indeed attributable to the decay of ^{8}B in the sun. One can prove that the neutrinos come from the sun by observing the event directly and correlating the direction of the emitted electron or scattered electron with the sun's location. The ^{8}B neutrinos are the only solar neutrinos with sufficient energy to obtain even a rough angular correlation. In the past a number of ^{8}B neutrino detectors were suggested and development work was carried out. In recent years Herbert Chen has developed a liquid argon time projection chamber that could be applied to observing ^{8}B neutrinos.[17] The technique has the resolution, but one cannot foresee at the present time whether a full scale detector is feasible and would have a sufficiently low background counting rate. The possibility of applying the Kamioka proton-decay detector to observe ^{8}B decay neutrinos will be discussed in Alfred Mann's report at this conference.[18]

THE GALLIUM AND BROMINE EXPERIMENTS

The radiochemical method of observing solar neutrinos has the advantage of high sensitivity, low energy threshold and low cost. In the foreseeable future it appears unlikely that the direct counting method for determining the solar neutrino energy spectrum and neutrino direction will be able to determine the critical neutrino fluxes from the H-H reaction, the PeP reaction and ^{7}Be decay in the sun. The development of gallium and bromine radiochemical detectors is essentially complete, and full scale detectors could be built. Because of the fact that the radiochemical method is not capable of observing a single neutrino source, it is necessary to have the individual rates from ^{37}Cl, ^{81}Br and ^{71}Ga to determine the solar neutrino energy spectrum. In addition there is the question of the contribution from excited states in ^{71}Ge and ^{81}Kr, a question that will be resolved by p,n reaction studies.[1,19]

For each of these detectors, Table III gives the percent of the total solar neutrino capture rate that would be anticipated from each neutrino source in the sun. The solar model selected for this table gives a total neutrino capture rate in ^{37}Cl of 1.9 SNU, consistent with our observations. This model was chosen as the best estimate of the solar neutrino fluxes to use for planning new experiments. The dominant source is indicated by [] around the percentage value for each of the four detectors. We would like now to summarize the present status of the gallium and bromine radiochemical detectors.

Gallium. The gallium method was developed in a collaborative effort by Brookhaven National Laboratory, the Max-Planck-Institute for Nuclear Physics (Heidelberg), the Weizmann Institute, and the Institute for Advanced Study. The neutrino capture reaction

Table III Comparison of radiochemical solar neutrino detectors. The percent of the capture rate from various solar neutrino sources is given for a solar model with a rate of 1.9 SNU in ^{37}Cl

Neutrino source	Gallium $^{71}Ga-^{71}Ge$	Bromine $^{81}Br-^{81}Kr$	Lithium $^{7}Li-^{7}Be$	Chlorine $^{37}Cl-^{37}Ar$
$p + p \rightarrow d + e^{+} + \nu$	[81]	0	0	0
$p + p + e^{-} \rightarrow d + \nu$	2.7	17	[51]	12
^{7}Be decay	14	[64]	8.9	23
^{8}B decay	0.3	6.2	20	[59]
^{13}N decay	1.0	4.6	3.5	1.4
^{15}O decay	1.4	4.6	16	4.4
Total rate in SNU	88	6.8	19	1.9
Tons of element needed for 1 neutrino capture per day	39	460	7.6	1460

$\nu + {}^{71}Ga \rightarrow {}^{71}Ge + e^{-}$ has a threshold of 232.2 keV and the half life of ^{71}Ge is 11.4 days. The target material used is a hydrochloric acid solution of gallium chloride. Germanium is easily removed from this solution by purging with gas, the germanium being released as the volatile compound, $GeCl_4$. The germanium tetrachloride is easily removed from the gas stream by a simple water scrubber column. The germanium recovered is then converted to germane, GeH_4, a gas that can be introduced into a small gas proportional counter. A pilot experimental system containing 1.3 tons of gallium (liquid volume 3 m^3) was built to test the procedures on an engineering scale. We found that germanium could be recovered, and placed in the counter as germane with a 95% yield in a period of 16 hours.[20] With this 1.3-ton facility the cosmic ray gackground production of ^{71}Ge, ^{68}Ge, and ^{69}Ge was measured and the yield of ^{71}Ge produced by fast neutrons was determined. A 15-ton detector could be built by scaling this system up by a factor of 12. This quantity of liquid could be contained in thirteen 750-gallon glass-lined tanks. Tanks of this design, chosen because of the corrosive nature of the acid gallium chloride solution, are commercially available and of suitable size to be carried underground by a mine hoist.

A valuable feature of the gallium solar neutrino detector is that it is possible to show that the signal observed is indeed from neutrinos and not from background reactions. The major background effect underground arises from cosmic ray muon interactions. Measurement with gallium chloride targets in the Fermilab muon beam show that the production of ^{69}Ge (39 hour half-life) is four times greater than that for ^{71}Ge.[21] One can thus easily search for ^{69}Ge in a full scale solar neutrino experiment to test whether the ^{71}Ge signal observed is from muons or neutrinos. The neutrino reaction producing ^{69}Ge has a higher threshold (2.23 MeV) and a lower cross section,[22] so ^{69}Ge would not be produced by solar neutrinos. Another background effect arises from internal natural alpha emitters. Our experience shows that the ^{71}Ge production from alphas emitters is very low in commercially available gallium chloride solutions. Nevertheless, this background effect can be monitored in these chlorine-containing solutions by observing the production of ^{37}Ar.

The gallium collaboration requested funds to build a gallium solar neutrino detector using 45 tons of gallium during the period 1981-1983 without success. Included in the plans was a calibration test using 2-3 megacuries of ^{51}Cr as a neutrino source. Tes irradiations were performed in the HFIR reactor at Oak Ridge, and it was concluded that only 0.95 megacuries could be prepared. A source of this intensity would require 12 tons of gallium in solution form to make the measurement and would require a 2-3 year effort.

With this experience behind us we now propose carrying out a solar neutrino measurement using 15 tons of gallium. Since it is most important to determine the solar neutrino flux, we recommend that all effort be directed to this problem and the source experiment be deferred. A Monte Carlo analysis has been made of the statistical error that would be achieved. The results of our analysis are presented below.

<u>Experimental parameters used</u>

Cost of 15 tons gallium, \$0.35/g = \$5.25 M
Total neutrino capture rate = 88 SNU
^{71}Ge production rate = 0.39 per day
Exposure period/run = 21 days
Counting time/run = 59 days
Counter background = 0.05 count/day
Extraction efficiency = 95 percent
Counting efficiency = 0.56

<u>Results of the Monte Carlo Calculation</u>

Number of runs	Years required	Error in SNU (1σ)
20	1	28
35	2	21
50	3	18
70	4	15

It is clear from this analysis that an experiment using 15 tons of gallium operated for three years would be capable of obtaining a significant measurement of the solar neutrino capture rate in ^{71}Ga. We regard 15 tons as the <u>minimum</u> quantity of gallium needed for obtaining a significant result in a reasonable time. It is interesting to note that for a given number of runs the estimated error in SNU's is approximately independent of the neutrino capture rate. For example, if only the PPI chain is operating in the sun then the only source of neutrinos would be the H-H reaction. The neutrino capture rate anticipated for ^{71}Ga would be 67 SNU's and the estimated error would be 22 SNU's in three years of operation.

Bromine. The bromine detector depends upon the neutrino capture reaction $\nu + {}^{81}Br \rightarrow e^- + {}^{81}Kr^* \rightarrow {}^{81}Kr$ (half-life 2.1 x 10^5 years). Neutrino capture in ^{81}Br (49.3%) feeds primarily the $1/2^-$ (E = 190 keV) 13-second isomeric state of ^{81}Kr, with a threshold of 467 keV for neutrino capture. The electron capture decay of this state was observed by Bennett et al,[23] and the calculated neutrino capture cross section was derived from their measurements.[24] A $5/2^-$ state at 457 keV may also contribute to the neutrino capture cross section. The properties of this state are not sufficiently well known at the present time[25] but in the near future will be evaluated by p,n reaction studies.

The bromine experiment was originally suggested as a means of testing the constancy of the solar neutrino flux over the last 500,000 years by using an old underground salt deposit as the target material.[26] However, the concentration of bromine is low in these deposits, and because of this fact the alpha particle background effect from U and Th impurities in known salt deposits is large.[27]

Recently a method of counting 500-1000 atoms of ^{81}Kr has been developed by G. S. Hurst and his associates at Oak Ridge National Laboratory. This development makes it possible to observe the present solar neutrino flux with the ^{81}Br-^{81}Kr method by measuring the number of ^{81}Kr atoms accumulated in a tank of a bromine containing liquid over a period of a year. In a detector comparable in size to the Cl detector, a solar model that is consistent with the result of the Cl experiment predicts that approximately two atoms of ^{81}Kr will be produced per day. The $^{81}Br(\nu,e^-)^{81}Kr$ reaction is predominantly sensitive to the monoenergetic neutrinos from ^7Be decay and therefore is well suited for measuring the rate of the PPII branch. Since krypton is a rare gas, the operation of the system would be identical to that of the Homestake chlorine experiment. In fact experiments have been underway for two years to measure krypton recovery from the Homestake tank of perchloroethylene. Krypton is separated from argon by a gas chromatography step in our normal operations. Krypton is more soluble than argon in organic liquids, and of course is removed more slowly, at about 40% of the argon recovery rate. Several bromine-containing compounds are available commercially; dibromoethane, dibromomethane, and tetrabromoethane. The least expensive is dibromoethane because this compound is manufactured on a very large scale for leaded gasoline and various agricultural uses, but recent prohibitions based on its presumed toxicity may rule it out.

The technique for counting 500-1000 atoms of ^{81}Kr takes advantage of a resonance ionization spectroscopy (RIS) technique for ionizing krypton atoms by multiphoton absorption.[28] The identification of ^{81}Kr is accomplished by a mass spectrometer. To increase the efficiency of the laser-ionization step a finger cooled by liquid helium is used to concentrate and localize the krypton atoms. They are released from this surface suddenly by warming the surface with a laser pulse which is followed 7 μs later by the RIS laser pulse. The ionized ^{81}Kr atoms that pass the mass filter are accelerated to implant them in a silicon target, and counted by the secondary electrons released. All these detector components are contained in a single envelope into which the krypton sample is introduced. To apply this technique to krypton gas extracted from 400,000 liters of a bromine-containing liquid it is necessary to reduce the total volume of krypton introduced by contamination from air to a very low level. This requirement is essential because of interference from ^{80}Kr and ^{82}Kr in the mass identification. In the Homestake system the total krypton introduced in the recovery processing is no more than 10^{-6} cm^3 STP. Even so it will be necessary to enrich the ^{81}Kr concentration, or utilize repeated operation of the ^{81}Kr RIS counting system.

Background effects from cosmic ray muons, internal alpha emitters, and fast neutrons are estimated to be lower than for a chlorine detector. These background problems will also produce ^{79}Kr ($t_{1/2}$ = 35 hours) as well as ^{81}Kr, whereas the production of ^{79}Kr by solar neutrinos would be far lower than the production of ^{81}Kr. Therefore a bromine detector has a built-in monitor for muon background, exactly analogous to that already noted for the gallium detector.

The technology for isolating and measuring ^{81}Kr is essentially developed and a full-scale detector is now feasible.[29] A bromine detector program could be carried out in three stages:

(1) Perform background studies in which ^{81}Kr is measured using the RIS technique along with ^{79}Kr by radioactivity measurements.

(2) Use the Homestake chlorine detector as a full-scale feasibility test facility to set limits on ^{81}Kr counting, and develop a routine operating procedure.

(3) Build the full-scale detector.

We anticipate two years of effort are required to carry out the first two steps. We have estimated the approximate costs for a bromine experiment containing 400,000 liters of dibromomethane.

Cost of dibromomethane, CH_2Br_2	\$1.2 M
Provide an underground cavity	0.5
Tank fabrication, pumps, extraction system	0.5
Total	\$2.2M

Our concept is to build a new experiment rather than fill the Homestake detector with dibromomethane. This course is recommended for the following reasons:

(1) The chlorine detector is now yielding important results in our search for solar variations and solar flare effects.

(2) The chlorine detector is the only existing reliable monitor for the integrated neutrino flux (ν_e) from a stellar collapse or other pulsed neutrino source.

(3) When a new detector that is sensitive to some other component of the solar neutrino spectrum is operational (such as the Ga or Br detectors) the data from the chlorine experiment will be needed. This is because of the possibility that the solar neutrino output may be varying with a period of several years and it would be most desirable to have concurrent measurements of the high-energy neutrino flux with the Cl detector.

One should bear in mind that a bromine experiment requires long exposure times, of the order of a year. If ten runs are considered reasonable, a period of ten years would be needed to make an accurate measurement of the ^7Be flux. During this long period the chlorine data would be lost, and the search for solar variations, solar flare effects, and neutrinos (ν_e) from stellar collapse would have to be abandoned.

Underground sites. The Homestake facility, built in the period 1965-1967, has developed into a center for underground science. Four experimental programs are now established and operating in our chamber: a 500 m^2 scintillation spectrometer hodoscope built by the University of Pennsylvania, a ^{76}Ge double beta decay experiment developed by the Battelle-Northwest Laboratories and the University of South Carolina, a radiochemical experiment to measure the nuclear interactions of muons, built by the Smithsonian Center for Astrophysics and BNL, and the Brookhaven solar neutrino experiment. These experiments occupy all the space available to science in the Homestake mine. The Homestake management at the present time is not willing to devote the manpower and hoisting capacity needed to build a new room for additional experiments.

It is our present view that a new site is needed to house a gallium or bromine experiment. A group of Canadian physicists is interested in developing an underground science laboratory in the Creighton mine operated by the International Nickel Company (INCO) near Sudbury, Ontario.[30] This mine has an excellent hoist that reaches a depth of 7000 feet with access to many intermediate levels. Possible deep levels that could be used for science are at 5600 and 7000 feet. The rock structure is competent, and rooms as large or larger than the Homestake room (60 ft x 30 ft x 32 ft high) could be excavated. The mine management is quite receptive to the concept of developing an underground science laboratory in the Creighton mine. We believe that an unusual opportunity exists for developing a joint Canadian-U.S. program to build a new solar neutrino observatory in the INCO mine.

THE SOVIET SOLAR NEUTRINO PROGRAM

There has been a long standing interest in solar neutrino research in the Soviet Union. It is interesting to remember that both the chlorine and gallium experiments were suggested by Soviet scientists.[31] They have followed the development of the chlorine experiment and have made many valuable contributions over the course of the last twenty years.[3] In the late 1960's a large scale program was initiated that included building a 2-million liter chlorine detector, a 50-ton gallium detector, and a 460-ton scintillation hodoscope. To accommodate these experiments a 4-km long horizontal adit is being excavated in Baksan Valley[32] that will reach an underground depth approximately equal to that of the Homestake facility.

Their chlorine detector is designed and a half-scale version will be built on the surface as a test facility. A six-ton gallium test facility has been in operation for about three years. They use metallic gallium as the target material and employ a germanium extraction technique that was developed at BNL. Their program was allotted 55-60 tons of gallium and they plan to begin building a full-scale experiment in 1985 upon completion of an underground room near the end of the adit. The full-scale chlorine detector will be built in a very large room, 20 m x 20 m x 150 meters at the end of the adit. The scientists directing the solar neutrino project are excellent, and support for their program is firm. There has been a long standing cooperation and exchange of information between BNL and the Soviet program, and occasional short term exchange visits of a few scientists.

ACKNOWLEDGMENT

This research was carried out at Brookhaven National Laboratory under contract DE-AC02-76CH00016 with the U.S. Department of Energy and supported by its Office of High Energy and Nuclear Physics.

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