TITLE: A PROPOSED GEOLOGICAL SOLAR NEUTRINO MEASUREMENT

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A PROPOSED GEOLOGICAL SOLAR NEUTRINO MEASUREMENT

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ABSTRACT

It may be possible to measure the boron-8 solar neutrino flux, averaged over the past several million years, from the concentration of technetium -98 in molybdenum-rich ore. This geochemical experiment could provide the first test of nonstandard solar models that suggest a relation between the chlorine-37 solar neutrino puzzle and the most recent glacial epoch. The necessary conditions for achieving a meaningful measurement are identified and discussed.

INTRODUCTION

The standard solar model¹ postulates a complex set of thermonuclear reactions which evolve and change with time. The rate at which energy is generated is determined by conditions in the deep solar interior. Although there is considerable reason to believe that the model is generally correct, there is, unfortunately, almost no way to probe the solar interior to check its details.

A general solar model should comprehend processes leading to solar variability. Evidence for variability exists in the cycle of sunspot activity which appears to affect the terrestrial climate. This cycle is presently explained in terms of the dynamics of convection and rotation and does not call into question the details of energy production. However, long term changes have occurred in the terrestrial climate and, if these are due to solar variability, they imply possible changes in the rate of energy production which are not presently explained by the standard model.

Dramatic changes in climate have occurred several times in terrestrial history when warm periods of hundreds of million years duration have been interrupted by major glacial epochs which last a few million years. There is, as yet, no consensus that glacial epochs are related to energy changes in the sun. Such a relationship is hypothesized because the standard solar model can be modified to produce a cyclic change in solar temperature with a pattern corresponding to that of the glacial epochs. For example, the "solar spoon," proposed by Dilke and Gough² ten years ago, postulates that the ratio $^3\text{He}/^1\text{H}$ varies sharply with radius when equilibrium burning is achieved. This large concentration gradient induces large amplitude, non-radial oscillations with a characteristic period of about 1 hour. Such oscillations produce a mixing of the core with colder material at larger radii. The approach to equilibrium prior to the onset of instability requires about 200 million years. The mixing is relatively sudden and the consequent core expansion produces a cooling trend with a 5% drop in solar luminosity for a period of about 3 million years.

The last glacial epoch, the Pleistocene, began only three million years ago. If it were due to a solar instability, the core should presently be cooler than predicted by the standard model. Thus, this hypothesis can be used to help explain the solar neutrino anomaly, i.e., the fact that the high energy neutrino component measured by the ^{37}Cl - ^{37}Ar reaction is nearly a factor of four lower than the flux predicted by the standard model. The hypothesis can be tested by measuring a product which is proportional to the high energy neutrino flux integrated over several million years.

The neutrino measurement being developed at Los Alamos involves the separation and analysis of ^{98}Tc , with a half-life of 4.2 million years, made by neutrino absorption in ^{98}Mo contained in a deeply buried ore deposit. An additional, potentially useful product is ^{97}Tc with a half-life of 2.6 million years. A number of requirements must be met in order to perform this measurement with useful accuracy and at acceptable cost. These include:

1. Accurate neutrino capture cross sections must be available from theory and experiment.
2. A molybdenum ore deposit must exist in a working mine which is deep enough to reduce cosmic-ray-induced backgrounds to acceptable levels.
3. Backgrounds induced by naturally radioactive elements must be minor and measurable.
4. Separative and analytical chemistry procedures must be developed to measure extremely small quantities of ^{97}Tc , ^{98}Tc , and ^{99}Tc .
5. Geochemical immobility of Tc in the chosen ore body must be demonstrated.

These requirements are discussed in more detail in the following sections of this paper.

NEUTRINO CAPTURE CROSS SECTIONS

The threshold for the $\text{Mo}(\nu, e)^{98}\text{Tc}$ reaction is 1.68 MeV but, because transitions from the 0^+ ground state of ^{98}Mo to the $(6)^+$ ground state and $(4.5)^+$ first excited state in ^{98}Tc are strongly hindered, the effective threshold is ~ 1.74 MeV and only high energy ^{98}B neutrinos contribute significantly.

The model-independent Fermi strength contribution to the formation of ^{98}Tc is negligibly weak. With sufficient accuracy for our present calculations, we estimate the model-dependent GT strength distribution and calculate a production rate of 5.0 SNU ($1\text{SNU} = 10^{-36}$ captures per target atom per second) based on the standard solar model neutrino flux of Bahcall et al.³ The GT transition can be mapped experimentally with a typical accuracy of 5% based on measurements of forward angle (p, n) reactions.⁴ Such measurements are planned for Mo and should be available relatively soon.

From similar calculations for the productions of ^{97}Tc , we obtain a total production rate of 5.9 "equivalent" SNU, the result including a contribution from deexcitation by neutron emission in excited ^{98}Tc .

THE ORE DEPOSIT

Although a number of unexploited Mo ore deposits may be known which are buried at a sufficient depth, the amount of ore needed per sample is so great that we are limited by practical considerations to the use of working mines. We know of only one such active mine. It is located at the Henderson ore body at Red Mountain in Clear Creek County, Colorado. The ore averages approximately 0.5% molybdenite (MoS_2) and comes from a depth in excess of 1000 m. The ore body extends to a depth >1500 m below the surface⁵. At the time of ore body formation (~ 25 million years ago) the depth of burial was 1500-1800 m. The present minimum depth of overburden is due to glacial scouring which occurred about 10,000 years ago.

We calculate that 1410 m of overburden at a density of 2.9 reduces the cosmic ray background to 10% of the solar neutrino signal.

NATURAL RADIOACTIVITY BACKGROUNDS

The most common Mo mineral at Henderson is molybdenite embedded in altered granitic rock. A representative sample contains 11.8 ppm of uranium. The associated radioactivity is the source of a number of potentially bothersome reactions which produce ^{97}Tc and ^{98}Tc . Direct (α, p) reactions are suppressed to negligible levels by high thresholds and Coulomb barriers. However, (α, p) reactions on S followed by (p, n) reactions on ^{97}Mo and ^{98}Mo may be serious. If uranium is found only in the veinlets containing molybdenite crystals, the ratio of neutrino-induced to alpha-induced Tc is given by $R\langle d \rangle / 3.75U$ where R is the neutrino capture rate in SNU, U the uranium content in ppm, and $\langle d \rangle$ the mean thickness of molybdenite in micrometers. For ^{98}Tc , if U is 11.8 and $\langle d \rangle$ is 100, the ratio is 11.3. The result is more favorable if the U is concentrated in macroscopic grains of host minerals which degrade the energy of the alpha particle.

Fission neutrons produce (n, p) reactions on S followed by (p, n) reactions on Mo. The signal-to-background ratio is $510R/U$ or about 216.

Neutron capture on ^{96}Ru can make ^{97}Tc to the extent that 0.11 ppm of Ru in the ore concentrate will generate a 10% background. The (α, γ) reaction on ^{93}Nb generates a similar background level of ^{97}Tc at a Nb content of a few ppm. We conclude that background levels of ^{97}Tc may prove to be unacceptable.

SEPARATIVE CHEMISTRY AND ANALYSIS FOR Tc

Our calculations indicate that the untreated ore will contain 5×10^4 atoms of ^{99}Tc per gram, the secular equilibrium level for mass 99 produced by the spontaneous fission of ^{238}U at a concentration of 12 ppm. Neutrino-produced ^{97}Tc and ^{98}Tc concentrations should be a factor of 10^7 lower. When the molybdenite is concentrated from 0.5% to 90%, the ^{238}U concentration should fall to 1.2 ppm if all the U is associated with minerals outside the molybdenite. A representative sample of concentrate actually contained 1.8 ppm. Thus, the concentrate can be expected to contain 7×10^3 atoms of ^{99}Tc per gram and 10^4 less ^{98}Tc , the most troublesome mass number due to the ubiquity of Mo contamination. The concentrate from 2600 tons of ore divided by the recovery efficiency will be required to produce such a sample. This represents considerably less than one day's production at the mine.

In the industrial process, the concentrate is roasted to produce molybdenum oxide at a controlled temperature of 700°C . An effluent gas stream, consisting largely of SO_2 and excess air, is scrubbed with water to remove particles and volatile impurities before conversion of the SO_2 to sulfuric acid. The scrub water, known as the acid wash, should contain most of the environmentally objectionable element selenium together with chemically similar rhenium and technetium. The selenium is precipitated as the sulfide for environmental reasons. This precipitate will contain the Tc. We are developing separative techniques to recover traces of Tc from kilograms of selenium sulfide. The necessary chemistry is known, but the efficiency must be determined.

THE GEOCHEMICAL MOBILITY OF Tc

Based on measurements of loss rates of decay products of uranium, particularly radiogenic lead, in a variety of uranium ores, we are hopeful that Tc loss rates will not exceed 10^{-9} per year in the reducing sulfide-rich environment of the Henderson ore. We intend to measure the degree to which ^{99}Tc is in secular equilibrium with uranium. However, final reassurance on this question will rest on the reproducibility of results obtained from more than one location in the ore body.

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