Hints for the existence of sterile neutrinos mixing with electron and muon neutrinos come from several observations \[1\]. Evidence comes both from appearance, when the source is a muon neutrino and from observed event rates being below expectations, when the source is an electron neutrino. If one uses a neutrino oscillations framework to model the observations the short distances involved suggest a large mixing mass and the low transition rates suggest a small mixing angle. In this model the transition rate for electron neutrinos can be approximated by:

$$P_{e\rightarrow e} = 1 - \sin^2(2\theta_{es}) \sin^2(\Delta_{es})$$

where $\Delta_{es} = 1.267(m_e^2 - m_j^2) \frac{L}{E} = 1.267\Delta m_{es}^2 \frac{L}{E}$. This is a reasonable approximation when $\Delta_{es} >> \Delta_{ij}$. Where $\Delta_{ij}$ is the scale of the known three flavor oscillations. Suggested values for $\Delta m_{es}^2$ are about 1 eV$^2$ and $\sin^2(2\theta_{es}) = 0.1$ \[1\]. So the approximation is good for short baseline experiments. The small value of $\sin^2(2\theta_{es})$ suggests that high statistics are needed to see the effect and that systematic errors may dominate the measurement. Values as high as $\Delta m_{es}^2 > 5$ eV$^2$ can be fit \[1\].

The interaction of MeV scale antineutrinos (such as from fission products) on hydrogen, $\bar{\nu}_e + P \rightarrow e^- + N$ is a well understood process that lends itself to the background resistant delayed coincidence method where the neutron is measured after the initial neutrino interaction occurs to produce a positron. Almost all of the neutrino energy is carried by the positron so neutrino energy ambiguity is determined by detector resolution and not neutrino reaction kinematics.

The transition probability depends on the distance from the neutrino source to the detection point. Even if the detector has good spatial resolution one must average over the source size.

$$\frac{1}{L} \int \sin^2(1.267(m_e^2 - m_j^2) \frac{L}{E})dL \approx \frac{1}{2}$$

If the source size is comparable to about $\frac{1}{4}$ of the oscillation length ($L_{osc} = \frac{2\pi E}{1.267\Delta m_{es}^2}$) or larger averaging over the source size is equivalent to shifting the flux normalization. This leads to an ambiguity between the sterile neutrino hypothesis and the normalization of the source flux. It is advantageous to have a small source size.

A short baseline experiment from an intense compact low energy antineutrino source is an ideal tool to study sterile neutrinos. $^{144}Ce$ has been chosen as a compact neutrino source for such an experiment \[2\]. The end point energy of the $^{144}Pr$ daughter beta decay is about 3 MeV. The difficulty of creating, transporting and maintaining such a source has encouraged a search for alternatives.

In reference \[3\] it is suggested that cyclotrons be used to produce beta unstable radionuclides such as $^8Li$ near a large mass detector so the transportation issues associated with radioactive sources is mitigated. The end point energy of the $^8Li$ beta decay is about 16 MeV. The $^8Li$ is made \textit{in situ} from neutron capture on $^7Li$. The interaction length for neutron capture determines the source size. For an isotopically pure target of $^7Li$ metal the neutron capture length is about 475 cm. The presence of $^6Li$ is problematic since its neutron capture cross section is 21 times larger but it yields no neutrinos.

Application of accelerator technology to produce subcritical fission power sources \[4\] suggests a more efficient

Compact Neutrino Source

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Some evidence for sterile neutrinos has been found in short baseline observations where the measured neutrino flux did not agree with expectations. Systematic uncertainties from the expected values has limited the sensitivity of this approach. Observation at multiple distances can remove the normalization uncertainty by isolating the distance dependence. This doesn’t work for high $\Delta m^2$ sterile neutrinos since they are fully mixed at most observation distances and only shift the normalization of the flux. A compact intense source of neutrinos based on a subcritical fission reactor would permit observation of oscillations on submeter distance scales and clearly distinguish between a systematic normalization and the $L/E$ dependence expected from oscillations.

Keywords: sterile neutrinos, neutrino oscillations, neutrino source
way to generate an intense compact neutrino beam. In the subcritical fission reactor, accelerator induced fission greatly amplifies the power injected and produces the neutron rich beta decay unstable fission products that are responsible for the antineutrinos produced at nuclear power stations. Unlike self sustaining chain reactions where the geometry and design require a large core, a subcritical source has some advantages. For example, cooling the source could be engineered to permit much shorter distance between the neutrino source and the detector. This minimum being determined by radiation shielding requirements. Backgrounds which are not beam associated can be measured by turning off the accelerator hence removing the neutrino source. Removing the source of neutrinos is rarely practical for commercial nuclear reactor operations.

In reference [4] most of the fission power comes from $^{233}$U bred in situ from $^{232}$Th but reactors utilizing $^{239}$Pu bred from $^{238}$U are also possible. For a neutrino source it also might be reasonable to dispense with the breeding phase and start with a subcritical assembly of $^{233}$U, $^{235}$U or $^{239}$Pu. Due to the high neutron fission cross section for these materials interaction lengths for pure metals is below a millimeter. The actual source size is determined by safety and engineering issues.

A low power compact fission source might be able to dispense with the high power accelerator and provide neutrons another way. About $3 \times 10^{13}$ thermal neutrons per second are needed to sustain 1 kW of fission power, enough to probe the short distances of the highest values of $\Delta m^2_{23}$. The rate of neutrino interactions in a liquid scintillator detector $(CH_2)$ is about 76 events per ton-day 10 meters from a 10 MW source. We have used the neutrino spectrum estimates for $^{239}$Pu from reference [6] and the cross section from reference [7].

Figure 1 illustrates the spectral distortion of a compact $^{239}$Pu fission product neutrino source due to sterile neutrinos for several different source to detector distances. The peak in the unoscillated event rate is at about 3.5 MeV.

Fission product neutrino sources are well studied and understood. In fact discrepancies [3] at modest distances from nuclear reactors between the measured neutrino rate and the expected one is one hint for sterile neutrinos.

A compact source would permit the L/E measurement and distinguish normalization errors from a true neutrino oscillation. An L/E measurement could do this with no dependence on the calculated neutrino source error by measuring simultaneously at different distances from the compact source.

The rate of neutrino interactions in a liquid scintillator detector $(CH_2)$ is about 76 events per ton-day 10 meters from a 10 MW source. We have used the neutrino spectrum estimates for $^{239}$Pu from reference [6] and the cross section from reference [7].

The neutrino spectrum may change with time as the isotopic content of the target and its spatial distribution changes. But as long as spectra at all baselines are compared to the same exposure, fuel evolution issues are restricted to integrating over the source. If the source is compact it is less sensitive to inhomogeneities due to burn up.

Since the oscillation length is a function of the neutrino energy ($L_{osc} = \frac{2 \pi E}{\Delta m^2 \sin^2 \theta}$), one can reduce the effect of the neutrino source size by using a higher neutrino energy. But the higher neutrino energy requires longer baselines which reduces the neutrino flux. Higher neutrino energy also means that additional detection channels will open up making energy resolution an issue as more of the neutrino energy gets transferred to nuclear excitation and neutron emission. There are also fewer convenient sources for higher energy neutrinos.

There are cosmological observations [8] which are in tension with the possible existence of sterile neutrinos ($N_{eff} = 3.2 \pm 0.5$ and $\Sigma m_{\nu} < 0.32$ eV).

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