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Technology and Instrumentation in Particle Physics

The HANOHANO Detector and Ongoing Research and Development

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Abstract

The Hanohano neutrino detector is a deep sea module that can be submerged to the ocean floor far away from surface radiation. Its Physics goals are the study of geo-neutrinos to probe the isotope source of the 45 TW of heat driving all of geodynamic processes in the earth, enhanced studies of neutrino oscillation from reactors through variable distance observations, and as an observatory for astro-physical neutrino sources. Nuclear surveillance of unknown nuclear reactors can be a key mission for a mobile neutrino detector that is also under consideration. The Hanohano detector details will be presented and a summary of the continuing research and development at the University of Hawaii for neutrino direction detection development will be reviewed.

Geoneutrinos; nuclear proliferation; georeactor; hanohano; neutrino; θ_{13}

1. A mobile neutrino detector

The HANOHANO neutrino detector will be a 10 kiloton scintillation detector that can be utilized for many purposes. The HANOHANO detector differs from other projects in that the detector will be portable and will be placed on the ocean floor. There are many aspirations for the HANOHANO detector but there are three goals that are the driving force behind the design and deployment. Those goals are to build a portable detector that can be transported large distances in order to be used for nuclear proliferation, to take measurements of the unknown mixing angle θ_{13} to further assist in determining the neutrino mass hierarchy, and to probe the neutrino flux from the mantle of the earth in order to determine the possibility of a natural nuclear reactor located at the earth's core.

1.1 The Detector

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The detector will be a 10 kiloton liquid scintillation detector. It is set to contain 4300 photomultiplier tubes (PMT) each spaced 0.8 m apart and each containing two hemispherical glass casings with syntactic foam between the casings to prevent implosion (since one PMT implosion is roughly equal to 600 kJ of energy and could cause a cascade of PMT failures). The scintillation liquid will be Linear Alkybenzene (LAB) which is a precursor to soap and is quite cost effective [1]. The casing will be stainless steel with a surface roughness less than 6 µm. Each PMT will run on less than 1 W and this will be effective in keeping the total power of the detector low. The detector will then be loaded on an oil tanker whose size cannot exceed 32.3 m in width and 6 m in draft (in order to fit through the Panama Canal and the locks of the Volgograd Seaway) [1]. The main tanker will contain quarters that

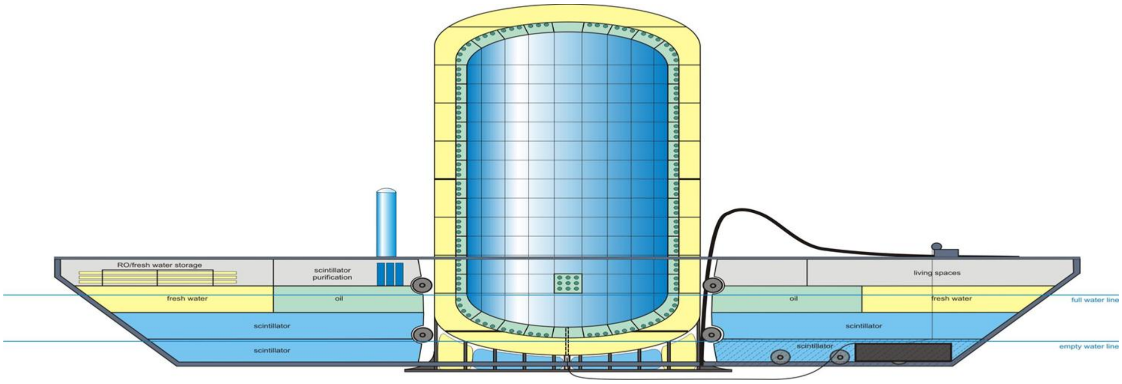

Figure 1: A schematic of the proposed neutrino detector, (CEROS), by J. VanRyzin et al [1]

scientists can live and work in while carrying out their research (Figure 1). The detector will be filled prior to deployment and an anchor will be attached. The detector will then descend to the ocean floor (approximately 4 km) where the anchor will hold the detector in place as it floats above the ocean plain. (figure 2). The deployment will last approximately 1 year and upon completion the anchor will be discarded and the detector can then float to the surface for maintenance or redeployment. Additionally, the detector can be kept on the tanker and observations can be taken directly on the boat.

1.2. Geo-neutrinos

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A geo-neutrino is an anti-neutrino resulting from the inverse beta decay of Uranium, Thorium Potassium, and other radioactive elements and is described by the reaction $n+p \rightarrow d+\gamma$. After the first reaction, the positron will emit a flash of light when it annihilates with an electron. The unstable neutron will then pair off with the proton to create deuterium and energy. The energy given off in the product of this reaction is proportional to the initial anti-neutrino energy. However, the 1.8 MeV will be the threshold energy that will be measured and noting the maximum energies of the three elements (Table 1), one can see that Potassium will not be able to be detected by inverse beta decay.

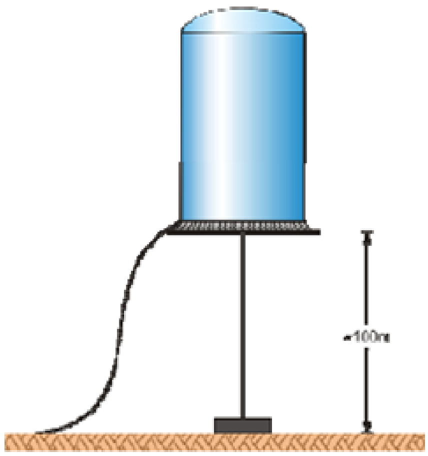

Figure 2: Neutrino detector deployed on the sea floor (picture from Makai Ocean Engineering Inc.) [1]

The first geo-neutrino discovered was by the KAMLAND project in Japan [2]. However, the geological aspirations of using KAMLAND to find geo-reactor anti-neutrinos is difficult due to the sheer amount of background crustal anti-neutrinos [2]. However, a detector far away from commercial nuclear reactors and at the bottom of the ocean (like Hanohano) would be perfect for finding a hypothetical geo-reactor.

Table 1. Maximum energies (adapted from Fiorentini et al) [3]

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The main properties of geo-nuetrinos	$T_{1/2}$ (10^9 yr)	E_{max} (MeV)
$^{238}U \rightarrow {}^{206}Pb + 8\,{}^{4}He + 6e + 6\,\bar{\nu}$	4.47	3.26
$^{232}Th \rightarrow {}^{208}Pb + 6\,{}^{4}He + 4e + 4\,\bar{\nu}$	14	2.25
$^{40}K \rightarrow {}^{40}Ca + e + \bar{\nu}$	1.28	1.31

1.3. Portability

One of the HANOHANO's main goals is portability. Many neutrino detectors such as KAMLAND's, SNO's and Borexino's are firmly entrenched underground and once in place, are extremely difficult to remove. What sets HANOHANO apart is that it is portable and can be deployed all over the world.

1.41 Mixing Angle θ_{13}

Another goal of HANOHANO is to determine the unknown mixing angle θ_{13} in the three neutrino mixing scenario in order to determine the mass of neutrinos. This will be done by placing the detector approximately 30, 40, 50 and 60 km offshore of the San Onofre Nuclear Reactor and then measuring the resulting reactor neutrino flux [1]. A unique aspect of the HANOHANO project is the portability. Not only can the project use the San Onofre site, but it could also utilize the anti-neutrinos from many other commercial reactors simply by relocating this portable detector.

1.42 Astro-physical research

In addition, another goal is to use this massive detector for astro-particle research. This detector will have a much higher flux due to its massive size and could yield a plethora of useful results once the background activity has been identified and accounted for. And due to its portable nature, the detector

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could be deployed at many locations across the globe and could produce results from both the northern and southern hemisphere.

1.42. Mantle Geo-neutrinos and Geo-reactor anti-neutrinos

The third goal is to measure the geo-neutrinos emanating from the earth's mantle. According to the Bulk Silicate Earth Model (BSE), Uranium, Thorium and Potassium are lithophile elements and exist as oxides, therefore they will only appear in the mantle and crust but not in the core [4]. About 19 TW of power comes from the decay of Uranium, Thorium and Potassium (as measured by geochemists sampling the upper mantle). The heat flux for a square meter is 60 mW which leads to the total power of the earth somewhere between 35 and 45 TW. The BSE model holds that the terrestrial heat comes from radioactive decay. If this were true then the two previously given values would match up. But this is not the case because estimates show the radioactive heat at 100% of the power emanated [3]. This is problematic because gravitational energy, tidal friction, and other forms of thermal radiation are neglected. As a result, there is a huge discrepancy between the measured heat flux and the flux predicted by the BSE [3].

A solution to this mystery could be a hypothesized geo-reactor, a theory put forth by J. Marvin Herndon that is gaining attention from geoscientists. The ratio of Thorium to Uranium is 4 which matches up with chondritic meteorite samples, however the ratio of Potassium to Uranium is 10,000 and is off by a factor of 7 when compared to meteorites. In addition to this, the $^3He/^4He$ ratio is much higher than those sampled from the meteorite samples. This is interesting since ^3He is a direct result from nuclear fission. Also to note is that there is evidence of nuclear fission in Earth's past. In 1972 a Uranium ore seam in a mine in West Gabbon, Africa showed evidence of nuclear fission which leads one to hypothesize that fission could occur deep inside the earth.

Another interesting mystery is the earth's magnetic fields. The BSE model holds that the convection of the conductive mantle acts as a dynamo and the radioactive heat is what supplies the energy to keep the dynamo going. As a result, the earth has a magnetic field. However, a 1 TW nuclear reactor at the core (where the BSE holds the core to be a nickel-iron alloy), could provide the heat to keep the

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dynamo moving [5]. In addition, many other planets have magnetic fields and some, such as Jupiter, also have heat flux discrepancies. If there is a nuclear reactor at the core of all planets with a magnetic field, then this have a major impact into the fields of both geology and planetary sciences.

1.43 Nuclear Surveillance

The portability is particularly important with nuclear proliferation enforcement. If a certain nation wants to monitor another government for nuclear purposes, they can take the neutrino detector to a location off the shore of that country and coast by effectively creating a crude sonogram. Reactor anti-neutrinos are more energetic than their geo-neutrino relatives and average around 6 MeV. The detector's threshold could be set at 3.26 MeV (the maximum energy from Uranium decay) and the vast majority of the anti-neutrinos detected above that energy threshold will have to come from a reactor (neglecting a hypothetical geo-reactor). And unless the nuclear operations are shielded with ½ a light-year thick sheet of lead, there will be anti-neutrinos available for detection.

1.43. Detector Placement

In order to utilize a detector to find geo-neutrinos and geo-reactor neutrinos one needs to get rid of as much background as possible by going deep into the earth. And while many other neutrino detectors are located in the crust of the earth, this detector differs from the others by its proposed location on the ocean floor. Since a large part of the background is continental and oceanic crustal neutrinos, then the solution is to get as close to the mantle as possible. In Figure 4, one can notice in the cross-section in the top right-hand corner how the oceanic crust is much smaller than the continental crust. Therefore a detector placed on the ocean floor would be close to the earth's mantle and far from commercial reactors.

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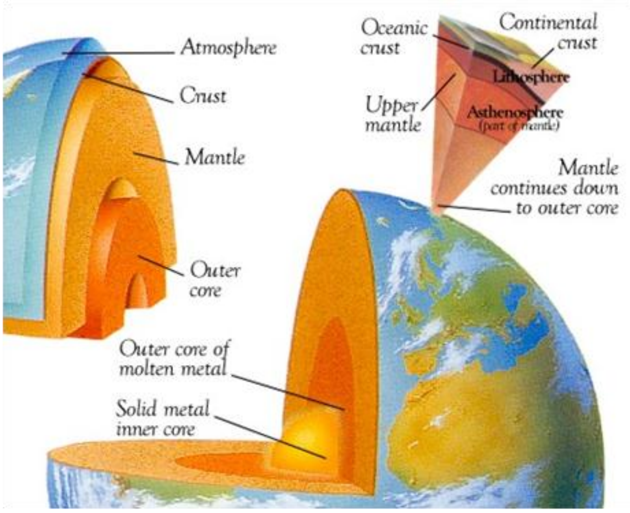

Figure 4: Earth's Interior (Colin Rose, Dorling Kindersley) [6]

(located inside the stars on Figure 5). So the perfect location would be Hawaii's Abysmal Plain which is also close to the University of Hawaii, a key player in the HANOHANO project.

Despite being on the ocean floor, there will still be background coming from the crust, the atmosphere, and space. These background events include (but are not limited to) Lithium-9, fast neutrons and commercial reactors [4]. In particular, notice that by placing the detector on the ocean floor far from commercial nuclear projects that the reactor and crustal anti-neutrinos drop dramatically. Table 2 summarizes the lower energy backgrounds and compares them to two other neutrino projects to give a scale of the potential of HANOHANO. When viewing the higher energy neutrinos (from 3.4 MeV to 9.3 MeV), the commercial reactor neutrino background jumps, however, 38 events from a hypothetical geo-reactor should be recorded. Table 3 summarizes the higher energy backgrounds.

1.7. Conclusion

In conclusion, the Hanohano project will have a broad reach into many fields and could yield

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results that could change the world of particle physics by unraveling the mysteries of the cosmos and by finding the unknown mixing angle θ_{13}, the world of geochemistry and geophysics by solving the problem of the missing terrestrial heat, and even the world of national defense by creating a fool-proof way of monitoring rogue nations' nuclear pursuits. But these three goals are unlikely to be achieved unless a portable ocean-based detector is used.

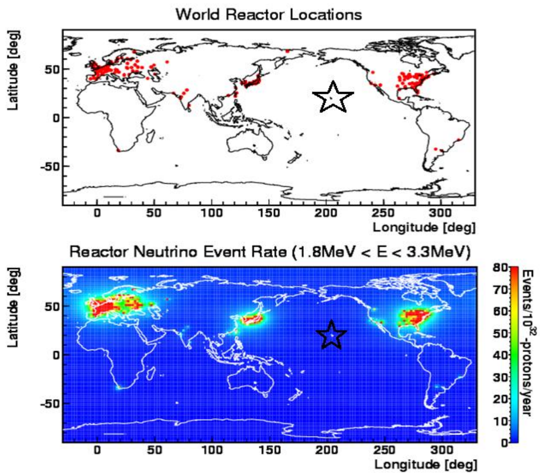

Figure 5: (a) Reactor Events [7]

Table 2: Background for 1.8 MeV – 3.4 MeV [4]

		Events (10 kT-yr)$^{-1}$	
	SNO+	Borexino	Hanohano
^{9}Li	0 ± 0	3 ± 1	3 ± 1
^{210}Po	8 ± 2	8 ± 2	8 ± 2
Accidental	42 ± 1	42 ± 1	42 ± 1
Reactor	528 ± 21	295 ± 12	12 ±1
Crustal Geo-neutrinos	368 ± 74	279 ± 56	31 ± 6
Total Background	946 ± 77	627 ± 57	96 ± 7
Mantle	79	79	79

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Table 3: Background for 3.4 MeV – 9.3 MeV [4]

Geo-reactor Background	Rate (10 kT-yr)$^{-1}$
^{9}Li (at 4 km depth)	4 ± 1
210Po	1 ± 1
Accidentals	1 ± 0
Commercial Reactors	24 ± 1
Total Background	30 ± 2
Geo-reactor	38

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