The Hunt for Red October

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Nuclear-powered submarines are useful only as long as their position is unknown to the enemy. However, they emit a steady flux of electron antineutrinos resulting from the beta-decays of the fission fragments. Your task is, to either come up with a neutrino-based scheme which can pinpoint the location of a submerged nuclear-powered submarine or to convince the admirals that their submarines are safe from this threat.

Nuclear energy has revolutionized submarine warfare. Military submarines can stay submerged for months and move stealthily at high speeds through the oceans. Submarine-launched ballistic missiles (SLBM) are the backbone of nuclear deterrence since they offer an assured retaliatory capability. A submarine whose location has been uncovered by an adversary is usually relatively defenseless and thus avoiding detection is the operational priority of any submarine captain. Any major breakthrough in either avoiding detection or improving detection would have major consequences for naval and nuclear doctrine, see Ref. [1].

Conventional means to detect submarines center on acoustic signatures, but also electro-magnetic, temperature and chemical signatures have been proposed. Even exotic means outside of the realm of science like extrasensorial perception have been seriously investigated.

For the purpose of this mission, assume that a nuclear-powered submarine has a reactor with a thermal power of 150 MW. Its submerged top speed is 45 knots and its maximum diving depth is 300 m. The reactor power is proportional to the speed, a rough but useful approximation.

The antineutrino spectrum per fission from a submarine reactor can be approximated to stem only from fission in uranium-235, neutrino fluxes can be found in Ref. [2]. Neutrinos from reactors can interact via both charged current and neutral current reactions, for a review see [3]. Common detector types for charged current neutrino reactions are either liquid scintillator, *e.g.* KamLAND [4], or water Cerenkov types, *e.g.* Super-Kamiokande [5]. Both detector types profit from the addition of gadolinium to improve neutron tagging [6, 7]. Also neutral current reactions of low-energy neutrinos have been measured, for a recent results see Ref. [8].

During the Cold War the focus was on finding or concealing SLBM carrying submarines in the open, deep blue ocean and a detailed analysis of neutrino detection can be found in a JASON report [9]. The conclusion is rather negative, however the basic concepts how to approach the problem are sound. Neutrino detector technology has however made great progress in the past 30 years.

In your analysis focus on scenarios not involving the open ocean and not necessarily involving SLBMs. Think of current political events. Your task is, to either come up with a neutrino-based scheme which can pinpoint the location of a submerged nuclear-powered submarine or to convince the admirals that their submarines are safe from this threat.

You will need to come up with a detection reaction, a detector technology and then be able to compute event rates as a function of distance and speed of the submarine. Based on the specific application your thinking of, you will need come up with a search strategy or avoidance strategy. Statistical analysis would be useful, you can resort to the PDG review of statistics (written by G. Cowan who is lecturing at this school). Think of backgrounds, if you can. Note, that a submarine costs about as much as the LHC, that is 10^{10} USD/EUR. Some reactions allow to reconstruct neutrino direction. Imagine future technologies.

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[1] "The Hunt for Red October," Paramount Pictures (1990).
[2] P. Huber, Phys.Rev. **C84**, 024617 (2011), arXiv:1106.0687 [hep-ph].
[3] J. A. Formaggio and G. P. Zeller, Rev. Mod. Phys. **84**, 1307 (2012), arXiv:1305.7513 [hep-ex].
[4] K. Eguchi *et al.* (KamLAND), Phys. Rev. Lett. **90**, 021802 (2003), arXiv:hep-ex/0212021 [hep-ex].
[5] Y. Fukuda *et al.* (Super-Kamiokande), Phys. Rev. Lett. **81**, 1562 (1998), arXiv:hep-ex/9807003 [hep-ex].
[6] F. P. An *et al.* (Daya Bay), Phys. Rev. Lett. **108**, 171803 (2012), arXiv:1203.1669 [hep-ex].
[7] J. F. Beacom and M. R. Vagins, Phys. Rev. Lett. **93**, 171101 (2004), arXiv:hep-ph/0309300 [hep-ph].
[8] D. Akimov *et al.* (COHERENT), Science **357**, 1123 (2017), arXiv:1708.01294 [nucl-ex].
[9] S. T. C. Callan, F. Dyson, *Neutrino Detection Primer*, Tech. Rep. JSR-84-105 (JASON, 1988) `www.dtic.mil/dtic/tr/fulltext/u2/a193805.pdf`.