Neutrino Emissions from Plutonium-241 and Spent Nuclear Fuel

Patrick Huber, Morgan Roadman

Abstract

This project examines the emissions of neutrinos from plutonium-241 and spent nuclear fuel. By analyzing these signals, we aim to improve our understanding of the behavior of neutrinos in different storage environments for used nuclear material. The study evaluates the characteristics of these emissions, concentrating on detection and measurement, and the potential use of plutonium-241 in experimental applications.

Introduction/Background

Spent Nuclear Fuel and Plutonium:

Spent Nuclear Fuel is intensely radioactive for a long period of time, requiring long-term safe storage. Spent fuel poses the risk of radiation, and it also contains large amounts of plutonium, which could be used to create nuclear weapons. The amount of plutonium-239 required to make a bomb is about 4 kg. A singular storage container holding 5 tons of fuel can contain 25-50 kg of that isotope.

Neutrino Detection:

Detection of neutrinos from spent nuclear fuel using inverse beta decay (IBD) has been considered [1]. However, only fission fragments, chiefly strontium-90, make neutrinos of sufficient energy for this reaction. We present here, for the first time, a study of the neutrino signals arising from the decay chains of the actinides themselves. Their neutrino emissions are all very low energy and hence cannot be detected via IBD. Detection through coherent elastic neutrino-nucleus scattering (CEvNS) is ideal for neutrinos from actinides since, in principle, it has a zero energy threshold.

Neutrino Yield:

The table below illustrates the event rates obtainable for 1 kg of isotope with a 1 kg detector at 1 meter in one year:

Isotope	CEvNS 0eV	CEvNS 1eV	CEvNS 10eV	CEvNS 100eV
Pu-239	4.019 E-10	1.479 E-11	1.045 E-11	1.864 E-12
Pu-241	0.0266	1.381 E-6	5.128 E-10	8.316 E-11
U-235	4.280 E-7	3.343 E-9	4.453 E-10	2.463 E-15
U-238	3.437 E-7	1.609 E-7	4.015 E-9	4.834 E-12

Plutonium-241:

Out of these isotopes, plutonium-241 is the most promising candidate. It is also a direct tracer of the total plutonium content. Pressurized water reactor (PWR) spent fuel contains .15% Pu-241, while boiling water reactor (BWR) spent fuel contains .12% Pu-241 [2].

Neutrino Emissions

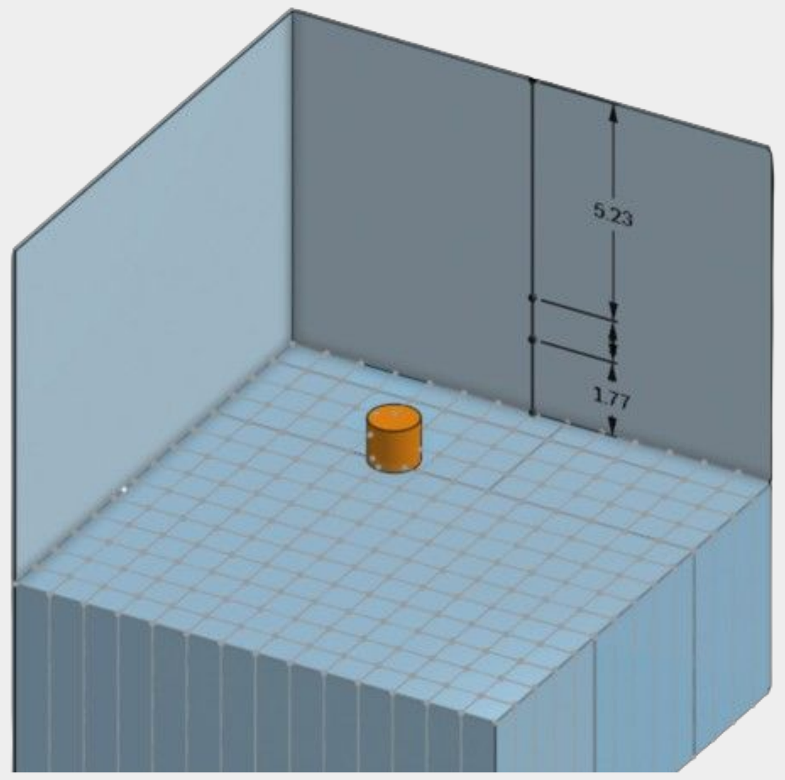
Dry Storage at Big Rock Point

Big Rock Point was a boiling water reactor that operated from 1962 to 1997. It has since been decommissioned, and the site now holds 8 canisters of nuclear waste [3]. The site approximately contains 69.48 kg of plutonium-241 [4]. The distance between the detector and the center of the storage on the concrete pad is 31.64 meters.

Signals per year:
0 eV CEvNS - 1.848
1eV CEvNS - 9.583 E-5

Wet Storage at Clab

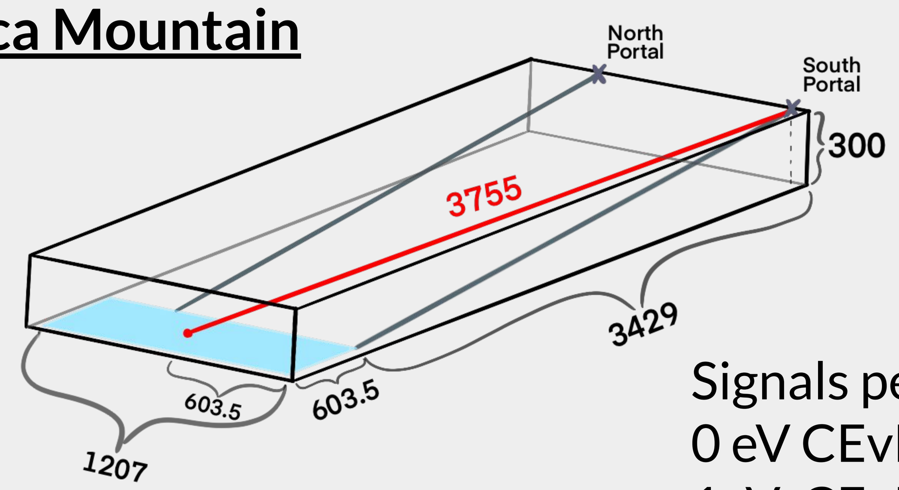
The Clab is a waste repository for spent fuel from all of Sweden's nuclear plants. It consists of 8 sections of cooling pools, each approximately holding a 14-by-14 grid of storage canisters [5]. Each cooling pool contains about 705 kg of plutonium-241 from BWRs, 281.25 kg from PWRs, and 67.5 kg from miscellaneous sources [6]. With a distance of 4.77 meters we obtain:



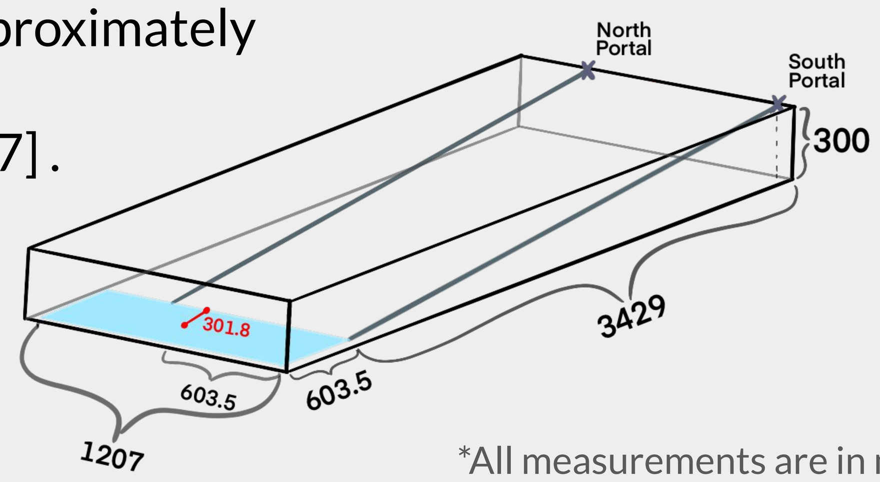
Signals per year:
0 eV CEvNS - 1233
1eV CEvNS - 0.06395

Geological Repository at Yucca Mountain

The proposed design of Yucca Mountain features a waste storage repository 300 meters underground, accessed by two ramps which lead to portals on the surface. The repository can hold 70,000 MTHM, approximately 98,000 kg of plutonium-241 [7].



Signals per year:
0 eV CEvNS - 0.1850
1eV CEvNS - 9.597 E-6



0eV CEvNS - 28.64
1eV CEvNS - 0.001486

All measurements are in meters and we assume a 1000kg detector

Conclusion

- To obtain a sufficient number of actinide neutrino signals, we need the lowest possible recoil threshold of 1 eV or better
- Need to be very close to the source for best results
- Only spent fuel ponds have enough inventory combined with a close enough standoff to yield usable rates
- Ton-scale detectors would work with those caveats
- Backgrounds were not considered, but the spent fuel pond location likely provides reasonable shielding from cosmic ray neutrons

Currently, no technology exists that can provide detectors of the required scale with the necessary very low recoil energy threshold. Once such a technology becomes available more detailed studies of the backgrounds will be needed to assess feasibility as safeguards technology.

References

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Acknowledgements

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