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Antineutrino detection concepts for safeguarding spent nuclear fuel

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Abstract. Spent nuclear fuel (SNF) from nuclear power generation requires long-term safeguards in interim storage and final disposal. Current safeguarding approaches for spent fuel storage facilities (SFSFs) propose a combination of material accountancy, containment and surveillance, and design information verification. Antineutrino emissions from the ongoing beta decay of fission fragments could provide complementary information on the potential diversion of nuclear material and misuse of the facility or assist in reverification scenarios as antineutrinos pass through any shielding, structure, or geology effectively unhindered.

Antineutrino-based safeguards approaches have been discussed and have been under development for nuclear reactor sites for several years. In this relatively recent field of applied antineutrino monitoring, several approaches have been developed, ranging from scintillator-based technologies to large water Cherenkov detectors, each of which is suitable for different deployment scenarios. Utilising this principle for SNF is uniquely challenging, as the antineutrino flux of cooling fuel elements is several orders of magnitude lower than of an active core. In addition, the typical beta decays in SNF emit a softer antineutrinos energy spectrum, requiring large detectors sensitive to signals close to the inverse beta decay energy threshold. This study investigates a range of current technologies that have been proposed for reactor monitoring, along with a novel antineutrino detection concept using a liquid organic (LOr) time projection chamber (TPC). The LOr-TPC concept combines the scalability and high-resolution particle reconstruction of TPCs with the large quantity of target hydrogen atoms provided by organic compounds.

The expected signal rate, sensitivity to inventory changes, and directional capabilities of all technologies are estimated and compared against each other for two simplified storage sites, namely one based on an interim storage facility and one based on a geological repository. For each simplified site, varying fuel ages, cask distributions, and detector deployment scenarios are investigated. This comparison will be used to determine the feasibility and potential of antineutrino monitoring as a complementary safeguards tool for SNF storage sites.

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