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Development of two-phase emission detector technology for monitoring nuclear reactor cores using the effect of coherent elastic scattering of reactor neutrinos off nuclei

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The fundamental process of coherent elastic neutrino-nucleus scattering (CEvNS) has been predicted based on the Standard Model of elementary particles and interactions more than 40 years ago. For heavy nuclei, the cross-section of this process exceeds (in more than two orders of magnitude) the cross-sections of other known low-energy neutrino interaction processes such as inverse beta decay and neutrino scattering off atomic shell electrons. This interaction channel plays a significant role in Universe processes accompanied by intensive neutrino fluxes and can be used to monitor the state of nuclear reactor cores enhancing nuclear power safety. The CEvNS process was first detected in an accelerator experiment in 2017 by the international COHERENT collaboration, in whose work some of the authors of this project participate. Detecting the CEvNS process for reactor neutrinos is a significantly more challenging task, as the energy release from elastic coherent scattering off heavy atomic nuclei does not exceed a few hundred eV. At the Inter-departmental Laboratory for Experimental Nuclear Physics of NRNU MEPhI the RED-100 cryogenic two-phase emission detector has been developed and constructed to study the CEvNS process for reactor electron antineutrinos. The detector is based on a technology first proposed at MEPhI approximately 50 years ago and currently used worldwide in experiments searching for dark matter particles in the Universe. In 2020–2022 the RED-100 detector, utilizing ˜200 kg of liquid xenon as working medium, underwent testing at the Kalinin Nuclear Power Plant. The experiment demonstrated that the reactor neutrino detection technology developed at NRNU MEPhI is capable of detecting the CEvNS effect in a nuclear power plant environment. This study provided the best current upper limit on the CEvNS cross-section for xenon nuclei, which is consistent with the Standard Model. Preparatory work has since been carried out for an experiment using a modified version of the RED-100 detector aimed at detecting reactor neutrinos via the CEvNS interactions with argon nuclei serving as the neutrino target. An analysis of the results from the first experiment using liquid xenon as the working medium of the RED-100 (2020–2022), combined with laboratory tests of the RED-100 using liquid argon (2025–2026), has shown that using argon atoms as a target for reactor neutrinos will enable reliable observation of the CEvNS effect. To verify this conclusion, it is proposed to conduct the second test of the RED-100 setup with liquid argon working medium at the Kalinin NPP. This project aims to develop independent methods for the remote monitoring of the active core of NPP reactors.

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