Final Report for Award DE-SC0019316
Title: Collaborative Research Towards a tonne-scale bolometer-based neutrinoless double beta decay experiment
PI: Prof. T.O'Donnell, Virginia Tech

Narrative:

This award supported Virginia Tech scientists to execute and analyse data from cryogenic tests of scintillating bolometers for a next-generation neutrinoless double beta decay search concept called CUPID. The tests were carried out at the Cryogenic Test Facility in Hall C of Gran Sasso Underground Laboratory.

Cryogenic bolometers are an excellent technology for neutrinoless double beta decay searches owing to their very high energy resolution and potential for high radiopurity. The current most advanced large-scale experiment using these detectors is the Cryogenic Underground Observatory for Rare Events (CUORE) [1]. The largest source of background in CUORE is degraded alpha particles, emitted from shallow depths of the detector holders, which can deposit a thermal energy signature similar to neutrinoless double beta decay. To mitigate this α particle background, the CUPID concept (CUORE Upgrade with Particle IDentification) proposes to use scintillating cryogenic detectors. Detecting both the scintillation light and the thermal signal allows discrimination between alpha particle events and beta/gamma events. The purpose of the R&D test measurements was to optimized the design of the single detector module, in particular the scintillation light collection efficiency and explore the impact of pileup of events on the background.

The test detector array consisted of 8 cubic Lithium Molybdate crystal ($Li_2^{100}MoO_4$) enriched to $\sim 97\%$ in ^{100}Mo, the candidate isotope for the neutrinoless double beta decay search. The 8 crystals were assembled into a mini tower (see left part of Figure 1) with two floors containing 4 crystals each. Each crystal measured 45 mm on the side and had a mass of 280 g. Each crystal was instrumented above and below with a cryogenic light detector (a thin Ge wafer, also operated as a bolometer) to detect the scintillation light. To explore the impact on the

light collection efficiency the crystals on the bottom floor were surrounded by a reflecting foil. To investigate the time resolution of the detectors, each one was instrumented with heaters via which controlled thermal events could be injected into the system.

The detector was operated at approximately 18 mK in the cryogenic test facility operation by the CUPID collaboration at Gran Sasso Underground Lab in Italy. The Virginia Tech personnel supported by the grant contributed to assembly of the test array, cryogenic operations onsite at Gran Sasso and analysis and interpretation of the data. The right plot in Figure 1 summarizes the observed light yield vs thermal energy for crystals with and without reflecting foil. Based on this data, we conclude that with two light detectors per crystal the light collected is sufficiently high even without reflecting foil to distinguish between alpha particle and beta/gamma particle events. This is an important result for the design of the CUPID experiment.

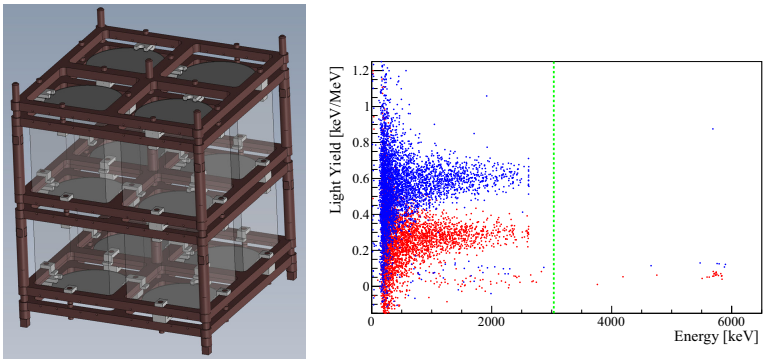

Figure 1: Left: Rendering of the mini-tower of prototype detectors tested during the R&D measurements. Light yield measured in a cryogenic light detector as a function of the energy deposited in the main thermal detector surrounded by the reflecting foil (blue) and without reflector (red). Data were collected with a 232Th γ source and a smeared α source. Images reproduced from Ref [2].

The results of the R&D measurements supported by this award have played a crucial role in informing the design of the single detector modules to be used in the CUPID experiment. The award supported training and research-education opportunities for junior researchers from Virginia Tech including a postdoc and graduate students.

Publications from the final grant period

Refereed Journal Publications

- A. Armatol *et al.* [CUPID], "Characterization of cubic $Li_2^{100}MoO_4$ crystals for the CUPID experiment," Eur. Phys. J. C **81**, no.2, 104 (2021)
- A. Armatol *et al.* [CUPID], "Novel technique for the study of pileup events in cryogenic bolometers," Phys. Rev. C **104**, no.1, 015501 (2021) doi:10.1103/PhysRevC.104.015501

Bibliography and References Cited

[1] C. Alduino *et al.* [CUORE], Phys. Rev. Lett. **120**, no.13, 132501 (2018) doi:10.1103/PhysRevLett.120.132501 [arXiv:1710.07988 [nucl-ex]].

[2] A. Armatol *et al.* [CUPID], "Characterization of cubic $Li_2^{100}MoO_4$ crystals for the CUPID experiment," Eur. Phys. J. C **81**, no.2, 104 (2021) doi:10.1140/epjc/s10052-020-08809-8 [arXiv:2011.13656 [physics.ins-det]].