The CUPID project aims to find new physics by detecting neutrinoless double beta decay. Since it is critical to ensure low backgrounds, we analyzed the radioactive spectrum of Lithium Molybdate, placing upper limits on the activity at high energies.

**BACKGROUND**

**Beyond the Standard Model - Neutrinoless Double Beta Decay**
- The Cryogenic Underground Observatory for Rare Events (CUORE) and the CUORE Upgrade with Particle Identification (CUPID) are the largest projects using cryogenic particle detectors to search for neutrinoless double beta decay.
- Double beta decay (DBD) occurs when a (2) parent nucleus decays to a (A Z+2) daughter. In normal modes, two electrons and antineutrinos are released.
- Neutrinos are hypothesized to be Majorana fermions – in neutrinoless DBD, the neutrino acts as its own antiparticle and self-annihilates, releasing only two electrons.
- Since neutrinoless DBD violates lepton number conservation, its discovery would provide powerful evidence for theories beyond the Standard Model. Furthermore, no antileptons are released, making this an important mechanism to study in explaining the matter-antimatter asymmetry.

**CUORE’s search for new physics**
- Theoretically, neutrinoless DBD has a clear experimental signature. Since no antineutrinos are released, the transition energy of the nucleus is transferred to the outgoing electrons. Neutrinoless DBD is then marked by a distinct peak in the electron energy spectrum, at the endpoint of the normal DBD spectrum.
- CUORE’s challenges are in distinguishing this peak; neutrinoless DBD has a small signal since it occurs extremely rarely, with lifetime limits above $10^{26}$ years.
- To achieve the energy resolution and low backgrounds necessary, it is critical to carefully research detector materials. CUORE’s solution is bolometers, cryogenic particle detectors with high resolutions and efficiencies. Ton-scale arrays of Tellurium dioxide crystals, the DBD source, are coupled with thermal sensors to maximize the probability of detecting neutrinoless DBD.

**RESULTS**

**High Energy LMO Spectrum**
- We find no statistically significant evidence of excess events in LMO above 3034 keV.
- At the 90% confidence level, we place an upper limit of 1.0 counts/day on additional activity at 3034 keV.
- However, the high background limits our detector’s sensitivity to small signals.
- Activating the sample under high intensity neutron and proton beams at an accelerator facility will amplify cosmogenic signals. Analysis on this will more conclusively show if significant features in the high energy spectrum exist.

**Potassium-40 Impurity**
- We observe significant activity at the 1461 keV energy and conclude that the LMO sample contains potassium-40 impurities.
- Preliminary simulations in Geant4 place 23.5 ± 2.8 micrograms in the sample.
- Future work will need to address this; pile-up events from potassium-40 can interfere with measurements of activity at higher energies.

**Detector Background Bismuth-207 Peaks**
- In the detector background, two peaks at 569 and 1063 keV were noted.
- These energies are not consistent with decay radiation in uranium-238, thorium-232, or other common radioisotopes and are attributed to bismuth-207.
- The source of bismuth-207 in our experiment is under investigation.
- Bismuth-207 is not naturally occurring - it could be a product of cosmogenic activation in lead or environmental contamination from nuclear fallout.
- Simulations in Geant4 of bismuth-207 decay in lead can help determine which is more consistent with the observed activity.

**ACKNOWLEDGMENTS**

I would like to thank my program mentor Dr. Thomas O’Donnell and his graduate students Vivek Sharma and Joe Camillieri for their comments and advice on this project. I would also like to thank the NSF for funding this project as part of the Virginia Tech Center for Neutrino Physics REU program.

**REFERENCES**
- CERN, APPEC Community Meeting On Neutrinoless Double Beta Decay (2010).
- The CUPID Interest Group, CUPID Preprint (2019).
- Virginia Tech Center for Neutrino Physics Site, CUORE Experiment Reaches Major Milestone.