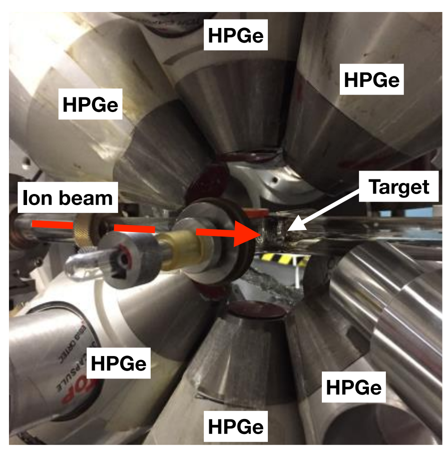
TECHNICAL SUPPLEMENT

Motivation and relevant background: The release of excess energy from atomic nuclei typically occurs on rapid timescales (on the order of femtoseconds). However, metastable states can occur that store excess energy for timescales spanning over 30 orders of magnitude. Such long-lived excited states, or nuclear isomers, have been proposed as supporting future energy-and-power applications, as recently reviewed by scientists from the CCDC/Army Research Laboratory (ARL) [1]. Energies stored by isomers are extreme, being typically 100,000 times larger than the chemical limit. However, their utilization will require external means to induce a release of the stored energy upon demand. Detailed mapping of the nuclear levels connected to the isomer is of paramount importance in searching for depletion mechanisms for nuclides of interest.

The complex interplay between nuclear particles (protons and neutrons) is an N-body problem, with N as large as 200 in many relevant cases, which makes it impossible to accurately predict the existence of suitable depletion mechanisms for nuclei. The ARL has an established program of research dedicated to searching for energy-release mechanisms for various isomers, as exhibited in the open literature. These include ^{108}Ag (isomer half-life of 438 years) [e.g. 2] and ^{186}Re (isomer half-life of 200,000 years) [e.g. 3]. The experiments providing those results were obtained at multiple facilities in separate ad hoc collaborations. Recent study of ^{93}Mo (isomer half-life of 6.85 hrs) yielded the first experimental observation of Nuclear Excitation by Electron Capture (NEEC), by which the nuclear isomer is excited to an intermediate state with a rapid depletion pathway via the electron capture process [4].

Research objective: In discussions with ARL scientists, it has been made clear that there is timely need to initiate similar studies across a number of candidate nuclei. The purpose of the proposed research is to conduct a dedicated campaign of investigation into the nuclear levels of ^{113}Cd [5], on behalf of ARL's isomer depletion program. The experimental study will map the energy levels and transitions between excited states for this nucleus, and identify, if they exist, suitable levels to support an induced energy release from a 14-year isomer. This research will utilize a combination of nuclear-spectroscopic techniques and reactions at the Heavy Ion Accelerator Facility (HIAF), Australian National University (ANU). Part of the proposed research will leverage off a new particle detector device developed by Lane in a previous ITC project.



Approach: The HIAF possesses both tandem and linac-type accelerators, and can produce a variety of particle beams for different reactions. Of particular importance is the uniquely flexible beam-pulsing capability that enables the separation of beam bursts to be closely matched to isomer lifetimes to optimize measurement sensitivity. In addition, HIAF possesses the CAESAR gamma-ray spectrometer (see figure right and Ref. [6]), consisting of up to eleven high-purity germanium (HPGe) detectors that can be used to obtain time-correlated, gamma-ray coincidence spectra. The presence of two LEPS detectors in CAESAR, tailored for the detection of low-energy transition between levels and emission of X rays, is an important tool in identifying new gamma-rays associated with the decay of ^{113}Cd from their observed coincidence relationships. The combination of flexible beam-pulsing in almost any time range and the design of CAESAR that enables coincidences to be measured within and between beam bursts, as well as time-correlations across long-lived states, provides maximum capability for identifying isomeric states, measuring their lifetimes and characterizing their feeding and decay transitions. This type of gamma spectroscopy is critical to being able to map the nuclear levels and transitions, as needed to explore energy-release mechanisms for ^{113}Cd.

A series of experiments are proposed to study ^{113}Cd. The ^{110}Pd(α,n)^{113}Cd reaction can be used to validate the locations and characteristics of the low-spin states in ^{113}Cd. Delivery of alpha-particle beams are currently under development; this project will be one of the first to capitalize from this new research capacity. The ^{110}Pd(^{7}Li,*t* n)^{113}Cd breakup reaction will bring more angular momentum into the ^{113}Cd nucleus to better access states above the 14.1-year isomer. Depending on the nature and quantity of new states revealed by the Li-7 reaction, a ^{110}Pd(^{9}Be,αn)^{113}Cd breakup study with a Be-9 beam may also be deployed. In the breakup reactions [7], outgoing charged particles will be detected by a novel charged-particle detector developed under a previous ITC Project. Measuring these alpha-gamma coincidences provides another check that new transitions can be reliably confirmed as belonging to ^{113}Cd. It is worth noting that relatively few accelerator facilities around the world are willing to use ion beams that generate high neutron fluxes with HPGe detectors due to the damage associated with neutron reactions degrading the energy resolution of the detectors. This will utilize a new technical capability for HIAF that is being developed in 2019.

Analysis of these very large datasets involves exploitation of correlations in the data to reconstruct pathways through which excited nuclear states decay through gamma emission. This is a complex task and the length of time required to deduce the level scheme varies depending on the individual nature of each nucleus. We anticipate that by performing the experiments early in the first year and employing a research student to work on the data, progress will be made within 12 months to gauge the level of success in identifying the intermediate states relevant to inducing energy release from the isomer.

If a 12-month option year were available, it would be possible to extend this work to include the nucleus ^{127}Cs. This is a proposed candidate for NEEC and, adopting the above approach, significant expansion to the nuclear level scheme would be achievable.

Conclusion: The ability to perform multiple experiments at one facility, using cutting-edge experimental techniques and a flexible accelerator system, should greatly enhance the pace of discovery for the nuclide ^{113}Cd. It will improve the mapping of nuclear levels and transitions, and the identification of energy-release mechanisms. The project will comprise a campaign of study into the long-lived isomeric nuclide ^{113}Cd and will be conducted in collaboration with ARL scientists to ensure the greatest possible value to ARL isomer research.

References:

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