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EXTERNAL REPORT
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Topical workshop on Detailed Decay Spectroscopy at ISOL@MYRRHA

Round-up and discussion

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This report summarizes the research opportunities discussed during the topical workshop" Detailed decay spectroscopy at ISOL@MYRRHA", held in April 2012 at SCK•CEN in Mol, Belgium.

1. Physics cases

This workshop highlighted the importance and even the need for complete and detailed spectroscopy (including nuclei at or near the line of stability) in nuclear-structure studies using a complete set of techniques. This was nicely illustrated in John Wood's presentation. Although future experimental prospects are excellent and a large arsenal of powerful and highly-sophisticated models are available, John's view is that there is a serious need for experimental results that effectively advance our understanding of nuclear structure. As he pointed out, there is no mass region where we are anywhere near an adequate view of nuclear structure beyond the yrast states and (maybe) a few non-yrast states, where one can distinguish between competing models and achieve a consensus on the interpretation of structure.

It was made clear that in order to advance our understanding of nuclear structure, one needs complete spectroscopy by which unique spins and parities can be unambiguously assigned and precise lifetimes of levels determined. As Paul Garrett mentioned: "The mad dash to the furthest reaches from stability will produce much speculation about structure, with few probes that provide conclusive evidence. Detailed systematic studies, anchored on nuclei on or near stability that can be studied with a wide variety of probes are a necessity. These detailed studies will fit into the philosophy of ISOL@MYRRHA." Throughout the workshop, the following arsenal of techniques, of interest to the low-energy RIBs at ISOL@MYRRHA, were illustrated to be important:

- Combined gamma and conversion-electron detection in beta-decay spectroscopy for fixing multipolarities. In addition, E0 strengths are a good probe for the degree of mixing of coexisting structures. In alpha-decay spectroscopy, alpha-decay widths need to be determined.
- Angular gamma-gamma correlations, which is complementary to the conversion electrons, for fixing multipolarities.
- Fast-timing and Gamma-Ray Induced Doppler Broadening (GRID) to determine level half-lives, which are a good probe for transition matrix elements and collectivity. The advantage of the GRID technique is that not only nuclear half-live information can be extracted. Also nuclear energies and spins can be determined, as well as time processes at the atomic level relevant for collision sequences and atomic interactions. Important to note is that calibration measurements of fast-timing experiments take as long as the experiment itself.
- Branching of low-energy (highly-converted) transitions between low-lying transitions and weak low-energy transitions between high-lying levels in high-

statistics beta-decay spectroscopy may be crucial parameters to reveal the nuclear structure. An illustrative example is the case of ^{94}Zr, see Paul Garrett's presentation.

- There is the unique case of the beta-delayed fission process presented by Andrei Andreyev. For several cases (e.g., ^{178}Tl and ^{202}Fr), long beam times with high yields are desired to obtain the level of statistics for an unambiguous determination of the mass distribution in the beta-delayed fission process. In addition, detailed spectroscopy can be parasitically performed with ultra-high statistics.
- As illustrated by Maria Borge and Pierre Descouvemont, studies of beta-delayed particle emission are challenging, but when conducted with high precision, they are an unbeatable probe of nuclear structure at the microscopic level.
- Total-absorption spectroscopy is an important tool to obtain complete (and correct) B(GT) distributions within the Q-value window. This information reveals the sign and mixture of the quadrupole deformation, which is absent from in-beam studies and quadrupole-moment measurements. Systematic studies will facilitate the mitigation of systematic-error issues. Moreover, large statistics combined with a careful measurement of all contamination and background is essential.
- The measurement of the B(GT) strength in beta decay is also important for anchoring the relative B(GT) strengths determined from (^{3}He,t) charge-exchange measurements. This was outlined by Yoshitaka Fujita. He showed that there is a high chance that GTR structure is observed in beta-decay studies of the mirror nuclei of the already performed (^{3}He,t) experiments.
- Beta-decay information (Pn and $T_{1/2}$ values, and B(GT) distributions) is also of particular interest for nuclear astrophysics.
- Although not illustrated in the present workshop, precise determination of magnetic and quadrupole moments, and isotope and isomer shifts are also important sources of information on the single-particle and collective character. These cases will be treated in the topical workshop on atomic physics.
- As treated in previous topical workshop on fundamental interactions, but also mentioned in the current one, there is a need for precise mass measurements of ground states and long-lived isomers.

2. Instrumentation

The quest for complete spectroscopy will require a permanent position of the larger detection setups in the experimental hall. The necessary space has to be defined in the design phase. Important detection setups mentioned during the workshop are listed below.

- A high-efficiency gamma-array spectrometer with auxiliary detectors. Currently existing examples are AGATA (presented by E. Farnea) and the 8-

pi spectrometer at ISAC, which will be replaced by the GRIFFIN array (commissioning in 2014). Paul Garrett outlined the importance of the auxiliary instruments and detectors of the gamma-ray array itself. One needs following devices:

- A moving tape collector
- Thin segmented plastic scintillators for beta tagging which have a 1-to-1 correspondence with the Ge detectors in the array in order to veto out high-energy betas.
- Segmented Si detectors for detection of conversion electrons. The segmentation is important to cope with pile-up and DACQ dead time due to high decay rates.
- A neutron array, for which a large space and/or a false floor need to be foreseen in order to minimize neutron scatter background.
- A high-throughput DACQ, which also records pile-up and dead time.

- A fast-timing array consisting of $LaBr_3$ detectors.
- A TAS array, both consisting of NaI detectors (high efficiency) and HPGe detectors (high resolution) in a (near) 4-pi configuration. A permanent setup will mitigate systematic errors.
- A crystal spectrometer will enable gamma-ray detection with ultra-high resolution. Two types of crystal modes can be used. In the double-flat crystal mode, energy resolutions of 10^{-6} can be achieved but these come along with efficiencies of 10^{-13}. If feasible, this mode allows GRID measurements. In the single bent-crystal mode, better efficiencies of $\sim 10^{-7}$ are obtained but with worse resolutions of $10^{-5} – 10^{-3}$ for E<1 MeV. For the E<1 MeV, however, the resolution is significantly better than HPGe detectors, which opens opportunities for decay spectroscopy and the search for very weak transitions, which may play a significant role for the nuclear structure. Important to note is the fact that large space is needed for the crystal spectrometer in order to separate the diffracted gamma rays. The extremely low efficiencies, however, will be a limiting factor, even for the long beam times with high yields at ISOL@MYRRHA. A promising outlook is therefore the development of gamma-ray lenses, which can boost up the efficiencies significantly.
- A Penning trap in front of the arrays, so that trap-assisted spectroscopy becomes possible.

In the philosophy of conducting complete spectroscopy and making optimal use of the available beam time, one could consider to perform the high-statistics beta-decay spectroscopy simultaneously in the gamma-ray array, the fast-timing array, the TAS array, and the crystal spectrometer. It was already emphasized in the fundamental-interaction workshop that a multi-user scheme making use of the same (or similar) RIB is relatively easy to achieve.

Other interesting ideas to optimize the user beam time are harvesting of the beam dump, which requires a hot chemistry lab, and a collection station for long-lived implanted sources, which is used in parasitic mode by positioning it after the pre-separator. The collection station will enable:

- conversion electron measurements on long-lived activities, e.g., ^{152}Eu.
- Production of exotic targets: long-lived species can be deposited on C (or other) foils for subsequent experiments at ISOL@MYRRHA (or at other facilities). At TRIUMF, for example, a ^{26}Al target is produced.