Proposal for TRIUMF Commitment (5YP 2015-2020)

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PROJECT/COMMITMENT TITLE: V.A.S.T – Versatile Advanced Spallation Target

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PRINCIPAL COLLABORATORS:

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PROJECT DESCRIPTION:

The project aims to provide novel methods for the production of high intensity medium-to-long lived radioactive beams, primarily for the astrophysics program. It would develop production targets deviating from the standard solid, high-temperature, 'steady-state' ISOL target approach currently employed at ISAC. This project will employ spallation on targets containing lithium salts or other suitable materials with higher vapour pressures, to induce spallation on light nuclei such as fluorine or chlorine, producing compounds that can diffuse out of the graphite container with high efficiency. The goal is to provide high-intensity beams such as ^{15}O, ^{30}P and ^{44}Ti that have not been produced from standard ISAC production targets. We use these beams as the main examples, but others such as ^{11}C, ^{13}N and ^{14}O would also benefit from these approaches.

One class of such targets would interpose a thin graphite window between the production target and the ion source, as was done in a ^{15}O production target at Louvain-la-Neuve. That target consisted of LiF in a matrix of graphite, the product nuclei forming CO that diffused through the graphite window. Other salts such as LiCl might provide access to higher-mass nuclei. As an alternative, for products that would not readily diffuse through a graphite window, it would be possible to run a target in hot and cold cycles. A hot production cycle at substantial vapour pressure of the target material would be followed by a low-temperature phase in which a volatile product would be allowed out of the target cell and into the ion source. A third class of target would have a high-pressure helium gas jet, 'salted' with nano-scale carrier material to transport product atoms at high speed through a capillary to the ion source inlet, where another helium jet deflects the majority of the transport gas allowing the un-deflected carrier material and the adsorbed atoms of interest to enter the ion source.

Three stages of R&D may occur. First, offline target heating and gas diffusion tests would use a test box to generate the required vacuum and temperature conditions. Second, tests with nano-Amp proton beam could investigate the efficiency of formation and diffusion of volatile product nuclei. Most of the beams of interest decay by positron emission, enabling the movement of product nuclei to be observed by PET, without need

for an ion source. Third, tests with a prototype production target and an ion source would ramp up to full beam intensity. This requires a facility to be installed in a suitable proton beam-line, for example near the planned BL4N beam dump.

The project is envisaged to start with the hiring or acquiring from existing personnel, of 4 scientists and one engineer, and a technician to initiate the R&D, as well as the addition of lab space and equipment to prepare and test targets.

SCIENTIFIC JUSTIFICATION:

Experiments involving ^{15}O, ^{30}P, and ^{44}Ti have been endorsed by the EEC as priorities for the astrophysics program. The $^{15}O(\alpha,\gamma)^{19}Ne$ reaction remains one of the most important reactions in nuclear astrophysics due to its role as the 'ignition reaction' in Type I X-ray bursts. The critical value of the strength of the E_{cm}=505 keV resonance in this reaction has escaped direct measurement for over 20 years since it was first identified as being the parameter of critical importance. Although indirect methods have enabled attempts to pin down this strength, a direct measurement is highly desired by the nuclear astrophysics community and you will see this reaction used as a motivation for newly proposed RIB facilities. We believe however that ISAC has the best chance of measuring this reaction.

The $^{30}P(p,\gamma)^{31}S$ reaction is a critical reaction in determining silicon isotopic ratios in nova ejecta. Such ratios need to be known in order to identify whether inclusions in meteoric pre-solar grains are of nova origin, a question which is of high relevance in nuclear astrophysics today. If uniquely identified as being of nova origin, these grains can be used as diagnostics for nova models and answer a host of questions about their dynamics and evolution.

$^{44}Ti(p,\gamma)$ and $^{44}Ti(\alpha,p)$ are the two proposed reactions at TRIUMF that require ^{44}Ti beams. There is considerable interest in the world community in these reactions, since they destroy ^{44}Ti in high temperature environments such as core-collapse supernovae (CCSN). This is important due to the observation of ^{44}Ti in the CCSN remnant Cas A, with a determination of ^{44}Ti yields in SN 1987A in progress. Many groups around the world have initiated plans to attempt extraction of ^{44}Ti from beam dumps at laboratories such as PSI. However, these samples are small, certainly not enough to perform decisive measurements to tie down the reaction rates. Thus we propose also to target development of this isotope either online or parasitically in order to make the measurements. DRAGON is uniquely positioned in the world for making the $^{44}Ti(p,\gamma)$ measurement.

In summary all these beams are highly sought after at RIB facilities internationally in order to measure these critical rates. The reason they have not been done is that it is nearly impossible to provide beams of sufficient intensity, even at ISOL facilities using current techniques, in order to perform the measurements. New beam production methods are required that use cutting edge technology and methodology.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY:

As previously mentioned, the reactions we have chosen as examples are highly sought after measurement targets for the world nuclear astrophysics community. The thermonuclear reaction rate of $^{15}O(\alpha,\gamma)^{19}Ne$ in particular is often cited as one of the most important quantities in nuclear astrophysics due to its apparently strong influence on the behaviour of Type I X-ray bursts, and has been a sought after quantity for over 20 years, since the advent of radioactive beam physics, and indeed was one of the first targets for measurement at Louvain-la-Neuve. The Canadian nuclear astrophysics research community consists of scientists based at TRIUMF and Canadian universities who perform these experiments in order to provide astrophysical modellers with input data in order to properly explore the relationship between astrophysical models and stellar observations. With the McGill group in Canada performing the relevant observations and modelling, the impact of these experiments is further reaching than just the experimental side. In addition, the recent close collaboration between TRIUMF and UVic/JINA using the MESA/NuGrid codes to evaluate the impacts of particular nuclear reactions will place TRIUMF in a strong position to tie together the experiment, observation, and models based on any experimental data obtained as a result of these beams being produced.

BROADER IMPACTS:

The beams we propose to produce will enable experiments to be performed that the global nuclear astrophysics community has desired for a long time. Having experimental values for these reaction rates that do not rely on combinations of multiple indirect measurements will provide thermonuclear reaction rates with relatively small uncertainties. These rates will be used to constrain a variety of explosive stellar models, such as for Type I X-ray bursts, classical novae or recurrent novae, and core-collapse supernovae. The constraints imposed on these models will allow the deep interpretation of astronomical observations of these stellar objects at a variety of wavelengths or through other means. In short, these data will enable substantial steps in the understanding of these objects to be taken.

A large international nuclear astrophysics community exists that performs experiments in an attempt to extract these rates, most of which remain out of reach for direct measurement. The combination of DRAGON and the ISAC low energy accelerator at a RIB facility is unique, and as such, TRIUMF remains the best hope in the world of ever making direct measurements of these rates. For this reason cutting-edge development is required that steps away from the restrictive approach of the current steady-state ISAC targets.

The success of this project will not only provide these important experimental results, but will represent a major achievement in the field of radioactive beam development beyond the approaches that ISAC has been using for the last decade.

MAJOR MILESTONES:

Description	Date
Conceptual designs for VAST target modules; design of test setup	2013
Construction of first test setup	2014
Detailed design of target modules and beam transport system	2015
Begin construction of BL4N beam-dump and target modules	2016
Beam to ISAC and experiments	2017

RESOURCE REQUIRMENTS:

CASH FLOW REQUIREMENTS						
\YEAR SOURCE \	ONE	TWO	THREE	FOUR	FIVE	TOTAL
TRIUMF	150,000	150,000	150,000	10,000	10,000	470,000
EXTERNAL	25,000	25,000	25,000	25,000	25,000	125,000
TOTAL	175,000	175,000	175,000	35,000	35,000	595,000
TRIUMF NON-CASH RESOURCES (FTE-Weeks)						
\YEAR RESOURCE\	ONE	TWO	THREE	FOUR	FIVE	TOTAL
Physicist (Nuclear BAE)	20	20	20	20	20	100
Engineer (Mechanical)	30	30	30	1	1	92
Technician (Mechanical)	20	20	30	30	30	130
Mechanical Designer	20	20	20	1	1	62

EXTERNAL FUNDING INFORMATION:

Partial NSERC support will be sought.

ONGOING OPERATIONAL REQUIREMENTS:
It is estimated that once operational VAST will have an annual cash flow requirement of $10,000.

DECOMMISSIONING REQUIREMENT:

Standard ISAC target requirements would apply.

Accepted: Date: