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Letter of Intent to the INTC

Astrophysics Using Post-Accelerated Aluminum Beams at REX-ISOLDE

John D'Auria[1], Lothar Buchmann[2], Jac Caggiano[2], Joakim Cederkall[3], Alan Chen[4], Hans Fynbo[5], Henrik Jeppesen[3,5], Reiner Kruecken[6], Alison Laird[7], Alex Murphy[8], Chris Ruiz[1,2], and Pat Walden[2]

1. Simon Fraser University, Burnaby, Canada
2. TRIUMF, Vancouver, Canada
3. CERN, Geneva, Switzerland
4. McMaster University, Hamilton, Canada
5. Aarhus University, Aarhus, Denmark
6. Technische Universitat Munchen, Munich, Germany
7. University of York, York, UK
8. University of Edinburgh, Edinburgh, UK

Spokesperson: John D'Auria
Contactperson: Joakim Cederkall

Abstract

This letter indicates our interest in establishing a program at REX-ISOLDE using post-accelerated beams of aluminum for studying key questions in nuclear astrophysics, and follows along with and complements a previous letter (CERN-INTC-2004-011).
In particular we plan to the process of proton capture onto ^{25,26m}Al through elastic/inelastic and transfer reactions as this process can be directly related to the production of the isotope ^{26}Al (7.2 x 10^5y) in the universe. Gamma emission (E_γ=1.809 MeV) from the decay of this long-lived isotope has been observed with space borne, gamma-ray detection systems.

1. Introduction

An important question in nuclear astrophysics is concerns the production site of the gamma observable isotope, ^{26}Al, in the universe. Proposed sites include core collapse supernovae, ONe novae, Wolf-Rayet stars and Asymptotic Giant Branch stars. Although the overall contribution to galactic ^{26}Al from novae is thought to be no more than 0.4 M_o [1] (~20% of the total), it cannot be disregarded. In addition, determining the production rate of ^{26}Al will further constrain nova models. A large uncertainty in determining the production rate are due in part to the uncertainties in key nuclear reactions, namely ^{26g,m}Al(p,γ)^{27}Si and ^{25}Al(p,γ)^{26}Si [2,3]. These are part of the production and destruction sequence for ^{26}Al in such environments. Recently, the rate of the ^{26g}Al(p,γ)^{27}Si reaction at novae temperatures was measured directly in inverse kinematics with an intense ^{26g}Al beam (~5x10^9/s) and using the DRAGON facility at ISAC [4]. However, the Al production target released aluminum relatively slowly which reduced significantly the intensity of the much shorter ^{25,26m}Al isotopes. Given a relatively intense beam (>10^6 /s) of either isotope at ISOLDE, elastic/inelastic scattering studies and transfer reactions could be performed which could be of importance to determining key parameters of these radiative proton capture reactions. It should be noted that there is some dispute as to the key resonance states for capture on ^{25}Al, while there is really not sufficient knowledge of the states involved for capture on ^{26m}Al. This project involves two phases, namely, the first to perform target R&D studies to obtain an appropriate, fast releasing aluminum production target for obtaining intense beams, and the second, to initiate the development and use of appropriate detection systems to perform appropriate scattering and transfer reactions at REX-ISOLDE with beams of $^{25,26m}Al$ (as available). This nuclear astrophysics project is of interest to a new collaboration of scientists.

2. Scientific Rationale

The main rationale for this project falls in the area of nuclear astrophysics but the development of radioaluminum beams can also be used to perform nuclear structure studies of neutron-rich isotopes far from stability.

a. Nuclear Astrophysics

1. ^{25}Al(p,γ)^{26}Si

As mentioned above, the isotope, ^{26}Al, has been observed by various gamma observational satellites[5] such as HEAO-3, COMPTEL, and now INTEGRAL. The site of its production is still a subject of much debate. The present project relates to its production in nova explosions, and possibly X-ray bursts. ^{26}Al is ejected from novae as a result of the reaction sequence $^{24}Mg(p,\gamma)^{25}Al(\beta^{+}\nu_{e})^{25}Mg(p,\gamma)^{26g}Al$. It is ^{26g}Al which β-decays into ^{26}Mg, in turn emitting the 1.809 MeV γ-ray. However ^{25}Al beta decay ($T_{1/2}$ = 7.18 s) can be bypassed by radiative proton capture if this process is faster than the beta decay, resulting is a reduction of the ^{26}Al production.

The rate of this reaction is thought to be dominated by resonances, whereby the rate is dominated by the resonance strength, ωγ, and the temperature. While this reaction has never been measured directly, a number of the parameters of the key resonances of ^{26}Si through indirect studies including (p,t)[6-8], (^{3}He,n)[9-11], (^{3}He,^{6}He)[12] reactions have been performed. It has been shown that the largest uncertainties in the $^{25}Al(p,\gamma)^{26}Si$ rate are the uncertainties in the resonances of ^{26}Si that lie <1 MeV above the proton threshold (5.518 MeV) in ^{26}Si. More specifically, recent studies [8,11] have observed two new states in the region 5.9-6.0 MeV , however some serious discrepancy/disagreement exists in the spin and energies of these key states [6]. Further, additional data is needed on the gamma and proton partial widths of these states. Such information is needed in order to deduce the reaction rate in the absence of a direct proton capture study.

2. ^{26m}Al(p,γ)^{26}Si

The short lived ($T_{1/2}$ = 6.35 s) isomeric state, ^{26m}Al is formed via the $^{25}Mg(p,\gamma)^{26}Si$ reaction as well as the beta decay of ^{26}Si (see above). Because of the large spin difference between this isomeric state and the ground state, no direct communication exists between them. Thus this reaction is not directly important for the destruction of ^{26g}Al. However, a better understanding of the role of this reaction could be important part of nucleosynthesis studies since abundance ratios in the Al-Si range may be affected in supernovae scenarios rather than novae. The existing data on the isomeric reaction rate is solely based on the Hauser-Feschbach calculations although some recent transfer reaction studies are in progress [13] and may elucidate properties of some of the resonances in the regions of interest. In order to ascertain the existence of resonances in the ^{26m}Al + p system, it is proposed that a resonant elastic scattering study be performed

3. Experimental Methods

a. Beam Development

While a radioaluminum beam has been developed at ISOLDE, a relatively intense, pure beam is needed for REX-ISOLDE to perform these studies. Aluminum is released by SiC and very intense beams of ^{26g}Al have been produced at TRIUMF-ISAC using a combined surface and laser ion source, the aluminum is desorbed slowly leading to much weaker beams of the $^{25,26m}Al$. It has been proposed at ISOLDE to use CF_4 to speed up the release but the AlF molecule needs to be dissociated and the LIS used to ionize the aluminum [14]. This needs further testing. Further it may be necessary to use a 13+ charge state from the EBIS system at REX to obtain a pure Al beam given unwanted molecules in the system. Alternatively there may be other aluminum releasing targets that may be useful such as a heavy metal silicide. A number of tests could be performed using a UC target studying the release of neutron rich aluminum isotopes which have minimal background as compared to neutron deficient isotopes. ^{29}Al could also be used as a probe in diffusion studies to optimize the target material.

b. Reaction Studies

An array of silicon detectors, optimally DSSSD is needed as the detection system in elastic/inelastic scattering studies. A design similar to the TUDA system at TRIUMF-ISAC is proposed and initially a solid target would be used for these inverse kinematics studies with beam energy of the order of 3 MeV and intensities of the order of $>10^{4}$ initially.

4. Request to CERN

It is difficult at this time to submit a full proposal as there is a need to develop the appropriate beam to perform the experiment. A letter is submitted to indicate the intention to submit such a proposal however; it would be useful if beam time could be assigned to the development of the aluminum beam. Such beam time could be as part of other assigned experimental studies as target tests can be performed using ^{28}Al that is produced with a UC target system. Such tests could be used to study diffusion/effusion in different materials. For this purpose about 2-3 beam shifts (e.g. 1 shift per target) could be very useful.

5. Conclusion and Summary

These studies represent a beginning of an experimental nuclear astrophysics program at REX-ISOLDE focused on measuring reaction rates. Indirect studies provide an optimal start to such studies as cross sections are usually higher requiring lower beam intensities as compared to direct studies. The required experimental systems are also less demanding. If successful, more challenging programs can be initiated. A key part of this study is the development of the aluminum beams, a development which could be shared with other facilities leading to the completion of a number of important studies in this area. Such cooperation between major facilities is an activity that needs to be encouraged.

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