TRIUMF - RESEARCH PROPOSAL	**Experiment no.**	**Sheet** 1 **of** 13

Title of proposed experment

Novae observables – ^{18}F abundance and the ^{18}F(p,α)^{15}O reaction

Name of group

TUDA

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Members of group (name, institution, status)

(For each member, include percentage of research time to be devoted to this experiment over the time frame of the experiment)

A. M. Laird	University of York	Lecturer	50 %
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L. Buchmann	TRIUMF		
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C. Ruiz	TRIUMF	Research Assistant	10 %
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Date for start of preparations: Spring 2004

Date ready: Fall 2004

Completion date: Fall 2005

Beam time requested:

12-hr shifts	**Beam line/channel**	**Polarized primary beam?**

SUMMARY

The observation of gamma rays from novae outbursts will provide theorists with a unique opportunity to test the predictions of current models. Assuming that the nuclear reaction rates are sufficiently well known, such observational data would allow the underlying hydrodynamics of these models to be put to the test. The recent launch of the INTEGRAL satellite aimed at making these observations emphasises the current need for improved information on the relevant nuclear reaction rates.

The decay of ^{18}F is the major source of gamma rays of 511 keV and below from novae. Consequently, knowledge of the final abundance of ^{18}F synthesized during such an event is important to constrain novae models. Moreover, the distance from which these gamma rays could be detected and thus the expected number of nova events which could be observed in this fashion also relies on such information.

The uncertainty in the final abundance of ^{18}F is dominated by the uncertainty in its rate of destruction via the ^{18}F(p,α) ^{15}O reaction. This proposal describes our intention to measure an excitation function of the ^{18}F(p,α) ^{15}O reaction in the region of the astrophysically important 330 keV resonance.

Silicon strip detectors will be used in the TUDA chamber to measure, in coincidence, the reaction products from a ^{18}F beam impinging on a polyethylene target. Angular distributions will be measured at several energies and an excitation function calculated for the centre of mass energy range 0.28 – 0.5 MeV. From this, the contributions from the key 330 keV resonance as well as that from the tails of nearby resonances will be determined.

BEAM and SUPPORT REQUIREMENTS | **Sheet** 3 **of** 13

Experimental area

ISAC-HE, TUDA

Primary beam and target (energy, energy spread, intensity, pulse characteristics, emittance)

p(500MeV)

Secondary channel

ISAC high energy TUDA beamline

Secondary beam (particle type, momentum range, momentum bite, solid angle, spot size, emittance, intensity, beam purity, target, special characteristics)

10^8 pps ^{18}F (unstable)
10^8 pps ^{18}O (stable)

TRIUMF SUPPORT:
Summarize all equipment and technical support to be provided by TRIUMF. If new equipment is required, provide cost estimates.

NOTE: Technical Review Forms must also be provided before allocation of beam time.

Development of ^{18}F beam
^{18}F and ^{18}O bunched beam production.
Operational support

NON-TRIUMF SUPPORT:
Summarize the expected sources of funding for the experiment.
Identify major capital items and their costs that will be provided from these funds.

The TUDA scattering facility, targets, electronics and detectors as well as manpower will be provided by the Universities of Edinburgh and York.

SAFETY	Sheet 4 of 13

Summarize possible hazards associated with the experimental apparatus, precautions to be taken, and other matters that should be brought to the notice of the Safety Officer. Details must be provided separately in a safety report to be prepared by the spokesperson under the guidance of the Safety Report Guide available from the Science Division Office.

Standard TUDA operation with short lived radioactive isotopes (^{18}F).

Low voltage detectors and electronics.

Standard alpha particle calibration source.

1. Motivation

In addition to the generation of significant amounts of energy, novae outbursts are responsible for the synthesis of many proton-rich nuclides. In order to model the contribution to the interstellar medium of such outbursts, accurate information is needed on the reaction rates which play a role in these objects. Direct tests of such models can be provided by the observation of gamma rays originating from novae ejecta. Measured gamma fluxes would provide observational constraints on the final abundances of certain nuclides and thus on the underlying models, assuming that the relevant reaction rates are sufficiently well known. The observation of ^{22}Na, which, via its decay to an excited state in ^{22}Ne, is responsible for a characteristic gamma ray of 1.275 MeV, could be used in this context. Several successful studies have been performed at TRIUMF using the DRAGON[1] and TUDA[2] facilities to gain much needed data on the reactions determining the final abundance on ^{22}Na.

Another important nuclide in this context is ^{18}F. This nuclide is thought to be the most significant source of gamma rays at energies of 511 keV and below[3]. These gamma rays dominate the gamma flux during the first few hours after an outburst. ^{18}F is considered the main contributor since it is produced in relatively high abundances and its half life (109.8 min) is such that the decay positrons are emitted after the expanding ejecta becomes transparent to gamma rays.

The distance from which these gammas can be observed is determined by the amount of ^{18}F synthesised during the outburst. In turn, the final abundance of ^{18}F depends upon the relative rates of the processes which produce and destroy it. In novae, ^{18}F is produced mainly by the decay of ^{18}Ne or by the ^{17}O(p,γ)^{18}F reaction while its destruction is via the ^{18}F(p,α)^{15}O and ^{18}F(p,γ) ^{19}Ne reactions. The influence of these two reactions has been investigated by Coc *et al.* [3] who concluded that in the relevant temperature regime the rates of these reactions remain uncertain, emphasising the need for additional experimental information on both these reactions as well as on the ^{17}O(p,γ)^{18}F reaction. Of these two reactions, however, it is the ^{18}F(p,α) ^{15}O which dominates the rate of destruction of ^{18}F[3].

The ^{18}F(p,α) ^{15}O reaction also influences the abundances of ^{16}O, ^{18}O and ^{19}F[4] as well as that of ^{18}F, and so improved reaction rate data also helps to constrain the final abundances of these nuclei.

It is the aim of this proposal to investigate the ^{18}F(p,α) ^{15}O reaction, in the energy region relevant to novae, through a direct measurement of the cross section.

2. Current Status of the $^{18}F(p,\alpha)^{15}O$ reaction

The $^{18}F(p,\alpha)^{15}O$ reaction rate at the relevant temperatures is dominated by contributions from resonances in the intermediate nucleus ^{19}Ne (see Figure 1). At temperatures above 0.4 GK the rate is dominated by a resonance at 665 keV, corresponding to the state at 7.076 MeV in ^{19}Ne. This resonance has been the focus of significant experimental effort in the last ten years (see [5],[6],[7],[8],[9] and [10]) using both direct and indirect approaches, but some disagreement existed between the different measurements. More recently, however, a simultaneous measurement of the $p(^{18}F,p)^{18}F$ and $p(^{18}F,a)^{15}O$ excitation functions by Bardayan *et al.* [11] at the Oakridge HRIBF appears to have resolved this issue.

For temperatures below about 0.25 GK, the dominant contribution is thought to come from a resonance at 38 keV ($E_x(^{19}Ne)$ = 6.449 MeV). A recent paper by de Sereville *et al.* [12] investigated this resonance indirectly by studying the analogue levels in the mirror nucleus via the neutron transfer reaction $d(^{18}F,p)^{19}F$. This study measured the one nucleon spectroscopic factors of the relevant states in ^{19}F and, by assuming the equality of these factors for analogue levels, determined spectroscopic factors for the states at 6.419, 6.437 and 6.449 MeV in ^{19}Ne. The results indicated that the analogue of the 6.449 MeV state (6.528 MeV in ^{19}F) dominates. These analogue assignments, however, are not firmly established. Nevertheless, the results indicate that at least one of the low lying resonances (8, 26 and 38 keV) will play a role at novae temperatures.

Under nova conditions between 0.25 and 0.4 GK, the contribution of a resonance at 330 keV is expected to dominate the $^{18}F(p,\alpha)^{15}O$ rate. The recent direct measurement of this resonance by Bardayan *et al.* [13] determined a resonance strength of 1.48 ± 0.46 eV, significantly reducing the uncertainty in the reaction rate. Using this value for the strength, the total reaction rate was a factor of two lower than previously assumed [3] resulting in twice the final ^{18}F abundance. This new reaction rate also produced significant changes in the calculated abundances of ^{18}O and ^{19}F. Figure 3 shows the new reaction rates as calculated by [13].

The study by [13] determined the resonance strength of the 330 keV resonance by measuring the cross section on and off resonance using a thick target technique, since the resonance width (Γ=3keV) is considerably less than the energy range covered by the target thickness (approx. 45 keV). The uncertainties given in the cross sections, 30% for on resonance and 60% for off resonance, are dominated by statistical uncertainties.

The proton width was extracted from a fit to the cross section data assuming two resonances, one at 330 keV and one at 665 keV. However, there are two other levels in this energy region (287 keV and 450 keV) whose spins are not firmly established and thus could contribute to the cross section. It is also likely that the tails of the lower lying resonances could play a role at these energies and in particular, the (3/2+) 38keV can be expected to interfere with the higher 3/2+ level at 665 keV. These factors could result in a systematic error in the determination of the 330keV resonance strength.

Consequently, further measurements which could reduce the uncertainty in the cross section in the region of the 330 keV resonance would help to further constrain the $^{18}F(p,\alpha)^{15}O$ reaction rate and thus the ^{18}F abundance in novae.

This proposal presents our intention to exploit the high intensity ^{18}F beam, soon to be available at TRIUMF, to measure the excitation function of the $^{18}F(p,\alpha)^{15}O$ in the region of the

330 keV resonance. These measurements will cover the on and off resonance points, previously measured by [13], with improved statistics as well as several points above and below the resonance to constrain the contribution from nearby states, the nonresonant background and possible interference terms.

Er [keV]	$E_x(^{19}Ne)$ [MeV]	J^π	Γ_p [keV]	Γ_α [keV]	Ref
8	6.419	3/2+	$(3.9 \pm 3.9) \times 10^{-37}$	0.5	[13]
26	6.437	1/2-	$(2.8\,^{+5.6}_{-1.9}) \times 10^{-20}$	220	[13]
38	6.449	3/2+	$(2.4 \pm 2.4) \times 10^{-14}$	4.0	[13]
287	6.698	5/2+	$(3.8 \pm 3.8) \times 10^{-5}$	1.2	[13]
330	6.742	3/2-	$(2.22 \pm 0.69) \times 10^{-3}$	2.7	[13]
450	6.681	7/2-	1.6×10^{-5}	3.1	[8]
665	7.067	3/2+	15.2 ± 1.0	23.8	[13]

Table 1: Summary of resonance parameters.

3. Experimental Method and Set up

The proposed experiment is the measurement of the excitation function of the $^{18}F(p,\alpha)^{15}O$ reaction in the centre of mass range $E_{cm} = 0.28 - 0.50$ MeV, using the thick target technique. This energy range covers the resonance at 330keV which is expected to dominate the rate of this reaction at novae temperatures. This range also covers possible contributions from the tails of higher and lower lying resonances.

The experimental setup will consist of silicon strip detector arrays and a polyethylene target within the TUDA scattering chamber. A radioactive beam of ^{18}F, in the energy range 0.29 – 0.53 MeV/u, will be utilised. The proposed method is the coincident detection of the ^{15}O ejectile and recoiling alpha from the $^{18}F(p,\alpha)^{15}O$ reaction. Such a coincident measurement should allow the events of interest to be extracted with very little background contamination. The main background contribution may come from the $^{18}O(p,\alpha)^{15}N$ reaction arising from an ^{18}O contamination in the beam. Due to the difference in Q-value for this reaction (ΔQ=1.1 MeV) however, these events can be readily distinguished by comparing the kinematics of the α-particle, as well as the summed energy of the alpha particle and heavy ion. Possible background contribution from fusion reactions on the carbon content in the target are expected to be negligible at these low energies. The extent of this contribution will be determined from background runs using a ^{12}C target.

The detector arrays will be positioned so as to optimise coverage of the angular range of the particles of interest (see Figure 4). The energy and timing resolutions of the TUDA silicon detectors are sufficient to easily distinguish alphas from protons or heavy ions and although the ^{15}O cannot be distinguished from similar mass particles, such as ^{15}N or ^{12}C, the coincident requirement together with a kinematic reconstruction of the event will uniquely identify the event.

Absolute normalisation will be accomplished using elastic scattering events. The simultaneous measurement of the $^{18}O(p,\alpha)^{15}N$ reaction will provide a check on this normalisation since the cross sections of this reaction are well known. The detector solid angle calibration will be determined from elastic scattering from a thin gold target. Target thicknesses for all targets will be calculated from the energy loss of known energy alpha particles in each foil.

4. Beam Request

The total beam time requested is 45 shifts with ^{18}F beam and 5 shifts with ^{18}O, to be delivered in two stages. Stage I will study the energy range 0.33-0.50 MeV using 15 shifts. Stage II will then investigate the lower energy range and due to the lower cross section will require more shifts, namely 30. This beam request has been based on the following assumptions: a beam intensity of 10^8 pps; a coincident detection efficiency of 20%; total cross sections as given in [13]; and the required statistics are 200 events at each of 20 angles.

During the first stage of the measurement, data points will be taken at centre of mass energies of 0.33, 0.35, 0.42, 0.47 and 0.50 MeV. These energies have been chosen as they have relatively high cross section. The first of these data points is the on resonance point as measured by [13]. The higher energy points provide important information on the contributions from the high energy tail of the 330 keV resonance as well as that from the low energy tail of the 665 keV resonance. In addition, these data will constrain the possible contribution from the 450 keV resonance and from the interference between the 38 keV and 665 keV resonances.

The data from stage one will be used to confirm the predictions of the cross section from [13].

The more challenging stage II measurements can then be undertaken, using the experience of stage I to further optimise the setup and analysis techniques. Stage II will take data at 0.37, 0.31 and 0.28 MeV in the centre of mass. Due to the lower expected cross sections, longer running time is required to accumulate the necessary statistics and so 30 shifts are requested. The data point at 0.37 MeV is the off resonance point as measured by [13] and the higher beam intensity should allow us to improve upon the statistics of that measurement. Since the cross section is expected to drop off rapidly below the resonance, we will put a less demanding limit on the required statistics for the data taken at 0.28 MeV (100 events at 10 angles).

The table below details the shift requirements for each data point. Additional shifts have been requested to cover energy changes as well as calibration and normalization runs with carbon and gold targets.

E_{cm} (MeV)	Yield (particles per hour)	Number of shifts
0.50	576	1
0.47	288	1
0.42	86	4
0.37	49	7
0.35	86	4
0.33	127	2.5
0.31	29	11.5
0.28	72	5.5

5. Future Directions

A further stage of this measurement covering lower energies in the centre of mass can be foreseen once these data have been analysed and the better estimate of the cross sections can be given.

6. Readiness

The TUDA scattering facility is essentially ready should beam time be granted. The required detectors for more backward angles are available and the recently installed VME data acquisition is capable of handling the number of channels as described in section 3 as well as the predicted event rate. The forward detector will be ordered early in the spring should this proposal be granted beam time and will be ready for fall 2004.

It is expected that the TUDA facility will be capable of running the proposed experiment when a ^{18}F beam of the required intensity becomes available.

7. References

[1] S. Bishop *et al.,* Phys. Rev. Lett. **90** (2003) 162501

[2] C. Ruiz *et al.,* Phys. Rev. **C 65** (2002) 042801(R)

[3] A. Coc *et al.,* Astro. Astrophys. **357** (2000) 561

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[5] R. Coszach *et al.,* Phys. Lett. **B 353** (1995) 184

[6] K.E. Rehm *et al.,* Phys. Rev. **C 52** (1995) R460; **53** (1996) 1950

[7] J.S. Graulich *et al.,* Nucl. Phys. **A 626** (1997) 751

[8] S. Utku et al., Phys. Rev. **C 57** (1998) 2731

[9] D. Bardayan *et al.,* Phys. Rev. **C 62** (2000) 042802(R)

[10] J.S. Graulich *et al.,* Phys. Rev. **C 63** (2001) 011302(R)

[11] D. Bardayan *et al.,* Phys. Rev. **C 63** (2001) 065802

[12] N. de Sereville *et al.,* nucl-ex/0206014

[13] D. Bardayan *et al.,* Phys. Rev. Lett. **89** (2002) 262501

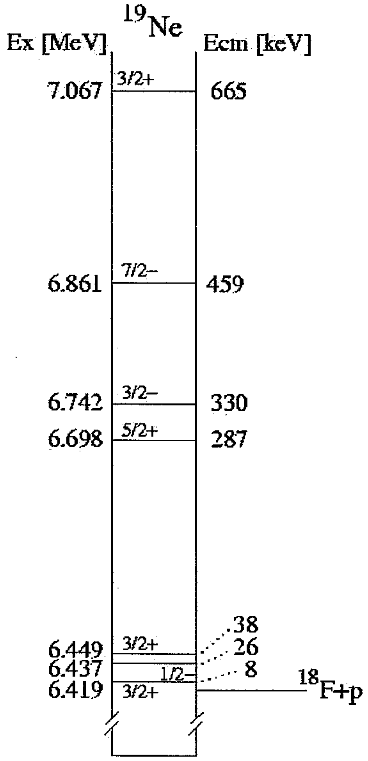

Figure 1: Relevant levels in ^{19}Ne.

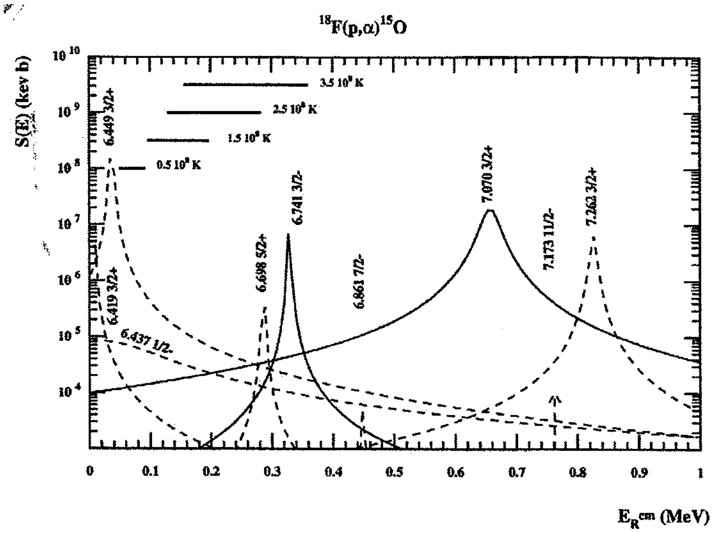

Figure 2: Astrophysical S-factor for the ^{18}F(p,α)^{15}O reaction. Solid lines represent contributions from resonances whose strengths have been directly measured. Dashed curves represent assumed contributions from resonances corresponding to known ^{19}Ne levels. Taken from ref[3].

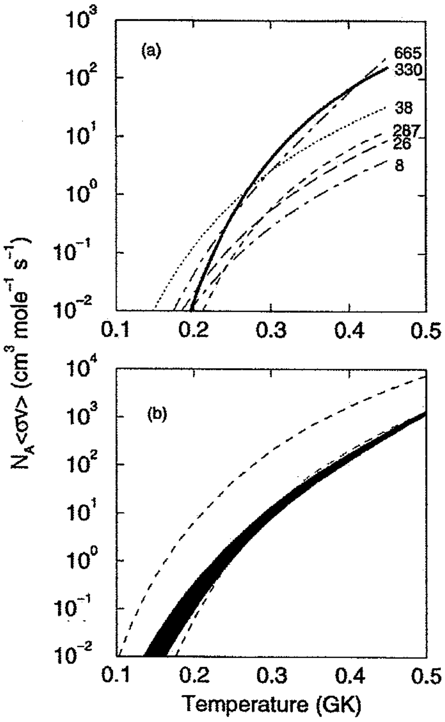

Figure 3: Reaction rate calculations taken from [13].

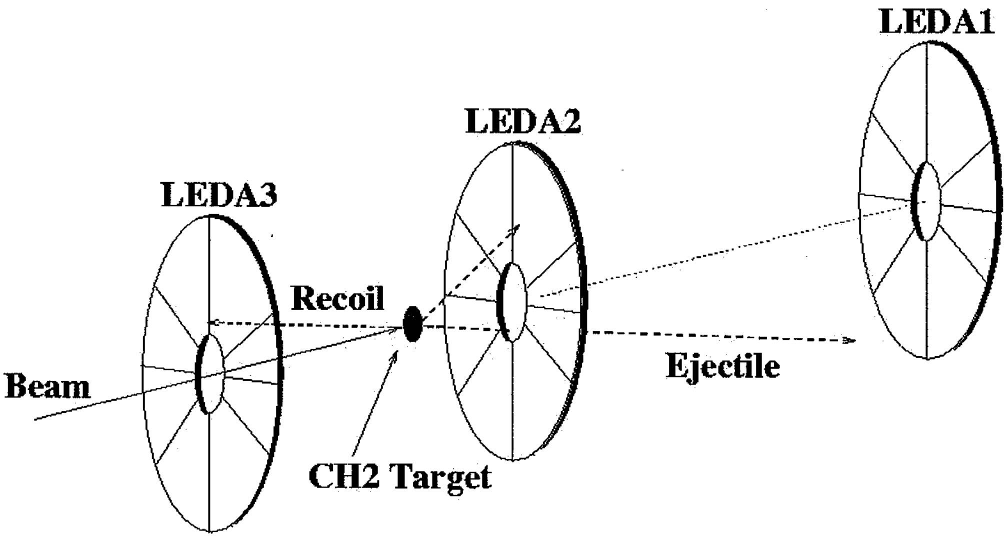

Figure 4: Schematic of experimental setup

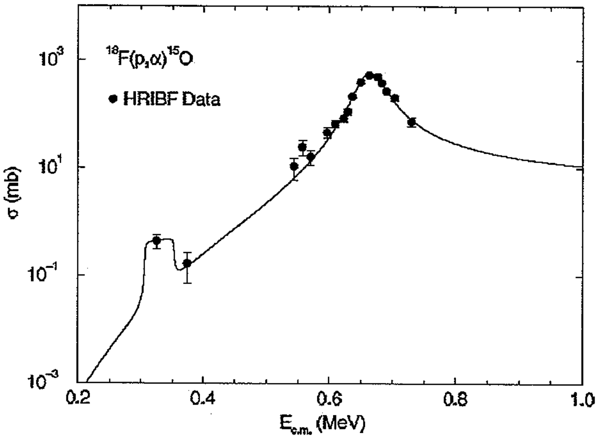

Figure 5: Excitation function taken from [13].

PUBLICATION LIST OF SPOKESPERSON (previous five years)	**Sheet** 13 **of** 13

1. A. Spokesperson and A. Coauthor. Title of paper. Journal, vol, year, page (any format).
2.