TRIUMF — RESEARCH PROPOSAL	Experiment no. 922	Sheet 1 of 18

Title of proposed experiment:

On the Production of ^{26}Al in Novae: Measurement of the ^{25}Al(p,γ)^{26}Si Reaction Rate

Name of group: DRAGON

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Start of preparations:	2001
Date ready:	March 2002
Completion date:	2003

Beam time requested:

12-hr shifts	Beam line/channel	Polarized primary beam?
34 (^{25}Al)	2A / ISAC	No
15 (stable)	na / ISAC	na

Recent studies of ^{26}Al gamma-emission in the galaxy and of ^{26}Al/^{27}Al isotopic anomalies in meteorites have advanced our understanding of galactic and stellar evolution, as well as the origin of the solar system. While the observations of galactic gamma-ray emission point to massive stars as possible major contributors to the ^{26}Al distribution, the need to understand the potential contribution from nova explosions has led to recent progress in nova modelling. Within the present framework of explosive nucleosynthesis in novae, the production of ^{26}Al can be bypassed if the ^{25}Al(p,γ)^{26}Si reaction becomes faster than the β^+ decay of ^{25}Al. The strengths and locations of ^{25}Al+p resonances in ^{26}Si have been estimated, but the reaction rate remains uncertain by about a factor of 1000, and no direct measurements have been attempted.

Using the DRAGON facility and ^{25}Al beams from ISAC, we propose to measure the resonance strengths of the ^{25}Al(p,γ)^{26}Si reaction. With beams in the energy range 180 to 900 keV/u, the measurement will cover the ^{25}Al + p resonances in ^{26}Si considered to be important for explosive nucleosynthesis in novae. The measured resonance strengths will then provide the first direct experimental determination of the ^{25}Al(p,γ)^{26}Si stellar reaction rate, and place tighter constraints on the production of ^{26}Al in novae.

Experimental area

DRAGON facility in the ISAC experimental hall.

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

500 MeV proton beam from the TRIUMF cyclotron.

Secondary channel ISAC - HE

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

The secondary beam required is ^{25}Al with intensities $> 10^9$ ions per second and with energies from 180 to 900 keV/u. In addition, stable beams of ^{25}Mg, ^{27}Al and ^{28}Si will be needed to calibrate the DRAGON facility.

TRIUMF SUPPORT:

Continued infrastructure support from TRIUMF for DRAGON at ISAC, including assigned personnel.

NON-TRIUMF SUPPORT

NSERC DRAGON Project Grant (J.M. D'Auria et al.), approved by NSERC in 2001 for 3-year support.

This experiment does not introduce any additional safety hazards beyond those covered under the normal operation of the DRAGON and ISAC facilities. Safety procedures for the operation of DRAGON have been developed and approved.

1 Scientific Motivation

1.1 ^{26}Al in the Galaxy

Since the interstellar medium (ISM) is the birthplace of new stars, one must understand the characteristics of the ISM at different times in order to understand better the process of star formation, including our solar system, as well as the chemical evolution of our galaxy. One source of information regarding the ISM is the study of gamma emission from radioisotopes. If the half-life of the isotope in question is sufficiently short on a cosmological timescale, for example, then such measurements can give us knowledge about the recent conditions within the galactic ISM.

Another important source of information is the measurement of isotopic abundances in meteoritic inclusions. The birth of the Sun is an obvious example of star formation, and we would like to understand the conditions under which the solar system was formed, as well as the timescale involved. Since meteoritic material found in our solar system was solidified during the collapse of the proto-solar cloud, these measured abundances give insight into the conditions of the ISM at that time.

In light of the above, the origin of galactic ^{26}Al is an important question in nuclear astrophysics, since data from both gamma emission studies and meteoritic abundance measurements are available. In the former case, the COMPTEL telescope has mapped out the gamma-ray emission from the decay of ^{26}Al ($T_{1/2}$ = 0.7 million years) in our galaxy [1]. The measured flux gives a ^{26}Al/^{27}Al ratio averaged over the last one million years, and therefore gives us an indication of nucleosynthetic activity within the ISM in the recent past. In the case of meteorite studies, the ^{26}Al/^{27}Al ratio in the inclusions was inferred from the excess abundance of ^{26}Mg [2]. These measurements give the ^{26}Al/^{27}Al ratio in the ISM just before collapse of the solar nebula, roughly 4.5 billion years ago.

A comparison between these two measurements shows that the present ^{26}Al/^{27}Al ratio (derived from gamma emission) is ten times smaller than that determined from meteoritic abundances, pointing to changes in the ISM since the solar system was formed. Based on a qualitative analysis of the COMPTEL results, the observed gamma distribution suggests that massive stars, such as Wolf-Rayet stars and supernovae, are the primary contributors of ^{26}Al to the measured map [3]. However, the sources of ^{26}Al have not yet been firmly identified to date, and present models of galactic evolution have encountered difficulties in fitting the distribution.

In determining the potential source(s) of ^{26}Al, the global analysis of the COMPTEL map discussed above should be complemented with a deeper understanding of specific nucleosynthesis sites, especially with regard to ^{26}Al yield predictions. From a nuclear physics perspective, our present framework shows that significant ^{26}Al production also happens in nova explosions and AGB stars, in addition to Wolf-Rayet stars and supernovae.

1.2 ^{26}Al Production in Novae

In the case of novae, an accurate prediction of ^{26}Al yield is important even apart from considerations of the COMPTEL results. In particular, nova simulations suggest that

^{26}Al is produced in significant amounts in ONe novae. For CO novae, on the other hand, ^{26}Al production will take place only if substantial break-out from the Hot CNO cycle happens. (The possibility of break-out in CO novae presently appears to be unlikely, although this conclusion may change.) With the next-generation gamma-ray telescope INTEGRAL, the detection of gamma emission (or lack thereof) from the decays of ^{26}Al and other radionuclides for nearby novae are expected to provide important constraints on nova nucleosynthesis and modelling. For example, if the nova ^{26}Al yield inferred from observations is negligible, then the frequency of ONe novae in the galaxy is lower than expected, and/or break-out from the Hot-CNO cycle in novae does not happen.

Furthermore, the ^{26}Al yield in novae is also important because the isotopic ratio ^{26}Al/^{27}Al serves as a marker for identifying candidate sources for pre-solar meteoritic grains. Recently, a number of pre-solar grains have been discovered with a handful of isotopic features, such as high ^{26}Al/^{27}Al ratios suggestive of nova origin [4]. Hence, a more accurate prediction of the expected isotopic ratios in the ejecta of explosive sites, such as classical novae, will help identify the source of these particular grains.

Recent developments in nova modelling have led to estimates of the ^{26}Al yield in the explosion (José et al. 1997 and 1999 [5][6], Wanajo et al. 1999 [7], and Starrfield et al. 2001 [8]). To illustrate the nuclear physics behind the ^{26}Al production in the explosion, we consider the case of a 1.25 $M_\odot$ ONe nova as modelled by José et al. in Ref. [6]. In short, the resulting ^{26}Al nucleosynthesis occurs as follows:

- At the onset of thermonuclear runaway, ^{26}Al in its ground state (^{26}Al$_g$) is produced by p-capture on pre-existent ^{25}Mg.
- Through the path ^{24}Mg(p,γ)^{25}Al(β^+)^{25}Mg, ^{25}Al is produced, the ^{25}Mg supply is replenished, and the ^{26}Al$_g$ yield is increased through ^{25}Mg(p,γ)^{26}Al.
- At T = 0.2 GK, ^{24}Mg is replenished through leakage from the NeNa cycles through the reaction ^{23}Na(p,γ)^{24}Mg. Furthermore, the reaction ^{25}Al(p,γ)^{26}Si begins to compete favorably with the β^+ decay of ^{25}Al.
- After the peak temperature of 2.44 GK is reached, the burning envelope expands and cools. The final Al abundances are determined by β^+ decays of ^{26}Si, ^{27}Si, ^{25}Al, and ^{26}Al$_m$.

A comparison among models from different studies shows that details of the explosion have a strong effect on the final ^{26}Al yield. Moreover, on the nuclear physics front, José et al. (1999) investigated the effects of uncertainties in reaction rates on the production of ^{26}Al, and concluded that in this regard, the reactions ^{23}Na(p,γ)^{24}Mg, ^{25}Al(p,γ)^{26}Si and ^{26}Al$_g$(p,γ)^{27}Si significantly affect the final yield. The ^{25}Al(p,γ)^{26}Si reaction, which is the focus of this proposal, has an especially important role since the ^{26}Si produced in this reaction decays to the isomeric excited state in ^{26}Al (which in turn quickly decays to ^{26}Mg with a half-life of 6 seconds), therefore bypassing the production of ^{26}Al in its ground state [9].

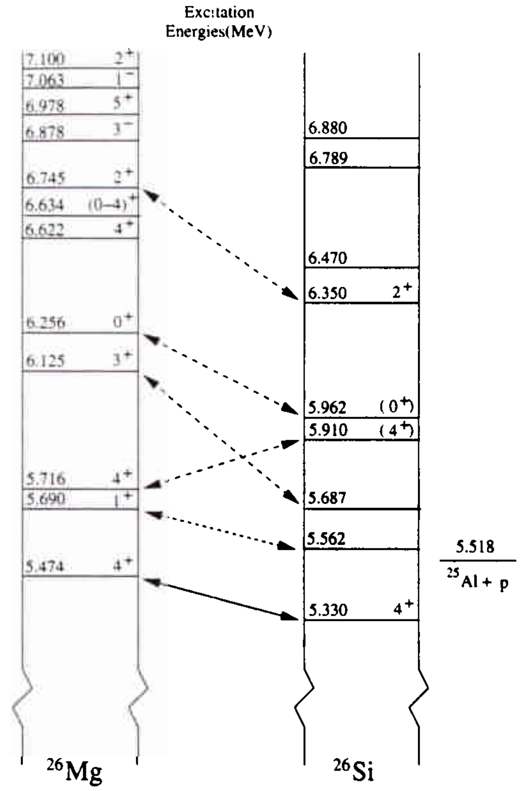

Fig. 1 Level structure of ^{26}Si close to the ^{25}Al+p threshold and the analog state region in ^{26}Mg. The solid arrow shows a firm mirror assignment, while dashed arrows show tentative assignments used in the present proposal.

1.3 The ^{25}Al(p,γ)^{26}Si Reaction: Spectroscopy of ^{26}Si

The ^{25}Al(p,γ)^{26}Si reaction rate has been estimated by Iliadis et al. [10]. The Q-value is 5518 keV. While resonances within 1 MeV of the proton threshold of ^{26}Si can contribute for temperatures less than 1.5 GK, they find that the rate at lower temperatures is dominated by an s-wave ($J^{\pi} = 3^{+}$) resonance whose mirror is a known state in ^{26}Mg at $E_x = 6.125$ MeV. Iliadis et al. use Coulomb displacement energies to assign an energy of $E_x = 5.970$ MeV ($E_r = 452$ keV), with an associated uncertainty of $\pm$100 keV. The widths and resonances strength have not been measured, and were also calculated using information available on the respective mirror state. The proton partial width (Γ_p) of the 3^+ resonance was calculated from $\Gamma_p = C^2 S\, \Gamma_{sp}$, where C^2 is the isospin Clebsch-Gordon coefficient. The single-particle spectroscopic (S) factor was determined from experimental values adopted from the mirror ^{26}Mg state. The single-particle partial width (Γ_{sp}) was calculated considering elastic scattering of nucleons by an optical-model potential. The resulting proton partial width used in the rate calculation was $\Gamma_p = 9.2$ eV. The gamma partial width (Γ_γ) was determined from experimental data on the mirror state in ^{26}Mg (Γ_γ(exp) = 0.033 eV), and calculated with the shell-model (Γ_γ(SM) = 0.10 eV). The resonance strength $\omega\gamma$ of the $E_{cm} = 452$ keV resonance was calculated to be 58 meV, using Γ_γ(SM) = 0.10 eV, $\Gamma_p = 9.2$ eV, and relevant spins.

Unfortunately, no 3^+ resonance in ^{26}Si has been observed in this energy region to date. The level structure of ^{26}Si near the proton threshold is shown in Figure 1, along with known levels in the mirror nucleus ^{26}Mg. The presently known structure of ^{26}Si has been determined from measurements of the ^{28}Si(p,t)^{26}Si [11] and ^{24}Mg(^{3}He,n)^{26}Si [12] [13] reactions, and more recently through a study of the ^{29}Si(^{3}He,^{6}He)^{26}Si reaction [14]. Note that the (^{3}He,^{6}He) measurement should be sensitive to unnatural parity states, while the two-nucleon transfer reactions are expected to populate them only weakly at best. Lastly, the ORNL/University of North Carolina group has recently remeasured the ^{28}Si(p,t)^{26}Si reaction [15], which should provide confirmation of the (p,t) results from Ref. [11] with better energy resolution (uncertainties $< \pm 10$ keV), and determination of spins and parities for many of the observed states. The data analysis is still in progress.

Relatively little is known about the level parameters of the important resonances. All the widths and resonance strengths were estimated by Iliadis et al. as delineated above for the 3^+. Our present understanding of the resonances in ^{26}Si near the proton threshold (5.518 MeV) is described in the following:

- $\mathbf{E_x = 5.562}$ **MeV** (E_r = 44 keV): the energy was determined in an early (p,t) study [11] to ± 28 keV. The J^{π} has not been measured, and so we rely on the 1^+ assignment resulting from the mirror assignment proposed by Iliadis et al. [10]. Note that this resonance will not be accessible with beams from the ISAC facility. However, for our purposes, this is not a problem since this resonance contributes to the rate at temperatures below that of interest to novae.

- $\mathbf{E_x = 5.687}$ **MeV** (E_r = 169 keV): the energy was determined in the recent (^{3}He,^{6}He) measurement to ± 15 keV. No spins and parities were measured in this study. Since this state was populated strongly in (^{3}He,^{6}He) but never observed in any of the two-nucleon transfer reactions, it could very likely have unnatural parity. Therefore, it is a candidate for the 3^+ resonance, although its energy is much lower than that estimated by Iliadis et al.

- $\mathbf{E_x = 5.910}$ **MeV** (E_r = 392 keV): this state was only seen in the (^{3}He,n) reaction study by Bohne et al. [12], with the energy determined to ± 30 keV. From the angular distribution, an unresolved doublet with 0^+ and 4^+ components was assigned. We will use the assignment of 0^+ by Iliadis et al., for lack of any better information.

- $\mathbf{E_x = 5.962}$ **MeV** (E_r = 444 keV): this level was measured with the (p,t) reaction by Paddock et al. [11] and also in the (^{3}He,^{6}He) study. The energy uncertainty is ± 15 keV. In previous compilations [16] and in Iliadis et al. this state was assigned to be the 4^+ component of the (0^+, 4^+) doublet mentioned above. We shall adopt the same spin assignment here.

- $\mathbf{E_x = 6.350}$ **MeV** (E_r = 832 keV): seen by the early (p,t) and (^{3}He,n) studies. The energy is determined to ± 25 keV. The spin was measured to be 2^+ from a (^{3}He,n) angular distribution, and therefore this state is an s-wave resonance for ^{25}Al + p, possibly contributing significantly to the ^{25}Al(p,γ)^{26}Si reaction rate.

Table 1 summarizes the information above and lists the level parameters from Ref. [10], which we will use in this proposal. The 5.562 MeV level has been left out for reasons already mentioned. For our present purposes, we will assume that the E_x = 5.687 MeV (E_r = 169 keV) state is the important 3^+ resonance. Recall that Iliadis et al. calculate an energy of 5.970(100) MeV for this 3^+ state. The proton width was scaled with the

Coulomb penetrabilities at the respective energies. Since the gamma-decay of the analog state in ^{26}Mg has a major branch to an excited 3^+ state, the gamma width Γ_γ was scaled with the ratio of the gamma-ray energies.

Table 1 Resonance parameters adopted for the ^{25}Al(p,γ)^{26}Si reaction, Q-value = 5518 keV (see text for details).

$E_x(^{26}\mathrm{Si})$ (keV)	E_r (MeV)	J^π	Γ_p [a)] (eV)	Γ_γ(SM) [b)] (eV)	$\omega\gamma$ [c)] (eV)
5687(15)	169(15)	(3^+)	7.2×10^{-5}	0.081	4.2×10^{-5}
5910(30)	392(30)	(4^+)	0.037	0.0067	4.2×10^{-3}
5962(15)	444(15)	(0^+)	0.017	0.0046	3.0×10^{-4}
6350(25)	832(25)	2^+	79	0.11	4.5×10^{-2}

a) From Iliadis et al. (Ref. [10]).
b) Shell-model results from Ref. [10].
c) With $\omega\gamma=(2J_r+1)\Gamma_p\Gamma_\gamma/12\Gamma$

This 3^+ state assignment must be qualified with the fact that further information from ongoing and planned studies of levels in ^{26}Si may change the picture. Results from the recent ORNL/UNC (p,t) measurement will soon be available, with an expected improvement in the precision of resonance energies which will make this direct measurement easier. Also, a measurement of the p(^{27}Si,d)^{26}Si is planned at the Michigan State University coupled-cyclotron facility next year [17]. Lastly, we note that a separate proposal will be submitted to measure ^{25}Al + p elastic scattering with the TUDA facility at ISAC prior to performing the direct measurement. In addition to confirming our present knowledge, this study should provide further information on s-wave resonances that may have been missed thus far, as has been already demonstrated for the ^{21}Na + p system [18].

Overall, using the presently available nuclear structure information, the ^{25}Al(p,γ)^{26}Si rate at nova temperatures is uncertain by a factor of 100 - 1000. This uncertainty would be reduced with better spectroscopy of ^{26}Si although even then a direct measurement would still be necessary. The proposal will be modified accordingly as further results from ongoing measurements become available. In the interim, we have designed this proposal to measure the strengths of all resonances in Table 1.

2 Experimental Description

2.1 Experimental Technique

The ^{25}Al(p,γ)^{26}Si reaction will be measured in inverse kinematics using a recoil mass separator. The resonance strengths will be determined by measuring the yield of the ^{25}Al(p,γ)^{26}Si reaction for each resonance. The resonances are narrow, so a thick target yield will be measured. In thick target yield measurements, the yield is related to the resonance strength $\omega\gamma$ through the following relationship,

$$Y = \frac{\lambda^2}{2\epsilon}\frac{M+m}{M}\omega\gamma, \tag{1}$$

where λ^2 is the reduced de Broglie wavelength in the centre-of-mass frame, M is the target mass, m is the projectile mass, and ϵ is the beam energy loss per atom per unit area within a target of density n, given by $\epsilon = \frac{1}{n}\frac{dE}{dx}$.

A windowless differentially pumped gas target of hydrogen will be used. A gas target minimizes effects due to changes in target composition, instability in the beam, and the energy resolution of the beam. A target density of 5.4×10^{18} atoms/cm^2 will be used, corresponding to a gas pressure of 4.5 Torr. At this density, the thickness of the target is large compared to the total resonance widths, the beam energy spread, and the straggle of the beam in the gas target.

The ^{25}Al ($T_{1/2}$ = 7.2 seconds) beam will be produced in an on-line source using the ISOL method. The beam intensity on target will be normalized to the elastic scattering of ^{25}Al from the hydrogen. Stable beams of ^{25}Mg, ^{27}Al, and ^{28}Si for calibration purposes will be produced from an off-line ion source.

The DRAGON (Detector of Recoils And Gammas Of Nuclear reactions) facility has been optimally designed to measure alpha- and proton-capture reactions in inverse kinematics using heavy-ion beams incident on a gas target of hydrogen or helium. DRAGON (see Fig. 2) is comprised of a differentially pumped, windowless gas target with an array of BGO gamma-ray detectors, a state-of-the-art electromagnetic mass separator (EMS) which selects one charge state of the beam and recoils, and an assembly of focal plane detectors. For a more detailed description of the DRAGON facility, the reader is referred to Ref. [19]. The DRAGON recoil mass separator will be tuned to select the most abundant charge state of the ^{26}Si recoils, and will transmit 100% of the selected charge state. The estimated yield per ion listed in Table 2 gives the required separator beam suppression factor. The electromagnetic separator alone is expected to give a beam suppression of 10^{12}.

With the BGO array, the overall background rejection is expected to be greater than 10^{15}, albeit at the expense of detection efficiency. The gamma-decay branching ratios of the states of interest have not been measured. However, based on branching ratios known for mirror states in ^{26}Mg, all of these resonances decay through a gamma cascade. The important 3^+ resonance for example decays with the emission of 1.241 MeV, 2.367 MeV, and 1.513 MeV gamma-rays, assuming our energy assignment of E_x = 5.687 MeV. The total gamma-ray energy for an event detected in the BGO array will be reconstructed in software, and events whose total energy is less than that expected from the capture reaction will be rejected. Under these conditions, the efficiency of the gamma array is about 30%.

For further identification of recoils, we will perform the following measurements. For total energy measurements, a double-sided silicon strip detector and an ionization chamber are available and can be easily interchanged. Additional background reduction is achieved by measurements of time-of-flight between the accelerator RF and BGO gamma-array, between the BGO gamma-array and the separator focal plane, and a local time-of-flight at the focal plane. The mass difference between the beam and the recoil is 4%. A timing resolution of 1.4 nsec gives a local time of flight resolution of 2.5% Furthermore, the energy of the highest resonance may be high enough for E-ΔE to be feasible, using the segmented ionization chamber at the focal plane.

Based on presently available information, Table 2 lists experimental parameters for the important ^{25}Al + p resonances in the Gamow window corresponding to peak nova temperatures. The column labelled E_r gives the resonance energies in the centre-of-mass frame (cm) and the lab system (lab). E_{beam}/A is the energy of the beam per unit mass that is needed to place the resonance at the target center; ΔE is the energy loss in the target calculated with SRIM, while σ_{beam} is the beam energy spread, assumed to be 0.2%. The half opening angle for the ^{26}Si recoils, $\Delta\theta$, was determined for a ground state gamma transition. Lastly, the total yield per ion was calculated using equation (1) and resonance parameters from Table 1.

Table 2 Experimental parameters of the important ^{25}Al(p,γ)^{26}Si resonances for nova temperatures, as calculated in the centre-of-mass (cm) and laboratory frames (see text for details).

E_x (MeV)	ref. frame	E_r (keV)	E_{beam}/A (keV/u)	ΔE (keV)	σ_{beam} (keV)	$\Delta\theta$ (mrad.)	Yield per ion
5.687(15)	cm	169(15)		18.9	0.35		
	lab	4358(15)	180	485	9	12.6	3.0×10^{-13}
5.910(30)	cm	392(30)		20.8	0.82		
	lab	10108(30)	411	535	21	8.6	1.2×10^{-11}
5.962(15)	cm	444(15)		20.7	0.89		
	lab	11449(15)	464	530	23	8.2	7.6×10^{-13}
6.350(25)	cm	832(25)		18.9	1.7		
	lab	21457(25)	864	487	43	6.4	6.6×10^{-11}

2.2 Experimental Programme

As already mentioned, DRAGON selects one charge state of the ^{26}Si recoils. Therefore the charge state distribution of the recoils will be measured. The measurements will be done with a ^{28}Si stable beam, since isotopic effects will not affect the results. To account for the fact that not all recoils pass through the same amount of hydrogen gas, measurements will be performed for different pressures in the gas cell.

The DRAGON facility will be calibrated with stable beams as a check of the DRAGON setup from the gas target and gamma array, to the end-detectors. Stable beams of ^{25}Mg ^{27}Al and ^{28}Si of intensity 10-20 pnA will be tuned through the separator up to the final focus. Insertion of a beam attenuator will reduce the beam intensity to 100-1000 Hz, and the beam can then be used to test and calibrate the end-detectors. The efficiencies can be checked using the ^{25}Mg(p,γ)^{26}Al and ^{27}Al(p,γ)^{28}Si reactions. Both reactions have resonances in the energy region of interest that can be used for this purpose.

The purity of the ^{25}Al beam will be determined. The selectivity of the ISAC mass separator ($\Delta M/M = 1/10000$) should be sufficient to prevent isobaric beam contamination of ^{25}Mg ions ($\Delta M/M = 1/6180$). The contamination level should be checked, in any case. The beam energy will be set to a value where Z discrimination is possible. In stable beam tests to date, the ionization chamber displayed useful Z discrimination for beam energies down to 770 keV/u. The beam is then tuned through the separator into a Faraday cup at the final focus. Following insertion of the attenuators, the beam will be put into the ionization chamber, where two groups would be observed in an E-ΔE spectrum if there is significant contamination present. Furthermore, with a ^{25}Mg beam from the off-line ion source, the ^{25}Mg(p,γ)^{26}Al reaction will be measured at the same energies at which the ^{25}Al(p,γ)^{26}Si reaction will be measured. The beam contamination can then potentially be determined by the ionization chamber, which would separate the recoils from the two reactions.

As already mentioned, the beam intensity will be normalized to the elastic scattering of ^{25}Al from hydrogen. Therefore the elastic scattering cross-section must be measured before the direct measurements are performed. The cross section will be measured by introducing a known amount of a heavy noble gas, such as Ar or Kr, into the hydrogen gas. At the low energies under consideration, the cross-section of elastic scattering from the heavy gas can be assumed to be Rutherford. Therefore from the Rutherford scattering the beam intensity can be deduced. With the beam intensity known, the absolute yield of ^{25}Al + p elastic scattering is determined for the required beam energies. Note that information can also be extracted from a TUDA measurement of the ^{25}Al(p,p)^{25}Al reaction.

Additionally, in order to ensure that the potential contribution from the (d,n) channel due to deuterium contamination in the gas target is understood, we will measure the ^{25}Al(d,n)^{26}Si reaction with the ^{25}Al beam, using a deuterated polyethelene foil to avoid contaminating the gas target cell.

Lastly, the strengths of the ^{25}Al(p,γ)^{26}Si resonances listed in Table 2 will be measured. The following estimates will be modified as the structure of ^{26}Si is further clarified in other studies. To estimate beam intensities and required beam time, we assume that the efficiency of the separator due to single charge-state selection is about 40%; the gamma array has an estimated total efficiency of 30%; and the recoil detection efficiency of the end-detector is close to 100%. The coincidence efficiency for gammas and recoils in coincidence is therefore about 12%. Using present estimates for the resonance strengths and a beam intensity of 10^9 ^{25}Al beam particles per second on target, the estimated coincidence count rate for the 169 keV resonance is about 0.1 count per hour. We therefore will aim to place an upper limit on its resonance strength. The same is true of the 444 keV resonance at a count rate of 0.4 event per hour. For the 392 keV and 832 keV resonances, we estimate count rates of 5 per hour and 29 per hour, respectively (see next page for full beam time requirements).

3 Beam Time Required

Measurement	Shifts Required
• Charge state distributions	
^{28}Si	3
• DRAGON calibration with stable beams:	
^{28}Si	3
^{27}Al	3
^{25}Mg	3
• Radioactive beam purity tests:	
^{25}Mg	3
^{25}Al	3
• Elastic scattering cross-section:	
^{25}Al	3
• Resonance strengths of the p(^{25}Al,γ)^{26}Si reaction:	
On resonance at 832 keV	3
On resonance at 444 keV	3
On resonance at 392 keV	3
On resonance at 169 keV	3
Off-resonance runs (2 energies per resonance)	16
TOTAL:	49 shifts

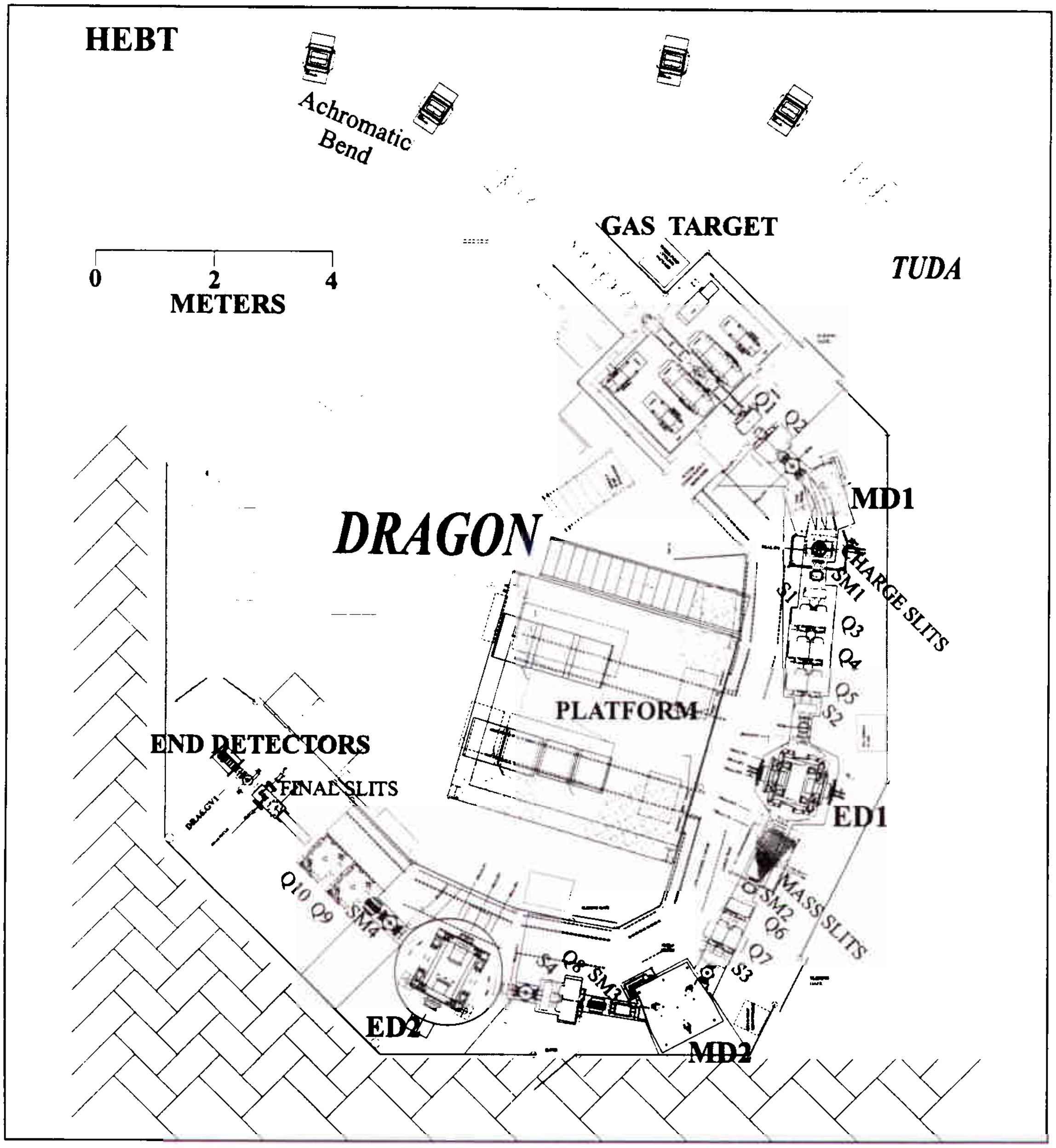

Fig. 2 The DRAGON facility. The four major components are shown: the windowless gas target, the gamma detector array, the EMS (composed of two magnetic dipoles and two electrostatic benders) and the recoil end-detector station.

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