ELSEVIER

Nuclear Physics A 701 (2002) 625c–631c

NUCLEAR PHYSICS A

www.elsevier.com/locate/npe

Astrophysics with a DRAGON at ISAC

J.M. D'Auria for the DRAGON collaboration

Department of Chemistry, Simon Fraser University, Burnaby, BC, Canada V5A 1S6

Abstract

A new facility, DRAGON, designed specifically to measure radiative proton- and alpha-capture reaction rates involving radioactive reactants is being installed at the new ISAC accelerated radioactive beams facility. A description of the planned experimental program, specifications of the components, status of the installation (as of March 2000), and the planned schedule is provided in this report. Further, details on the gas target, the electrostatic dipole system and the detection system are also provided. © 2002 Elsevier Science B.V. All rights reserved.

1. Introduction

The DRAGON (Detector of Recoils And Gammas Of Nuclear reactions) facility is being installed at the new ISAC (see Fig. 1) accelerated radioactive beams facility in Vancouver, Canada.

This facility is specifically designed to measure the rates of radiative proton- and alpha-capture reactions. These reactions, involving exotic nuclei as reactants, take place in various explosive nucleosynthesis phenomena such as novae, supernovae and X-ray bursts. Such rates are important in elucidating these processes which play a role in the production of most of the stable elements.

2. The program

The reactions of interest initially for this program are given in Table 1 and the first study involving a radioactive beam will be $^{21}Na(p,\gamma)^{22}Mg$. Inverse kinematics will be employed with the accelerated short-lived radioactive beam intercepting a windowless gas

E-mail address: dauria@sfu.ca (J.M. D'Auria).

0375-9474/02/$ – see front matter
PII: S0375-9474(01)01656-6

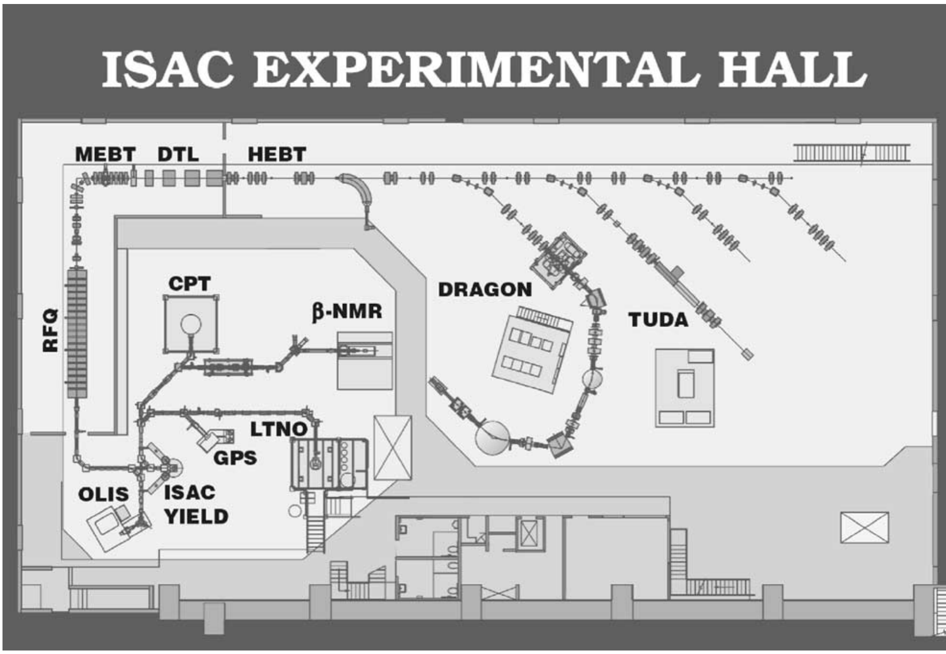

Fig. 1. Plan view of ISAC experimental hall.

Table 1
Experimental parameters of selected radiative capture reactions

Reaction	E_x (MeV)	E_{beam}/A (MeV/u)	E_{recoil}/A (MeV/u)	$w\gamma^a$ (meV)	Yield ($\times 10^{-12}$)	Count rate[b] (s^{-1})	Recoil cone (mrad)
$^{15}O(\alpha,\gamma)$	4.033	0.16	0.10	0.02	0.003	$0.8h^{-1}$	15.6
$^{17}F(p,\gamma)$	4.561	0.68	0.60	17.3	27	0.02	7.6
$^{18}F(p,\gamma)$	6.742	0.35	0.31	3.0	11	0.1	14.7
	6.862	0.48	0.43	12	35	0.3	12.8
$^{19}Ne(p,\gamma)$	2.646	0.47	0.42	7	23	0.25	4.7
$^{20}Na(p,\gamma)$	3.508	0.31	0.28	240	890	5.2	7.3
$^{21}Na(p,\gamma)$	5.714	0.22	0.20	2	11	0.32	13.3
$^{23}Mg(p,\gamma)$	2.38	0.53	0.49	41	96	0.10	3.3
$^{25}Al(p,\gamma)$	5.97	0.47	0.44	58	160	0.01	8.1
$^{26m}Al(p,\gamma)$	7.893	0.23	0.21	10	140	0.04	15.0

[a] References for these resonance strengths to be provided upon request.
[b] Projected beam intensities taken from ISAC proposal.

target. Essentially all of the reaction products as well as the relatively more intense beam of similar momentum will be accepted by a complex recoil mass separator. The parameters of the reactions are given in Table 1 and these set the specifications of the separator.

3. The DRAGON facility

3.1. General

In order to separate the reaction products (using inverse kinematics) from an ion beam of similar momentum, electric and magnetic fields are needed. Recoil mass separators have been built before for high-energy reactions such as the FMA device at ANL, the RMS system at HRIBF and others. The older Daresbury facility also now at HRIBF has been reconditioned for use at low energies. These systems take advantage of the small difference in energy and momentum of the products to effect a clean separation, but none were built specifically for use at the low energies needed for studies of nuclear astrophysics reactions. The DRAGON facility is the first (of several) specifically designed for such low-energy reaction studies.

DRAGON is composed of an extended (10 cm) gas target, surrounded by a BGO-based gamma array of high geometric efficiency. The ions enter the recoil separator with the first magnetic dipole used to separate one-charge state of both the beam and reaction product. The second main component of the separator is an electrostatic dipole which operates at up to 40 kV/cm (10 cm separation between two Ti electrodes). This device is used to separate the beam and recoil based upon the different energies. A second sequence of magnetic and electrostatic dipoles are used to provide further separation. It is expected that a beam suppression factor of about 10^{12} will be achieved in this stage. The specifications of the separator components are given in Table 2 while Fig. 2 presents the optics as calculated using computer codes, Raytrace and GIOS.

A time-of-flight start signal provided by an MCP/C foil electron detection system coupled with a stop signal from an energy detector will provide the primary measurement of the mass of the resultant ions from the separator. Identification of the Z of these ions will be attempted but given the energies involved (of order 200 to 800 keV/u), this may not prove feasible. It is expected that an additional beam suppression factor of up to 100 will be realized with these approaches. Finally, a gamma array based upon BGO crystals

Table 2
Specifications for the DRAGON electromagnetic separator

- Optical path length: 20.4 m
- Mass dispersion: 0.46 cm/%, 1st stage
- Acceptance:
  - angular (hor./ver. ±20/25 mrad) 2 cm/%, 2nd stage
  - velocity (±2%)
- Mass resolution: 90 after 1st stage, 150 after 2nd stage
- Spot size: 5 mm after 1st stage

Components

- First sector dipole magnet: 1 m, 10 cm gap, 50°, 0.22 T
- Second dipole magnet: 0.81 m, 12 cm gap, 75°, 0.27 T
- First electric dipole: 2 m, 20°, 10 cm gap, ±200 kV
- Second electric dipole: 2.5 m, 35°, 10 cm gap, ±160 kV
- Q1: 10.8 cm, Q2–Q8: 15.9 cm, Q9–Q10: 15 cm
- Sext 1–4: 16 cm

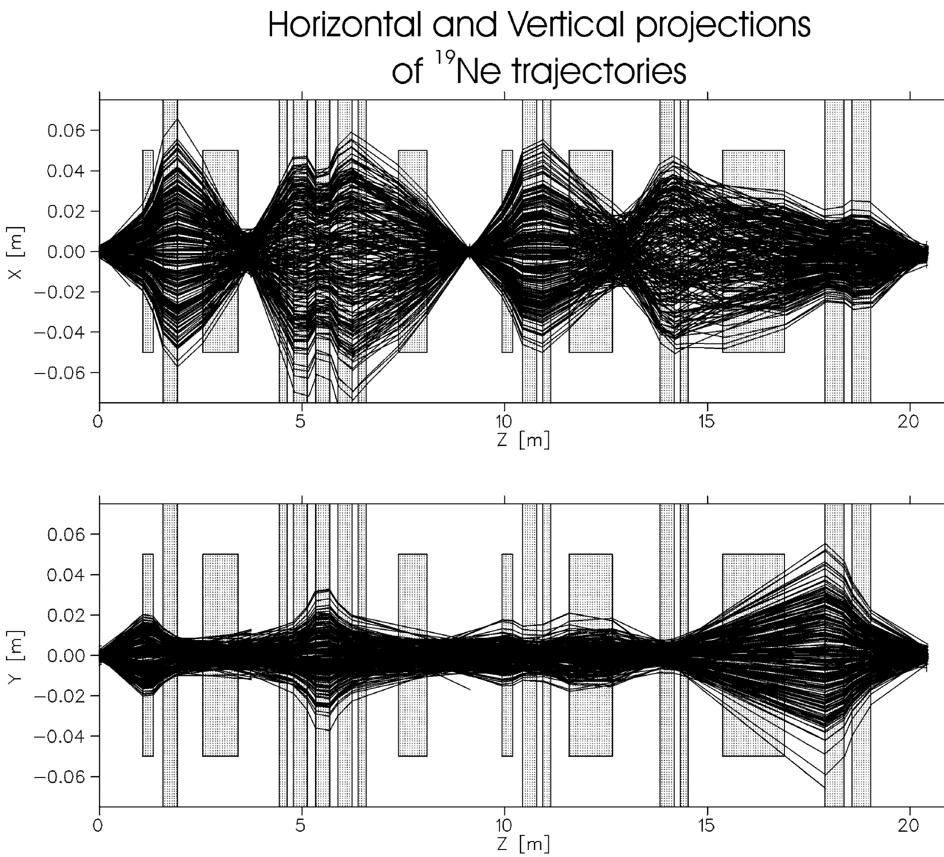

Fig. 2. Optics for DRAGON.

situated around the gas target is planned to provide a coincident signal from the prompt reaction gammas. This should add a further factor of 100 in beam suppression.

3.2. Detailed description and status

Fig. 3 presents a detailed picture of the planned layout of the DRAGON facility. It shows not only all units for the system itself but also all required peripheral units such as security fence, service platform and cable runs.

The first phase of the windowless gas target has been assembled, installed and tested successfully. Using all of the pumps prescribed (five 1000 l/s turbos and three roots blowers) the upstream and downstream pressure at the entrance to the separator was about 2×10^{-6} torr for the required target pressure of 5 torr. This was achieved not only for He and air, but also for H_2 gas (after some detailed study of a jet effect). A system is being

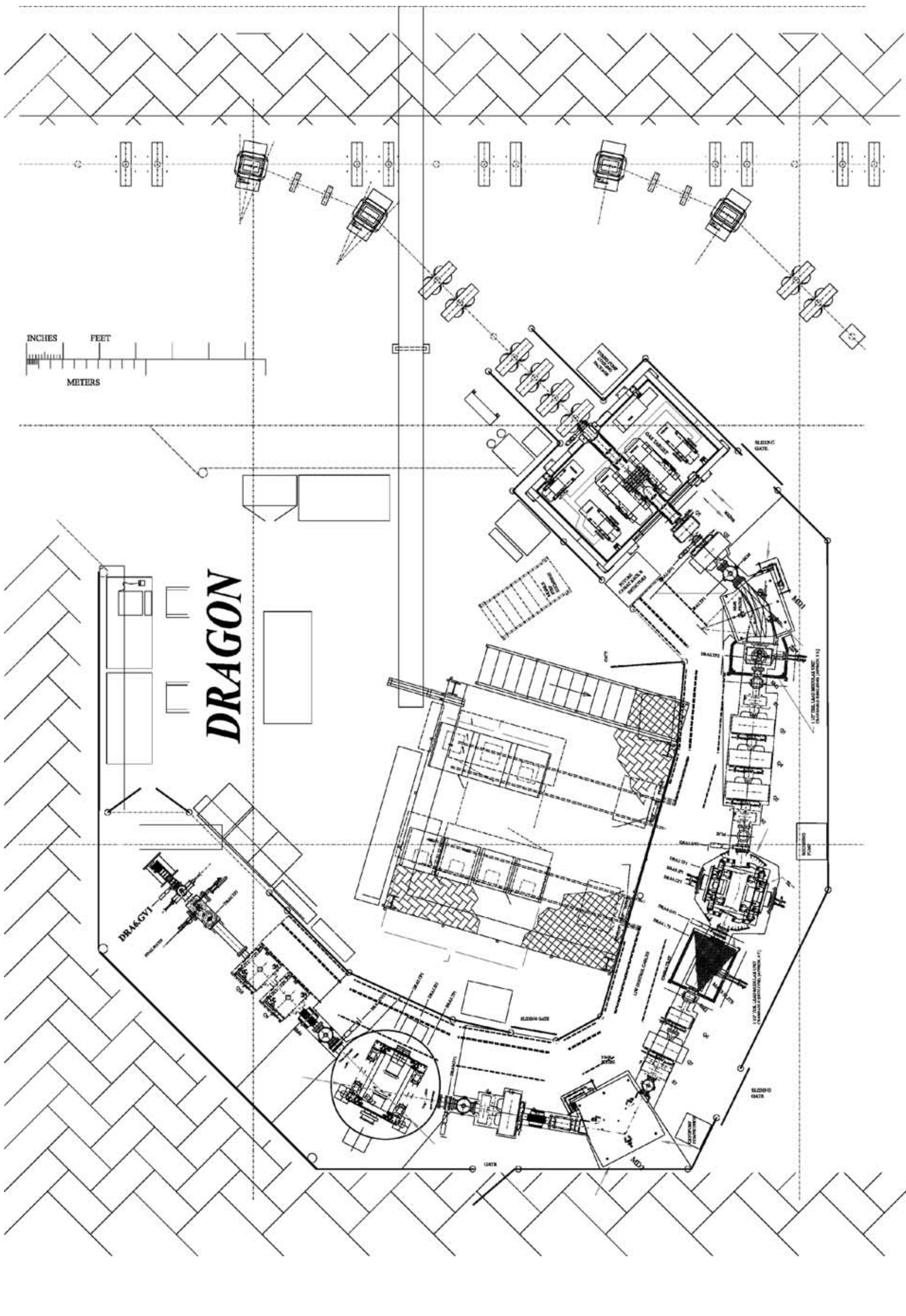

Fig. 3. Detailed layout plan for DRAGON in ISAC hall.

installed to allow for recirculation of the H_2 gas to minimize quantities used along with a remotely operable, control system. A study of the possible charge state distribution of ions from the gas target will be performed initially using a similar system at the University of Naples.

The magnetic dipoles have been built and their magnetic properties mapped. Following construction of vacuum tanks and stands, they will be installed. Delivery of the eight new magnetic quadrupoles has begun and following mapping, and construction of their stands, they will be installed. The sextapole units and the new steering magnetics are ready for installation. The new electrostatic dipole systems are almost completed. The TRIUMF-constructed power supply has been tested to 225 kV and a contract for the construction of the tank and support structure has been given. Diagnostic elements are in the early stage of detailed designing.

The now ionization chamber for the measurement of the total energy of the recoils as well as possibly the Z of the ions is undergoing an extensive series of tests (using the Tandem at Yale University) with low-energy heavy ions. The thin windows ($\sim$ 30–50 μg/cm^2) have been obtained and a new spinning method has been developed for future replacements. The MCP detection system is presently being systematically tested.

Funds for the new BGO-based gamma array have been requested. This array will subtend a geometric efficiency of about 80% and will exhibit energy resolutions of about 5%. Some position sensitivity may also be possible. It is anticipated that this array would be designed, constructed, installed and operational within 12 months of receiving final funding.

Component performance of DRAGON units using probably an intense ^{148}Gd alpha source (to be made at TRIUMF) will initiate within 7 months and this will be followed by commissioning studies using accelerated stable heavy ion beams. The ^{20}Ne(p, γ)^{21}Na and ^{21}Ne(p, γ)^{22}Na are two reactions being considered to measure the overall efficiency of the DRAGON system (see Table 3).

Table 3
Stable beam studies: reaction parameters (assumes 100% transmission, 40% charge distribution, 1 μA beam)

Reaction	E_x (keV)	E_{beam} (MeV/u)	$\omega\gamma$ (eV)[a]	Yield (p/s)[b]
^{20}Ne(p, γ)^{21}Na	2798 (1)	0.384	$1.1 \pm 0.2 \times 10^{-4}$	0.9
$Q = 2431$ keV	3544 (1)	1.17	1.13 (0.07)	4046
	3680 (1)	1.31	0.035 (0.01)	135
^{21}Ne(p, γ)^{22}Na	7009 (D)	0.284	0.66 (0.1)	7707
$Q = 6738$ keV	7239 (2)	0.525	0.76 (0.15)	5217
	7408 (1.6)	0.702	1.5 (0.37)	8177
	7470 (1.6)	0.768	6.38 (1.9)	31800
	7800 (1.8)	1.112	0.54 (0.16)	2081
^{24}Mg(p, γ)^{25}Al	3082	0.823	0.49	2028
$Q = 2271$ keV	3424	1.201	0.03	96

[a] $\omega\gamma$ resonance strength values taken from Endt except 7009 keV state.
[b] Thick target resonance yields.

Table 4
Radioactive beam studies: parameters of first reaction (assumes 100% transmission, 40% charge distribution, beam 10^{10} pps)

Reaction	E_x (keV)	E_{beam} (MeV/u)	$\omega\gamma^a$ (eV)	Yield[b] (p/h)
^{21}Na(p, γ)^{22}Mg	5714	0.223	0.002	80
Q= 5501 keV	(5837)	(0.352)	0.0075	191
	5961	0.482	0.002	35
	6046	0.571		

[a] Thick target resonance yields.
[b] Present estimates by C. Illiadis, private communication.

4. Experimental program: details

As mentioned the first reaction to be pursued will be ^{21}Na(p, γ)^{22}Mg, followed possibly by ^{20}Na(p, γ)^{21}Mg due to the availability of the radioactive beam and their astrophysics importance. In anticipation, a new study of the levels of ^{22}Mg was performed using a p, t reaction, resulting in new information of the energies of key states. Predicted results are presented in Table 4 along with some estimates of expected production rates. It is planned to initiate the full study of the reaction rate early in 2001.

5. Summary

A new facility, called DRAGON, is being built at ISAC to measure the rates of radiative proton- and alpha-capture reactions involved in the rp-process of explosive nucleosynthesis. It is expected to initiate experimental measurements late in 2001.