The DRAGON Facility at TRIUMF-ISAC

Installation Status and Commissioning Plans

Beam Time Request for E824

I. OVERVIEW

This report provides a status report of the construction and installation of the DRAGON facility and as well provides information on what is required in terms of both stable and radioactive beams for the commissioning of DRAGON and the first planned experiment, E824, the study of ^{21}Na(p,γ)^{22}Mg reaction. Assuming a ^{21}Na beam intensity of 10^{10}/s, 54 beam shifts are requested for this study.

II. INTRODUCTION

The primary purpose of the DRAGON (Detector of Recoils And Gammas Of Nuclear reactions) facility is to measure the astrophysical S-factor or resonance strengths in radiative proton and alpha capture reactions. These reactions will be studied using inverse kinematics with gaseous targets of hydrogen or helium, and heavy ions with center of mass energies from 0.15 to 1 MeV/u. Since the facility is located at TRIUMF-ISAC, these heavy ions will consist primarily (but not exclusively) of short-lived radioactive species and the reactions are of interest to increasing our understanding of the process of explosive nucleosynthesis in nova, supernova, and x-ray bursts. Funding for the DRAGON Facility was received April 1998 and the present plans are to initiate commissioning in the fall of 2000. The purpose of this report is to give the TRIUMF Experimental Evaluation Committee a report on the status of the building program, and the plans for the experimental program. Included will be a request for both stable beams and radioactive beam for the first planned experiment.

III. THE FACILITY: A STATUS REPORT

A. Overview

Figure 1 displays a schematic representation of the DRAGON facility. It is composed of a windowless gas target, a multi-unit electromagnetic separator (EMS) and a recoil detection system. All products of radiative capture reactions will be accepted by the separator and their momentum is essentially the same as the beam itself. The philosophy of the EMS is to first allow only one charge state of the beam and reaction products to pass the first magnetic dipole. Beam and reaction products are then separated in the first electrostatic dipole, taking advantage of the difference in kinetic energy. Additional separation is achieved in the second stage; parameters of the system are displayed in figure 3 of attached E824 proposal. In the recoil detection system there is an initial time-of-flight MCP detector to provide a start signal and this is likely (see further discussion below) to be followed by a specially designed ionization chamber (IC) with a PGAC (parallel plate avalanche counter) front-end, which provides a stop signal. This t-o-f coupled with an energy determination from the IC will allow determination of the mass of the particle. Particle identification will also be attempted in the multi-chamber ionization chamber however this may be difficult to achieve given the low energies of the reaction products.

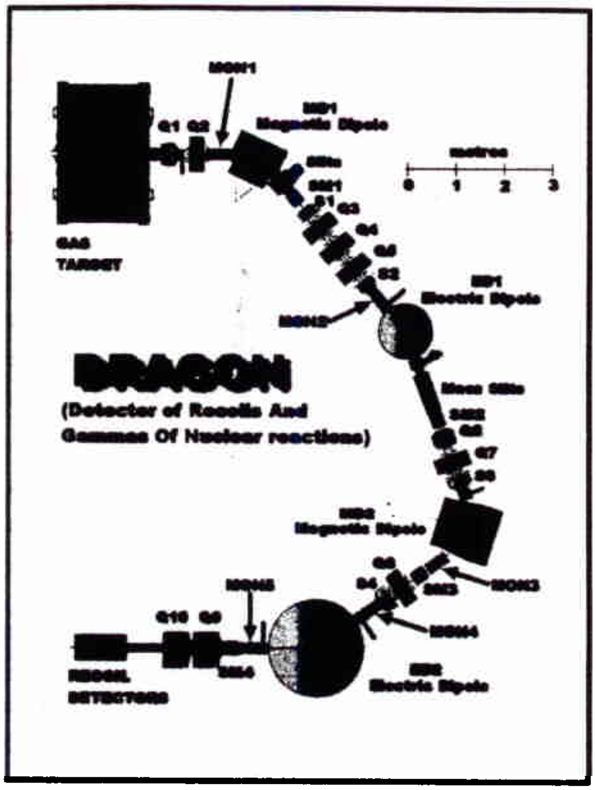


Fig. 1 Schematic Layout of the DRAGON facility

B. Layout

Prior to proceeding with actual construction of the components of the DRAGON, intensive reviews by professional members of the TRIUMF-ISAC group were conducted. Figure 2 presents a detailed layout in a plan view of all components of the DRAGON facility.

C. Components

1. The Windowless Gas Target

The target will be a windowless, differentially-pumped gas cell; the advantages are the uniformity of the target, the greater yield for resonance reactions, and no background from other materials. The requirements of the cell vary from reaction to reaction depending upon the beam energy, energy spread, energy of emitted gamma ray, accuracy of known resonance energy, energy loss in the target and whether reaction is resonant or non-resonant. The most difficult case is the $^{21}Na(p,\gamma)^{22}Mg$ reaction which requires a thick target and exhibits a large recoil cone angle. Using this along with the optics of the EMS and the needed target thickness, set the specifications of the system: a 6 mm cell entrance aperture, a target pressure of 3.75 Torr, and a cell length of 10 cm. Figure 3a displays a schematic view of the differential pumping system while 3b shows a view which includes the gas recirculation system.

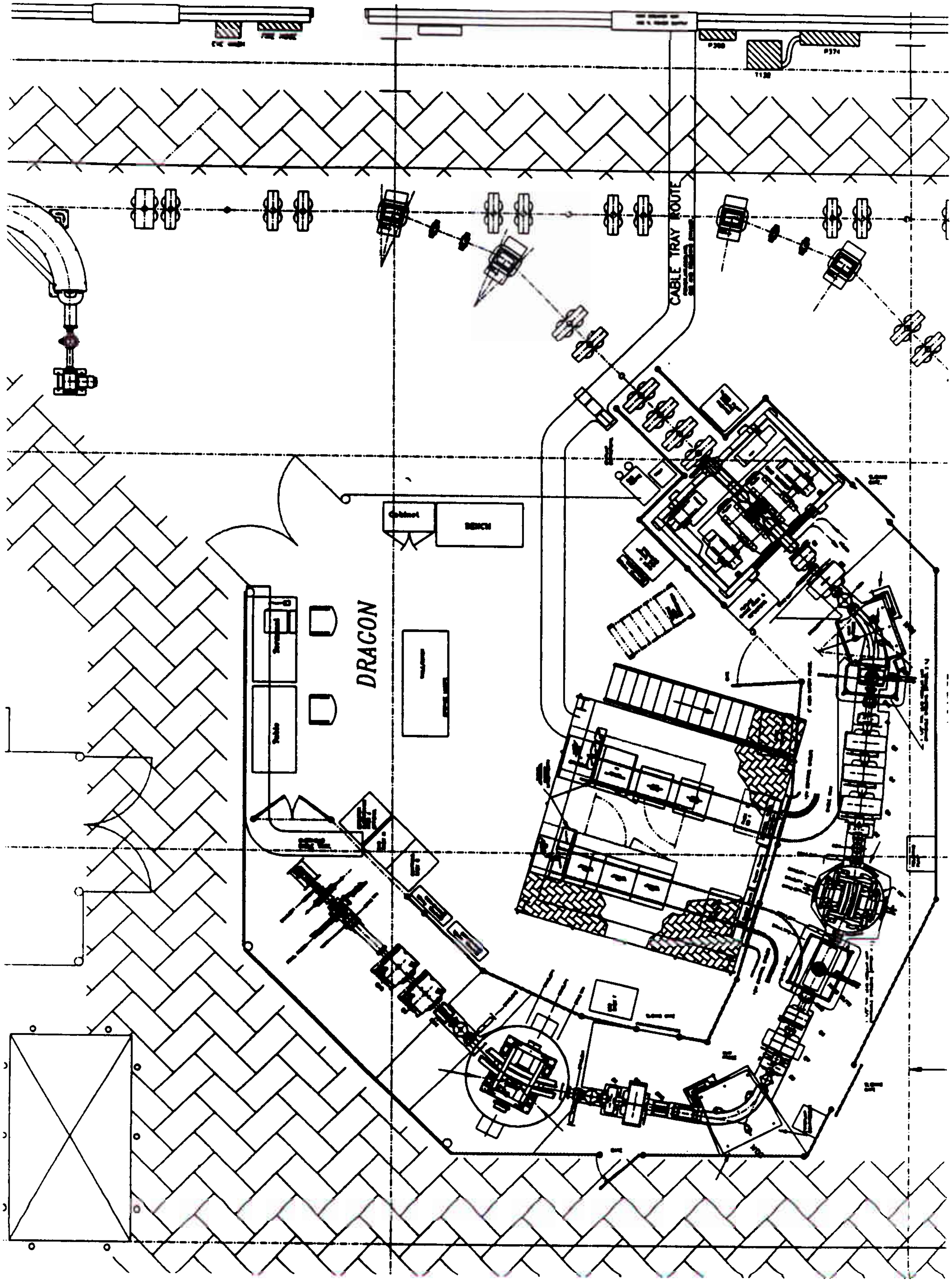


Fig. 2 Detailed Layout of the DRAGON facility

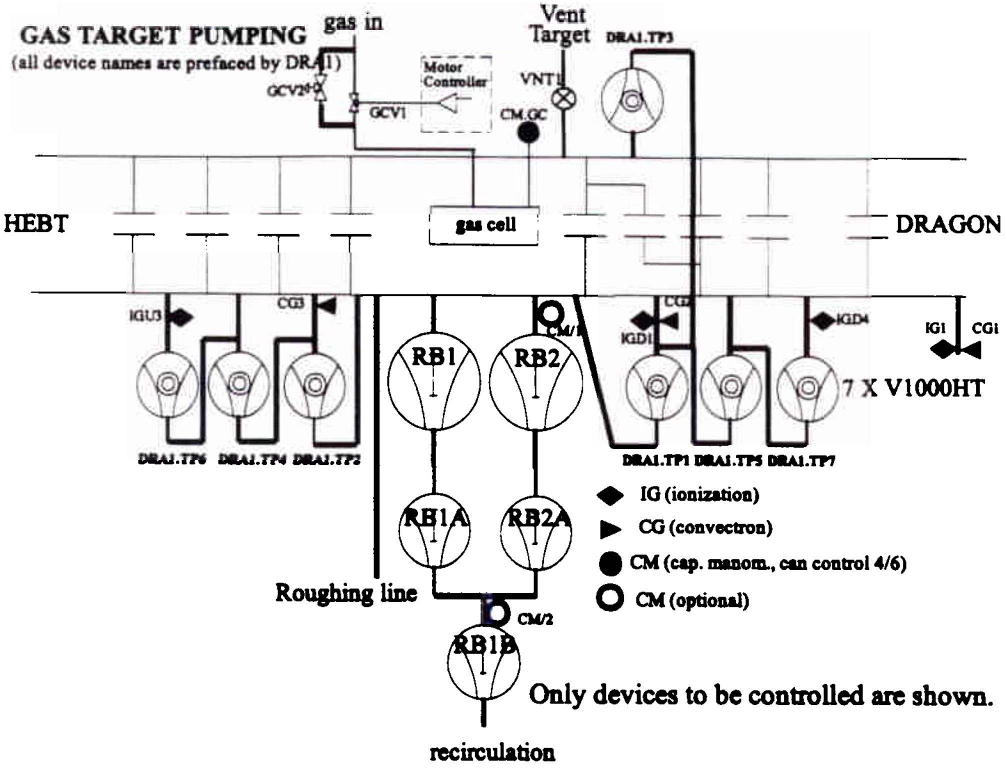


Fig. 3a Diagram indicating the differential pumping section of the gas target.

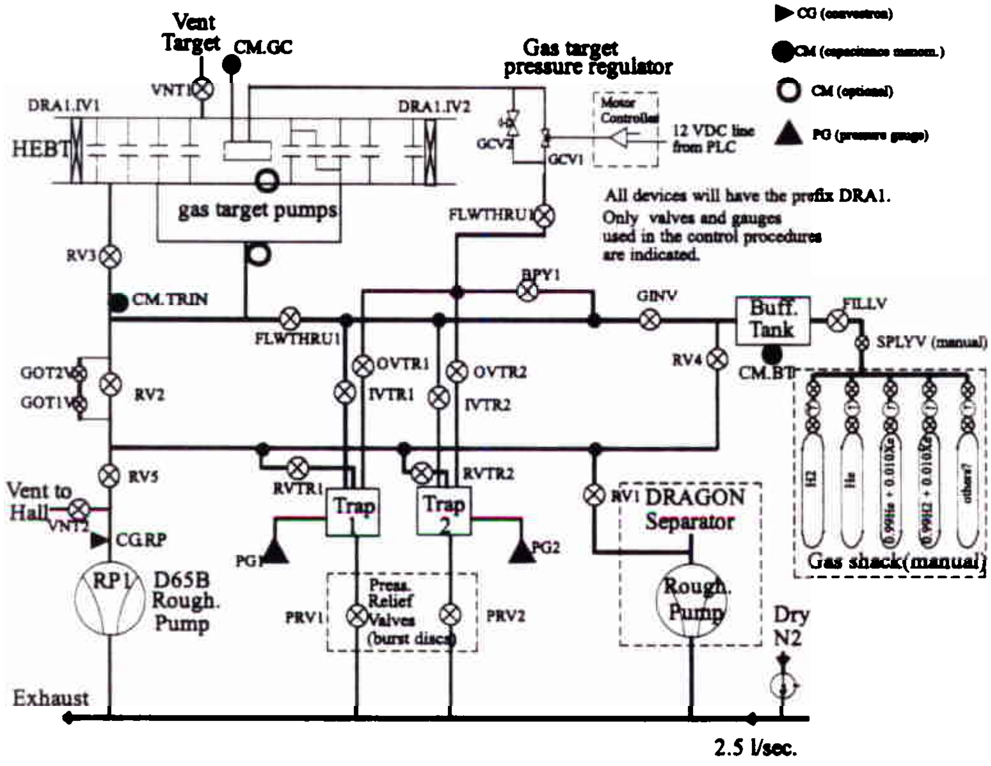


Fig. 3b Diagram indicating the gas target with the recirculation and cold trap of the gas handling system

A more complete description of the gas target and recirculation system can be found in a report prepared for purposes of technical review (May 5, 1999) of the safety and control aspects of the system; available upon request.

Funding for the gas target system was received in 1997 and the phase I system was assembled in the University of Alberta. The system is now at TRIUMF in location on the ISAC floor. Figure 4 gives a recent picture of the actual target system. A series of tests are in progress to assess the pumping capacity of the system for He and H_2 gas. A gas recirculation system is also being coupled to the system.

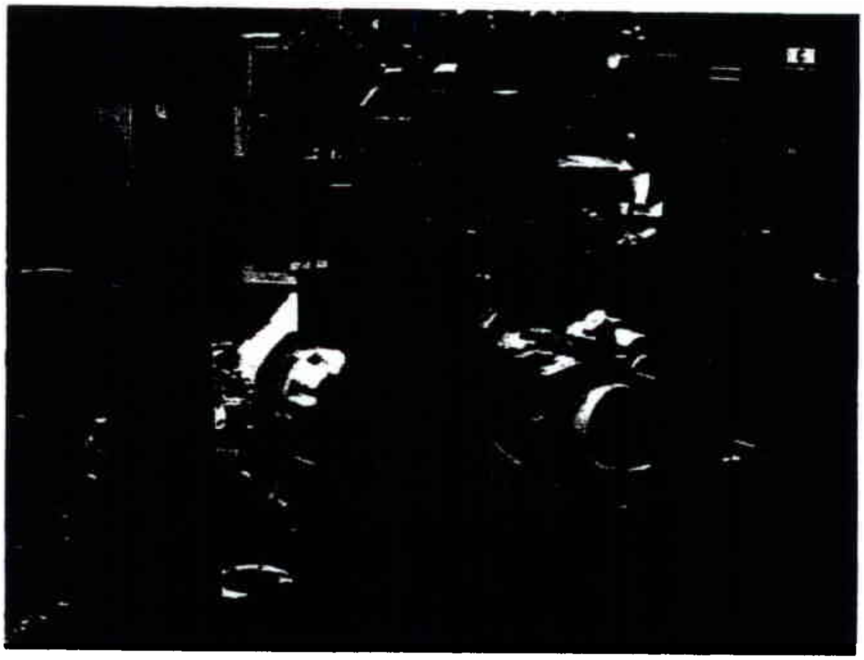


Fig. 4 Picture of gas target in ISAC experimental hall

A project has been initiated in collaboration with members of the DRAGON Collaboration from the University of Naples to study the charge distribution of ions resulting from the interaction of selected low energy heavy ion beams upon passing through a gas target. This study to be performed in Naples will form the basis of an (SFU) M.Sc. program.

2. The Electromagnetic Separator (EMS)

The EMS is designed to transmit the desired recoil product ions with good efficiency, while providing beam suppression of at least 10^{-12} orders of magnitude. The momenta of the recoil ions bracket the momenta of the beam particles, both in magnitude and direction. Therefore it is necessary to have both magnetic and electrostatic dipoles to accomplish separation.

The two magnetic dipoles were received at TRIUMF and have been mapped. Sextupoles (2) satisfying the requirements of DRAGON were obtained from TRIUMF. They have been mapped and refurbished. There are three different types of quadrupoles needed, 2 with 4" diameter and 5 with 6" diameter. These are presently being manufactured and will arrive in Feb., 2000. A similar situation exists for the steering magnets.

The electrostatic dipoles represent a unique situation for TRIUMF as such units are now made as commonly as magnetic units. There are four main components, namely the electrodes, the inner support structure including insulators, the power supply, and the outer support structure and vacuum tank. The maximum fields of the ED1 and ED2 are 40 kV/cm and 32 kV/cm, respectively. The operating potentials are up to +/- 200 kV. A formal review of the conceptual design of all units was successfully passed before proceeding to detail design and building.

Both the cathode and anode electrodes are made of Ti and these units are under construction. The design of the inner support structure and insulators has been completed including detailed calculations of the fields in the various regions.

With respect to providing the high potentials needed into the vacuum system, it was decided to redesign a power supply which allowed the driver to be outside and the high potential obtained through a series of stacks inside a ceramic cylinder containing SiF_6 to shield against voltage discharges. This approach was pioneered with the FMA device at ANL. The first board built here at TRIUMF was tested successfully up to a potential of 150 kV. Following testing up to 300 kV, the power supplies will be completed.

The present timetable calls for the completion of the ED units by February, 2000; the dipoles will be assembled and aligned on the bench, and then installed into the vacuum tanks located on the ISAC floor.

3. Non-field components

Specifications of diagnostic elements and slits have been provided. Detailed designs are in progress for the charge slits and mass as well as other components in the layout. All pumps for DRAGON are purchased. The control system has been designed, all units of DRAGON included in a data base and implementation of the ISAC control software in progress.

4. The Recoil Detection Systems

Two options are presently being considered to provide necessary signals of the recoil products of interest. In both cases the intention is to measure the time-of-flight of the heavy ions and their total energy in order to determine their mass.

In the first approach a start signal is obtained from a micro-channel plate (MCP) detection system (includes a C foil at 45 degrees to beam) located at the focus of the EMS. The stop signal comes from the first stage of an ionization chamber(IC), specifically a parallel grid avalanche counter (PGAC). The IC will provide the total energy and possibly some indication of Z of the heavy ion through ΔE measurements. A prototype of the IC and the PGAC have been built and tested. These will be combined to explore how they work in close proximity of each other. Very thin windows for the IC are being manufactured and these units will be combined in anticipation of testing using low energy stable heavy ion beams at some facility in the U.S.

In the second approach the same MCP system will be used to generate a start system with the stop system generated by a similar detector. The total energy of the ion will then be measured by an appropriate surface barrier, Si detector. Given the low energy of the ions involved, efforts on the development of an appropriate Si detector are in progress.

5. The Gamma Array

Detection of the prompt reaction gamma rays will provide additional degree of background suppression, possibly needed to measure very weak resonance strengths. Considerable effort has been devoted to the design of an appropriate gamma array that can function in the high radiation background of the positron emission of the scattered beam in the neighborhood of the target. Initially special attention and testing had been given to considering a new scintillator, LSO, which has a relatively high brightness and is also quite fast. However for a variety of reasons, not the least being availability of high quality scintillator material for a reasonable price, it was decided to use BGO units. A proposal has been submitted to NSERC to receive funding in 2000 for building and installing such an array using BGO; a conceptual view of the proposed gamma systems is shown in figure 5.

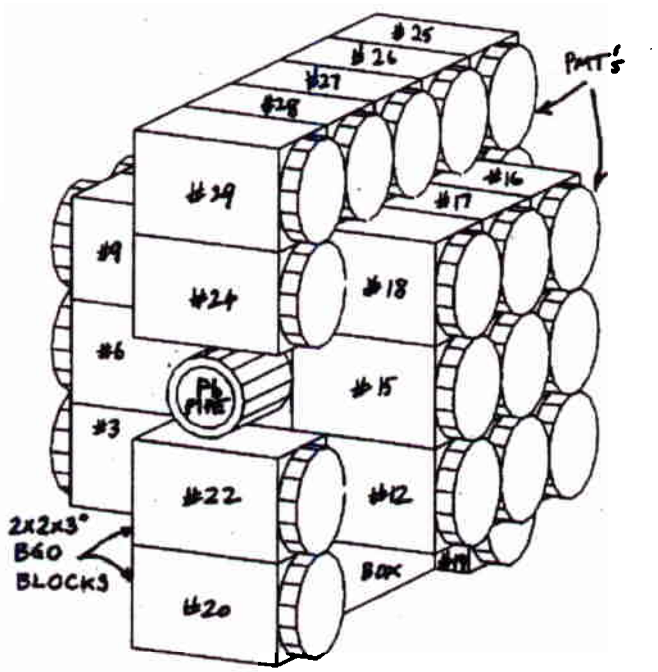
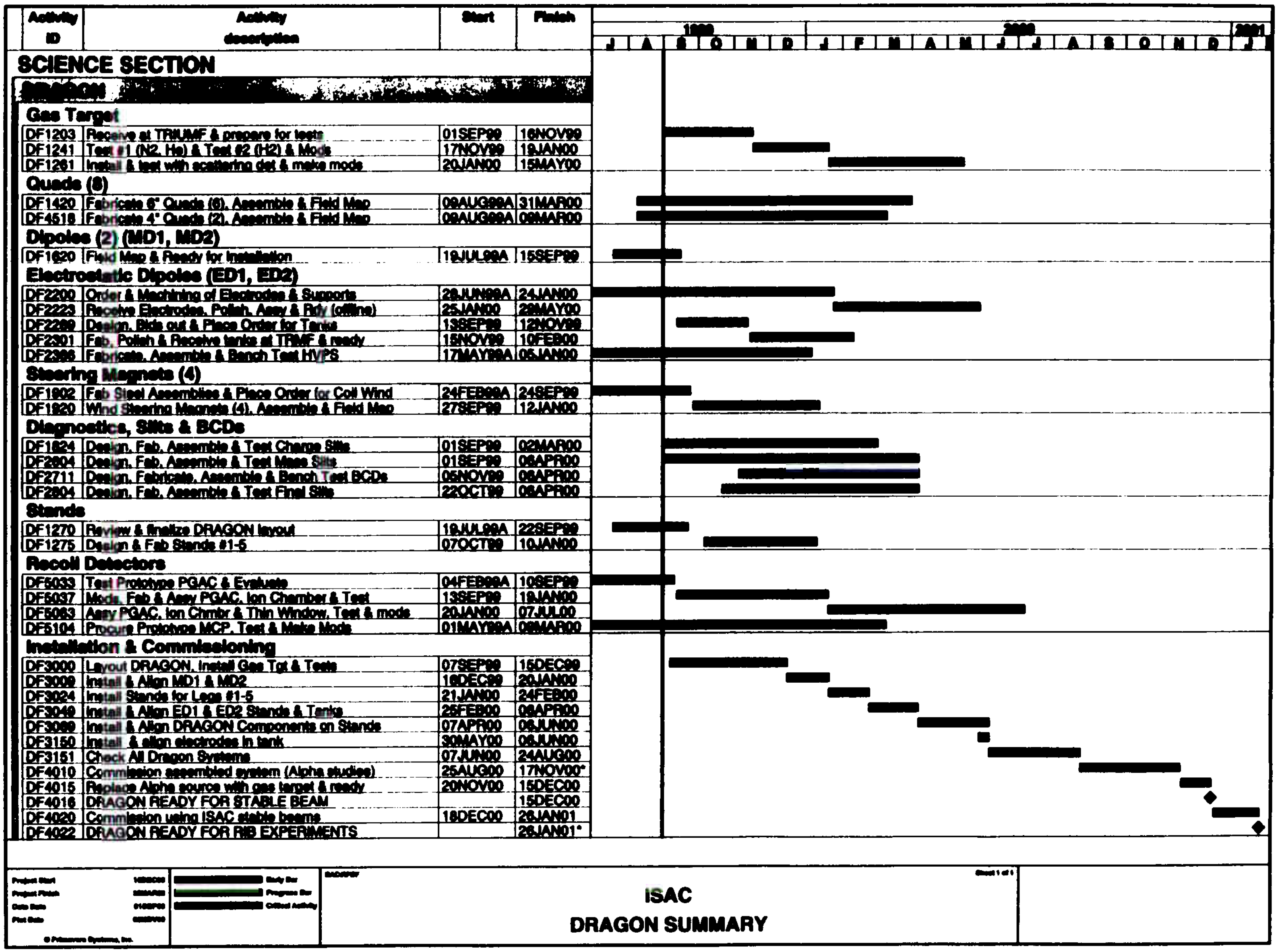


Fig. 5 29 BGO Blocks with Pb Shielding

It will take about one year after funding is received to complete and install the full gamma array system.

D. The Schedule

A standard TRIUMF PERT diagram (summary sheet) has been included (fig. 6) to indicate the plans for the completion of the Oct/Nov running period. A copy of the more complete PERT is available upon request.



SCIENCE SECTION

DRAGON

Activity ID	Activity description	Start	Finish
Gas Target			
DF1203	Receive at TRIUMF & prepare for tests	01SEP99	16NOV99
DF1241	Test #1 (N2, He) & Test #2 (H2) & Mods	17NOV99	19JAN00
DF1261	Install & test with scattering det & make mods	20JAN00	15MAY00
Quads (8)			
DF1420	Fabricate 6" Quads (6), Assemble & Field Map	09AUG99A	31MAR00
DF4518	Fabricate 4" Quads (2), Assemble & Field Map	09AUG99A	09MAR00
Dipoles (2) (MD1, MD2)			
DF1620	Field Map & Ready for Installation	19JUL99A	15SEP99
Electrostatic Dipoles (ED1, ED2)			
DF2200	Order & Machining of Electrodes & Supports	28JUN99A	24JAN00
DF2223	Receive Electrodes, Polish, Assy & Rdy (offline)	25JAN00	29MAY00
DF2269	Design, Bids out & Place Order for Tanks	13SEP99	12NOV99
DF2301	Fab, Polish & Receive tanks at TRMF & ready	15NOV99	10FEB00
DF2366	Fabricate, Assemble & Bench Test HVPS	17MAY99A	05JAN00
Steering Magnets (4)			
DF1902	Fab Steel Assemblies & Place Order for Coil Wind	24FEB99A	24SEP99
DF1920	Wind Steering Magnets (4), Assemble & Field Map	27SEP99	12JAN00
Diagnostics, Slits & BCDs			
DF1924	Design, Fab, Assemble & Test Charge Slits	01SEP99	02MAR00
DF2604	Design, Fab, Assemble & Test Mass Slits	01SEP99	06APR00
DF2711	Design, Fabricate, Assemble & Bench Test BCDs	05NOV99	06APR00
DF2804	Design, Fab, Assemble & Test Final Slits	22OCT99	06APR00
Stands			
DF1270	Review & finalize DRAGON layout	19JUL99A	22SEP99
DF1275	Design & Fab Stands #1-5	07OCT99	10JAN00
Recoil Detectors			
DF5033	Test Prototype PGAC & Evaluate	04FEB99A	10SEP99
DF5037	Mods, Fab & Assy PGAC, Ion Chamber & Test	13SEP99	19JAN00
DF5063	Assy PGAC, Ion Chmbr & Thin Window, Test & mods	20JAN00	07JUL00
DF5104	Procure Prototype MCP, Test & Make Mods	01MAY99A	09MAR00
Installation & Commissioning			
DF3000	Layout DRAGON, Install Gas Tgt & Tests	07SEP99	15DEC99
DF3009	Install & Align MD1 & MD2	16DEC99	20JAN00
DF3024	Install Stands for Legs #1-5	21JAN00	24FEB00
DF3049	Install & Align ED1 & ED2 Stands & Tanks	25FEB00	06APR00
DF3069	Install & Align DRAGON Components on Stands	07APR00	06JUN00
DF3150	Install & align electrodes in tank	30MAY00	06JUN00
DF3151	Check All Dragon Systems	07JUN00	24AUG00
DF4010	Commission assembled system (Alpha studies)	25AUG00	17NOV00*
DF4015	Replace Alpha source with gas target & ready	20NOV00	15DEC00
DF4016	DRAGON READY FOR STABLE BEAM		15DEC00
DF4020	Commission using ISAC stable beams	18DEC00	26JAN01
DF4022	DRAGON READY FOR RIB EXPERIMENTS		26JAN01*

ISAC

DRAGON SUMMARY

Fig. 6 Summary Sheet of PERT Diagram

1. Commissioning Plans

It is planned to initiate commissioning of DRAGON by August 2000 using alpha sources (^{148}Gd/3.18 MeV and ^{241}Am/5.48 MeV) at the target position. Studies with ISAC stable heavy ion beams will initiate following these studies, and when these beams are available. The list of stable beams needed are indicated below.

IV. THE SCIENCE

A. Overview

While there are a series of important reactions that will be pursued using the DRAGON facility, it was decided by the DRAGON collaboration at its meeting held at TRIUMF in July, 1999 that the first reaction to be studied will be the ^{21}Na(p,γ)^{22}Mg reaction. This is strongly influenced not only by the importance of the measurement but also the availability of the required radioactive beam with intensities to achieve this result in a reasonable period of time.

B. The ^{21}Na(p,γ)^{22}Mg Reaction Rate - E824

1. EEC Proposal

Attached is the previously submitted EEC proposal for this study. Given the completeness of the proposal, only minor corrections are presented below. It should be pointed out that a more complete description of the planned experimental program is given in the EEC proposal.

In general, the program is composed of :

a. Performing related studies on states in ^{22}Mg to ensure that sufficient knowledge is known to actually perform the experiment at hand;
b. Perform a series of commissioning reaction studies with stable beams to determine accurately the efficiency and performance of the DRAGON (and its components) so that absolute measurements can be performed;
c. Perform the actually measurements of the ^{21}Na(p,γ)^{22}Mg reaction rate.

2. Related Studies

a. Studies of the levels of ^{22}Mg

Initially it was believed that there were only three levels that contribute to the radiative proton capture resonance reactions. Since the energy of one of these states was known to only 25 keV, a value larger than the energy loss in the gas target, it was decided to re-measure this energy to better than 10 keV. A series of (p,t) studies on ^{24}Mg were performed using a high resolution spectrometer system available at the INS facility at the University of Tokyo. In the first measurements the energies of the observed states were measured to a precision of the order of 5 keV or better. However there were certain discrepancies from what was expected. In particular the state at 5.84 MeV was not observed although expected to be. In addition the 0+ state was observed at energy of 6.05 MeV while a very weak state was observed at 5.96 MeV. In addition two other new states were observed which would not be involved with the astrophysics reaction.

Because of these observations an additional study was performed at INS to measure the angular distribution of the state at 6 MeV and these data are still under analysis.

3. Required Stable Beams

Stable heavy ion beams are a definite requirement for the commissioning of the DRAGON facility and in particular, to measure the absolute efficiency of the entire system. Stable beams are needed to characterize the operation of the gas target, particularly to further understand the equilibrium charge distribution resulting from it. Stable beam induced reactions are also of great value in calibrating the absolute energy of the heavy ion beams from the LINAC accelerator. Finally the operational performance of the various components of the DRAGON, e.g., the recoil detectors to the various heavy ions of different A,Z is of prime importance to performing a good experiment with this complex facility.

While a full range of beams from ^{12,13}C to ^{31}P may be required to fulfill the full program planned for DRAGON, for the initial commissioning and the first planned experiment[^{21}Na(p,γ)^{22}Mg], only selected heavy ions are needed at this time.

In order to characterize the performance of the DRAGON with a focus to do the ^{21}Na(p,γ)^{22}Mg study, heavy ion beams of ^{20,21,22}Ne, ^{23}Na, ^{24}Mg with energies from 0.2 to 1.0 Mev are needed. Beam intensities of the order of 100 µA's would be acceptable.

In order to perform a measurement of the efficiency of the system, the plan is to study several well known radiative proton reactions. The criteria for choice of the reaction are that it be well known, small recoil angle, high cross section, and exhibit measurable resonant and non-resonant components. Some are listed below in the table. For a radiative proton-capture resonance reaction in which the resonance strength is 10 MeV, the target thickness is 1 x 10^{18} cm^{-2}, the stable beam intensity is 1 µA, the charge state distribution is 30%, the expected yield is about 45 cps in the end detection system.

Reaction	Q-Value	E_R [keV]	ω_γ [MeV]
^{12}C(p,γ)^{13}N	1.944	non-resonant	
^{20}Ne(p,γ)^{21}Na*	2.431	366	0.11
		398	0.06
		1113	1130
		1248	35
		1432	50
^{21}Ne(p,γ)^{22}Na*	8.655	269.6	8.3 x 10^{-5}
		520.6	7.6 x 10^{-4}
		761.9	3.4 x 10^{-3}
^{24}Mg(p,γ)^{25}Al	2.271	214	10
		402	31
		790	505
		1153	31
		1178	68
		1424	144
^{28}Si(p,γ)^{29}P	2.747	370	1.8
		724	.16
		1380	.30

*High priority

4. Required Radioactive Beam

Two aspects of the beam request require special discussion, namely the intensity and the plan for the use of the beam.

a. Beam Intensity

All calculations of required beam time are based upon an intensity of the desired radioactive beam of 10^{10} /s. This is a realistic number given that an intensity of 1.3×10^9 /s-μA was observed at ISOLDE for a Ti foil target. At TISOL a yield of only 5×10^7/s was observed using a SiC target but it was a single development run with 1 g target. Given that ISAC can run 10 μA beam or higher, then it is not unreasonable to expect a beam intensity approaching 10^{10} onto the DRAGON gas target. The proponents are prepared to assist the ISAC staff in achieving this desired goal. TISOL could be used to confirm target release yields and for proton beam intensities < 2 μA.

b. Required Beam Shifts

With a beam of 10^{10} /s, we expect to have about 200 ^{22}Mg recoils produced per second for the most important 212 keV resonance. With a total efficiency for the DRAGON of 40% (30% including the gamma array), approximately 48 hours would be needed to be sensitive to resonance strengths a factor of 10 weaker than the calculations predict. The total beam time estimated is as follows (as modified from the EEC proposal)

Runs for the 212 keV resonance	6	shifts
Runs at possible 336 keV resonance	6	shifts
Runs at projected 500 keV resonance	12	shifts
Runs at higher resonances	10	shifts
Contingency	20	shifts
Total	**54**	**shifts**

It should be noted that there are important studies that can be performed prior to obtaining the full beam intensity of 10^{10} /s of ^{21}Na. For example the performance of the DRAGON with the real beam(correct A,Z) can be tested with intensities much lower and the beam/background reduction factor measured. The deposit of radioactivity along the beam line of DRAGON is an excellent diagnostic that is available to be used to improve the performance of DRAGON. In addition the performance of the gamma array can be fully tested with much lower beam intensities. It should be noted that the use of a radioactive beam gives an additional probe which is not available when using stable beam. In addition elastic scattering studies can be performed also with lower studies. Finally, given the importance of this result and the fact that this reaction rate has never been measured, even the setting of a limit on the rate would be significant and publishable.

V. SUMMARY (AND BEAM TIME REQUEST)

The DRAGON Facility is being installed on the floor of the ISAC hall. Commissioning is expected to begin before September 2000 using an alpha source. Commissioning with stable beam will commence when beam is available. We request 54 shifts of the radioactive beam ^{21}Na.

VI. PERSONNEL

A number of the technical, professional and scientific members of the TRIUMF staff and others have contributed significantly to the project. While not all are still involved, these include:

Engineers

George Clark
Don Dale
Naimat Khan
Rolf Kietal
Jan Soukup
Hart Sprenger
Glen Stinson

Designers

Linda Ellstrom
Tim Emmens
Roland Kokke
Siggy Turke

Professionals

Dennis Healey
Robert Henderson
Miguel Olivo
Robert Openshaw
Dave Ottewell
V. Verma

Research Scientists/ Faculty

Gordon Ball
Lothar Buchmann
Ahmed Hussein
Dave Hutcheon
K. Peter Jackson
(Bruce Milton)
Art Olin
Joel Rogers
Gerry Roy

Graduate Students

Shawn Bishop
Wenjie Liu
Aaron Sanderson

Research Post-doctoral Associates

(Nick Bateman)
Alan Chen
Don Hunter
(Patricia Wrean)

Externals

Dick Boyd
Uwe Greife
Peter Lipnik
Alan Shotter

John D'Auria
For the TRIUMF-DRAGON Collaboration

Nov. 4, 1999