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DECEMBER 2004

The contributions on individual experiments in this report are outlines intended to demonstrate the extent of scientific activity at TRIUMF during the past year. The outlines are not publications and often contain preliminary results not intended, or not yet ready, for publication. Material from these reports should not be reproduced or quoted without permission from the authors.

INTRODUCTION

The following ISAC sections outline the various activities in ISAC-I operation, ISAC-I developments and the progress towards finishing ISAC-II. Although, there have been many highlights during the year, only a few are outlined here. Operational experience had pointed out the need to reduce the impact of the time needed to safely exchange targets. Considerable proton beam time was not being used due to this significant scheduling overhead. Consequently a second target station was brought into operation this year to increase the exotic beam availability. There were numerous target and ion source highlights. Six targets, including a new ZrC, were used to provide a wide variety of thermally ionized beams. The charge state booster was used on the test bench to produce multi charged ions of various species (i.e. perfomed as charge state booster). A resonant laser ion source test stand has been set up. An initial ECRIS test failed to demonstrate the anticipated performance, although subsequent measurements are leading to a much better understanding of the ECRIS operating specifications. A high power target has been developed and tested in the conditioning chamber. This target design has the potential of permitting full power operation at ISAC in the coming year. The accelerators achieved a remarkable 94% availability for the second year in a row. The ISAC-II civil construction was completed and technical staff moved in to convert the new building into a functioning laboratory. In ISAC-II, a major effort was to prepare the superconducting rf clean assembly area for assembly of the cryomodules since nearly half of the medium beta superconducting rf cavities have been fabricated and are already at TRIUMF. Good progress is being made on achieving adequate cavity tuning and rf coupling. Resource (personnel and financial) limitations prevented ISAC from realizing its full potential. Nevertheless, as the result of detailed planning and careful resource allocation, the major objectives for the year were successfully achieved.

ISAC OPERATIONS

This year, routine RIB operation provided beams to DRAGON and TUDA in the high energy area and to low energy experiments at LTNO, 8π, GPS β-NMR and Osaka. As in previous years, the first quarter was devoted to shutdown activities. Beam schedule 103 began in the second quarter and carried on through the summer. Beam schedule 104 followed a short shutdown in September. An overview of RIB operation is shown in Fig. 243 in terms of proton beam on the production targets. The hours of RIB and stable beam operation for schedules 103 and 104 are shown in Figs. 244–247.

Operational performance statistics are provided for the ISAC beam production of RIB from ITW and ITE and stable beam from OLIS. These are summarized separately for each beam schedule in Tables XXV to XLIV (p. 208–216).

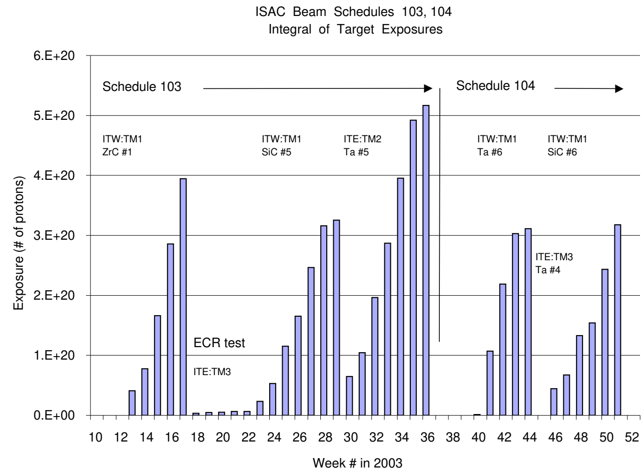

Fig. 243. Integral target exposures by week for RIB delivery in 2003.

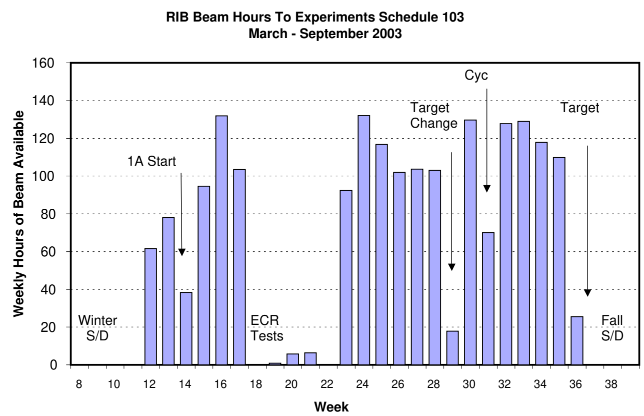

Fig. 244. Weekly hours of RIB beam available to experiments during schedule 103.

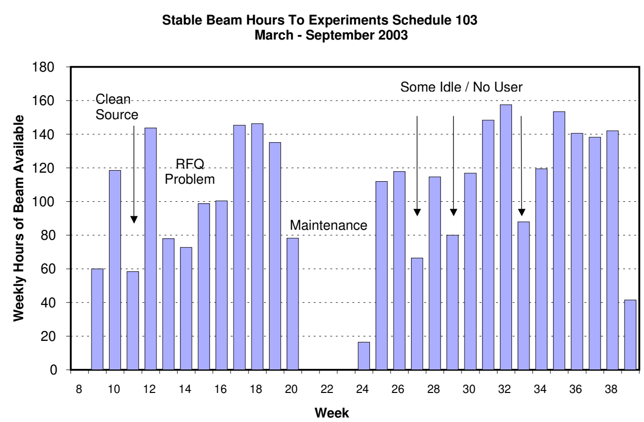

Fig. 245. Weekly hours of stable beam available to experiments during schedule 103.

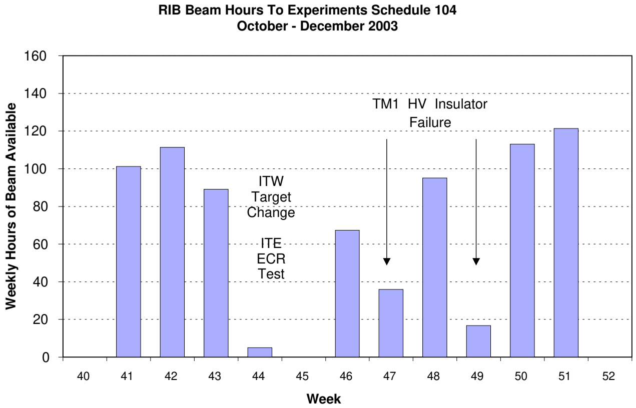

Fig. 246. Weekly hours of RIB beam available to experiments during schedule 104.

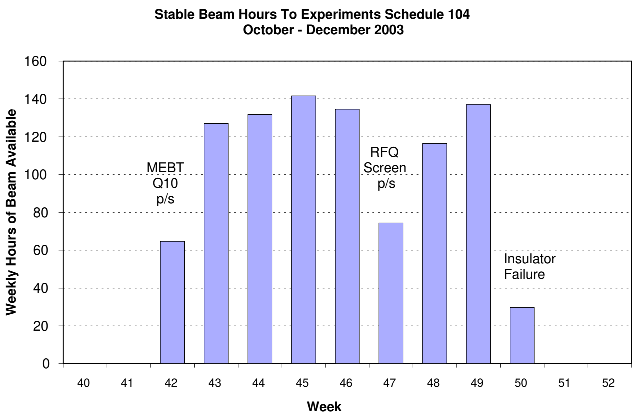

Fig. 247. Weekly hours of stable beam available to experiments during schedule 104.

In some instances OLIS was used by an on-line experiment as part of procedures to change mass or energy. Other times it was used for commissioning or when the RIB was unavailable such as during a maintenance period. The RIB availability as an indicator of operational efficiency is complicated by the incentive to minimize activation when the beam is not required, and by the coincident use of OLIS. Furthermore, while a surface source was available and operated on TM 2 in ITE, the uncertainty in the schedule for the commissioning of the ECR source on TM 3 affected the beam scheduling of the ITW modules and as a result, a number of experiments were affected. In the performance statistics presented here, the "combined facility efficiency" is quoted giving the actual beam delivered to experiments in comparison to the scheduled hours. This summary information includes the effects of experiment operational performance, ISAC system performance and proton beam availability with overhead as well as downtime components. The ISAC system performance is quantified by comparing the unscheduled downtime to the availability. Some interpretation is required to extract the relevance of overhead due to operational procedures such as the extensive time required to set up the beam transport and accelerator systems for different beams. The OLIS performance is affected by its part-time use during parasitic operation simultaneous with RIB production to another user who has higher priority for technical support. Finally, there are some impacts on the schedule caused by logistical constraints of target hall operation. For beam schedules 103 and 104, the total unscheduled downtime for RIB and OLIS was 1637 hours compared to total scheduled user time of 7839 hours giving an availability of 79.1% for combined cyclotron, ISAC system performance.

A major milestone was achieved in beam schedule 103 when the first proton beam was delivered on a target module in the east target station on April 30 (week 18). This was also the first attempt at commissioning the ECR target/ion source on TM 3. The proton beam exposure on TM 3 was limited for the duration of the four week test to facilitate subsequent inspections and maintenance/development of the ECR TIS. The ECR progress is reported on p. 220. The east target station was used later in the summer with a tantalum target (Ta #5) and a surface ion source mounted on TM 2. Due to scheduling constraints related to the ECR development program, this target was operated beyond its normal life expectancy and it failed in week 36 due to an ionizer tube open circuit. Because beam from the SiC #5 target had exhibited an instability in the source optics, the optics tray was replaced during the target change, which added several weeks to the time that TM 1 was in the hot cell. As a result, TM 1 was not ready for operation when Ta #5 failed, and beam time was lost in the turn around. This was further compounded when a vacuum leak occurred in the TM 1 shutter bellows. The downtime carried into the scheduled fall shutdown which occurred in week 38. Beam delivery in schedule 104 was very good until a vacuum leak occurred in a HV feedthrough on TM 1 in week 47. This was caused by HV sparking from an unused thermocouple lead, which had held for extended operation with a bias at 30 kV, but became problematic when the bias was increased above 40 kV for normal operation. (The system had been conditioned to over 50 kV but only for brief periods.) A similar leak had occurred previously and, as then, the insulator was replaced. In this instance due to the higher bias requirements, the sparking recurred shortly after startup and the new insulator developed a leak in week 49. The problem was finally identified as arising from field emission from a small tube that carried the thermocouple lead into the vicinity of the nylon feedthrough. It was addressed by making minor modifications to the geometry, including the use of a corona cap.

A new position was created within ISAC Operations to provide console hardware and software applications support specifically for Operations and beam development activities. Chris Payne assumed this responsibility in September at the end of beam schedule 103, vacating his shift position. Working closely with the target chemist and beam line physicists, yield and collection station tunes were investigated, with the goal of developing standard tuning procedures for the front end of the low energy beam lines. A tool to easily compare harp and RPM data to accepted standard scans has been created, which aids tracking and correction of drift in the beam tune. A new network firewall was installed, doubling bandwidth to the rest of TRIUMF to nearly the theoretical limit. Operations consoles were updated to the latest version of RedHat Linux, and new and upgraded consoles were installed in the ion source and ISAC-II control rooms respectively. As part of an effort to consolidate electronic record keeping systems (electronic logbook, fault reports, work permits), a number of electronic systems of other labs were investigated for applicability, with the conclusion that an in-house solution will work best. An SCRF electronic log based on the current ISAC e-log was set up for tracking SCRF commissioning. The ISAC-II control room is now available for insulated off-line training, including simulating all EPICS functions as well as e-log, e-fault and work permit tasks. Further console and control system improvements and development of beam tuning applications are on-going.

The staffing complement remains critical, with five on-shift operators required for skeletal operation (one operator per shift) of a multiple source, complex RIB facility. The operators are assisted by two day-shift coordinators, who are responsible for beam quality assurance and the coordination of maintenance activities. The coordinators are also required to fill in for operators who are off shift due to illness or vacation – which is approximately 30% of the time. Including the coordinator absences, beam quality and maintenance tasks are supported at a level less than 60%. With the loss of one operator, shift coverage was down by one throughout beam schedule 104. Two new operators were hired in October. When they are trained, the shift complement will include a contingency of one operator, but any single-coverage shift will remain stressed at times of simultaneous activities. A recruitment plan has been proposed to increase the resources within ISAC Operations to provide adequate coverage on all shifts.

Documentation and training responsibilities continue to command the full-time attention of Mike Hauser, who has been assigned those duties within ISAC Operations. In compliance with the Quality Assurance program being implemented at TRIUMF, a 31-page document, entitled "Document Planning for an ISAC Operations Manual" was produced. It describes the methodology for preparing and revising the ISAC Operations Manual. Development of the SAT training program for ISAC Operations continued although progress was slower than planned due to the time required for the training of new personnel. The development phase was completed June 30 and approved in the fall. Some progress was made on the design phase (third of five phases), but efforts were diverted to the orientation and training of four operators: the two hired in October and two from the 500 MeV Facility Operations Group. The four trainees completed the ISAC orientation in December and will undergo the latest version of the training program in the new year. They should be ready for unaided shift responsibilities by May, 2004. The two Facility operators will return to the main control room, but will be available to assist in ISAC if required.

The MEBT and HEBT beam operation has become more routine. This year, while new beams and large energy changes required support from the beam dynamic experts, a large fraction of the experts' time was devoted to establishing effective tuning procedures. Again, as always with complex accelerator systems, there are still occasions that challenge even the experts. The members of the ISAC operations group take great pride in their contributions to the success of the experiments and major ISAC milestones that have been highlighted elsewhere in this Annual Report. In the coming year, in addition to providing beam for the scheduled experiments and performing systems maintenance, the major effort will be to complete the SAT training program for ISAC operators, migrate many of the control functions to the ISAC-II Control Room, and to continue to improve the ability of ISAC Operations to provide the beams of interest to the ISAC science program.

A concerted effort was undertaken to schedule and perform regular systematic yield measurements in order to track the target performance (RIB yield) as a function of operating hours to better understand how to schedule and operate high power targets. The target histories are given in Table XLV (p. 217); yield results are given in the target ion source report.

The target hall and hot cell operations have become quite well organized. The engineering that has been done for the east target station module access area (MAA) services will be applied to upgrade the west target systems, which were installed as prototypes. There were four target changes done this year, each one completed as planned and without incident. The history of operation of ISAC production targets for 2003 is given in Table XLV. Schedule 103 started with ZrC #1 – a target of zirconium carbide pellets. The Ta #4 target installed on TM 3 (the ECR ion source module) was installed twice for development tests. For scheduling purposes, Ta #5 on TM 2 was run for more than its expected lifetime. It failed due to an open circuit in the ionizer heater. Initial experience with two working target stations indicates that careful planning is required to be able to manipulate the service requirements during brief maintenance periods in the beam schedule. Also, operation with the ECR gas loads has an impact on the capacity of the containment of the vacuum exhaust system. These activities will be better optimized with more operational experience.

Figure 248 shows the beam operation on the first target (ZrC #1) that ran on TM 1 in ITW from March 24 to May 8. The graph has two components: the proton beam delivered on target (up to 50 μA at 500 MeV), interspersed with the residual radiation fields recorded during maintenance periods. The radiation monitor is located near a target primary vacuum turbo pump where volatile products impinge on the vanes and many decay to adhering daughter products. The ZrC target has interesting characteristics in that the residual radiation includes the build up of progeny from the primary products that come to dominate the fields after the end of beam. Initially the field decays with a short half-life, characteristic of the primary production. Later the field shows a growth and much slower decay – from the progeny that has collected at the pumps. Until now, all other targets have had decay curves of short enough duration that a two-day cool down is sufficient for access to the module for target service (e.g. target SiC #6 shown in Fig. 249). The experience shows that beam scheduling must include consideration of the cool down requirements for the subsequent service of the various production targets.

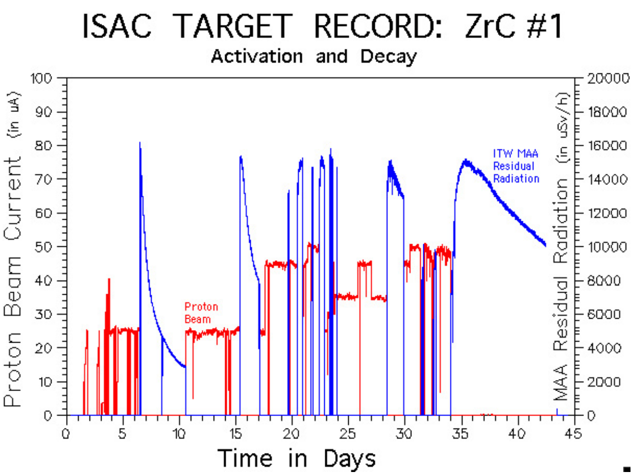

Fig. 248. Beam operation showing the proton beam current delivered and the residual radiation fields for the ZrC#1 target which was operated on TM 1 in ITW from March 24 to May 8 during schedule 103.

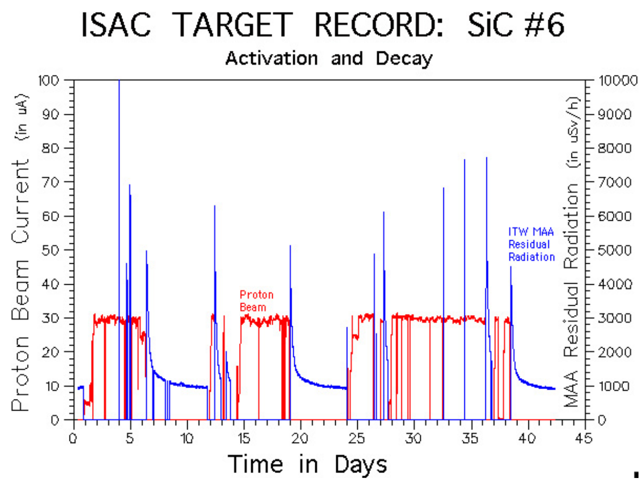

Fig. 249. Beam operation showing the proton beam current delivered and the residual radiation fields for the SiC#6 target operated during schedule 104.

Table XXV. ITW beam schedule 103 (surface ion source targets ZrC #1 and SiC #5): February 19 – September 30 (weeks 8–39) (reporting period is from Monday, February 17 to Monday, September 29). ITW beam to ISAC experiments (hours).

Experiment	Scheduled	Actual	Tune	Off	Total
Etest ILY	216.0	52.9	2.5	0.0	55.4
E815 BNMR	275.0	200.0	18.6	8.5	227.1
E816 BNMR	360.0	261.1	38.0	4.3	303.4
E823 GPS	192.0	144.9	11.6	0.3	156.8
E824 DRA	0.0	56.7	1.5	0.0	58.2
E871 OSA	239.0	170.4	0.2	11.5	182.1
E909 8PI	132.0	12.0	9.5	13.0	34.5
E967 HEBT	156.0	22.1	12.2	3.8	38.1
Available		120.1			120.1
Totals	1570	920.1	94.1	41.4	1175.7

Total RIB experiment time = 920.1 hours
Combined facility efficiency = 58.6% (reflecting combined efficiency of cyclotron, ISAC and experiment systems; efficiency = (actual beam to the experiment / scheduled)).

Table XXVI. ITW beam schedule 103: detail of ITW beams to experiments (hours).

Experiment	Line	Isotope	Beam hours
815	BNMR	^{8}Li	200.0
816	BNMR	^{8}Li	261.1
823	GPS	^{62}Ga	144.9
824	DRA	^{20}Na^{5+}	21.4
824	DRA	^{21}Na^{5+}	35.3
871	OSA	^{20}Na	134.5
871	OSA	^{21}Na	35.9
909	8PI	^{26}Na	12.0
967	BRK	^{21}Na^{5+}	22.1
Test	ILY	Various	52.9
Total			920.1

Table XXVII. ITW beam schedule 103: detail of ITW RIB to HEBT experiments (hours).

Energy	Species	Experiment	Hours
488 keV/u	^{21}Na^{5+}	E824 DRA	56.7
Total			56.7

Table XXVIII. ITW beam schedule 103: ITW systems downtime and overhead.

ISAC systems	Hours
Downtime – unscheduled	
Controls	10.8
Magnet power supplies	7.9
Ion source	12.6
Polarizer	2.1
Stripper	0.1
DTL rf	0.5
Safety	0.6
Services	34.5
Site power	23.2
Vacuum	168.9
Subtotal	261.2
Downtime – scheduled	
Cyclotron maintenance	279
Cyclotron development	50.3
Beam line 2A off	165.3
ISAC shutdown	688.0
ISAC maintenance	48.0
ISAC development	77.7
ISAC idle	60.5
Procedures	146.6
Target conditioning	279.9
Target change	2125.5
ISAC startup	15.3
ITW cooldown	2.0
Subtotal	3938.1
Total	4199.3

RIB available from ITW = 1175.7 hours
ITW operational performance = 81.8% (reflecting the performance of ISAC systems; performance = available / (available + unscheduled downtime)).

Table XXIX. ITE beam schedule 103 (initial commissioning and development of new facility. ECR source and gases for target Ta #4 and surface ion source Ta #5): ITE beam to ISAC experiments (hours).

Experiment	Scheduled	Actual	Tune	Off	Total
Yield	372	45.0	1.8	2.8	49.6
E816 BNMR	110	88.0	6.0	4.8	98.8
E863 LTNO	144	97.6	2.3	1.3	101.2
E893 LTNO	144	7.5	2.1	58.8	68.4
E909 8PI	72	76.4	1.4	1.2	79.0
E920 POL	84	0.0	0.0	0.0	0.0
E921 8PI	240	155.1	6.7	18.7	180.5
E929 GP2	108	47.1	0.0	43.5	90.6
E955 8PI	60	38.4	2.2	0.0	40.6
Available		14.0			14.0
Total	1334	555.1	22.5	131.1	722.7

Total RIB experiment time = 555.1 hours
Combined facility efficiency = 41.6%

Table XXX. ITE beam schedule 103: detail of ITE beams to experiments (hours).

Experiment	Line	Isotope	Beam hours
816	BNMR	^{8}Li	88.0
863	LTNO	^{75}Ga	68.5
863	LTNO	^{91}Rb	29.1
893	LTNO	^{79}Rb	7.5
909	8PI	^{26}Na	76.4
921	8PI	^{172}Lu	4.4
921	8PI	^{178}Lu	100.5
921	8PI	^{179}Lu	27.2
921	8PI	^{25}Na	7.0
921	8PI	^{30}Na	4.9
921	8PI	^{31}Na	11.1
929	GPS	^{120}Cs	47.1
955	8PI	^{31}Na	2.0
955	8PI	^{32}Na	36.4
Test	ILY	Various	45
Total			555.1

Table XXXI. ITE beam schedule 103: ITE systems downtime and overhead.

ISAC systems	Hours
Downtime – unscheduled	
Controls	14.7
Diagnostics	11.5
Services	0.8
Ion source	316.1
Site power	13.0
Vacuum	59.8
Subtotal	415.9
Downtime – scheduled (overhead)	
ISAC maintenance	16.0
ISAC development	373.3
ISAC idle	800.7
p+ off	128.3
Procedures	132.7
Target conditioning	59.5
Cyclotron maintenance	111.8
Cyclotron development	38.5
Shutdown	527.0
Startup	827.1
Cooldown	4.0
Target change	1217.5
Subtotal	4236.4
Total	4652.3

RIB available from ITE = 722.7 hours
ITE operational performance = 63.5%

Table XXXII. OLIS beam schedule 103 (microwave source and gases): OLIS beam to ISAC experiments (hours).

Experiment	Scheduled	Actual	Tune	Off	Total
E824 DRA	120	104.3	6.3	4.2	114.8
E863 LTO	24				
E870 TUDA	312	33.9	6.2	0.3	40.4
E879 TUDA	120				
E893 LTNO	32	8.0	2.6	0.0	10.6
E909 8PI	12				
E920 McGill	76	75.3	1.0	0.0	76.3
E921 8PI	60	0.0	9.0	0.0	9.0
E952 DRA	1291	860.8	44.1	4.5	908.4
E967 POL	48				
Available			1827.9		1827.9
Total	2095	1082.3	69.2	1836.9	2988.4

Total RIB experiment time = 1082.3 hours
Combined facility efficiency = 51.7%

Table XXXIII. OLIS beam schedule 103: detail of OLIS beams to experiments (hours).

Experiment	Line	Isotope	Beam hours
824	DRA	$^{12}C^{3+}$	26.9
824	DRA	$^{20}Ne^{4+}$	7.6
824	DRA	$^{20}Ne^{5+}$	60.5
824	DRA	$^{4}He^{1+}$	9.3
870	TUDA	$^{12}C^{3+}$	33.9
893	LTNO	^{14}N	8.0
920	POL	$^{132/136}Xe$	60.0
920	POL	^{40}Ar	15.3
952	DRA	$^{12}C^{3+}$	662.4
952	DRA	$^{13}C^{3+}$	46.0
952	DRA	$^{16}O^{4+}$	152.4
Total			1082.3

Table XXXIV. OLIS beam schedule 103: detail of OLIS stable beams to HEBT experiments (hours).

Energy	Species	Experiment	Hours
0.200 MeV/u	$^{20}Ne^{5+}$	DRA test	16.2
0.200 MeV/u	$^{4}He^{1+}$	824 DRA	5.8
0.200 MeV/u	$^{20}Ne^{5+}$	824 DRA	25.8
0.200 MeV/u	$^{12}C^{3+}$	952 DRA	13.0
0.400 MeV/u	$^{4}He^{1+}$	824 DRA	1.5
0.400 MeV/u	$^{20}Ne^{5+}$	824 DRA	14.1
0.450 MeV/u	$^{13}C^{3+}$	952 DRA	8.6
0.540 MeV/u	$^{13}C^{3+}$	952 DRA	5.5
0.556 MeV/u	$^{13}C^{3+}$	952 DRA	11.1
0.571 MeV/u	$^{13}C^{3+}$	952 DRA	2.0
0.572 MeV/u	$^{13}C^{3+}$	952 DRA	5.7
0.650 MeV/u	$^{13}C^{3+}$	952 DRA	16.2
0.750 MeV/u	$^{12}C^{3+}$	952 DRA	58.9
0.775 MeV/u	$^{16}O^{4+}$	952 DRA	31.7
0.776 MeV/u	$^{16}O^{4+}$	952 DRA	72.9
0.778 MeV/u	$^{16}O^{4+}$	952 DRA	7.9
0.782 MeV/u	$^{16}O^{4+}$	952 DRA	1.1
0.810 MeV/u	$^{12}C^{3+}$	952 DRA	35.6
0.860 MeV/u	$^{12}C^{3+}$	952 DRA	36.4
0.900 MeV/u	$^{12}C^{3+}$	952 DRA	15.2
0.940 MeV/u	$^{12}C^{3+}$	952 DRA	40.1
0.965 MeV/u	$^{16}O^{4+}$	952 DRA	7.7
0.972 MeV/u	$^{16}O^{4+}$	952 DRA	20.5
0.975 MeV/u	$^{16}O^{4+}$	952 DRA	16.1
1.00 MeV/u	$^{12}C^{3+}$	952 DRA	20.6
1.02 MeV/u	$^{12}C^{3+}$	952 DRA	22.8
1.04 MeV/u	$^{12}C^{3+}$	952 DRA	15.2
1.05 MeV/u	$^{12}C^{3+}$	952 DRA	9.8
1.06 MeV/u	$^{12}C^{3+}$	952 DRA	2.5
1.07 MeV/u	$^{12}C^{3+}$	952 DRA	46.5
1.08 MeV/u	$^{12}C^{3+}$	952 DRA	17.1
1.09 MeV/u	$^{12}C^{3+}$	952 DRA	11.9
1.100 MeV	$^{12}C^{3+}$	952 DRA	19.7
1.110 MeV	$^{12}C^{3+}$	952 DRA	20.7
1.130 MeV/u	$^{12}C^{3+}$	952 DRA	13.1
1.160 MeV/u	$^{12}C^{3+}$	952 DRA	24.1
1.190 MeV/u	$^{12}C^{3+}$	952 DRA	15.6
1.220 MeV/u	$^{12}C^{3+}$	952 DRA	13.0
1.250 MeV	$^{12}C^{3+}$	952 DRA	22.1
1.280 MeV/u	$^{12}C^{3+}$	952 DRA	21.4
1.300 MeV/u	$^{12}C^{3+}$	952 DRA	19.1
1.310 MeV/u	$^{12}C^{3+}$	952 DRA	151.4
1.460 MeV/u	$^{12}C^{3+}$	824 DRA	13.9
1.460 MeV/u	$^{12}C^{3+}$	870 DRA	33.9
1.460 MeV/u	$^{20}Ne^{5+}$	824 DRA	12.8
1.500 MeV/u	$^{12}C^{3+}$	952 DRA	0.5
Total			997.3

Table XXXV. OLIS beam schedule 103: OLIS systems downtime and overhead.

ISAC systems	Hours
Downtime – unscheduled	
Controls	19.2
Diagnostics	1.0
Magnet PS	8.3
RF controls	14.6
Pre-buncher	2.0
RFQ	156.9
DTL rf	43.8
Charge-exchange stripper	11.3
MEBT rf	1.0
Services	86.7
Site power	23.0
Vacuum	34.8
Ion source	45.5
Subtotal	448.1
Downtime – scheduled (overhead)	
ISAC maintenance	223.5
ISAC idle	502.0
ISAC shutdown	579.7
ISAC startup	59.3
Procedures	319.5
Etest Development	254.5
Subtotal	1938.5
Total	2386.6

OLIS beam available = 2988.4 hours
OLIS operational performance = 87.0%

Table XXXVI. ITW beam schedule 104 (surface ion source target Ta #6 and SiC #6): September 29 – December 29 (weeks 40–52) (reporting period is from Monday, February 17 to Monday, September 29). ITW beam to ISAC experiments (hours).

Experiment	Scheduled	Actual	Tune	Off	Total
E817 BNMR	168	206.7	17.1	7.5	231.3
E824 DRA	168	25.2	1.8		27.0
E826 LTNO	120	29.7	12.4	38.4	80.5
E871 OSAKA	60	79.0	2.2	4.5	85.7
E927 TUDA	108	64.5	0.5	4.0	69.0
E955 8PI	144	125.0	7.5	2.9	135.4
Etest ICS	72	52.7			52.7
Etest ILY	204	52.1	1.9	6.9	60.9
Available		13.6			13.6
Totals	1044	634.9	43.4	77.8	756.1

Total RIB experiment time = 634.9 hours
Combined facility efficiency = 60.8%

Table XXXVII. ITW beam schedule 104: detail of ITW beams to experiments (hours).

Experiment	Line	Isotope	Beam hours
817	BNMR	^{8}Li	206.7
824	DRA	^{21}Na^{5+}	25.2
826	LTNO	^{79}Rb	5.7
826	LTNO	^{91}Rb	24
871	OSAKA	^{20}Na	76.9
871	OSAKA	^{21}Na	1.1
871	OSAKA	^{26}Na	1
927	TUDA	^{20}Na^{5+}	64.5
955	8PI	^{28}Na	1
955	8PI	^{31}Na	0.8
955	8PI	^{32}Na	123.2
Test	ILY	xLi/Al/Na/La	52.1
Test	ICS	^{26g}Al	52.7
Total			634.9

Table XXXVIII. ITW beam schedule 104: breakdown of ITW RIB to ISAC experiments (hours).

Species/ Experiment	8PI E955	LTNO E826	BNMR E817	OSAKA E871	ICS Etest	TUDA E927	DRA E824	Energy
^{79}Rb		5.7						45 keV
^{91}Rb		25.2						45 keV
^{8}Li			206.7					30.6 keV
^{26g}Al					52.7			30.6 keV
^{20}Na				76.9				30.6 keV
^{21}Na				1.1				30.6 keV
^{26}Na				1				30.6 keV
^{28}Na	1							30.6 keV
^{31}Na	0.8							30.6 keV
^{32}Na	123.2							30.6 keV
^{20}Na^{5+}						64.5		1.730 MeV/u
^{21}Na^{5+}							0.2	1.115 MeV/u
^{21}Na^{5+}							9	1.130 MeV/u
^{21}Na^{5+}							2	1.135 MeV/u
^{21}Na^{5+}							0.4	1.14 MeV/u
^{21}Na^{5+}							2.8	1.145 MeV/u
^{21}Na^{5+}							1.5	1.15 MeV/u
^{21}Na^{5+}							5.3	1.160 MeV/u
^{21}Na^{5+}							4	1.175 MeV/u
Total	125	30.9	206.7	79	52.7	64.5	25.2	584
Available				13.6				597.6

Yield Etest xLi/Al/Na/La 52.1 hours.

Table XXXIX. ITW beam schedule 104: ITW systems downtime and overhead.

ISAC systems	Hours
Downtime – unscheduled	
Controls	2.5
Ion source	237.2
Polarizer	0.8
RFQ	2.2
Site power	0.5
Subtotal	243.2
Downtime – scheduled (overhead)	
Cyclotron maintenance	122.7
Cyclotron development	46.0
Beam line 2A off	134.5
ISAC shutdown	369.5
ISAC idle	8.5
Procedures	141.3
Target conditioning	137.7
Target change	127.5
ITW startup	90.5
ITW cooldown	7.5
Subtotal	1185.7
Total	1428.9

Total RIB available from ITW = 756.1 hours
ITW operational performance = 75.7%

Table XL. ITE TM 3 beam schedule 104 (Ta #4 target with ECR source and gases; commissioning and development of new facility): ITE beam to ISAC experiments (hours).

Experiment	Scheduled	Actual	Tune	Off
Etest	312	0	0	0
Subtotal	312	0	0	0
Total	312	0	0	0

Total RIB experiment time = 0 hours
Combined facility efficiency = 0%

Table XLI. ITE TM 3 beam schedule 104: ITE systems downtime and overhead.

ISAC systems	Hours
Downtime – unscheduled	
Services	29.5
Subtotal	29.5
Downtime – scheduled (overhead)	
ISAC development	32.0
ISAC idle	971.0
Procedures	4.3
Target conditioning	67.6
Shutdown	865.0
Target change	215.6
Subtotal	2155.5
Total	2185.0

Total RIB available from ITE = 0.0 hours
ITE operational performance = 0.0%

Table XLII. OLIS beam schedule 104 (microwave source with gas feed): OLIS beam to ISAC experiments (hours).

Experiment	Scheduled	Actual	Tune	Off	Total
E824 DRA	24.0	34.1	2.0	0.0	36.1
E870 TUDA	36	0.0	0.0	0.0	0.0
E871 OSAKA	24	0.0	0.0	0.0	0.0
E927 TUDA	96.0	19.4	7.6	2.1	29.1
E947 DRA	108.0	134.2	4.3	0.0	138.5
E952 DRA	565.0	268.5	17.5	16.3	302.3
DEV	180	0.0	0.0	0.0	0.0
Available		451.2			451.2
Total	1484.2	456.2	31.4	18.4	957.2

Total OLIS experiment time = 456.2 hours
Combined facility efficiency = 30.7%

Table XLIII. OLIS beam schedule 104: breakdown of OLIS beams to ISAC experiments (hours).

Species	E952 DRA	E947 DRA	E927 TUDA	E824 DRA	Total	Energy
$^{12}C^{3+}$	0.2				0.2	0.879
$^{12}C^{3+}$	2.7				2.7	0.881
$^{12}C^{3+}$	42.2				42.2	0.894
$^{12}C^{3+}$	29.7				29.7	0.895
$^{12}C^{3+}$	40.4				40.4	1.314
$^{12}C^{3+}$		99.7			99.7	1.340
$^{12}C^{3+}$		12.4			12.4	1.400
$^{12}C^{3+}$		22.1			22.1	1.420
$^{12}C^{3+}$	73.1				73.1	1.460
$^{12}C^{3+}$	80.2				80.2	1.462
$^{20}Ne^{5+}$			9.8		9.8	1.5/1.8
$^{20}Ne^{5+}$			9.6		9.6	1.73
$^{21}Ne^{5+}$				34.1	34.1	1.130
Total	153.3	134.2	19.4	34.1	456.2	

Table XLIV. OLIS beam schedule 104: OLIS systems downtime and overhead.

ISAC systems	Hours
Downtime – unscheduled	
Controls	4.3
Beam lines	19.2
Magnet PS	16.2
RF controls	6.3
Pre-buncher	3.5
RFQ	28.2
DTL rf	17.8
Charge-exchange stripper	15.9
MEBT rf	4.1
Site power	0.5
Vacuum	119.5
Ion source	3.6
Subtotal	239.1
Downtime – scheduled (overhead)	
ISAC maintenance	95.7
ISAC idle	97.7
ISAC shutdown	624.0
ISAC startup	33.0
Procedures	120.3
ISAC development	18.0
Subtotal	988.7
Total	1227.8

Total OLIS beam available = 957.2 hours
OLIS operational performance = 80.0%

Table XLV. ISAC target history for 2003.

Target ID	In date	Out date	Exposure # of protons	Power μAh*g/cm^2	Comments
ZrC #1	28-Feb	11-Apr	5.11E+20	1.00E+06	33.21 gZr/cm^2 + 10.88 gC/cm^2 (435 foils 0.13 mm C + 0.24 mm ZrC).
Ta Foils #4 ITE:TM 3 R1	4-Apr	18-Jun	6.49E+18	6.30E+03	21.79 g/cm^2 Ta in the form of 525 × 0.025 mm foils.
SiC #5 ITW:TM 1	26-May	30-Jul	3.25E+20	3.84E+05	26.5 g/cm^2 SiC in the form of 425 × 0.23 mm foils. Steering optics replaced during scheduled service.
Ta Foils #5 ITE:TM 2	24-Jun	28-Oct	5.17E+20	5.01E+05	21.79 g/cm^2 Ta in the form of 525 × 0.025 mm foils. Failed due to ionizer open circuit.
Ta Foils #6 ITW:TM 1	25-Sep	31-Oct	3.11E+20	3.02E+05	21.79 g/cm^2 Ta in the form of 525 × 0.025 mm foils.
Ta Foils #4 ITE:TM 3 R2	28-Oct	5-Nov	* 5.08E+19	* 7.16E+04	21.79 g/cm^2 Ta in the form of 525 × 0.025 mm foils.
SiC #6 ITW:TM 1	6-Nov		2.74E+20	3.23E+05	26.5 g/cm^2 SiC in the form of 425 × 0.44 mm foils

* includes amount from R1: 4-Apr to 18-Jun.

ISAC TARGETS

ZrC Target Material

In 2003, ISAC target development involved production of new ion beams from previously commissioned target materials as well as initial operation of a new composite ZrC target material. The ZrC/graphite composite target foils were fabricated in an analogous manner to the SiC and TiC composite targets commissioned the previous year. In addition to ZrC, three Ta foil targets and two SiC composite targets were operated on-line during 2003.

The ZrC target was operated to explore the production of Rb, Sr, Y and especially Ga isotopes. Previous attempts to observe ^{62}Ga ($t_{1/2}$ = 116 ms) from Nb metal foil targets were not successful, although ^{63}Ga ($t_{1/2}$ = 32 s) was observed in 10^4/s quantity. The suppression of the shorter lived ^{62}Ga was attributed to a long effusion time resulting from strong physical and chemical Ga absorption on Nb surfaces. Thermochemical calculations suggest that the formation of metal-gallide phases of gallium with metals such as Nb, Zr or Ta is energetically favoured. However, for the same metals, the metal oxide and carbide phases are thermochemically more stable. With this in mind, ZrC was chosen as a potential target material based on calculations that suggested the Zr-Ga interaction could be blocked by the presence of a stronger Zr-C interaction. Additionally, the interior of the tantalum target container was coated with TaC to block tantalum gallide formation as well as to suppress reactions between ZrC and Ta. The ZrC was operated at a maximum proton current of 50 μA and proved to be a very good target material for Ga production with ^{62}Ga observed for the first time, as well as ^{62}Ga ($t_{1/2}$ = 168 ms). Additionally, Rb, Sr and Y (as the YF_2^+ ion) production was observed. Table XLVI lists the surface ionized Ga yields from the ZrC target.

Increased ^{11}Li Production from Ta

Of the previously commissioned target materials, the highest observed ^{11}Li ($t_{1/2}$ = 8.4 ms) yield was from Ta metal foils. Target Ta #1 consisted of 512 Ta foils (each 0.025 mm thick) with a total thickness of 21.3 g Ta/cm^2. At 20 μA proton current on target, the measured ^{11}Li yield was 1.4 × 10^4/s. For the Ta #2 target, the number of foils was approximately doubled to 1050 for a total thickness of 43.6 g Ta/cm^2. Doubling of the target thickness did not produce a doubling of the ^{11}Li yield; at 20 μA proton current on target, the ^{11}Li yield was only 5.2 × 10^3/s. At 40 μA proton current, the ^{11}Li yield from target Ta #2 was 2.2 × 10^4/s, less than twice the Ta #1 20 μA yield.

The decrease in ^{11}Li yield can be attributed to longer effusion delays for the very short-lived ^{11}Li. Doubling the number of target foils also doubles the surface area of the target as well as doubling the volume of the target container. The associated delays resulting from increased ^{11}Li interactions with target surfaces are sufficient to decrease the observed yield below the increase expected from the doubled target thickness. To verify the effusion effects on overall

Table XLVI. Comparison of Ga yields from ZrC and other targets.

Beam	Composite target	Yield (/s)	p^+ (μA)	Other target	Yield (/s)	p^+ (μA)
^{61}Ga	ZrC	10	50.0	not observed	–	–
^{62}Ga	ZrC	8.5×10^2	36.2	not observed	–	–
^{63}Ga	ZrC	7.9×10^5	35.7	Nb	1.6×10^4	29.2
^{64}Ga	ZrC	3.1×10^7	40.0	Nb	4.3×10^5	9.5
^{65}Ga	ZrC	5.1×10^8	40.0		–	–
^{66}Ga	ZrC	2.7×10^8	44.4		–	–
^{67}Ga	ZrC	8.0×10^8	44.9		–	–
^{68}Ga	ZrC	4.1×10^8	45.5		–	–
^{70}Ga	ZrC	2.2×10^8	45.5		–	–
^{72}Ga	ZrC	6.7×10^6	45.3		–	–
^{73}Ga	ZrC	9.0×10^6	45.1		–	–
^{74}Ga	ZrC	2.2×10^6	45.1	Nb	3.4×10^5	9.5

^{11}Li production, targets Ta #5 and Ta #6 were fabricated with 525 Ta foils with a total thickness of 21.8 g Ta/cm^2. For Ta #6, the 20 μA ^{11}Li yield was 1.0×10^4/s, similar to the Ta #1 target. Furthermore, at 40 μA, the ^{11}Li yield was 4.4×10^4/s, double the yield observed with the thicker Ta #2 target. Clearly, effusion delay effects can dominate in comparison to target thickness when very short-lived products are considered. The ^{11}Li yields as a function of proton current for targets Ta #1, Ta #2 and Ta #6 are displayed in Fig. 250. In the case of Ta #6, the proton beam current limit was raised to 50 μA, producing a ^{11}Li yield of 5.1×10^4/s.

^{26g}Al Beam Development

A total of six SiC targets have now been operated at ISAC. Since the SiC/graphite foils composite targets came into operation, ^{26m}Al activity has been observed in β-spectra of ^{26}Na used to cross-calibrate the ISAC yield station scintillator detector against the measured γ-activity observed using the yield station HPGe detector. As well, the Na beams extracted from SiC targets operating under high proton currents are sufficient to be measured as ion beam currents on Faraday cups throughout the ISAC low energy beam transport system. Generally, the yields of ^{20}Na, ^{21}Na, ^{24}Na and ^{25}Na deduced from measured currents agree well with yields determined by γ-counting of deposited activity at the ISAC yield station. Differences of up to a factor of 2 can be attributed to distortions of the current measurements by intense β^+ or β^- activity of the ion beams. However, for ^{26}Na the Faraday cup current yields are consistently 2 orders of magnitude above the ^{26}Na and ^{26m}Al yields obtained by γ and β counting. Since long-lived ^{26g}Al is an isotope of significant interest to nuclear astrophysics, investigations were undertaken to determine if the excess current at A = 26 was due to an ^{26g}Al beam. After excluding the possibility of ^{26}Mg or ^{26}Si contamination, the A = 26 beam was deposited in the ISAC collection station used for collecting samples of long-lived activity for off-line use. Two sample collections were made. The first collection was conducted with proton beam on target ($\sim$30 μA average) over a period of 21 hours. The average A = 26 beam current was $\sim$160 pA corresponding to a yield of $\sim 10^9$/s. A second additional collection was conducted over a period of approximately 60 hours with either proton beam on target or resistive target heating during p^+ beam off periods. A running total was kept of integrated A = 26 beam current at the collection position.

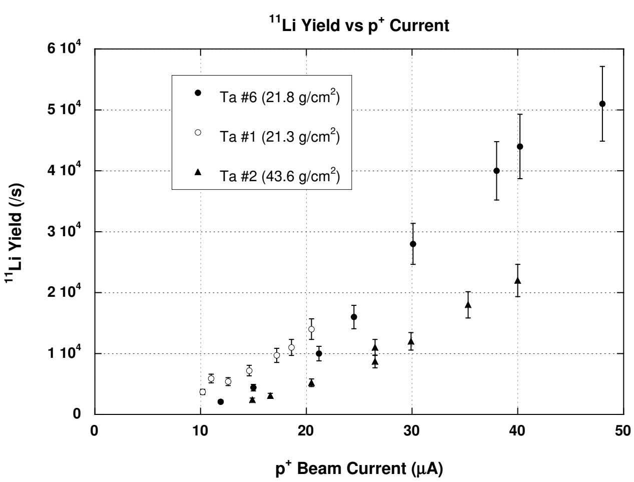

Fig. 250. Yield of ^{11}Li as a function of proton beam current on tantalum targets of varying thickness.

The collected sample was counted in β-γ coincidence in the ISAC 8π detector after decay of the short-lived ^{26}Na and ^{26m}Al activities. A 12.75 hour count of the sample yielded a total of 150 counts for the 1809 keV γ-branch (99.8%) of ^{26g}Al, corresponding to an estimated 1.6 Bq activity of ^{26g}Al. A second count of 18 hour duration yielded 200 counts for an estimated

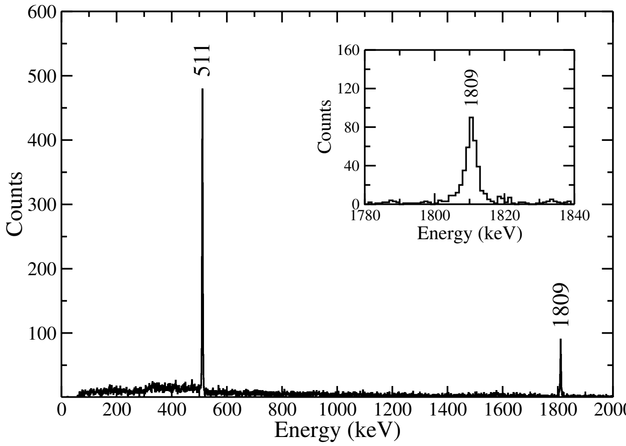

Fig. 251. A coincidence spectrum of the collected A = 26 beam obtained using the 8π spectrometer.

1.3 Bq activity. The integrated current on the collection station (if attributed entirely to ^{26g}Al) would provide an activity of 1.2 Bq. The β-γ coincidence spectrum of the ^{26g}Al sample is shown in Fig. 251.

High Power Target Development

Existing foil targets can accommodate up to 40 μA beam intensities and the available intensities of many radionuclides can be expected to scale with the proton beam currents. However, production targets capable of withstanding proton beam intensities up to 100 μA, without compromising the radionuclide yield and the lifetime of the target, are a challenge. Several approaches to the dissipation of the power in such targets have been investigated and a realistic solution for the removal of the heat from the target container is proposed.

The electron beam heating system

It is crucial to test off-line the high power target before going on-line to make sure that the thermal calculations are correct and to test the reliability of the target under such power.

The direct heating system uses a 10 V – 1000 A power supply that directly heats the target container by resistive heating. The maximum power we can achieve with such a system is around 4.5 kW. To go above that limit we developed an electron beam bombardment system. The electron beam heating system was built around an existing power supply capable of delivering 16 A at 1.2 kV. Figure 252 shows a schematic diagram of the heating system.

A filament located on the axis of the target tube is resistively heated to 2300 °C and biased negatively with respect to the target tube. The electrons leaving the hot filament impinge onto the target inside wall.

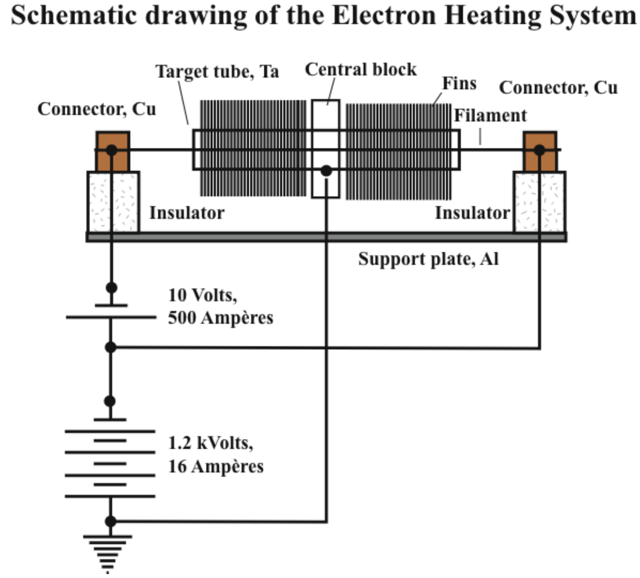

Fig. 252. Schematic drawing of electron heating system.

Instrumentation and measurement method

The target was equipped with a type C (W-Re) thermocouple attached to the corner of the fins. A second thermocouple measured the temperature of the heat shield. Two holes, 6 mm in diameter, in the copper heat shield allow us to measure the tube and central block temperature using a 2 frequency pyrometer. The output cooling water was recorded using a type K thermocouple. The filament temperature was also monitored during the test using the same pyrometer.

Figure 253 shows a photograph of the fin target installed in the conditioning box. First we bring the filament to its operating temperature (~2300 °C) using a 10 V – 500 A power supply. We found that the best way to stabilize the arc was to regulate the voltage on the filament power supply.

We discovered that the central part of the target (we call it the central block) which connects the two

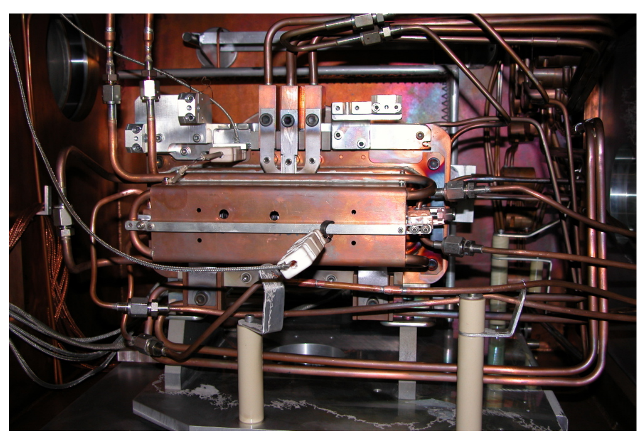

Fig. 253. Photograph of the high power target installed in the conditioning box.

Ta tubes was getting very hot. We had an excess of 450 °C at 13 kW. We decided to retrofit fins on the central block. The fins were machined from the same material thickness as the block, 9.5 mm in height and 1.5 mm apart. We operated the high power target up to 17.7 kW and observed that the central block temperature dropped to slightly lower than the tube.

Results and discussion

We measured the temperature of the fin, tube and central block as a function of the bias voltage. The input power originates from the electrons' power and the power radiated from the filament.

$$P_{in} = V_{EB} * I_{EB} + \sigma A \epsilon_{Ta} \left(T_{\mathrm{Fil}}^4 - T_{\mathrm{Tgt}}^4 \right) ,$$

where V_{EB} is the bias, I_{EB} is the electron current, σ is the Stefan-Boltzman constant, A is the filament emitting area and ϵ_{Ta} is the tantalum emissivity. T_{Fil} and T_{Tgt} are the filament and tantalum tube temperature, respectively.

In Fig. 254, the green triangles show the temperature of the actual ISAC target that does not have fins. The maximum power we can dissipate is only 4.5 kW. These results were obtained by resistive heating. The other three sets of points represent the temperatures obtained using the electron beam heating system. The temperature of the tube, the central block and the fins is represented by the blue dots, the red inverse triangles and the black squares, respectively.

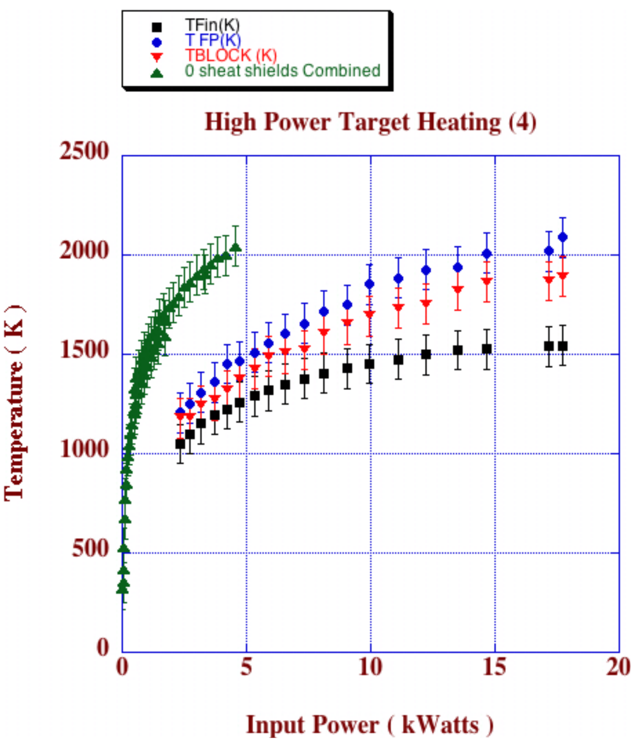

Fig. 254. Plot of the temperature as a function of the input power. The green points are the result of the resistive heating test for a Ta target without fins which goes only to 4.5 kW. The other three sets of points represent the temperature obtained with the electron beam heating system. The temperature of the tube, the central block and the fins is represented by the blue dots, red inverse triangles and the black squares, respectively.

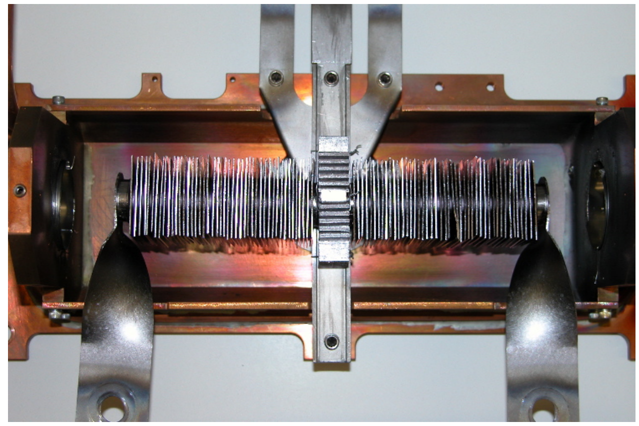

Fig. 255. Photograph of the high power target after the tests, with the heat shield removed. We can see the fins we added on the central block.

Figure 255 shows a photograph of the target itself after the tests. Even though the target was operated up to 17.7 kW there is no sign of degradation of the target and the fins.

ISAC ION SOURCES

ECRIS-1 Tests

The ECRIS-1 was installed for the first time in the east target station at ISAC in the summer of 2002. The ECRIS-1 at that time was equipped with an extraction hole of 5 mm in diameter. Extensive stable beam studies were carried out to establish a good tune. Unfortunately, the beam intensity was such that we experienced large copper sputtering from the interaction of the ion beam with the copper collimators located in front of each quadrupole lens. The copper coated all the insulators inside the exit module 1 and 2. The optics elements in the two exit modules had to be rebuilt and we added the following improvements to our design:

1. Two water-cooled collimators were installed after the extraction system and before the first quadrupole.
2. Current limits on these collimators provide a warning and if no action is taken after 30 seconds then the high voltage bias is turned off to avoid sputtering.
3. Current limits on all of the collimators in front of each quadrupole have also been implemented.
4. Shielding cups were added on each insulator to prevent deposition of metallic vapour coming from sputtering onto the insulator.

5. A smaller extraction hole of 3 mm replaced the 5 mm one in order to reduce the extracted beam intensity and consequently limit the sputtering.

The ECRIS-1 went back to the east target station in May, 2003 and we resumed operation with stable beam. We measured the neon ionization efficiency using a calibrated leak. A Ta target was installed onto the ECRIS-1 and we measured noble gases yield, Xe, Kr, Ar, Ne and He. These yields can be compared to the well known alkali yield of Cs, Rb, K, Na and Li measured already at ISAC and at ISOLDE, CERN for example. We found that the yield of the noble gases was low by a factor of 10 to 100.

We noticed that the efficiency dropped significantly with the proton beam current on target and discovered that the efficiency is greatly affected by the pressure increase when the proton beam hits the target.

Tests were performed during the shutdown period in order to determine the effect of the pressure on the neon ionization efficiency. At first we spent time to ensure we would obtain the best operating conditions to optimize the neon ionization efficiency by varying the magnetic field using the two coils, the rf, and the support gas flow. We were able to reproduce the neon ionization efficiency of 2 to 2.6% which was observed on the off-line test stand. In the best operating conditions, we measured an ionization efficiency of 25.9% for Kr^{1+} and 62.1% for Xe^{1+}. Once we had the operating condition optimized we began injecting krypton and xenon into the ECR.

The intent of this study was to determine the operating range under pressure of the ECR-1 installed in the east target station. Kr and Xe gases were injected into the ECR and we have measured the neon ionization efficiency with respect to the injected flux of gas. We also recorded the pressure increase inside the containment box, the extracted current, and the beam emittances as a function of the flux of gas.

We observed that the ionization efficiencies dropped by two orders of magnitude for a pressure increase of 1.5×10^{-6} torr while injecting Kr or Xe (see Figs. 256 and 257, respectively).

The measurements show also that the emittance increases with the gas flux injected into the ECR. Furthermore, we observed a low energy tail formation that increases with the injected gas flux. This is a sign that part of the beam experienced collision inside the accelerating gap.

We can conclude that the source is stable over a pressure range between 1×10^{-6} to 1.5×10^{-6} torr. Above that pressure the ionization efficiency starts dropping. That corresponds to an estimated flux of 10^{14} atoms/s. If we want to run the ECR on-line we have to make sure that we stay within those limits if we want to maintain the 2% ionization efficiency. On-line tests are scheduled in May, 2004 with a SiC target. The aim will be to produce ^{18}Ne for a high precision half-life determination.

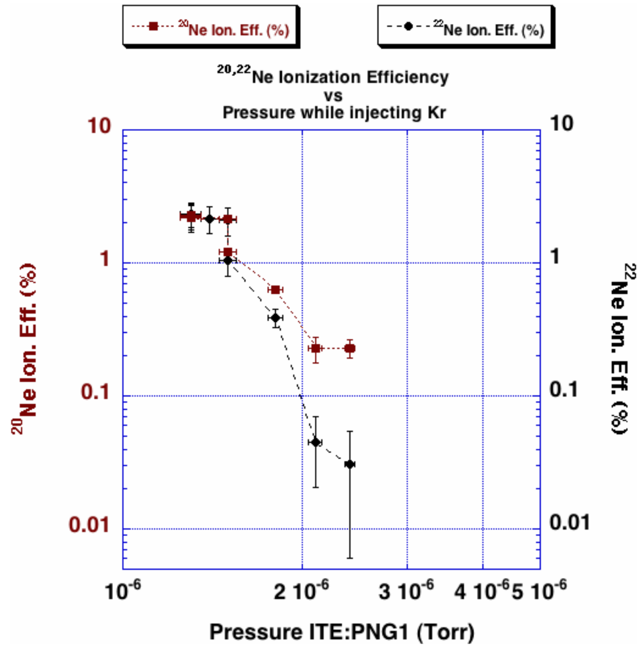

Fig. 256. Neon ionization efficiency as a function of the pressure while injecting krypton into the ECRIS-1.

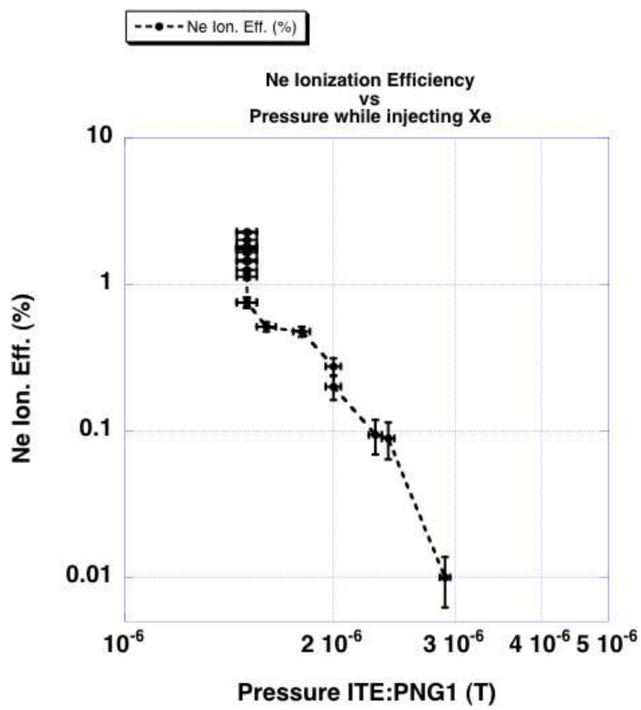

Fig. 257. Neon ionization efficiency as a function of the pressure while injecting xenon into the ECRIS-1.

Charge State Booster (CSB)

The 1+ ion source test stand (ISTS) facility has been extended to incorporate the CSB for tests and further development. The installation of the CSB, the beam transport and diagnostic elements, the high current and high voltage power supplies, the 14.5 GHz – 2 kW microwave generator and the vacuum and high-pressure water cooling systems has been completed.

Figure 258 shows the 1+ beam transport system upstream of the CSB during installation. Figure 259 shows the N+ beam transport system downstream of the CSB including the M/Q magnetic and electrostatic analyzing systems. Space has been provided in the 1+ beam line for the future installation of the rf beam cooler for tests with the charge state booster.

The computer control system (hardware and software) of the ISTS has been extended to include the control of the CSB test facility.

With some delay, due to lack of technical support at the assembly stage, the CSB was operated for the first time in November. This first run was principally to commission most of the devices including tests of the personal safety and machine interlock systems.

The CSB was operated as an ECR ion source (26 kV extraction – 150 W rf power) for a short time using oxygen as a buffer gas. The extracted beam consisting mainly of oxygen atoms was analyzed. Figure 260 shows the M/Q spectrum taken with the Faraday cup located at the exit of the analyzing magnet.

The preliminary layout to implement the CSB in the ISAC-I building has been finished and is waiting for approval.

The first three months of 2004 will be devoted to fully commission the CSB facility including the electrostatic analyzing system and diagnostic elements. Beam optic tuning and 1+/N+ operation is expected to begin in April.

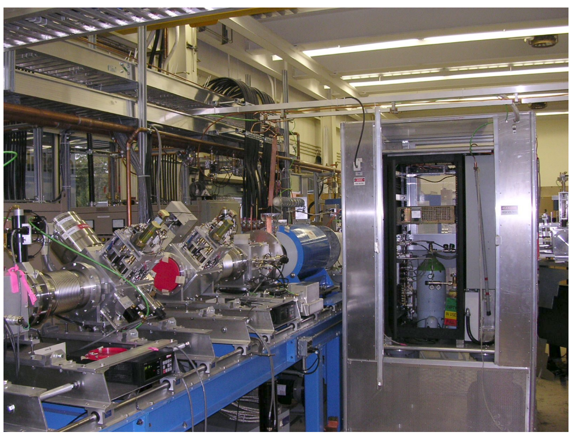

Fig. 258. Photograph taken during the assembly of the 1+ portion of the beam transport system. The CSB is the blue cylindrical object located at the left of the H.V. rack, which houses the gas supply system and auxiliary equipment.

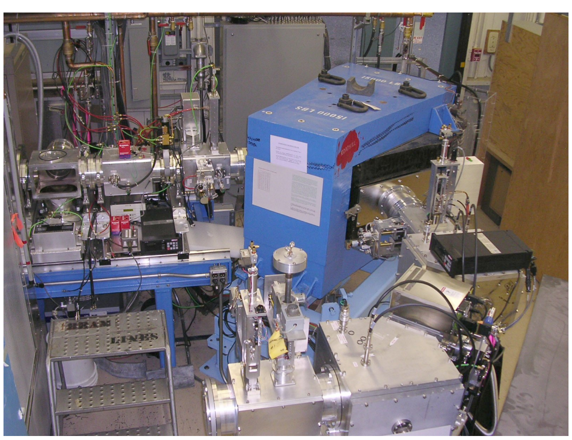

Fig. 259. This photograph shows the beam transport components downstream of the CSB. Seen are the 90° magnetic and the $2 \times 45°$ electrostatic analyzers.

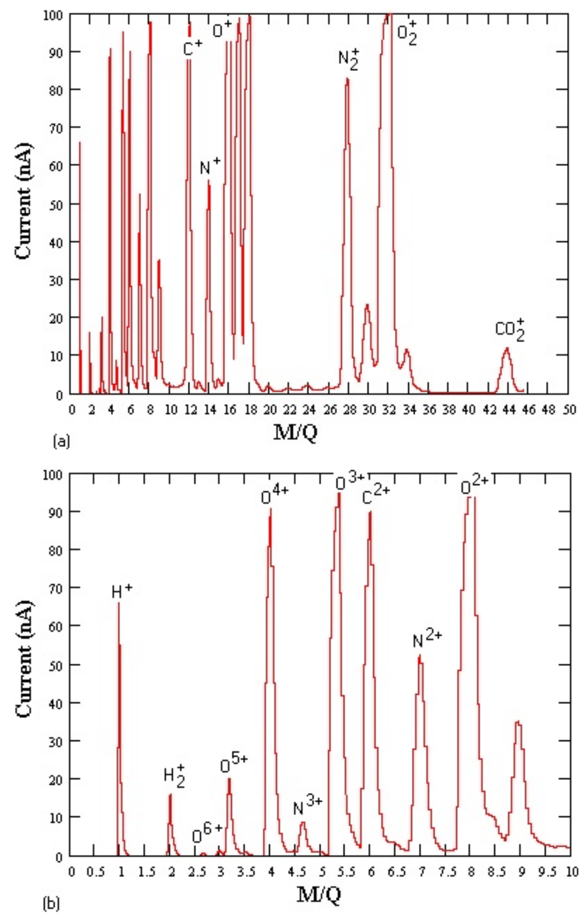

Fig. 260. (a) M/Q spectrum. This scan was made soon after the CSB was put into operation for the first time. The current amplifier for the O_2^{1+} peak is in saturation. Logarithmic current amplifiers have been designed and tested but not yet implemented. (b) Same spectrum but to M/Q = 10. The different charge states of oxygen are clearly seen here. The other peaks arise most likely from the out gassing process in the plasma chamber and from the rest gas.

Resonant Ionization Laser Ion Source (TRILIS)

Within the radioactive ion beam (RIB) development at ISAC a resonant ionization laser ion source (TRILIS) is to be implemented to provide radioactive ion beams complementing the existing ion sources. TRILIS uses multi-step resonant laser excitation and ionization and capitalizes on the potential for element-selective, efficient photo-excitation and ionization, with the major components of the LIS located far away from the highly radioactive target ion source.

The basic set-up of TRILIS is shown in Fig. 261 and is identical for off-line development and on-line beam production. In general TRILIS can supply beams of metals and transition elements that are otherwise difficult to obtain. Tunable, high-power, high repetition-rate, narrow bandwidth, and synchronizable pulsed lasers are required. Typical excitation schemes employ two and more commonly, three laser excitation steps for ionization, with the laser wavelength for the first excitation step usually being in the blue to ultraviolet region of the spectrum. In a typical laser excitation ladder each additional step requires higher spectral energy density. Therefore autoionizing states in the continuum are best suited for efficient ionization. These states have to be determined experimentally for each element individually. The initial beam development in 2003/04 is focused on Al and Ga. Figure 262 details the laser excitation schemes used in the initial investigations.

The TRILIS laser system employs state of the art, frequency-doubled YAG lasers pumping Q-switched solid-state titanium sapphire (TiSa) lasers (collaboration with Mainz University). This reduces the overall installation and operation cost over the competing copper-vapour laser–dye-laser combination. It does, however, involve the development or adaptation of some technologies:

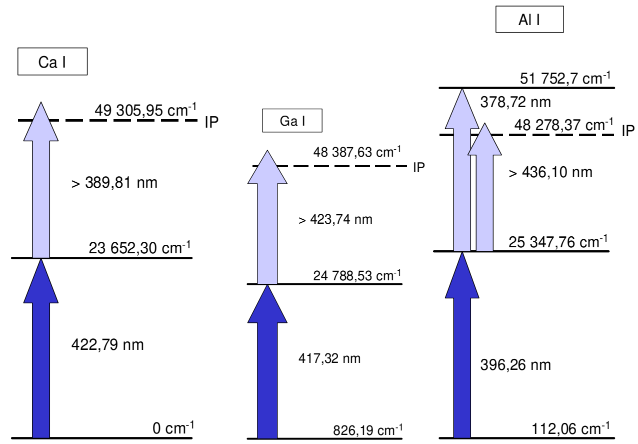

Fig. 262. Simple one-step resonant one-step non-resonant (1+1′) laser excitation schemes used for off-line excitation scheme development and search for auto-ionizing state for the initial target elements Ga and Al.

- new laser ionization schemes, as the wavelength range covered by the TiSa lasers differs from that of the dye-laser systems,
- frequency-tripling for efficient laser excitation of elements such as Be (under development at Mainz University), and
- pulse amplification of ionizing TiSa laser (future work).

After the completion of the proof of principle tests with the Mainz TiSa lasers in 2002, we fabricated,

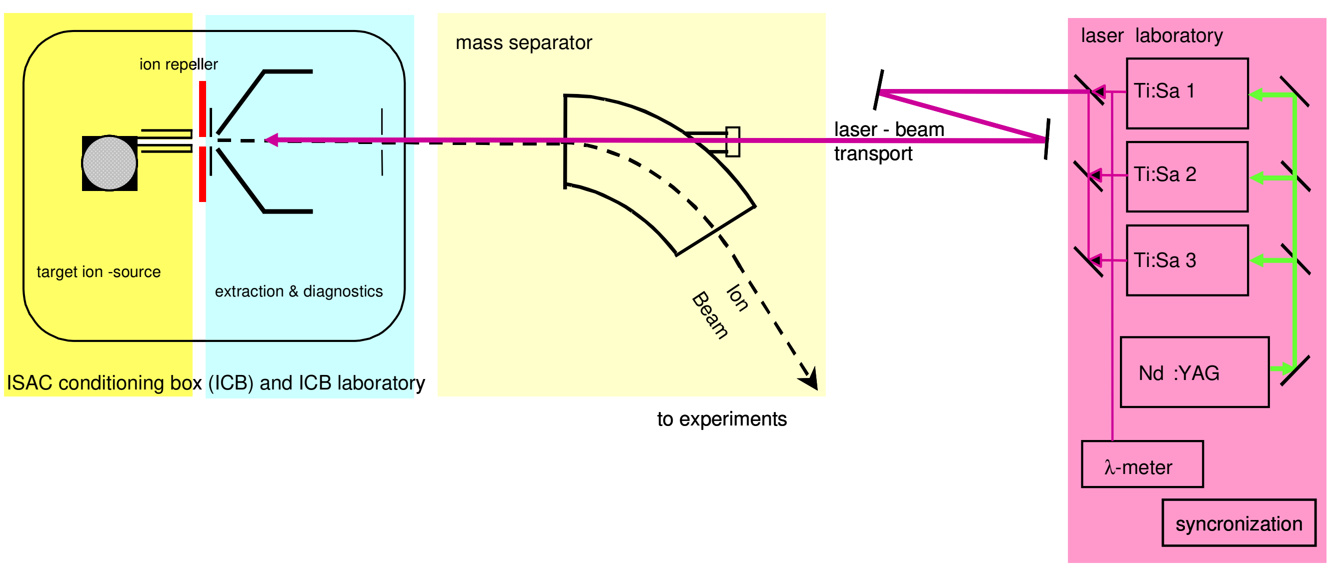

Fig. 261. Schematic of the TRILIS off-line development station with the principal functional groups: target ion source, mass separator and laser system. For TRILIS on-line the laser beam transport distance increases approximately five fold, thus requiring beam expansion and 2 in. diameter optics.

installed and tested a set of 3 TiSa using the Mainz design. At the same time the pump laser pulses and beam quality were fully characterized.

On the electronics side, a new Q-switch driver electronics built around a commercial fast push-pull transistor switch and a remotely programmable 3 channel trigger/digital delay generator with 0.5 ns resolution for TiSa laser synchronization were developed, prototyped and built by the TRIUMF Electronics Development group. The construction and commissioning of the laser laboratory and the laser systems was supported substantially (3 months) by Dr. Roland Horn, who graduated from the Mainz group, and Thorben Windeler a MSc. student in applied laser technology from FH Ostfriesland in Emden (Germany). Safety approval for the off-line laser lab and the lasers therein was obtained. Basic laser parameters of the TiSa lasers were determined, the lasers were operated in Q-switched mode and two manually controlled frequency doubling units were set up and operated in order to gear up for off-line ionization scheme development. The complete TRIUMF Mainz TiSa laser system is shown in Fig. 263.

First on-line work is planned with the fundamental and the frequency doubled laser wavelengths as this allows for substantially simplified laser beam transport into the west target station (ITW) which was designated for first laser ion source tests in the fall of 2004. Off-line testing will be done with quantitative

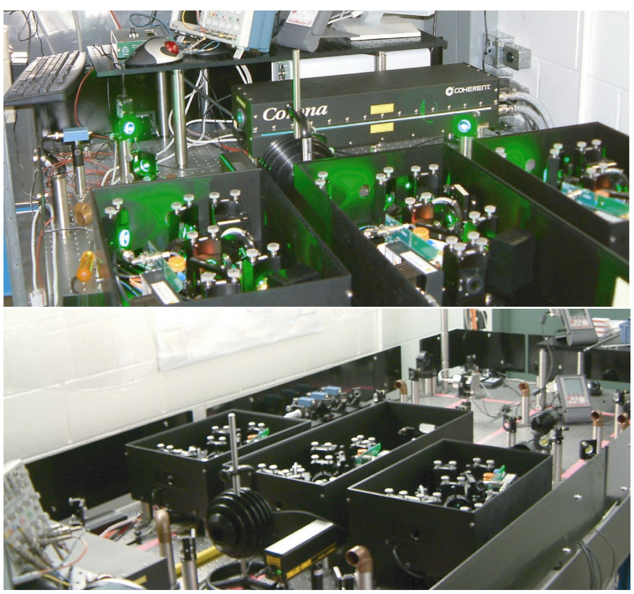

Fig. 263. TRILIS off-line laser laboratory adjacent to the ISAC conditioning station (ICB). Shown are the wavelength meter and wavemeter input multiplexing, the compact 75 W, 5 kHz–25 kHz Coherent Corona75 pump laser and the three TRIUMF built Mainz University narrow bandwidth, tunable titanium sapphire (TiSa) lasers. Not shown are the two frequency-doubling units.

evaporation of elements from crucibles attached to the standard ISAC target ion source surface ionizer/transfer tube. The heater-crucible combination is being tested with the surface ionizer and negative ion source in the ISAC conditioning box (ICB). This highlights the synergies in the RIB development group, however, it also shows the high level of facility sharing resulting in limited access for development work.

The laser beam transport from TRINAT to ITW was calculated and opto-mechanics installed for laser beam transport. This included modifications to the laser port on the pre-separator magnet during the 2002/2003 shutdown.

Further improvements to the TiSa lasers were tested and will be implemented as time permits. Preparation of the TRILIS laser laboratory location in the TRINAT clean-room for on-line work continues.

ISAC POLARIZER

Production of polarized lithium and sodium isotopes became routine and very reliable. The dye laser was used for polarizing all lithium isotopes, as well as sodium. DCM is the dye used for the red region of the spectrum including the Li transitions, and the solvent recommended by the laser manufacturer was ethylene glycol. However, ethylene glycol is very hygroscopic, and water forces DCM out of solution. Very stable operation was achieved by changing the solvent to EPH (ethyleneglycol phenyl ether).

An ATOS LM007 wavemeter was purchased and installed, after tests with one borrowed from the TRILIS group demonstrated its usefulness. It is an order of magnitude more accurate than the wavemeter it replaced. Formerly, one tuned the laser to an undetermined order of the spectrum analyzer (free spectral range 300 MHz), locked the laser frequency to a specific fringe spacing between it and a reference He-Ne laser, and finally scanned the Na cell bias to Doppler-tune the isotope beam energy onto resonance. If the laser frequency lock were lost, one would have to scan the Na cell bias again, since the wavemeter was not accurate enough to tune the laser to the same fringe order in the spectrum analyzer. The new wavemeter is accurate enough to tune back to the same order, eliminating the need for a Na cell scan. This upgrade is especially useful when running low intensity beams, when a Na cell scan takes too much time.

Concepts for producing polarized paramagnetic ion beams such as $^{11}Be^{+}$, $^{15}O^{+}$ and $^{20}F^{+}$ were explored. The polarization of such a beam would normally be lost during transport to the experiment, due to precession of the electron magnetic moment coupled to the nuclear spin. The simplest solution, applicable to all isotopes, is simply to extend the guide field to the experiment. Magnetic coil field calculations showed that this is feasible for both the existing BNMR platform and the polarimeter beam line. An optical pumping scheme for atomic metastable fluorine was identified.

The polarizer beam line is well suited for doing collinear laser spectroscopy. The Texas/McGill group modified a fluorescence monitor, originally used for tuning the laser to ^{8}Li, for detecting laser induced fluorescence from metastable La ions. Their experimental set-up was tested during the summer with an Ar^+ beam, and Ar^+ resonance lines were observed.

REMOTE HANDLING / TARGET HALL FACILITIES

Modules

Work began this year on the fourth target module (TM #4) with assembly of the shield plug, containment box, service cap and completion of the services tray.

Remote Handling

Regularly scheduled target exchanges for target module #1 (TM #1) operating in the ISAC west target station (ITW) are becoming a full time operation for both the remote crane system and the target handling hot cell.

In January the SiC #4 target was exchanged for the ZrC #1 target on TM #1, in May this was replaced with the SiC #5 target, with the Ta #6 target in July, and finally with the SiC #6 target at the beginning of November. The spent targets from all TM #1 operations were inspected and documented, packaged and remotely transported to the spent target storage vault in the target hall.

The spent target storage vault is now at one half of its storage capacity with 12 spent target pails, and the failed TIS service tray removed from TM #1 in 2001. At the rate of presently scheduled target exchanges for TM #1 alone, we will reach maximum target storage capacity by 2006. With TM #2 and TM #3 now beginning operation in the ITE station, this date will no doubt be reached even sooner.

A mechanical system for replacement handling of the hot cell tele-manipulators was designed and installed at the south hot cell. This was employed in June to replace a problematic manipulator for repair.

The TM #3 module, with the installed ECR source was serviced after initial trial operation in a contamination control enclosure within the target hall. The original ECRIS quartz tube was replaced with an alumina version, and the Ta #4 target subsequently reinstalled on the module in the hot cell.

ISAC CONTROLS

This year saw some slowing down of the frantic installation of new systems, which had to be dealt with during the past years. This "breathing space" was used to enhance the consistency, maintainability and reliability of the ISAC control system.

As in the years before, the Electronics Development Group supplied the hardware support for the ISAC control system, both for design and maintenance. Chris Payne from the ISAC Operations Group became an honorary member of the Controls Group and took over the responsibility of managing the console Linux workstations in the control room.

New Systems

Charge state booster

At the ion source test stand, the control system was expanded to support the new charge state booster system. This amounted to more than doubling the existing system. A small EPICS IOC, based on the PC104 form factor, was installed to supervise the vacuum controls PLC. A Linux packet-switching firewall was installed to shield the PC104 CPU from rogue network traffic. Beam optics and beam diagnostics controls were integrated with the existing VME based EPICS IOC. Two new PLC breakout cabinets were installed, one at ground and one at HV potential. Hardware and software support for 83 vacuum devices, 22 power supplies, and 22 beam optics devices, including 2 emittance measurement stations was provided.

TITAN rf cooler

The conceptual design for the TITAN rf cooler setup in the proton hall extension was finished. A VME based EPICS IOC will be located in the high voltage rack. This IOC will drive the trap power supplies and the voltage switches, and control the beam optics via ISAC style CANbus controllers.

The majority of the detailed design was finished. For the control of the trap supplies and pulse sequencing, special VME modules were developed (for details see the Electronics Development section of this Annual Report). EPICS device and driver support for these new modules is complete.

For the vacuum system, the PLC program was developed and simulation tests were performed. The PLC breakout panel was pre-wired and is ready for installation.

ISAC-II cryomodule

The control system for the ISAC-II superconducting cavity was disassembled at the BC Research location, moved to the new ISAC-II building and recommissioned. In addition, the system was upgraded to fully support the new ISAC-II cryomodule in the test location at the SCRF facility.

OLIS surface source

EPICS and PLC support for the new OLIS surface source was implemented. This also required modifications to the existing vacuum and beam optics systems.

Other small systems

For the GP2 experiment, a concept design for the experiment control system was developed. The experiment's summer student was guided during the implementation of the front-end Modicon Momentum PLC system. An EPICS system was implemented, which includes an operator interface and extensive sequencing control. For this, minor enhancement to the TRIUMF/EPICS cppe sequencing tool were implemented.

RF amplifier monitoring

The conceptual design of a monitoring system for all relevant parameters of the 14 ISAC rf amplifiers was finished. It consists of a Modicon Momentum PLC system, which uses the new Advantys I/O system and implements one I/O drop per amplifier. PLC code and EPICS support was developed. The PLC was installed and one amplifier was instrumented. This subsystem awaits final signal hook-up and is ready for testing. In addition, remote control of the RFQ amplifier was implemented.

Functionality Enhancements

The Probes Group installed absolute encoders for position read-back of all the motor systems in diagnostic box DB0 after the pre-separator magnet. EPICS support was implemented and the previously used tedious calibration procedures could be retired.

Work on the rf phase measurement system continued. A first version of the GPIB based readout of a vector voltmeter was implemented. It uses a dedicated PC104 EPICS IOC, which interfaces to GPIB via the GPIB-Enet10 module from National Instruments. Support code was written to support this interface using the EPICS stream device driver. This system has known performance and reliability problems, but it was the only available solution given time and manpower constraints. An upgrade, which will replace the GPIB-Enet10 controller with a PC104 board is being worked on at the moment. This upgrade will also move the signal selection from VME to PC104 and provide a dedicated phase measurement solution.

At the ITE target station, an interlock system was implemented in order to cope with the higher currents from the ECR source. This system balances the requirements of machine protection and operational convenience in a staged approach, increasing the machine protection the longer an overcurrent situation prevails. Sequencing code for automatic startup and shutdown of the ECR source was developed.

Optically isolated, CANbus based charge integrators were installed at the TUDA experiment for low current readout.

At the target conditioning box, many small modifications were made to support changing requirements for testing of the laser ion source and high current targets. A new 8-channel water flow controller with flow readout via CANbus was installed. The newly developed EPICS support for this device was tested.

Additions to the 8π vacuum system, both PLC and EPICS, were implemented to support extra devices for the new tape collector system.

An EPICS device and driver support were developed for a new TRIUMF-designed 8-channel VME ADC.

System Support

The homecoming of the superconducting cavity test set-up from BC Research freed up one SUN workstation. This allowed the reconfiguring of the production environments for the EPICS control systems outside the ISAC firewall (ion source test stand, target conditioning box, evaporator, TIGRESS). The responsiveness of the conditioning box system was considerably improved and the system topology was altered for future firewall protection of these systems.

Again this year, a considerable amount of time went into system maintenance on the development and production machines, especially operating system upgrades both for Solaris and Linux. Some time was spent evaluating a low-maintenance, commercial firewall system, which was finally abandoned because of insufficient throughput. In its place a PC/Linux-based firewall was installed to protect the development nodes in Trailer GgExt.

The introduction of PC104 based IOCs was delayed by several months due to problems with unexplained communication lock-ups. These did happen frequently, when the IOC was located on the site network, but not when located behind a firewall. Although the source of the problem was never clearly identified, it was resolved by upgrading the vxWorks Kernel from version 5.4 to 5.5.

In preparation for ISAC-II, a new VME CPU was evaluated. It is based on the Intel Pentium (Celeron) chip and provides a good balance of price and performance. Support for vxWorks 5.5 was implemented and all ISAC drivers and device support were built and tested with this CPU. Field tests at the ion source test stand are scheduled for the new year.

Development Support

In order to better control software deployment, the IOC boot system was reorganized. A Perl tool was developed which configures the IOC boot directories and allows roll-back to a previous IOC configuration.

As a major project during the fall, the ISAC database tools underwent a major upgrade with the goals of:

- converting from Paradox to PostgreSQL as the underlying relational data base system;
- implementing the existing functionality with a Web interface;
- integrating many of the group's development tools with this Web application.

After a short evaluation comparing Java, PHP, and Perl CGI, the latter was chosen for implementation of the tool applications.

The design of the database tables was reviewed and improved. Then the table data were exported from Paradox and imported with few difficulties into PostgreSQL.

The functionality of the Paradox application was recreated in Perl using the DBI module for accessing PostgreSQL. Other development tools, such as generation of Capfast schematics for building IOC software, PLC interlock checking, the IOC boot configuration system, and device control panel building, were integrated into the Web application. An automatic event registration system was implemented in order to keep track of control system changes.

Commissioning and Operation

The ISAC controls Web site was reorganized for better optics, navigation and information retrieval. More documentation, tutorial material and troubleshooting information was added.

The ISAC control system operation matured during this year, with the system settling down. Most IOCs were smoothly upgraded to vxWorks 5.5. A problem area remains the communication with the rf control PCs, where erratic behaviour occurred with unacceptable frequency late during the year and is not yet understood. A different approach is being tested for ISAC-II and may be retrofitted to the ISAC-I system as well.

VACUUM

ISAC-I

The Vacuum group supported all vacuum equipment for beam production and distribution, as well as some vacuum systems for the experiments. Most of the turbo pump repairs, including replacement of bearings and rebalancing of rotors, were done on site. More than 15 pumps have now been restored and returned to operation.

CAD-generated vacuum diagrams for CSB, S-bend transfer line, HEBT roughing system upgrade, RFQ cooler, cryomodule, GPS-2 and TUDA have been produced, most of the components purchased, and some of the systems have already been implemented.

Targets

Several vacuum leaks, located on the isolators of the service cap of the ISAC target west, have been repaired. The Vacuum group has been involved in turbo pump installation on target modules and leak checks of the target module cooling system.

The ion gauge has been replaced on TM #2.

The east target station is performing very well and holding an average vacuum of 8.0×10^{-7} torr. The new gas-insensitive membrane gauges are scheduled for installation during the spring shutdown of 2004.

A turbo pump failed on the IMS beam line and was replaced. A test was done by the addition of a cryo pump to improve the vacuum in that area for future requirements.

LEBT

ILY The Penning gauge controller failed and was repaired and replaced twice during the year. It is planned to replace the gauge and controller with an inverted magnetron from Varian.

8π An extra turbo pump was installed for lowering the vacuum in the detector area. The gate valve was rebuilt with new seals.

Polarimeter Two turbo pumps failed during the year. One was replaced with a rebuilt pump, the other one has been removed and the port planked off. The gate valve was rebuilt with new seals.

MEBT

RFQ All brass valves were refurbished or replaced with new ones. A turbo on the RFQ failed and was removed and will be rebuilt or replaced.

DTL Two turbo pumps failed and were replaced with new ones. The DTL tanks are performing very well and are holding an average vacuum of 4.5×10^{-7} torr. A few vacuum leaks were diagnosed and repaired by the Vacuum group.

HEBT

Two turbo pump controllers were repaired and are back in operation. Air cooling units have been added to all turbo pumps.

TCB The Vacuum group provided support for the installation of an extra turbo pump and the diagnosis of various vacuum leaks.

TUDA A new high vacuum gauge was installed and the Vacuum group diagnosed and repaired a few vacuum leaks.

Berkeley experiment The vacuum system has been set up for the experiment on the straight HEBT section.

Vacuum/Cryogenics, ISAC-II

Vacuum property measurements for different materials have been conducted on the vacuum test stand. These materials are intended for use in the ISAC-II cryomodule.

The CSB vacuum system has been assembled and is functioning well. The copper wool filters have been selected, purchased and installed to prevent migration of Teflon dust from the dry mechanical Scroll 300 pump to the vacuum chamber.

The Vacuum group participated in some of the cryogenic activities related to ISAC-II SC linac development, including participation in the design and development of the main components on the new SC linac, and the manufacturing and assembly of the nitrogen heat shield for cryomodule #1. CAD-generated cryogenic diagrams have been produced for the cryomodule, including the temperature sensors, level probes, heaters, and pressure gauge positions. Pressure relief valves have been tested.

The Vacuum group designed and assembled the SC solenoid helium test cryostat and tested the SC solenoid built by Everson.

Liquid Helium and Liquid Nitrogen

The Vacuum group is responsible for liquid helium and liquid nitrogen deliveries and distribution on site.

The liquid nitrogen service to BCRI was cancelled in September when the SCRF laboratory moved to its new home in the ISAC-II building.

The ISAC-II nitrogen distribution system has been inspected, and is scheduled for commissioning in the spring, 2004.

ISAC-I RF SYSTEMS

ISAC rf systems performed well over 2003 with a total availability of about 94%, the same as in the previous year.

RFQ

The RFQ operated reasonably well, though it contributed the most rf system down time (188 hours). Major problems were associated with a power amplifier (PA):

- two PA tubes (4CW150000) failed and were replaced with spares;
- screen bypass capacitor burnt. To fix it, the fabrication burrs on the screen plate were removed and a kapton insulator was replaced;
- driver power supply regulation circuit failed. A smaller dc supply was promptly built to provide temperate operation while troubleshooting the original unit;
- air conditioning deficiencies caused a few PA interruptions during the hot summer. Both ISAC hall and HV power supply air conditioning configurations were improved;
- ac distribution for the RFQ controls tripped due to overload from the experimental set-up energized from the same panel. The distribution was reconfigured to supply rf controls from UPS.

During the winter shutdown a soft start circuit was installed in the RFQ high voltage power supply and has shown reliable operation since. It is based on SCR elements and allows a slow voltage rise to prevent high inrush currents. It also provides very fast power cut off (8 ms compared to 24 ms in the mechanical switch) to reduce ignitron tube overloads. Soft start circuit implementation also allowed a PA remote controls update, permitting amplifier remote turn on/off. Previously this was not possible due to ac mechanical switch gear manual reset requirements. An RFQ PA filament power supply transformer was replaced during the September shutdown, providing proper tapping for reduced filament voltage in order to increase tube lifetime.

Bunch Rotator

The MEBT 105 MHz bunch rotator was routinely used in operation to allow a desired beam quality. Its amplifier failed once due to a burnt motor in an air blower. At that time a temperate 400 W amplifier was set up to ensure uninterrupted operation while ordering and replacing the broken unit.

During the course of the year, we realized that rotator startup is somewhat troublesome. After a day of idling it normally requires up to 30 minutes of conditioning to overcome a multipactor discharge, which does not happen to any other rf system. To investigate the problem the cavity was taken off-line and dismantled. The problem was traced to an extensive secondary electron discharge ignited between split-ring stem and cavity endplates (see Fig. 264). This area is exposed to low rf voltage and prone to multipactoring. A special surface treatment is foreseen to tackle this problem and will be accomplished during the next shutdown.

MEBT Rebuncher

The MEBT rebuncher solid state amplifier was replaced with a home made unit in 2002 and we have not

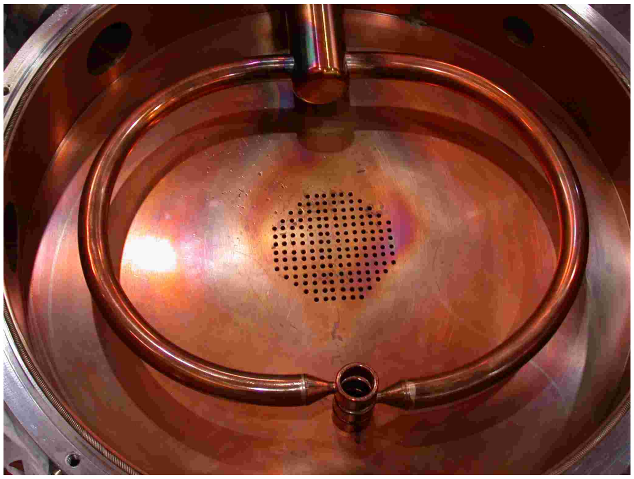

Fig. 264. MEBT bunch rotator structure with multipactor discharge traces around the stem.

experienced any trouble in its operation since. A cavity state has attracted our attention while servicing its cooling circuit. The endplates made of mild steel were originally nickel plated inside the cooling channels to prevent corrosion. Over time this coating has degraded and iron was exposed to water. As a result, heavily ionized water has contaminated the return circuit, painting the plastic flow meter cover in red. Buncher cooling requirements were reconsidered and a high power test was performed without water cooling of the endplates. The results have proven our estimate of insignificant power dissipation in the endplates. Running a system at 1.5 kW (50% over the nominal) we observed a temperature rise from 22 to 36° C. So a decision has been taken to operate this unit with non-cooled endplates.

DTL

DTL systems routinely operated mostly at about 4/9 full power ($A/q \approx 4$) according to the scheduled experiments. During the winter shutdown we continued the program of fine tuner modification. This time we have removed fingerstocks, which were scratching the tuner shafts, from DTL #3 and #4 tuners. None of the 9 modified tuners has shown any trouble in operation.

All rf pickups were removed from the cavities for detailed inspection. Two of them were replaced due to poor conditions traced back to original installation. Buncher #1 pickup loop was replaced with a capacitive probe giving more stable read back signal. The original loop showed a coupling dependence on the rf power level.

DTL #1 tank has shown the same problem with iron endplates as the MEBT rebuncher did. It has also been put under high power test with hope that we might be able to run without endplate cooling. The test has confirmed that cooling is vital. Under nominal 4 kW power, non-cooled tank structure has rapidly warmed up to about 60° C, and the frequency regulating tuner has reached its limit. To minimize the intervention with structure modifications it was decided to apply external detachable heat sink for endplates cooling. All required parts have been designed and will be installed next spring.

About 15 regulation valves were replaced in the DTL cavities cooling circuits in order to provide smooth water flow adjustment. The original valves were too coarse to satisfy the regulation requirements.

DTL amplifiers

After extensive maintenance in 2002 the DTL amplifiers did not require any specific service over the last year and worked very reliably. The only unit we worked on was a transmission line from PA to DTL tank #3. It showed an elevated standing wave ratio (VSWR) and excessive heat dissipation. The problem was traced to a distorted line section at a sharp bend where the internal insulator was melted (see Fig. 265) in 2000 during the commissioning period. To fix the problem, the entire Tx-line was replaced with a new piece.

An amplifier remote control system was developed and prototyped with DTL #5 PA. It provides all amplifier subsystem status signals, operational ac and dc voltages and currents, and forward and reverse rf signals to the ISAC main controls system via EPICS interface. All signals will be archived for postmortem analysis. This system will give us, as well as ISAC operators, a powerful tool for rf system troubleshooting and preventive maintenance. According to budget availability we plan to build such a controls for all rf amplifiers.

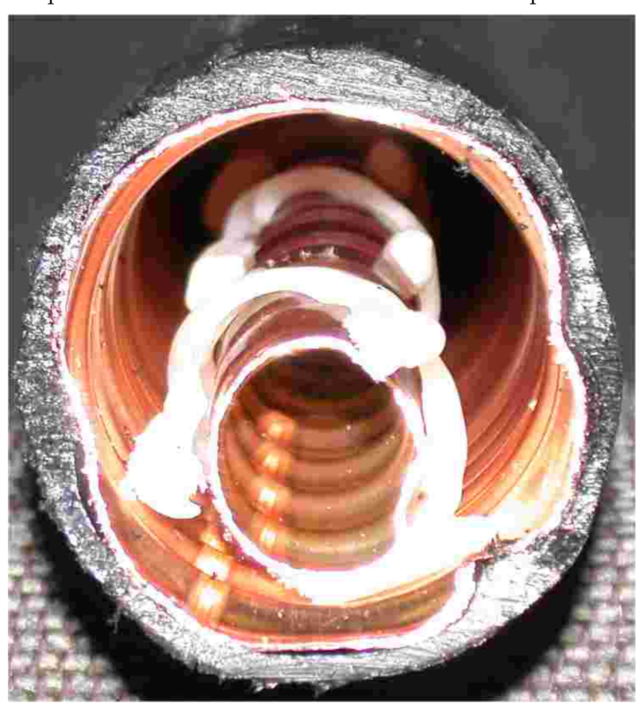

Fig. 265. Damaged semi-flexible Tx-line.

DTL couplers

During last year the previously troublesome coupler windows worked fine after some preventive and monitoring measures were taken (see last year's Annual Report). Nevertheless during the winter shutdown all the couplers were again taken out for inspection, which confirmed their good state. Then all coupling loops were copper plated to avoid possible spattering from the brazed joint, which we experienced in the past. Buncher #1 coupler was tested with the aim of better operation stability. Its coupling loop was found to be oversized, which caused excessive coupling, both inductive and capacitive acting in opposite polarity. A new smaller loop was installed that dramatically reduced the capacitive component and improved system stability.

HEBT High Beta Buncher

The 35 MHz buncher was tested to operate with a modified DTL#4 tuner (without fingerstocks), showing a temperature rise on a bellows of about 20° C. This is still acceptable for operation, though it is much more elevated compared to the DTLs. The difference is explained by another type of structure (spiral), which generates rf currents through the tuner shaft, heating it up, while in the DTL all tuner currents are localized on the tuner plate, which faces opposite voltages on the drift tubes, and thus shaft currents are compensated. Then the original buncher tuner was modified to improve operational reliability. Subsequent tests showed much more pronounced heat impact on the bellows than in the beginning. The difference appeared to be in the tuner design. It has a longer shaft providing higher coupling to the structure, and thus absorbing more rf power. The tuner was set close to the outer limit of the regulating range to keep the temperature reasonable (below 70° C) for the current operation. Next shutdown we plan to standardize the tuner design to be compatible between different rf cavities and to satisfy the operational temperature requirements.

Phase Measuring System

An auxiliary phase measuring system (PMS) has been commissioned for the ISAC rf system. It provides precise (∼0.2°) phase difference measurement between the reference rf source and each individual rf device. All hardware was tested and calibrated in 2002. Last year an EPICS based control system was commissioned. It provides remote control over the measurements both in manual and automatic modes. In manual mode a single cavity phase can be acquired with a variable repetition rate between 0.2 and 2 s. In automatic mode the system scans all 18 rf devices with 2 s intervals providing relative phase read back update every 36 s. At every point a number of samples is measured, and an average value together with a standard deviation is being archived for rf system troubleshooting and beam instabilities investigation.

Two additional rf pickups were installed in the MEBT and HEBT bunchers providing independent inputs for PMS. For other rf systems the amplitude monitoring signal is split to give an input for PMS.

Eventually PMS is expected to provide the rf reference settings for accelerator tune up.

RF Controls

Over the year the RF Controls group regularly provided routine tune up of the rf control system. Upgrade work had been done for the VSWR protection circuitry: new rf filters have improved system stability.

Upgrade of rf controls hardware has extended this year over 3 more personal computers (PC): 1 was replaced and 2 others were superseded with a modern PC. The latter operation required a substantial software upgrade. New equipment has demonstrated very stable and reliable operation giving no more computer crashes since they were upgraded.

ISAC-II Transfer Line 35 MHz Buncher

The RF group continued development activities for building a 35 MHz buncher for the transfer line to ISAC-II linac. The buncher tank was copper plated. Cooling pipes were attached to the spiral resonator, leak checked, and copper plated (see Fig. 266). The

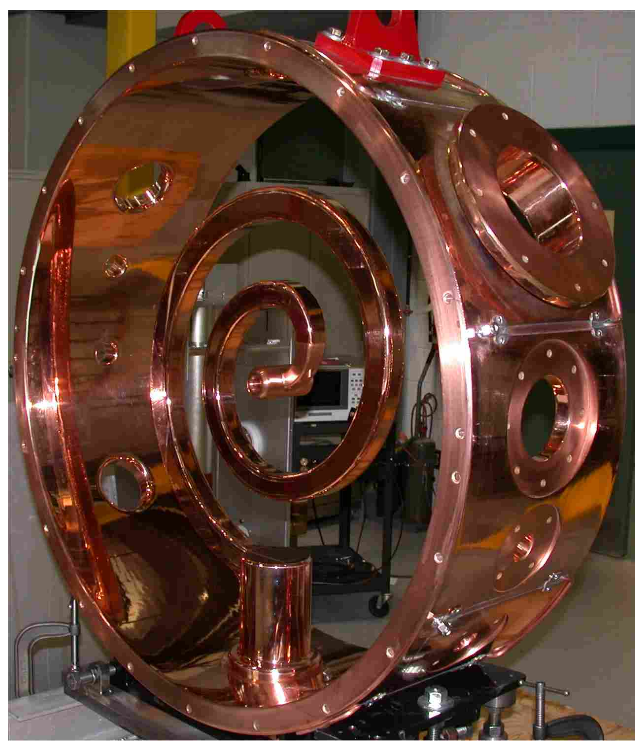

Fig. 266. New transfer line 35 MHz buncher.

structure assembly is ongoing. Fine and coarse frequency tuner drawings were updated for fabrication. Drawings for rf amplifier parts and sub-assembly have been made and submitted for production in the machine shop. The bias and screen power supplies and driver rf amplifier have been made in-house and tested. RF cold testing of the anode circuit, coupling loop and neutralization circuit was done. As a result of the test, the length of the outer tube for the anode circuit was reduced and sent for silver plating. The coupling loop size was re-designed and the external anode capacitor was modified.

BEAM DYNAMICS

LTNO Optics

Almost all of the focusing element settings in the low energy beam transport (LEBT) section are at or very near their theoretical values. The only exception has been the low temperature nuclear orientation (LTNO) optics. This consists of an ungridded electrostatic mirror, followed by a symmetric quadrupole triplet. These optics were obtained from ORNL and are not a TRIUMF in-house design.

From measurements of the beam centroid at a profile monitor downstream of the triplet, as a function of triplet setting, it was concluded that the mirror acts as an ideal mirror plus defocusing lenses at entrance and exit. The fitted focal lengths were on the order of 50 cm.

The electric potential inside the mirror was calculated numerically with RELAX3D, and particles were tracked through. These calculations confirmed the experimental findings.

GUIs

A graphical user interface (GUI) has been developed for beam envelope calculation. It has the capability of calculating beam envelopes for any section of beam line, and also to fit settings to a given set of constraints and free parameters. The purpose of this is to allow operators to calculate beam envelopes on the fly as they are changing beam line tunes. It is foreseen as a tool to aid in tuning all the ISAC beam lines, as well as ISIS and the cyclotron extracted beam lines.

ISAC DIAGNOSTICS

The accelerating components of the ISAC-II cryomodules must remain aligned at liquid helium temperatures: cavities to ± 400 μm and solenoids to ± 200 μm after a vertical contraction of $\sim$4 mm. A wire position monitor (WPM) system based on a TESLA design is being built and will be used to test a prototype cryomodule. The system is based on the measurement of signals induced in pickups by a 215 MHz signal carried by a wire through the WPMs. The wire is stretched between the warm tank walls parallel to the beam axis providing a position reference. The sensors, one per cavity and two per solenoid, are attached to the cold elements to monitor their motion during pre-alignment, pumping and cool down. A WPM consists of four 50 Ω striplines spaced 90° apart. A GaAs rf multiplexer scans the WPM signals and a Bergoz Instrumentation card converts them to dc X and Y voltages. National Instruments ADC and I/O cards read the dc signals and control the multiplexer. The data acquisition is based on a PC running LabVIEW. The system was developed in collaboration with LASA INFN Laboratory and the software was written at the SIDeA Corporation, both of Milan. The system will be used for initial alignment only and will be moved from one cryomodule to the next as they are built.

The amplitudes of the stripline signals vary nonlinearly with their position w.r.t. the wire. A test stand was constructed to calibrate the WPMs (see Fig. 267). A 0.5 mm diameter copper-bronze wire tensioned by a 10 lb weight passes through the WPM under test. A pair of Oriel translator stages, each with 1 in. of travel, forms an XY table to move the WPM about the wire. Optical encoders inside the dc servo motors provide 0.1 μm resolution. Figure 268 shows a plot of the electrical X and Y signals from the Bergoz unit as a WPM is moved in a raster scan under computer control. A scan of 3600 points using 0.2 mm steps covers a range of ± 6 mm and requires about 2 hours to perform. A 2D third order polynomial curve fit is used to reduce the data to a set of calibration coefficients. Though the range beyond ± 4.5 mm is still useable, signal compression occurs and these points were not included in the curve fits. A fitting error of less than 20 μm was achieved over most of the ± 4.5 mm range (see Fig. 269).

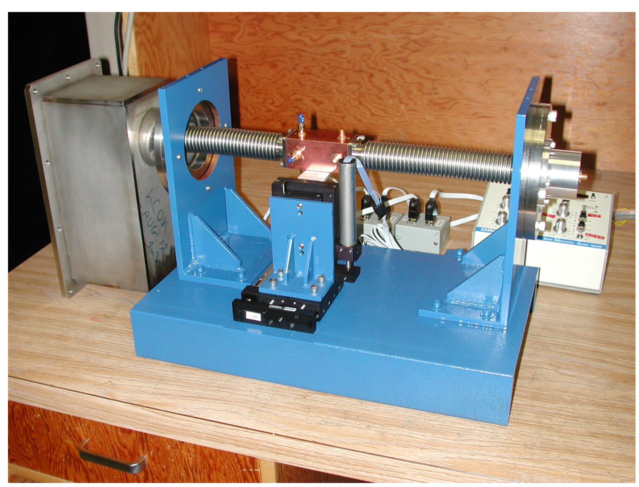

Fig. 267. The WPM calibration stand with the weight box on the left and the Oriel electronic interface behind. The stretched wire passes through bellows which form the outer conductor of the rf coaxial structure.

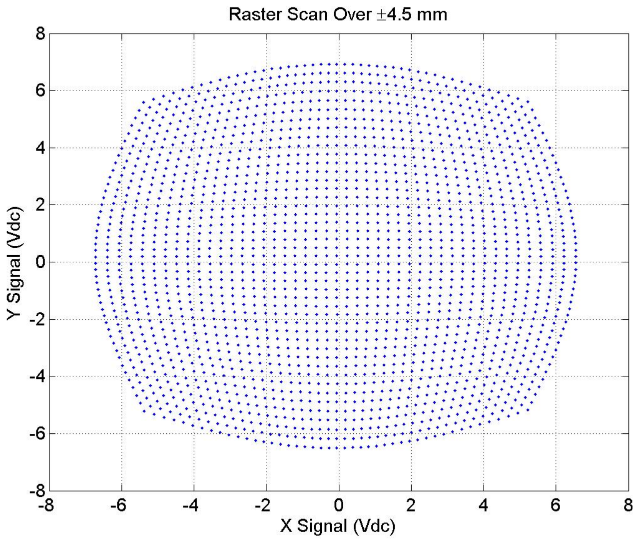

Fig. 268. Non-linearity away from centre is apparent in this plot of the electrical signal amplitudes collected during a raster scan of a WPM over ±4.5 mm.

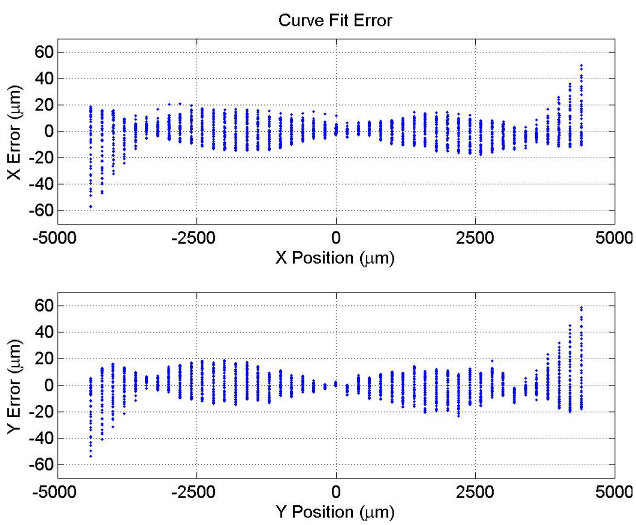

Fig. 269. The curve fit error is less than 20 μm over most of the ±4.5 mm range.

EXPERIMENTAL SUPPORT

The Experimental Support group provided technical assistance to experimenters and was responsible in part for the installation, alignment and maintenance of beam line elements. The Beam Lines group now has a permanent technical area complete with machine shop and welding room in the ISAC-II experimental hall. This allows better access for experimenters in search of technical assistance. For ISAC-I and ISAC-II, the Beam Lines group has provided technical support for the 8π detector as well as development for GPS, TITAN and TIGRESS. The group provided the layout of the S-bend and helped plan the future installation of the transfer beam line scheduled for 2004. The Alignment group continued to provide precision alignment for DRAGON, TUDA, Remote Handling and the RF group.

ISAC-I CONVENTIONAL FACILITIES AND INFRASTRUCTURE

This was an uneventful year on the operation and maintenance front without major breakdowns to report. Continuing engineering support was lent to the laboratory users. This included attendance at regular and engineering meetings, participation in engineering design review, cost estimating, services design, specification, procurement and installation coordination, as well attending to operational problems and maintenance.

Mechanical Services

Program debugging and re-commissioning of the radiation exhaust pressure zoning required additional effort during the implementation of the distributed digital controls.

A new heating coil and a new water pressure relief valve were added to the TRINAT air conditioning system heating coil. ISAC-I experimental hall services work included replacement of polyflo tubing for the RFQ, new valving for DTL, GP2 vacuum pump and glass tube venting to the radiation exhaust system, and cooling for DRAGON power supplies and the new laser room. Roof top air exhaust units were fitted with insect screens. Design Office HVAC work included a new pressure relief system and a balance damper for one of the diffusers. Target hall work included relocation of the target zone depression sensor to the middle leg of the extraction system to obtain a more equal depression between east and west targets, and consultation regarding the crane hook rotation system. Sprinkler heads were relocated in the south hot cell service area to accommodate the new manipulator removal system.

Electrical Services

Power distribution centre MCC-X was finally replaced during the winter shutdown.

A new power factor correction capacitor bank was added to MCC-T. The power factor in the unit jumped from 82% to about 98% under the present load. Engineering efforts focused on experimental facilities services (TITAN and GP2). The HV electrical interlocks for the CSB and TITAN were reviewed and are ready to be installed.

Upon review of the load requirements in light of the planned beam line and experimental additions to ISAC-I and the loading of the power distribution centre MCC-T, it was concluded that the most economical approach would be to relocate the RFQ amplifier feeder to MCC-U. After the capacitor bank was brought into service, MCC-T was running at 65% demand capacity (650 kVA), leaving only 350 kVA for future load growth. The planned installation of TITAN (about 150 kVA demand) and CSB (about 350 kVA demand) exceeds the remaining capacity.

About 20 installation orders were processed for ISAC-I. Among them were services to GP2 and the TITAN test stand. Services and lighting were re-arranged in the south target hall support area to make room for the new hot cell manipulators.

Conduit runs were completed for the electrical room radiation safety lock-up system and the future link of the ISAC-I safety system to the control room which will be relocated in ISAC-II.

ISAC PLANNING

This year the Planning group was involved in planning, scheduling, coordinating and expediting several sub-projects for ISAC-I (ECR source and upgrades to 8π and β-NMR); ISAC-II (medium-beta cavities, wire position monitor, cryogenics system, high-beta cavities, charge state booster (CSB), HEBT transfer, H-HEBT); ISAC experimental facilities (TIGRESS, TITAN); two step target, and actinide target test.

The Planning group was also extensively involved in preparing manpower and cash flow estimates for various ISAC projects included in the Five-Year Plan (2005–2010).

Technical details and progress on PERTed activities are described elsewhere in this report under the respective principal group. However, following is a summary of the main projects along with the major milestones achieved.

Various plans and PERTs were prepared and updated regularly with manpower estimates and analysis to identify critical areas and resolve any problems. ISAC priorities were evaluated and higher priority was assigned where necessary to optimize the scientific output.

ISAC-I

ECR source

ECR design improvements were made after tests with stable beam from the ECR-1 installed on TM 3 in late 2002. Two exit modules were damaged due to high current and absence of proper skimmers. Then skimmers with current limits and cooled collimators were installed, insulators were changed, and the aperture was reduced from 5 mm to 3 mm. Tests were done first on the test stand, followed by tests with stable beam and then with RIB in April, but still the efficiency and amount of RIB delivered was less than expected. After analyzing the test results, the design was modified and ECR-2 was fabricated and tested extensively on the test stand. The plan is to install and test the ECR-1 with modifications (mainly central piece with boron nitrate), first without the target and then with a target, in February and April, 2004 respectively, for further investigations and to optimize ECR performance.

Experimental facilities

Several modifications and upgrades were made to 8π and β-NMR during 2003.

ISAC-II

Medium-beta cavities

The major milestones achieved included: cavities #1–9 were fabricated, inspected, chemically treated and received at TRIUMF. Cavities #10–20 were fabricated and received at TRIUMF and are expected to be chemically treated by May, 2004. Tuners, coupling loops and amplifiers for the first two cryomodules have been received, with the remaining components expected to arrive early in 2004. The first cryomodule tank was received in July; all the internal components were fabricated and assembled in the tank by early December. A cold alignment was achieved with the wire position monitor before year-end. Cold tests and rf tests on cryomodule 1 were delayed due to manpower problems and technical challenges and are now planned for completion by April, 2004. The tanks for cryomodules 2–5 could not be ordered due to lack of funds and will therefore be ordered and received in 2004, with the last one to be at TRIUMF by October, 2004. Cold tests and rf tests on cryomodules 2 and 3 will require extensive expediting of components and appropriate manpower allocations to meet the scheduled completion dates of July and October, 2004 respectively. The plan is to install the last cryomodule, #5, and be ready for tests by fall, 2005.

Cryogenics system

It took much longer to prepare the specifications for the cryogenic system including the distribution system. After receiving the bids in October, it was decided that the distribution system would be designed, procured and installed by TRIUMF with help from outside contractors, to meet budget constraints. A detailed Work Breakdown Structure (WBS) and PERT was developed for this project. The contract for the cold box, compressor/ORS and He ambient vapourizer was awarded in November to Linde. These components will be arriving at TRIUMF in July and September, 2004. The buffer tank will be ready to be ordered by March, 2004 and ready to install on its pad by September, 2004. The plan is to complete the process and instrumentation drawings (PID) in January, 2004, with an aim to do a design review in February and specify all components, explore potential vendors and award contracts by May, 2004. Installation of the refrigeration and distribution systems should be done in early 2005 and the overall system commissioning by May, 2005.

High-beta cavities

Preliminary physics specifications for the high-beta systems were done with an aim to complete the conceptual design by July, 2004 and order Nb for all high beta cavities in April, 2004.

Charge state booster (CSB)

The CSB system, matching sections and analyzing magnet were installed. ECR mode and breeding mode were commissioned by the end of November. Tests with the rf cooler will take place in summer, 2004, and optimization will continue until the end of the year, when the CSB will be ready to move to its final location.

HEBT transfer

The 4 dipoles were designed and ordered in November and are expected to be received in July, 2004. All 20 quads were received and field mapped by July. Eight steering magnets were assembled and field mapped by December, and will be ready to install by March, 2004. The rebuncher was received at TRIUMF in March, and assembly of the components on to the rebuncher continued with an aim to be ready to install in the DSC line by July, 2004. The rebuncher was fabricated and assembled with an aim to do signal and power level tests in May, 2004.

H-HEBT

Due to manpower constraints, physics specifications and design of the H-HEBT were delayed and are planned to start in March, 2004.

Experimental Facilities

Detailed plans were developed for two major experimental facilities – TITAN and TIGRESS. Work breakdown structures (WBS) and detailed plans and schedules were developed for both projects along with some manpower analysis and planning. Following are some major highlights of these projects.

TITAN

The overall planning and scheduling of TITAN included the following major components:

RFQ cooler High voltage platform, RFQ, beam line support, RFQ cooler tests and related controls, and power supplies. High voltage platform design was reviewed in May, and fabricated in November with a plan to install by March, 2004. Fabrication of RFQ components was delayed to December due to the heavy workload in the Machine Shop. The plan is to assemble the components and test in proton hall extension in May, 2004, with an aim to test on the test stand by August, 2004.

EBIT EBIT modifications and ion optics that were designed at Heidelberg with a plan to finish fabrication and assembly by April, 2004. The TRAP was designed at TRIUMF in December to finish fabrication and assembly by April, 2004. A prototype electron gun was tested. EBIT superconducting magnet was ordered in June, with an expected delivery at MPI in May, 2004. The plan is to assemble the EBIT system by July, 2004 and test by the end of 2004 in Germany. A prototype Wien filter was received at McGill and the plan is to test by June, 2004.

Penning trap No progress as the postdoc who will do the simulations required to specify trap parameters will be joining the TITAN group in March, 2004.

Platform and services Initial concept for platform started towards the end of 2003 with an aim to design by May, 2004, fabrication by August, 2004, and installation in January, 2005 shutdown.

TIGRESS

The overall planning and scheduling of the TIGRESS project included the following major components with their main milestones:

Prototype substructure The plan is to make it initially for one detector and later for 4 or more detectors after tests. The stand and substructure was designed and reviewed by the end of the year with a plan to fabricate and assemble by April, 2004. The Ge detector was sent to the manufacturer for repairs. The electronic and readout system was designed with some help from collaborators, with a plan to test the prototype substructure by June, 2004.

4 detectors system The specifications were reviewed and negotiations for procuring 4 Ge detectors and BGeO's started to meet cashflow constraints.

Other components The conceptual specifications for target chamber, beam dump, beam line components with diagnostics, controls and services started with an aim to finish the overall assembly and prepare for beam by October, 2005.

CONTRACT ADMINISTRATION

In the past year three contracts were awarded: Linde Kryotechnik A.G. of Switzerland will supply one refrigeration system for the first phase of the ISAC-II linac. Sunrise Engineering Ltd. of Delta, B.C. manufactured 4 steel sub-assemblies and assembled all four HEBT S-bend dipole magnets for ISAC-II, with Alpha Magnetics Inc. of California supplying the eight excitation coils. Amplifier Systems Inc. of California will supply twenty rf amplifiers for the ISAC-II medium beta superconducting cavities.

Personnel Resources

ISAC-I

In 2003 the average monthly personnel effort for ISAC-I decreased by approximately 7.5 people per month to an average of 43.28 FTE people per month (see Fig. 270). In 2002 the FTE effort per month was 50.76 people.

The total work effort expended on ISAC-I from the start of the project on January 1, 1996 to December 31, 2003 has been 516.81 years, based on a FTE work-month of 150 hours per person.

Figure 271 shows the FTE persons per month for the various sections of ISAC-I in 2003.

ISAC-II

The recording of work effort for ISAC-II started October 1, 2000 (see Fig. 272). The work effort was recorded as "Project Management and Administration" up until March 31, 2002. Commencing April 1, 2002 the work effort was monitored by section. In 2003 the average monthly personnel effort for ISAC-II increased by approximately 6.5 people per month to an average of 19.5 FTE people per month (see Fig. 272). In 2002 the FTE effort per month was 13 people.

Figure 273 shows the FTE persons per month for the various sections of ISAC-II in 2003.

The total work effort expended on ISAC-II from the start of the project on October 1, 2000 to December 31, 2003 has been 35.79 years, based on a FTE work-month of 150 hours per person.

Figure 274 shows the FTE years of work effort for each section of ISAC-II since the project began.

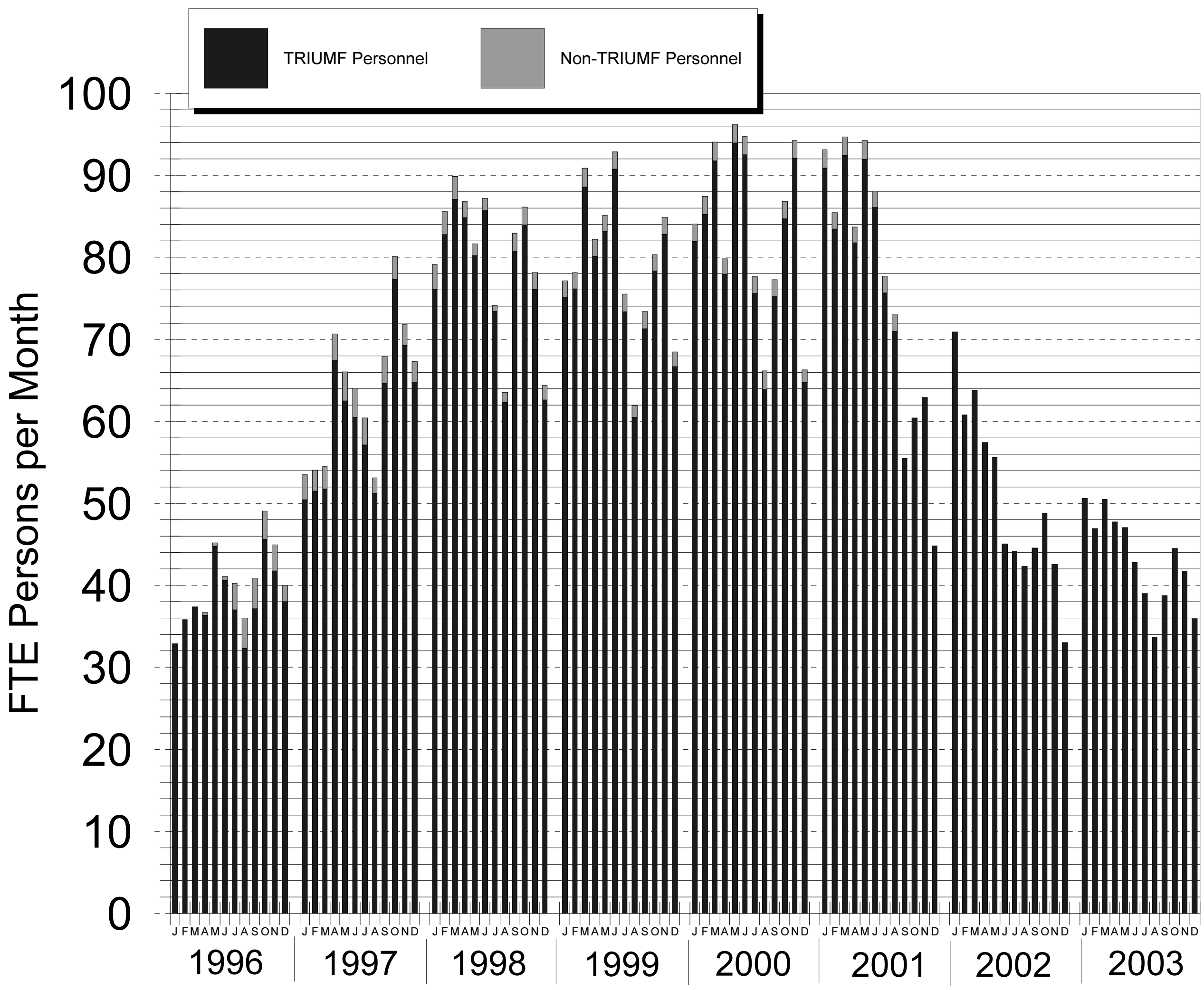

Fig. 270. ISAC-I monthly personnel effort, January 1, 1996 to December 31, 2003.

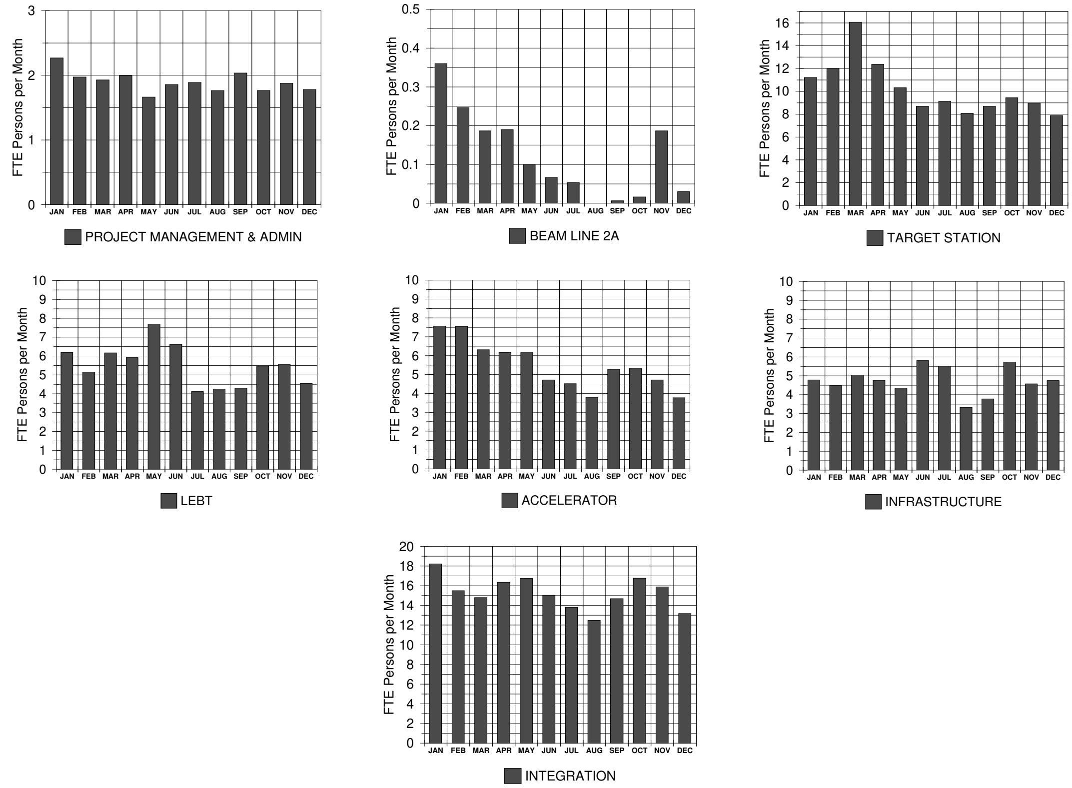

Fig. 271. ISAC-I monthly personnel effort, shown by section for 2003.

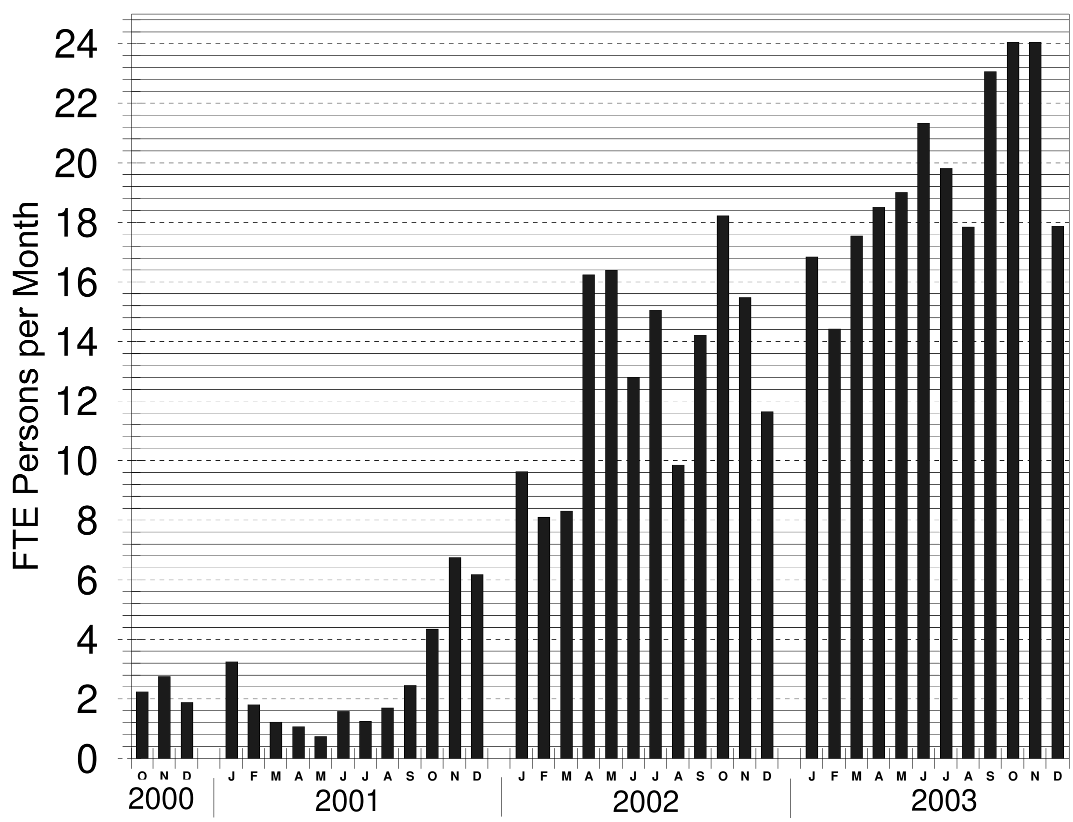

Fig. 272. ISAC-II monthly personnel effort, October 1, 2000 to December 31, 2003.

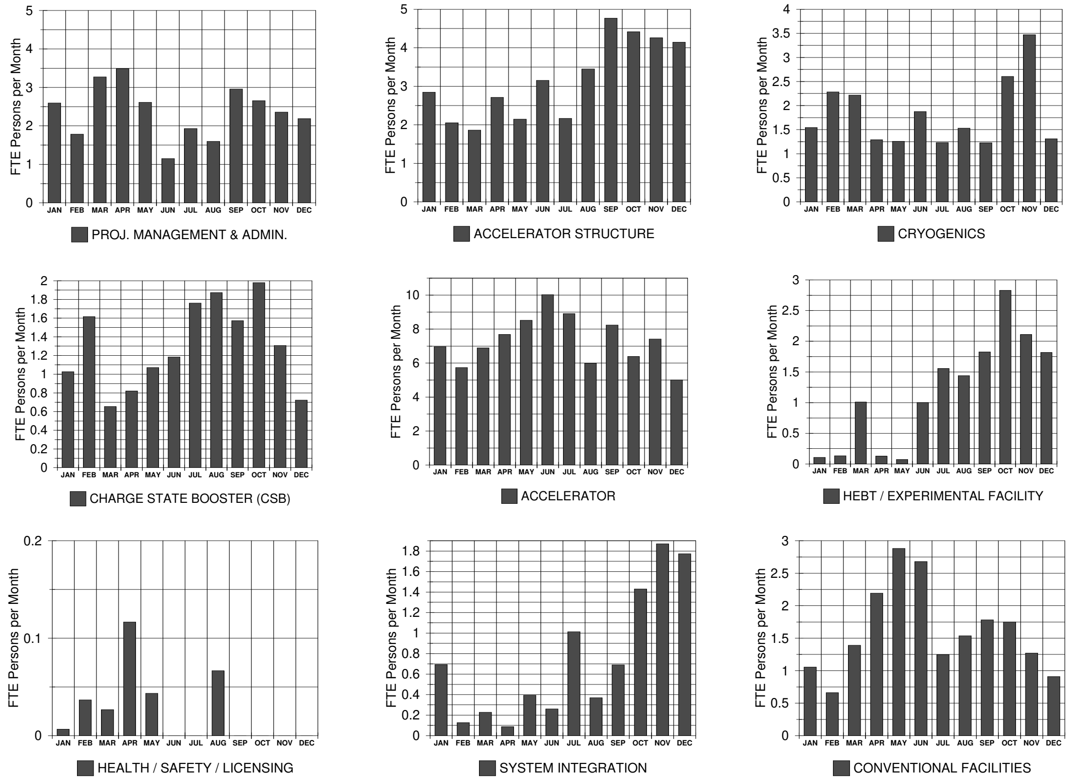

Fig. 273. ISAC-II monthly personnel effort, shown by section for 2003.

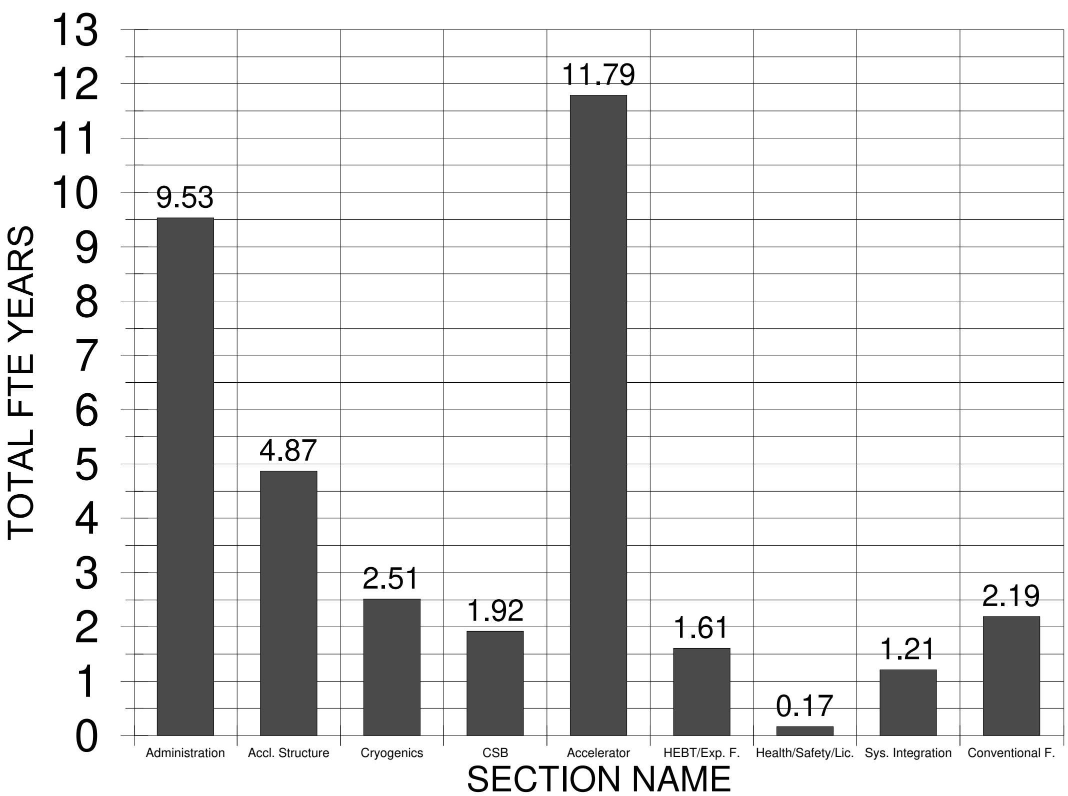

Fig. 274. ISAC-II total personnel effort, October 1, 2000 to December 31, 2003 shown by section.

ISAC-II CONVENTIONAL FACILITIES AND INFRASTRUCTURE

The highlight of the year was the delivery, under the direction of UMA Management Services Ltd., of the ISAC-II buildings (March, 2003) that culminated with the official opening on June 11, 2003 by the Hon. Gordon Campbell, Premier of British Columbia.

Upon completion of data and voice services by TRIUMF staff in April, a large number of technical and experimental staff relocated and took residence in ISAC-II. Formal building occupancy was granted on June 4, 2003 upon satisfactory submission of the Fire Safety plan also prepared by staff.

Architecturally, ISAC-II marks a departure from the traditional box structure of older TRIUMF buildings. The new facility's landscaping and pleasant modern features make it a vibrant place to work in (see Fig. 275). The buildings were completed on a tight budget and even tighter schedule. ISAC-II features a long Z-shaped, thick-walled vault, interconnected to ISAC-I, to house the future accelerator structures and connecting beam lines, an experimental hall surrounded by support shops and assembly areas, and locales for auxiliary systems and services. It also provides offices for approximately 95 technical support and experimental staff, a working clean room for the SCRF cavity research program first and for their maintenance later, and other laboratory spaces in support of the rf development program and experimental activities.

With the continuing support of UMA and PBK/Cochrane Engineering, the greatest single effort was the commissioning of the building systems and to address and rectify a number of construction deficiencies. The implementation of the DDC building controls required more effort than initially anticipated due to early device failures and program debugging. Work continues to optimize ambient temperature in various locales.

Parallel activities included:

- The installation of services (power, racks gas and vacuum vent lines, rinse water installation, and clean room air balancing) and commissioning of infrastructures to meet the stringent requirements of the SCRF clean room. The rented lab at BC Research was dismantled.
- Services for laboratory space in support of the accelerator and experimental program.
- The completion of infrastructures for the data network, video conferencing and on-line meeting room booking ("the wizard").
- A start to the rf test stand area in the experimental hall.
- Design and delivery of electrical and mechanical services from the CSB test area.

Fig. 275. A view of the ISAC-II building taken from the west side of the parking lot.

Other engineering work included participation in the preparation of the helium refrigeration work package, rf coupling loop thermal calculations, and revision of the oxygen detection system. The original design intent (nitrogen hazard detection) of the O_2 detection system was expanded to also cover the helium hazard. We plan to install the revised design in 2004. The S-bend services and logistics support went through design review and, once approved, working drawings were prepared.

Three new power factor correction capacitor banks (for a total of 1,125 kvar) were brought into service in April. Their function is to limit the kVA power demand increase by reducing the reactive power supplied by B.C. Hydro. As the kVA demand is paid in hard currency, the benefit of this installation will be even more noticeable when the B.C. Hydro rate increase (+7.23%) goes into effect in April, 2004.

ISAC-II S-BEND HEBT

The ISAC-II superconducting accelerator complex comprises a low beta, a medium beta and a high beta section. The energy range is between 400 A keV to 6.5 A MeV for mass $A = 150$. Due to budget and manpower constraints the construction will be done in three phases. The first phase will take the beam from the ISAC-I accelerator complex which has an output energy of 1.5 A MeV for $A = 30$. The beam will then be injected into the medium beta section. The beam will be accelerated to 4.3 A MeV and delivered to the ISAC-II experimental hall for experiments starting in December, 2005.

The second phase consists of the addition of the high beta section with an output energy of 6.5 A MeV. A third phase is necessary which will take $A/q < 30$ beam from the RFQ at 150 A keV. A room temperature or superconducting linac will accelerate the beam to 400 A keV and then a stripper foil will boost the charge state to $A/q < 7$. The beam will then be injected into the medium beta section to be accelerated to the final energy.

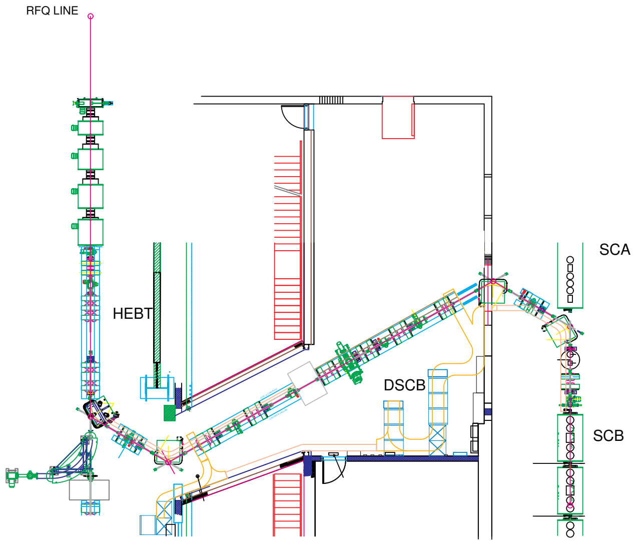

Fig. 276. Layout of the transfer beam line from the ISAC-I IH-structure linac to the ISAC-II superconducting linac.

Figure 276 shows the layout of the new transfer beam line.

We received all the necessary quadrupoles and the four dipole specifications were submitted for bid and the contract was awarded to Sunrise Engineering for the steel manufacturing and to Alpha-Magnetic for the coil fabrication. The coils will be completed in April, 2004 and the first magnet will arrive at TRIUMF in June, 2004.

ISAC-II ACCELERATOR DEVELOPMENT

Due to experimental pressure and budget limitations the installation of the linac has been grouped into three stages highlighted in Fig. 277. The initial Stage 0 to be completed in 2005 includes the installation of a transfer line from the ISAC DTL ($E = 1.5$ MeV/u) and the medium beta section to produce 18 MV of accelerating voltage for initial experiments. Stage 1, to be completed two years later, includes the installation of the three high beta modules for a further 18 MV. The ISAC-II accelerator final Stage 2 is foreseen for 2010. A new building complete with linac vault, experimental areas, office and laboratory is now complete. Present

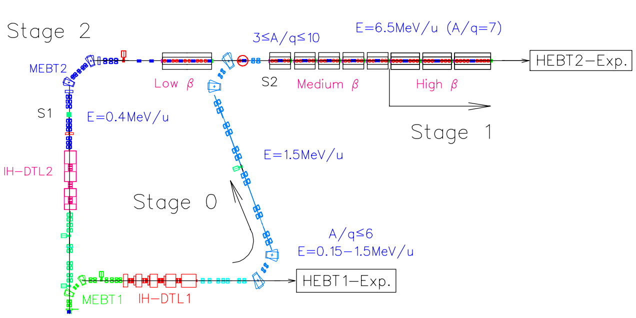

Fig. 277. Stages 0, 1 and 2 for the ISAC-II upgrade.

studies are concentrating on design and development for the first stage installation.

Hardware and Development

Work is ongoing on several fronts with the goal of realizing beam delivery in 2005. The first major milestone is the cold test of a completed medium beta cryomodule in spring, 2004. An SCRF lab, set up in a neighbouring facility, was used for development where cold tests were completed at the rate of one per month. The lab was closed in September and moved to the new ISAC-II SCRF lab. The new lab is an expanded space with clean assembly and rinse areas, a large high bay rf test pit area, a measurement console area and a preparation area. The lab was ready for cold tests to resume by year end. A summary of the year's developments is given below.

RF Systems Ancillaries

In previous linac installations the tuning of quarter wave cavities has been accomplished with mechanical or pneumatic tuners characterized by slow response, poor resolution and/or large backlash. Detuning by microphonic noise or rapid fluctuations in helium delivery pressure is accommodated by either overcoupling to reduce the loaded Q or with a variable reactive load using a PIN diode network at the cavity. A slow tuner response affects the required Q-loading and may limit the accelerating gradient due to constraints on the stored energy.

The ISAC-II medium beta cavities have a design gradient of 6 MV/m. This corresponds to a peak surface field of $\sim$30 MV/m and a stored energy of U = 3.2 J and is a significant increase over other operating heavy ion facilities. To achieve stable phase and amplitude control, the natural bandwidth of $\pm$0.1 Hz is broadened by overcoupling to accommodate detuning by microphonic noise and helium pressure fluctuation (1 Hz/torr). A rough rule is to use a loaded bandwidth of six times the microphonic noise plus twice the resolution of the mechanical tuner. The ISAC-II medium beta cavities are outfitted with a passive mechanical damper and the microphonics are not expected to be more than a few Hz RMS. The chosen tuning bandwidth of $\pm$20 Hz demands a cw forward power of 200 W and peak power capability of 400 W to be delivered to the coupling loop at the cavity.

Two complementary developments are ongoing at TRIUMF to achieve the design goal. In the first a new rf coupling loop is being developed with the goal to operate at 200 W forward power with less than 1 W of power being added to the helium load. Secondly TRIUMF is developing a mechanical tuner capable of both coarse (kHz) and fine (Hz) frequency adjustments of the cavity. The goal for the ISAC-II cavity tuner is to achieve fine (1 Hz) tuning capability with a response time to control fast helium pressure fluctuations allowing stable operation within a bandwidth of $\Delta f = \pm 20$ Hz.

Cavities

A prototype of the $\beta_o = 7.1\%$ cavity, designed in a collaboration with INFN-LNL, was routinely used for early SCRF development tests. The niobium subassemblies of the twenty cavities of the medium beta section, composed of eight $\beta_o = 5.7\%$ and twelve $\beta_o = 7.1\%$ cavities, are now delivered from industry. An initial delivery of four cavities was chemically polished at CERN and cold tested at TRIUMF. Three of these cavities meet specification but the fourth suffers from a poor Q. This fourth resonator does have a small dark spot on the rf surface at the root end that developed after chemical polishing. The plan is to recover this cavity with a combination of local hand polishing and further chemical treatment. To keep the schedule, the fourth cavity in the first cryomodule will be taken by the prototype cavity. A summary of cold tests for the cavities of the first cryomodule, consisting of three production cavities and the prototype is shown in Fig. 278. All cavities meet the ISAC-II gradient specifications (6 MV/m in 7 W) but the field emission at higher gradients evident in several of the cavities should be reduced through high pressure rinsing and rf conditioning. The remainder of the medium beta cavities will be chemically polished at Jefferson Lab prior to testing at TRIUMF.

RF Controls

The rf control system for the superconducting cavities is a hybrid analogue/digital system. Each system consists of a self-excited feedback loop with phase-locked loops for phase and frequency stabilization. Amplitude and phase regulations, as well as tuning control, are performed using digital signal processors. Special pulsing circuitry is incorporated into the system to facilitate "punching" through multipactoring. We have demonstrated fixed amplitude and phase regulation at the design gradient with the phase error used to drive the mechanical tuner to maintain cavity frequency.

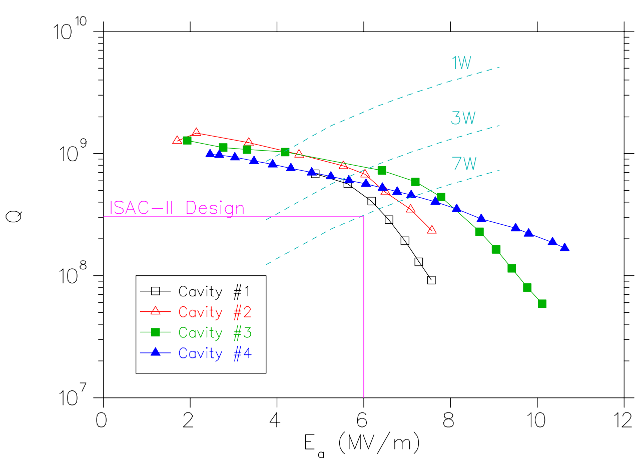

Fig. 278. Cold test results for the cavities of the first medium beta cryomodule.

Mechanical Tuner

Tuning plate The tuning plate (see Fig. 279) consists of 1 mm thick RRR niobium sheet of 240 mm diameter fixed to the bottom niobium flange by bolts and retaining flange. A flat plate can be used but the deflection force required is parabolic with distance and tends to assume a concave shape upon cooling leading to highly non-linear behaviour. To overcome these problems the ISAC-II tuning plate is spun with a single "oil-can" convolution and milled with eight radial 1 mm slots. The plate is capable of allowing ±20 kHz (±3 mm) of tuning range before yielding. Further, if required, the plate can be plastically deformed while cold by the mechanical tuner, removing the necessity of complicated tuning procedures on the finished cavity. Cold tests with the plate give Q and gradient values consistent with the flat plate performance (see Fig. 280).

Fig. 279. The tuner plate, lever arm, bottom of push-rod and cavity viewed from below.

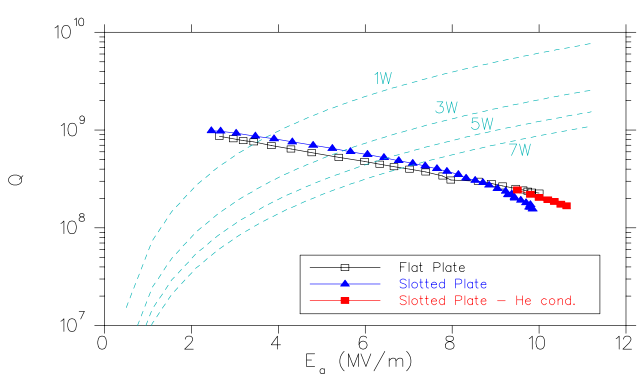

Fig. 280. RF cold test results comparing cavity performance with a flat tuner plate and the new slotted plate.

Mechanical tuner The tuning plate is actuated by a vertically mounted permanent magnet linear servo motor, at the top of the cryostat, using a "zero backlash" lever and push rod configuration through a bellows feed-through. The system resolution at the tuner plate centre is ~0.055 μm (0.3 Hz). The demonstrated dynamic and coarse range of the tuner are ±4 kHz and 33 kHz respectively. The tuner on-line performance is measured by altering the cavity frequency by forced variations of the helium pressure. Figure 281 gives the pressure change, the associated position drive signal for the tuner and the voltage and phase error at the design gradient. The tuner responds accurately to the pressure variation with a resolution better than 0.1 μm (0.6 Hz). The demonstrated response bandwidth is presently limited to 20 Hz by a mechanical resonance.

Coupling Loop

Original cold tests with a prototype quarter wave cavity were done with an adjustable coupling loop copied from an INFN-Legnaro design that we identify as Mark I. The loop consists of a brass outer housing, a copper plated stainless steel outer conductor and copper inner conductor. The outer conductor is driven in/out through a rotating mechanical shaft attached to a stepper motor on the cryostat lid via a rack and pinion mechanism on the loop housing. The original in-vacuum rf drive line consisted of a 1 m length of flexible coaxial cable with a 30 cm rigid section of copper coated stainless steel for thermal isolation. The loop was designed to operate at gradients of 3–4 MV/m with a forward power of about 50 W. Early cold tests at higher power showed significant heating of both the drive system and the loop assembly with several W of power being deposited in the helium. Cold tests are done by first measuring the static heat loss based on the helium boil-off rate after full thermalization. The cavity is then powered until thermal equilibrium is reached and the new static heat load is measured. The temperature of the loop is monitored by several sensors during power on and power off cycles.

The loop prototypes maintain the Legnaro dimensions and loop adjustment system but the loop materials are altered and LN_2 cooling is added. In Mark II the housing is changed to thin walled stainless steel for better thermal isolation and the outer conductor is copper. A copper heat exchange block is fastened to the outer conductor. Copper braid thermally links both the block and current maximum points on the cable to an LN_2 cooled copper pipe (Fig. 282). The stainless steel rigid line section is removed and replaced by one continuous flexible cable.

With an initial forward power at the loop of 140 W in fixed gradient mode the temperature of the inner conductor becomes sufficiently high to change the coupling and the forward power grows to 200 W during thermalization. The loop heating causes 4.5 W extra static boil-off. A reduction in heating to 2.5 W is obtained by adding heat shields tied to the LN_2 pipe around the rf cable.

The Mark III loop is identical to Mark II but two 1 cm long pieces of aluminum nitride (AlN) dielectric are added to thermally connect the inner and outer conductor of the loop near the heat exchange block to reduce inner conductor heating. In this case the loop heating adds only 1.5 W to the static heat load and

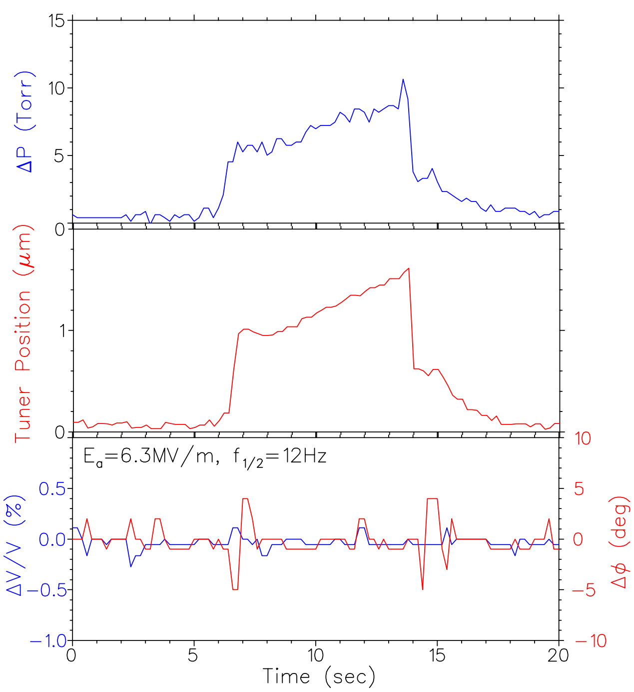

Fig. 281. Tuner response to forced helium pressure flucuation ($\frac{\Delta f}{\Delta P}$ = 1 Hz/torr) and corresponding voltage (blue) and phase (red) errors for high field (E_a = 6.3 MV/m) and a bandwidth of ±12 Hz.

Fig. 282. The Mark II loop prior to cold test.

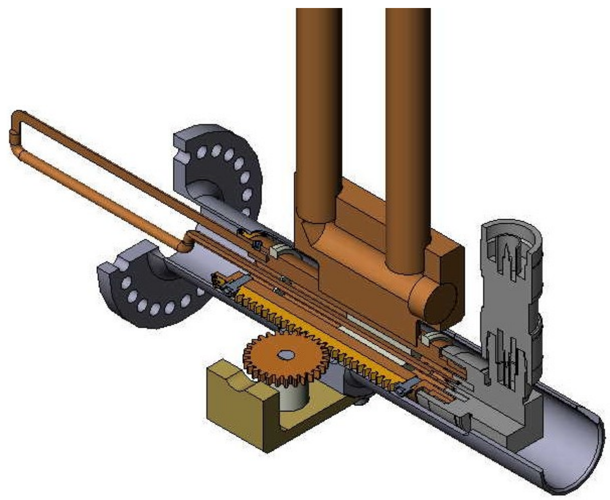

Fig. 283. A cut-away rendering of the Mark IV coupling loop.

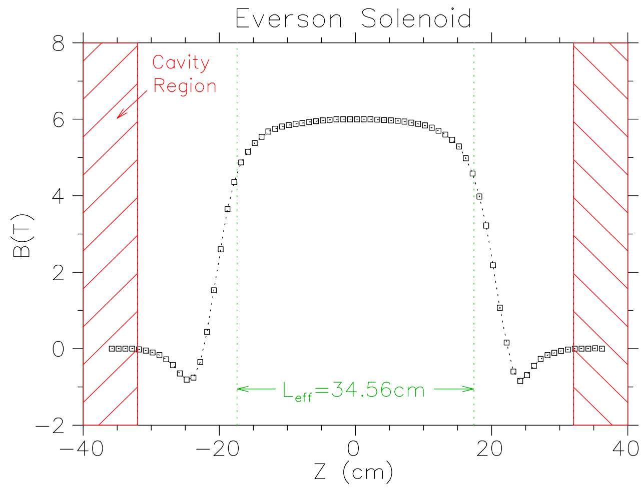

Fig. 284. Mapped axial field for the first superconducting solenoid.

the coupling and forward power remain constant at 200 W throughout the test. In addition the improvement in the thermal path reduces the thermalization time from 6 hours to 2 hours.

In the Mark IV prototype (Fig. 283) the outer conductor and heat exchange block form a solid piece. A cooling channel running through the block allows direct cooling with LN_2.

Solenoids

Focusing in the SC linac is provided by 9 T 26 mm diameter bore SC solenoids of lengths 16, 34 and 45 cm corresponding to the low, medium and high beta cryomodules respectively. The solenoids are equiped with bucking coils to actively limit the fringe field in adjacent cavities to less than 0.1 T to prevent reduction in cavity performance. The magnets are mounted in a liquid helium vessel fed from the common helium header. An order for five medium beta and two high beta solenoids placed in industry has been delayed as the company has gone into receivership. The prototype magnet was obtained from the company and was completed and tested at TRIUMF. The magnet reached the design field of 9 T without a quench (Fig. 284). A contract for the remaining seven magnets has been let to Accel in Germany.

Alignment

The cavities must be aligned to within 0.4 mm and the solenoid to 0.2 mm. TRIUMF is developing a stretched wire alignment system based on the TESLA design. Wire position monitors (WPM), each consisting of four striplines, are attached to the cavities and solenoid by off-centre alignment jigs. A wire running parallel to the beam axis and through the monitors carries an rf signal at 215 MHz. A Bergoz BPM card converts the rf signals from one monitor into dc X and Y signals while a multiplexer with GaAs switches scans through the monitors. A National Instruments ADC and I/O card controls the multiplexer and reads the dc signals. The striplines are fabricated and have been calibrated on a test bench.

Progress in ISAC-II Cryogenics

Refrigerator

The refrigerator system will be installed in two equal stages. The first stage includes a 500 W helium refrigerator with associated compressors, oil removal system (ORS), helium buffer tank, helium dewar, room temperature piping, helium distribution transfer lines, and nitrogen distribution network. The phase I cryogenic system supplies 4.5 K helium to five medium beta cryomodules and to two high beta cryomodules. Progress on definition of the cryogenic system continued in 2003. The main goal was to secure a contract for the phase I system. Initially TRIUMF was seeking a turnkey facility with a single source. Two vendors bid on the job but the cost of both were beyond the project budget. In meetings with each vendor the scope of the contract was reduced to the supply of the refrigerator main components with TRIUMF taking responsibility for the installation, the helium buffer tank, the helium dewar, the warm piping and the cold distribution. In November Linde was chosen as the supplier of this reduced contract. Delivery and installation is expected in the latter part of 2004.

The refrigerator-liquefier on order is the Linde TCF50 with liquefaction rate of about 5.2 g/s and refrigeration rate of 530 W at 4.5 K with simultaneous liquefaction rate of 0.71 g/s. The vendor supplied system consists of a cold box/liquefier, a main and recovery compressor, as well as oil removal and gas management system. The main compressor is a Kaeser ESD441SFC direct drive screw compressor of 268 KW producing a compressed helium flow of 79 g/s at 14 bara pressure to be delivered to the cold box/liquefier in the cryogenic room via the warm piping. The main compressor has a variable frequency drive option allowing part load performance during normal operating modes depending on the active load from the accelerator. The second compressor is a recovery compressor allowing the helium gas inventory to be recovered and compressed into the storage tanks. It is a Kaeser BSD62 screw compressor of 37.5 KW producing a compressed helium flow of 12 g/s at 14 bara pressure. The Linde refrigerator local control is designed to self adjust to flow returning from the distribution system. The variable frequency compressor allows the refrigeration power to vary. The refrigeration output will not be continuously variable since each level requires a control initialization. Linde promises to set up three such operating levels with refrigeration power suitable for a) rf off, b) rf on/maximum, peak liquefaction, and c) rf on/intermediate.

Distribution system

The design of the TRIUMF cryogenic system was solidified in 2003. Briefly, the refrigerator cold box delivers LHe to a main supply dewar located in the cryogenics (refrigerator room). The main supply dewar supplies LHe to the main distribution trunk line with a moderate push pressure. The ISAC-II cryomodules (CMs) are fed in parallel from the main distribution line with U-tube transfer lines. Each cryomodule has two associated female bayonet cans, one for the delivery bayonet and one for the cold return bayonet. There is also a main warm return line that takes warmer gas (>20 K) from the CM back to the suction side of the main compressor during cooldown. There is also gas from the solenoid power leads and for cooling of the stack that is valved into the warm return line through throttle valves. Internal to the cryomodules is a manifold system and valve that can force cold helium vapour to the bottom of each cold element during intial cooldown. Control of the helium levels in each cryomodule is monitored by a level probe in each helium reservoir and adjusted by the proportional liquid delivery valve into each cryomodule. The level in the helium main dewar is controlled during normal operation with the heater in the dewar. Each cryomodule reservoir has an immersion heater that can also be used for level control. It may be useful perhaps to use the cryomodule heaters to compensate for variations in rf power in that cryomodule.

The cryomodules contain a LN_2 cooled thermal shield consisting of a 1/2 in. copper tube soldered to a copper box. Liquid nitrogen is supplied to the cryomodules via a parallel distribution scheme from a local nitrogen dewar/phase separator. The dewar is fed LN_2 from an external 9000 USG nitrogen tank via existing nitrogen vacuum isolated piping. A separate LN_2 circuit is used to cool the vacuum jacketed cold distribution system.

During normal operation the linac will be cold and the rf will be on to accelerate the beam. The total expected cryogenic load for phase I is 390 W. This can be broken down into 192 W of static losses and 198 W of active rf loss. The static loss budget is split half and half with 96 W for the cold distribution system and 96 W for the cryomodules. This assumes static losses of 13 W and 14 W for the medium and high beta CMs respectively. The liquefaction loss from the cryomodule power leads is expected to be 0.7 gm/s. There will be times where a cryomodule or cryomodules will have to be cooled down from room temperature. A flow of 6 liquid l/hr of 100% liquid nitrogen will cool down the medium-beta cryomodule LN_2 shield in $\sim$24 hours. The bulk of the cold mass will cool by radiation to $\sim$250 K. Cold tests indicate that a flow of 20 liquid l/hr of helium is a sufficient flow to pre-cool the cavity from 250 K to 4 K in about four hours. The medium beta cryomodules require 100 l/hr and the high beta modules 150 l/hr for efficient cooling. The CMs are cooled one at a time and each filled cryomodule is topped up periodically as the cold mass thermalizes.

ISAC BEAM DYNAMICS

Operating the DTL Above 1.5 MeV/u

The ISAC DTL is designed for a maximum energy of 1.53 MeV/u and for a maximum $A/q = 6$. The DTL essentially operates as a fixed velocity accelerator with voltage and phase detuning in the last operating tank to accelerate to a reduced energy. The full energy range from 0.153–1.53 MeV/u can be spanned by this method. Conversely it is possible to reach a higher final energy than specified by increasing the voltage in the last operating tank and optimizing the phase for maximum acceleration. Assuming that the maximum voltage in a tank occurs for $A/q = 6$ then these higher energies are only possible for $A/q < 6$ values. Since the higher voltage increases the particle velocity above the design value, phase slippage during the tank crossing occurs. Therefore as the relative voltage increases, the incident particles must be pushed to more and more positive phases to achieve maximum acceleration. Some additional energy can be achieved by increasing the relative voltage on the second to last tank to maximize the energy entering the last tank.

Simulation results from LANA are summarized in Fig. 285. The results show that the tanks are short enough that a significant increase in final energy can be achieved by maintaining a fixed voltage near the maximum for the tank and optimizing the phase. The

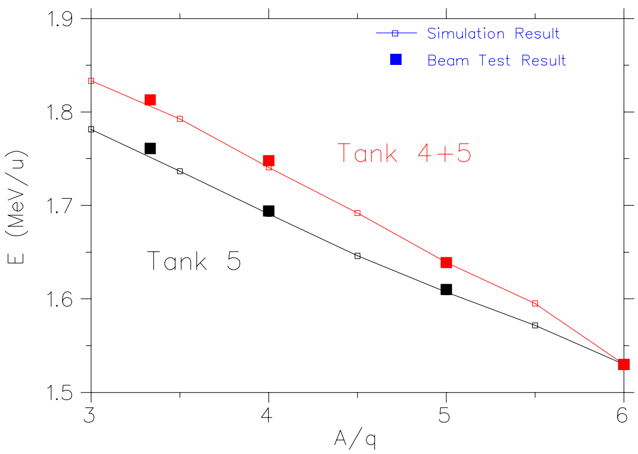

Fig. 285. Maximum energies of ISAC-DTL from simulations and experimental tunings.

gain cannot be duplicated by increasing the voltage in all tanks since the large phase slip caused by accelerating particles with a velocity higher than designed does degrade longitudinal beam quality. Beam test results from August are also reported that confirm the accuracy of the simulations.

ISAC-II HEBT

The beam line for the new ISAC-II experimental hall has been revisited during this year. We took advantage of several workshops with the ISAC-II users community to clarify some of the design goals and to obtain from the users the crucial specifications for the beam on target. This allowed us to propose a simpler and cost effective approach. We propose to use two Y dipoles and 22 quadrupoles that we acquired from Chalk River Laboratory. Figure 286 shows the proposed layout of the new ISAC-II experimental hall.

From discussions with future users it became clear that the multi detector array will be the common type of detection system foreseen at ISAC-II. Some good examples of that are the TIGRESS (16 HPGe detector array), HERACLES, and LEDA. It was clear also that sensitive diagnostics are necessary to tune in a time effective manner the low RIB intensity onto the user's target. We have designed the beam line in order to have a unit transformation from, and intermediate focus to, the final focal point. This allows the installation of a diagnostics box that can be equipped with all the state of the art diagnostics.

The superconducting linac was designed to take advantage of the possibility of accelerating several charge states. The beam line that can accommodate this has to be not only achromatic but also isochronous. The direct beam line and the one going to the recoil spectrometer are designed to accommodate multi-charge state ion beams.

ISAC-II CRYOGENIC SYSTEM

Refrigeration System

A specification was written for the phase 1 refrigeration system as a complete turn-key system. This included everything up to the delivery and transfer of 'U' tubes at the cryomodules. TRIUMF was responsible for all services necessary to support the refrigeration system. The two major suppliers of cryogenic refrigeration systems, Linde and Air-Liquide, responded to the tender package with a quotation. Unfortunately both quotations were beyond what TRIUMF had budgeted. At that time TRIUMF decided to negotiate with

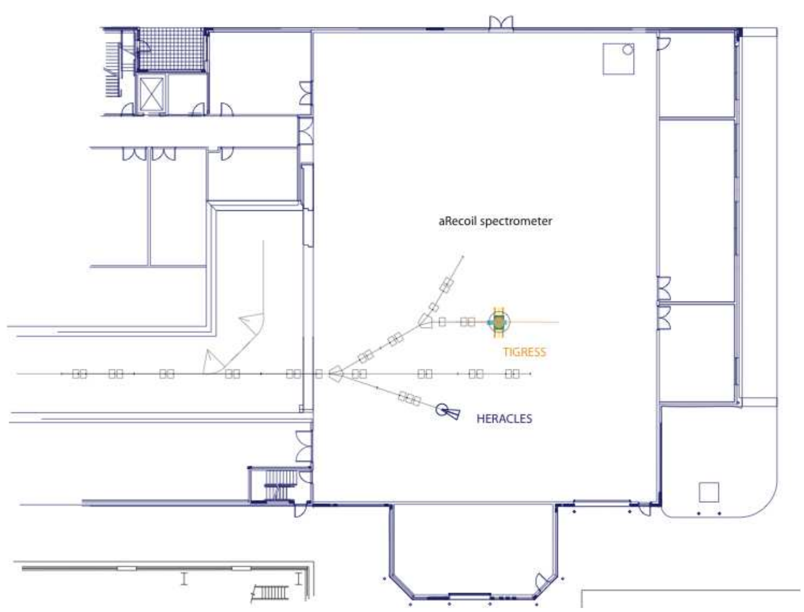

Fig. 286. Proposed layout of the new ISAC-II experimental hall beam lines.

both tenderers, asking for quotations for the supply of the refrigeration system components only, including process and instrumentation diagrams, installation instructions, etc. Quotations were received and a contract was awarded to Linde in November. TRIUMF will be the project manager for the refrigeration system which can be broken down into 3 categories:

1. Refrigeration system component installation including all services, warm piping and buffer storage tank.
2. Accelerator vault access platform and distribution system support structure.
3. Cryogenic distribution system (all vacuum jacketed, liquid nitrogen shielded piling from the liquifier cold box to the cryomodules, including the liquid helium dewar).

The third item is the most complex and specialized (other than the refrigerator itself), and a task force was formed to discuss how TRIUMF would approach the design, purchase and installation of such a system based on the simplest and most cost effective system but also one that has as high a transmission efficiency (low heat load on helium) as possible. To this end a conceptual design was produced, flow schematics were created and a package of information was put together along with a letter requesting interested parties to respond early in 2004. The intent is to have a complete phase 1 refrigeration system operational and commissioned by April, 2005.

Cryomodules

A complete description of the medium-beta cryomodule was presented in the 2002 Annual Report and will not be repeated here. The design was well under way by the beginning of this report period and drawing release began in March. The vacuum tank arrived in May, followed by the lid and the internal components such as the helium reservoir, support beam, struts and solenoid mounting frame.

The μ-metal was ordered for all 5 medium-beta cryomodules, however, it was not flat and was outside of our required tolerance. This required return of the shipment which was reworked to specification. A μ-metal liner was then produced that was installed adjacent to the inside vacuum tank wall. At the same time work commenced on the liquid nitrogen thermal shield box. The box is constructed of 0.125 in. copper sheet with copper tubes soldered in an array on the inside surface of all sides by a special fluxless solder procedure prior to the box being riveted together. There is a separate lid mounted thermal shield piece that overlaps the edges of the box when finally installed.

An assembly frame was constructed to support the lid and allow the installation of all the internal components. The helium reservoir mounts to the stack flange of the lid and all other components are suspended from 3 adjustable mounting lugs on the lid. This allows for cryo element alignment adjustment relative to the vacuum tank. The assembly frame also mimics the vacuum tank beam ports and wire position monitor ports allowing cryo elements to be aligned with respect to each other as well as the theoretical beam line, and this alignment is also transferred to 3 target posts on the lid since the beam ports will not be visible once the cryomodules are installed in the accelerator vault.

Assembly has progressed to the point where the assembly frame and internal components had been through the cleaning cycle, moved into the class 3 clean room and reassembled on the frame allowing the commencement of alignment. The vacuum tank and thermal shield box had been moved to the class 2 clean room awaiting completion of the lid assembly. The goal is to complete a cryomodule cold alignment investigation in March, 2004.