TRIUMF

ANNUAL REPORT
SCIENTIFIC ACTIVITIES
2002

ISSN 1492-417X

CANADA'S NATIONAL LABORATORY
FOR PARTICLE AND NUCLEAR PHYSICS

OPERATED AS A JOINT VENTURE

MEMBERS:	ASSOCIATE MEMBERS:
THE UNIVERSITY OF ALBERTA	THE UNIVERSITY OF MANITOBA
THE UNIVERSITY OF BRITISH COLUMBIA	McMASTER UNIVERSITY
CARLETON UNIVERSITY	L'UNIVERSITÉ DE MONTRÉAL
SIMON FRASER UNIVERSITY	QUEEN'S UNIVERSITY
THE UNIVERSITY OF VICTORIA	THE UNIVERSITY OF REGINA
	THE UNIVERSITY OF TORONTO

UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

DECEMBER 2003

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.

ISAC DIVISION

INTRODUCTION

This full year of ISAC operation has been both rewarding and challenging. Operational experience has highlighted the need for the east target station and increased operating staff. Target and ion source developments are key to a successful ISOL facility. ISOL targets have been developed that accommodate 20 kW of proton beam for extended running periods. Typically the integrated number of protons per target is about 5E+20. Yields of many isotopes continue to increase faster than the proton beam current on target. Target designs capable of handling the full 50 kW are being tested with an electron beam heater off-line. Initial tests were carried out with stable beams from an ECR ion source on the recently completed east target station. It is expected that the ECR source will be commissioned with RIB in 2003. OLIS has become an important part of the accelerated beam science program in ISAC and was modified to accommodate three ion sources to increase the range of stable isotopes. In collaboration with the group from the University of Mainz, a resonant laser ion source has been successfully tested on the modified target conditioning station. The accelerators have been modified to improve reliability during operation. One of the major changes to the TRIUMF site this year has been the civil construction of ISAC-II. The new building, which is now nearing completion, provides a marked change in architecture at TRIUMF. The ECR charge state booster, needed for accelerating heavier masses through ISAC-II, was ordered in January and delivered to TRIUMF in November. The ion source test stand is being extended to commission the charge state booster before it is installed in ISAC. Twenty superconducting, bulk niobium, medium-beta, rf cavities have been ordered for delivery in 2003. A temporary superconducting rf laboratory was set up at the nearby BC Research facilities and a number of initial tests were carried out with a prototype rf cavity in a liquid helium cooled cryostat. A mechanical tuner, coupling loop and rf control system for the cavity are being developed.

ISAC OPERATIONS

This year, operation of the ISAC-I low energy facility continued in parallel with the commissioning and operation of stable beam and RIB to the ISAC-I high-energy area. With the exception of a few weeks of stable beam operation from OLIS to DRAGON in February (beam schedule 100A), the first quarter was devoted to shutdown activities of which the most significant was the installation of the east target station. Beam schedule 101 began in the second quarter and carried on through the summer. Beam schedule 102 followed a short shutdown in September. The RIB delivery is shown in Fig. 195. The MEBT and HEBT beam operation continued to command extensive support from the beam dynamic experts, but by the end of the year after informal on-the-job training, all operators had become quite adept at performing routine mass, charge state and energy changes. But 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 successes of the experiments and major ISAC milestones that have been highlighted elsewhere in this Annual Report.

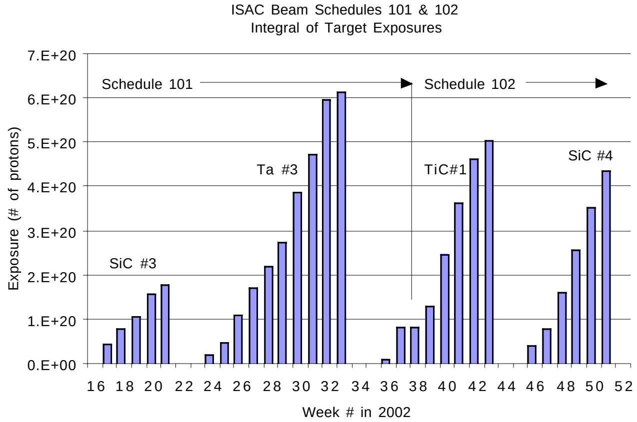


Fig. 195. Integral target exposures by week for RIB delivery in 2002.

Operational performance statistics are provided for the ISAC beam production of RIB from ITW and stable beam from OLIS. These are summarized separately for each beam schedule in Tables XXI to XLII. 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, uncertainty in the schedule for the completion of the east target station and ECR source affected the beam scheduling of a number of experiments. The availability is quoted in comparison to the actual scheduled hours, but 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. This year, a factor has been provided to indicate the expected beam delivery after taking into account system overhead – a factor that can not be scheduled in advance.

The experiment specific factors are given in Table XLI.

The system downtime in terms of total hours of interruption is useful data. In schedule 101, the major interruptions to RIB were: the failure of the SiC #3 target in which the high current ionizer circuit went open after about 4 weeks of operation, requiring an unscheduled target change; a vacuum leak in a feedthrough on the service cap of TM1; various controls problems including IOC trips and the failure of a plc 12 V circuit. The stable beam was interrupted due to vacuum leaks at the L-bend of the microwave guide – caused by sputtering during operation with magnesium beams. In schedule 102, the major problem was the loss of RIB yield in the SiC #4 target after a transient excursion of the ionizer heater. Some of the significant events are indicated in the downtime tables. For example, in schedule 102, 52.6 h of scheduled beam time was devoted to investigating the problem with the loss of yield (Table XXXV) and the RFQ was unavailable for 127 h due to a failed ac breaker (Table XXXIX). For beam schedules 101 and 102, the total unscheduled downtime for RIB and OLIS was 1095.5 hours compared to total scheduled user time of 5322 hours, giving an availability of 79.5% for combined cyclotron, ISAC system performance.

Some of the OLIS downtime is extended due to lower priority when it occurs during parasitic operation simultaneous with RIB to another user. The target histories are given in Table XLII. 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 yield results are given in the target ion source report. Data are presented for ITE operation although this time was all used for commissioning and development.

One operator was replaced in the first quarter, and the newest recruit was given the latest version of the training program and assigned to shift work at the beginning of the summer. Formal training now takes about 6 months. New operators pair up with an experienced operator for the first three weeks of their on-shift induction. Development of the SAT training program for ISAC Operations was delayed until the fall due to absences and operational priorities. By year-end, the analysis phase (first of five phases) of SAT had been completed and was ready for review. The first release of the ISAC Operations Manual (V1.0) was completed in February. It is available in PDF format on the ISAC Ops Web site.

The staffing complement remains critical, with five on-shift operators required for skeletal operation 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 stand 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%. There is no contingency for staffing turnover. A recruitment plan has been proposed to increase the resources within ISAC Operations.

In the control room, the EPICS control user interface was transferred to local workstations operating on Linux. This has provided a very stable operating system with the power of a local PC network to perform some of the user applications such as display management and data trending. Four separate workstations with a total of twelve monitor screens are available for operation. Much of this is required for the routine system monitoring and alarm system, so console desk space is scarce during periods of simultaneous operation of RIB with stable beam from OLIS, or other off-line activities. More control space is planned for the new control room in the ISAC-II building. Further console and control system improvements are on-going.

The electronic logbook has been transferred to a secure Web site behind a firewall and has replaced the traditional hard cover logbook, which is no longer maintained. The e-log is available to any on-site user, and the most recent entries are available through a mirrored Web page to off-site readers via the "internal" connection. The Web-based work permit system has been commissioned; improvements are on-going. A number of regular correspondences have been organized into electronic subscription list services. These include weekly maintenance request and maintenance list distributions and the weekly ISAC status meeting notes. An ISAC Operations Web page was created with information useful to ISAC operations and of interest to users.

In the coming year, in addition to providing beam for the scheduled experiments and performing systems maintenance, the major effort will be to establish and complete the SAT training program for ISAC operators.

Table XXI. OLIS beam schedule 100A: December 31 – April 1 (weeks 1–13). OLIS beam to ISAC experiments (hours).

Experiment number	Scheduled	Actual	Tune	Off
DRAGON commissioning	377.50	209.45	22.00	37.25
Development	78.00	48.00	8.00	13.00
Total	455.50	257.45	30.00	50.25

Beam available = 257.45 + 30.00 + 50.25 = 337.70 hours.
OLIS performance = 337.70/455.50 = 74.1 %.

Table XXII. OLIS beam schedule 100A. Breakdown of OLIS beams to ISAC experiments (hours).

Isotope	DRAGON commissioning	Development	Total
Mg-24	31.90	0.00	31.90
Ne-20	153.25	11.00	164.25
Ne-21	24.30	37.00	61.30
Total	209.45	48.00	257.45

Table XXIII. OLIS beam schedule 100A: OLIS systems downtime and overhead.

ISAC systems	Hours
Controls	14.20
Diagnostics	4.00
MEBT rf	2.50
DTL rf	15.20
Charge-exchange stripper	3.00
RFQ	7.10
Ion source	35.00
ISAC maintenance	21.40
ISAC shutdown (Feb. 19 – Apr. 1)	1025.00
ISAC startup	52.00
ISAC idle/no user	592.95
Procedures	41.85
OLIS/LEBT tuning	4.00
RFQ tuning	4.00
MEBT tuning	9.50
DTL tuning	5.50
HEBT tuning	1.00
Other	0.60
Total	1838.80

Table XXIV. ITW beam schedule 101: April 1 – September 23 (weeks 14–38). ITW beam to ISAC experiments (hours).

Experiment number	Scheduled	Expected	Actual	Tune	Off
Etest (ILY)	276	138	110.45	3.80	4.50
E715 (TNT)	336	302	161.35	3.15	4.60
E815 (BMR)	276	221	151.60	28.50	3.00
E824 (DRA)	534	267	195.05	18.10	12.50
E871 (OSA)	120	108	43.90	0.55	7.00
E893 (LTO)	252	126	125.40	2.80	5.00
E903 (OSA)	300	270	155.00	13.00	4.85
E903 (POL)	0	0	33.80	0.00	3.30
E909 (GPS)	80	72	56.75	0.10	4.25
E909 (8PI)	256	230	227.75	2.00	1.75
No scheduled user	(144)				
Total	2430 (2574)	1734	1261.05	72.00	50.75

RIB available = 1261.05 + 72.00 + 50.75 = 1383.80 hours.
Combined cyclotron/ISAC performance = 1,383.80/2430 = 56.9%.
System downtime = 508.40 hours = 508.40/2430 = 20.9%.

Table XXV. ITW beam schedule 101: Breakdown of ITW radioactive beam to ISAC experiments (hours).

Isotope	E715 TNT	E815 BMR	E824 DRA	E871 OSA	E871 POL	E893 LTNO	E903 OSA	E909 GPS	E909 8PI	Total
	Yield studies on Li series, K series, Na series, Rb series = 110.45 hours									110.45
^{7}Li (stable)							9.45			9.45
^{8}Li		151.60					6.35			157.95
^{9}Li							29.15			29.15
^{11}Li							110.05		50.85	160.90
^{37}K	83.50									83.50
^{39}K						16.30				
^{21}Na+5			195.05							195.05
^{23}Na				11.00						11.00
^{26}Na				32.90	33.80			56.75	176.90	300.35
^{79}Rb						109.10				109.10
^{80}Rb	77.85									77.85
Total	161.35	151.60	195.05	43.90	33.80	125.40	155.00	56.75	227.75	1261.05

Table XXVI. ITW beam schedule 101: Detail of ITW radioactive beams to HEBT experiments (hours).

Species and energy	Experiment	Current (pA)	Hours	nA-h
^{21}Na+5 215 keV/u	E824 DRA	400 pA	55.80	22
^{21}Na+5 360 keV/u	E824 DRA	150 pA	47.30	7
^{21}Na+5 492 keV/u	E824 DRA	200 pA	11.10	2
^{21}Na+5 504 keV/u	E824 DRA	200 pA	11.90	2
^{21}Na+5 580 keV/u	E824 DRA	200 pA	16.70	3
^{21}Na+5 590 keV/u	E824 DRA	200 pA	3.00	1
^{21}Na+5 850 keV/u	E824 DRA	200 pA	0.10	0
^{21}Na+5 857 keV/u	E824 DRA	200 pA	1.30	0
^{21}Na+5 867 keV/u	E824 DRA	200 pA	2.35	0
^{21}Na+5 878 keV/u	E824 DRA	250 pA	26.00	7
^{21}Na+5 887 keV/u	E824 DRA	200 pA	6.50	1
^{21}Na+5 891 keV/u	E824 DRA	125 pA	0.35	0
^{21}Na+5 901 keV/u	E824 DRA	125 pA	12.65	2
Total			195.05	47

Table XXVII. ITW beam schedule 101: ITW systems downtime and overhead.

ISAC systems	Hours
Downtime – unscheduled	
Beam lines	3.00
Controls (38.6 h plc 12 V fail; 24 h IOC faults)	71.65
DTL rf	6.80
Electrostatic power supplies	1.00
MEBT rf	0.50
Safety	0.10
Site power	7.50
Target/ion source (275.5 h SiC #3 ionizer; 124.5 h vacuum f/t)	416.75
Vacuum	0.10
Other	1.00
Subtotal	508.40
Downtime – scheduled	
Cyclotron maintenance	380.00
Cyclotron development	66.85
Beam line 2A off	242.75
ISAC cooldown	5.50
ISAC shutdown	24.00
ISAC startup	20.50
ISAC maintenance	127.80
ISAC development	7.40
ISAC idle	292.00
Procedures	259.30
Target conditioning	356.90
Target change	432.00
LEBT tuning	24.70
Other	3.75
Total	2751.85

Table XXVIII. OLIS beam schedule 101: OLIS beam to ISAC experiments (hours).

Experiment number	Scheduled	Expected	Actual	Tune	Off
E824 DRAGON	252	126	317.50	22.25	34.40
E870 TUDA	540	432	11.90	12.40	12.80
E871 Osaka	36	32	3.50		
E893 LTNO	60	30	41.75		
E903 TUDA	0	0	11.50	5.00	
Etest GPS	24	22	3.00	8.50	
No scheduled user	(1188)				
Total	912 (2100)	642	389.15	48.15	47.20

Beam available = 389.15 + 48.15 + 47.20 = 484.50 hours.
OLIS performance = 484.50/912.00 = 53.1%.
System downtime = 304.00 hours = 304.00/912.00 = 33.3%.

Table XXIX. OLIS beam schedule 101: Breakdown of OLIS beams to ISAC experiments (hours).

Isotope	E824	E870	E871	E893	E903	Etest	Total
	DRA	TUD	OSA	LTO	TUD	GPS	
^{4}He+1		11.90					11.90
^{15}N+1				25.75			25.75
^{20}Ne+1			3.50				3.50
^{20}Ne+5	60.05				11.50		71.55
^{21}Ne+1				16.00		3.00	19.00
^{21}Ne+5	108.00						108.00
^{24}Mg+6	149.45						149.45
Total	317.50	11.90	3.50	41.75	11.50	3.00	389.15

Table XXX. OLIS beam schedule 101: Detail of OLIS stable beams to HEBT experiments (hours).

Species and energy	Experiment	Current	Hours	nA-h
^{20}Ne+5 360 keV/u	E824 DRA	1 nA	60.05	60
^{21}Ne+5 215 keV/u	E824 DRA	1 nA	3.50	4
^{21}Ne+5 279 keV/u	E824 DRA	1 nA	27.90	28
^{21}Ne+5 287 keV/u	E824 DRA	1 nA	4.70	5
^{21}Ne+5 492 keV/u	E824 DRA	1 nA	3.30	3
^{21}Ne+5 497 keV/u	E824 DRA	1 nA	8.70	9
^{21}Ne+5 500 keV/u	E824 DRA	1 nA	3.30	3
^{21}Ne+5 501 keV/u	E824 DRA	1 nA	0.80	1
^{21}Ne+5 502 keV/u	E824 DRA	1 nA	5.70	6
^{21}Ne+5 503 keV/u	E824 DRA	1 nA	1.00	1
^{21}Ne+5 504 keV/u	E824 DRA	1 nA	1.70	2
^{21}Ne+5 505 keV/u	E824 DRA	1 nA	0.90	1
^{21}Ne+5 506 keV/u	E824 DRA	1 nA	4.85	5
^{21}Ne+5 510 keV/u	E824 DRA	1 nA	1.00	1
^{21}Ne+5 511 keV/u	E824 DRA	1 nA	2.90	3
^{21}Ne+5 515 keV/u	E824 DRA	1 nA	1.00	1
^{21}Ne+5 517 keV/u	E824 DRA	1 nA	14.70	15
^{21}Ne+5 520 keV/u	E824 DRA	1 nA	0.90	1
^{21}Ne+5 523 keV/u	E824 DRA	1 nA	1.00	1
^{21}Ne+5 524 keV/u	E824 DRA	1 nA	1.30	1
^{21}Ne+5 525 keV/u	E824 DRA	1 nA	0.80	1
^{21}Ne+5 526 keV/u	E824 DRA	1 nA	1.40	1
^{21}Ne+5 528 keV/u	E824 DRA	1 nA	0.80	1
^{21}Ne+5 530 keV/u	E824 DRA	1 nA	8.95	9
^{21}Ne+5 590 keV/u	E824 DRA	1 nA	6.90	7
^{24}Mg+6 215 keV/u	E824 DRA	1 nA	0.40	0
^{24}Mg+6 216 keV/u	E824 DRA	1 nA	8.70	9
^{24}Mg+6 219 keV/u	E824 DRA	1 nA	9.00	9
^{24}Mg+6 221 keV/u	E824 DRA	1 nA	7.20	7
^{24}Mg+6 222 keV/u	E824 DRA	1 nA	16.00	16
^{24}Mg+6 224 keV/u	E824 DRA	1 nA	14.60	15
^{24}Mg+6 225 keV/u	E824 DRA	1 nA	2.80	3
^{24}Mg+6 227 keV/u	E824 DRA	1 nA	8.30	8
^{24}Mg+6 228 keV/u	E824 DRA	1 nA	3.50	4
^{24}Mg+6 229 keV/u	E824 DRA	1 nA	4.00	4
^{24}Mg+6 230 keV/u	E824 DRA	1 nA	6.40	6
^{24}Mg+6 236 keV/u	E824 DRA	1 nA	8.00	8
^{24}Mg+6 360 keV/u	E824 DRA	1 nA	1.90	2
^{24}Mg+6 425 keV/u	E824 DRA	1 nA	58.65	59
^{4}He+1 1.50 MeV/u	E870 TUD	1 nA	11.90	12
^{20}Ne+5 1.45 MeV/u	E903 TUD	1 nA	11.50	12
Total			340.90	340

Table XXXI. OLIS beam schedule 101: OLIS systems downtime and overhead.

ISAC systems	Hours
Downtime – unscheduled	
Beam lines	1.00
Controls	12.70
Electrostatic PS (38.3 h IOS:Q3 fail)	39.25
Magnet PS (41.3 h water leak in OLIS:MB1)	42.50
DTL rf (38.3 h tank 2 p/s; 14.5 h tank 5)	37.35
Charge-exchange stripper	3.85
MEBT rf	6.25
RFQ	1.30
Site power	22.00
Ion source (L-bend vacuum failures after Mg beam = 92.3 h in week 18; 40.5 h in week 38)	137.80
Subtotal	304.00
Downtime – scheduled	
ISAC maintenance	210.00
Development	47.50
ISAC idle	1070.30
ISAC shutdown (includes 112 h repair to L-bend in week 38)	289.50
ISAC startup	35.50
Procedures	403.30
LEBT tuning	0.15
Total	2360.25

Table XXXII. ITW beam schedule 102: September 23 – December 30 (weeks 39–52). ITW beam to ISAC experiments (hours).

Experiment	Scheduled	Expected	Actual	Tune	Off	Total
Etest ILY	204	102	52.20	8.20		60.40
Etest 8PI	12	6				0.00
E715 TNT	372	335	319.10	10.05		329.15
E817 BMR	204	163	139.05	1.25	0.80	141.10
E823 GPS	132	119	101.05	5.95	38.05	145.05
E824 DRA	252	126	123.05	2.30	2.00	127.35
E871 OSA	96	86	86.30			86.30
E893 OSA	24	22	21.05	0.25	1.95	23.25
E928 TUD	132	106	105.65	0.70	5.75	112.10
No scheduled user	(156)					
Total	1428 (1584)	1065	947.45	28.70	48.55	1024.70

RIB available = 947.45 + 28.70 + 48.55 = 1024.70 hours.
Combined cyclotron/ISAC performance = 1,024.70/1,428.00 = 71.8%.
System downtime = 111.61 hours = 111.61/1428 = 7.8%.

Table XXXIII. ITW beam schedule 102: Breakdown of ITW radioactive beams to ISAC experiments (hours).

Species	E715 TNT	E815 BMR	E824 DRA	E871 OSA	E893 TUDA	E903 OSA	E909 GPS	Etest 8PI	Total
Multiple				Yield studies = 52.20 hours					52.20
^{7}Li (stable)		1.00							1.00
^{8}Li		138.05							138.05
^{20}Na+5					105.65	18.65			124.30
^{21}Na+5			123.05	77.70		2.40			203.15
^{23}Na (stable)				8.60				0.00	8.60
^{36}K	123.50								123.50
^{37}K	195.60								195.60
^{38}K							101.05		101.05
Total	319.10	139.05	123.05	86.30	105.65	21.05	101.05	0.00	947.45

Table XXXIV. ITW beam schedule 102: Detail of ITW radioactive beams to HEBT experiments (hours).

Energy	Species	Experiment	Hours	nA-h
1.25 MeV/u 2 pA	^{20}Na+5	E928 TUD	73.65	0.1
1.60 MeV/u 2 pA	^{20}Na+5	E928 TUD	32.00	0.1
470 keV/u 100 pA	^{21}Na+5	E824 DRA	6.50	0.7
490 keV/u 100 pA	^{21}Na+5	E824 DRA	15.82	1.6
500 keV/u 100 pA	^{21}Na+5	E824 DRA	7.60	0.8
570 keV/u 100 pA	^{21}Na+5	E824 DRA	41.13	4.1
580 keV/u 100 pA	^{21}Na+5	E824 DRA	1.80	0.2
774 keV/u 5 pA	^{21}Na+5	E824 DRA	40.90	0.2
781 keV/u 100 pA	^{21}Na+5	E824 DRA	9.30	0.9
Total			228.70	8.7

Table XXXV. ITW beam schedule 102: ITW systems downtime and overhead.

ISAC systems	Hours
<u>Downtime – unscheduled</u>	
Controls	8.90
Electrostatic power supplies	3.40
Magnet power supplies	11.50
Q-exchange stripper	0.30
Services	8.80
Site power	13.20
Target/ion source (52.6 h check target after drop in rates)	64.01
Vacuum	1.50
Subtotal	111.61
<u>Downtime – scheduled</u>	
Cyclotron maintenance	206.05
Cyclotron development	13.50
Beam line 2A off	132.54
ISAC shutdown	249.50
ISAC maintenance	7.50
ISAC development	1.40
ISAC idle	73.05
Procedures	97.40
Target conditioning	195.80
Target change	208.00
LEBT tuning	0.70
Subtotal	1185.44
Total	1297.05

Table XXXVI. OLIS beam schedule 102: OLIS beam to ISAC experiments (hours) with microwave source and gases.

Experiment	Scheduled	Expected	Actual	Tune	Off	Total
Etest DEV		60	108.50			108.50
E815 BMR	12	10				
E871 OSA	12	11		0.50		0.50
E824 DRA	264	132	155.60	11.95	9.65	177.20
E870 TUD	204	163	57.05	1.00		58.05
E928 TUD	60	38	50.90	1.50	7.40	59.80
No scheduled user	(852)					
Total	552 (1404)	414	372.05	14.95	17.05	404.05

Beam available = 372.05 + 14.95 + 17.05 = 404.05 hours.
OLIS performance = 404.05/552.00 = 73.2%.
System downtime = 171.50 hours = 171.5/552.00 = 31.1%.

Table XXXVII. OLIS beam schedule 102: Breakdown of OLIS beams to ISAC experiments (hours).

Species	E824 DRA	E870 TUD	E928 TUD	E871 OSA	E817 BMR	Etest DEV	Total
^{12}C+3	54.85						54.85
^{14}N+4	9.10	43.50					52.60
^{20}Ne+5	3.80	13.55	50.90			108.50	176.75
^{21}Ne+5	87.85						87.85
Total	155.60	57.05	50.90	0.00	0.00	108.50	372.05

Table XXXVIII. OLIS beam schedule 102: Detail of OLIS stable beams to HEBT experiments (hours).

Energy	Species	Experiment	Hours	nA-h
1.07 MeV/u 2 nA	^{12}C+3	E824 DRA	23.20	46.4
1.08 MeV/u 2 nA	^{12}C+3	E824 DRA	14.30	28.6
1.11 MeV/u 2 nA	^{12}C+3	E824 DRA	17.35	34.7
410 keV/u 1 nA	^{14}N+4	E824 DRA	9.10	9.1
1.45 MeV/u 200 pA	^{14}N+4	E870 TUD	43.50	8.7
500 keV/u 1 nA	^{20}Ne+5	E824 DRA	3.80	3.8
750 keV/u 2 pA	^{20}Ne+5	E928 TUD	12.00	0.0
1.0 MeV/u 2 nA	^{20}Ne+5	E870 TUD	13.55	27.1
1.25 MeV/u 1 nA	^{20}Ne+5	E928 TUD	34.80	34.8
1.25 MeV/u 2 pA	^{20}Ne+5	E928 TUD	3.10	0.0
1.6 MeV/u 3 pA	^{20}Ne+5	E928 TUD	1.00	0.0
500 keV/u 1 nA	^{21}Ne+5	E824 DRA	6.00	6.0
528 keV/u 1 nA	^{21}Ne+5	E824 DRA	4.20	4.2
543 keV/u 1 nA	^{21}Ne+5	E824 DRA	2.70	2.7
546 keV/u 1 nA	^{21}Ne+5	E824 DRA	8.90	8.9
547 keV/u 1 nA	^{21}Ne+5	E824 DRA	0.30	0.3
548 keV/u 1 nA	^{21}Ne+5	E824 DRA	0.00	0.0
550 keV/u 1 nA	^{21}Ne+5	E824 DRA	1.80	1.8
552 keV/u 1 nA	^{21}Ne+5	E824 DRA	1.80	1.8
553 keV/u 1 nA	^{21}Ne+5	E824 DRA	0.40	0.4
554 keV/u 1 nA	^{21}Ne+5	E824 DRA	2.20	2.2
556 keV/u 1 nA	^{21}Ne+5	E824 DRA	3.60	3.6
557 keV/u 1 nA	^{21}Ne+5	E824 DRA	3.00	3.0
558 keV/u 1 nA	^{21}Ne+5	E824 DRA	2.60	2.6
560 keV/u 1 nA	^{21}Ne+5	E824 DRA	4.70	4.7
774 keV/u 1 nA	^{21}Ne+5	E824 DRA	2.50	2.5
778 keV/u 1 nA	^{21}Ne+5	E824 DRA	0.50	0.5
781 keV/u 1 nA	^{21}Ne+5	E824 DRA	0.00	0.0
799 keV/u 1 nA	^{21}Ne+5	E824 DRA	2.40	2.4
802 keV/u 1 nA	^{21}Ne+5	E824 DRA	2.00	2.0
805 keV/u 1 nA	^{21}Ne+5	E824 DRA	2.00	2.0
808 keV/u 1 nA	^{21}Ne+5	E824 DRA	2.50	2.5
808 keV/u 1 nA	^{21}Ne+5	E824 DRA	3.00	3.0
809 keV/u 1 nA	^{21}Ne+5	E824 DRA	1.50	1.5
810 keV/u 1 nA	^{21}Ne+5	E824 DRA	1.50	1.5
814 keV/u 1 nA	^{21}Ne+5	E824 DRA	9.00	9.0
811 keV/u 1 nA	^{21}Ne+5	E824 DRA	1.50	1.5
817 keV/u 1 nA	^{21}Ne+5	E824 DRA	1.50	1.5
814 keV/u 1 nA	^{21}Ne+5	E824 DRA	1.10	1.1
818 keV/u 1 nA	^{21}Ne+5	E824 DRA	1.75	1.8
820 keV/u 1 nA	^{21}Ne+5	E824 DRA	0.00	0.0
817 keV/u 1 nA	^{21}Ne+5	E824 DRA	1.60	1.6
820 keV/u 1 nA	^{21}Ne+5	E824 DRA	2.80	2.8
824 keV/u 1 nA	^{21}Ne+5	E824 DRA	2.50	2.5
828 keV/u 1 nA	^{21}Ne+5	E824 DRA	3.00	3.0
835 keV/u 1 nA	^{21}Ne+5	E824 DRA	3.00	3.0
Total			263.55	281.1

Table XXXIX. OLIS beam schedule 102: OLIS systems downtime and overhead.

ISAC systems	Hours
Downtime – unscheduled	
Beam lines	6.00
Controls	2.20
Magnet PS	4.80
DTL rf (11.7 h buncher 1 trips November 25,26)	14.50
Charge-exchange stripper	0.30
MEBT rf	5.00
Electrical services (RFQ primary ac breaker failure)	127.00
Site power	7.80
Ion source	3.90
Subtotal	171.50
Downtime – scheduled	
ISAC maintenance	121.95
ISAC idle	354.80
ISAC shutdown	450.50
ISAC startup	44.50
Procedures	193.60
HEBT tuning	6.00
Subtotal	1171.35
Total	1342.85

Table XL. ITE beam schedule 102: ITE systems downtime and overhead with ECR source and gases.

ISAC systems	Hours
Downtime – unscheduled	
Controls	8.50
Diagnostics (IMS:FC0 signal fault)	21.00
Services	6.00
Subtotal	35.50
Downtime – scheduled	
ISAC maintenance	96.00
ISAC development	159.60
ISAC idle	1012.00
Procedures	0.40
Target conditioning	1048.50
Subtotal	2316.50
Total	2352.00

Table XLI. Estimated procedural overhead.

Line	Discount
DEV	5h/wk
ILY	.50
DRA	.50
LTO	.50
TUD	.80
BMR	.80
POL	.80
TNT	.90
GPS	.90
8PI	.90 in schedule 101 .50 in schedule 102
OSA	.90

Expected hours = scheduled hours × discount factor.

Discount values are estimated from operational experience of experiments on the respective lines. Higher numbers suggest higher uptimes. Generally, HEBT experiments have greater overhead due to multiple energy requirements. Yield runs, scheduled in 12 hour blocks, typically go for the better part of a regular business day. The 8pi run in schedule 102 was for commissioning only.

The target hall and hot cell operation has become quite well organized. The engineering that has been done for the east target station 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 2002 is given in Table XLII. Schedule 101 started with SiC #3 – a target of silicon carbide pellets. It failed prematurely due to an open circuit in the tube heater. The remaining targets lasted for the duration of their scheduled beam operation, albeit with decreasing yields as a function of target aging. The next target was Ta foils #3; it received the highest exposure to date: 6.15E20 protons. The next target was TiC #1; although receiving less exposure, this thicker target generated more RIB (exposure × target thickness).

Table XLII. ISAC target history for 2002.

Target ID	In date	Out date	Exposure # of protons	Power μAh*g/cm^2	Comments
SiC #3	15-Mar	24-May	1.773E+20	192516	18.9 gSiC/cm^2 + 5.5 gC/cm^2: Failure due to TBHT – open circuit
Ta Foils #3	7-Jun	15-Aug	6.148E+20	596217.98	21.79 g/cm^2 Ta in the form of 525 × 0.025 mm foils
TiC #1	26-Aug	29-Oct	5.050E+20	993880.32	29.65 gTi/cm^2 + 14.57 gC/cm^2 (590 foils 0.11 mmC + 0.25 mm TiC)
SiC#4	1-Nov		4.358E+20	519451.66	14.31 gSi/cm^2 + 12.47 gC/cm^2 (425 foils 0.13 mmC + 0.23 mmSiC)

The last target, SiC #4, experienced a precipitous loss of yield after an inadvertent transient spike in the ionizer heater set point. Curiously, the rate mysteriously recovered in the last few hours of operation before the winter shutdown. Hopefully the target inspection will provide some explanations. At these beam powers, considering the operating temperature, the productive life for this generation of targets appears to be about 4–6 weeks.

ISAC TARGETS

ISAC Targets and Beams

During 2002, ISAC target development concentrated on increasing proton beam current limits for refractory carbide target materials (SiC, TiC) and long term operation of a Ta foil target at high proton beam intensity. Three carbide targets (SiC #3, SiC #4 and TiC #1) were operated to provide Na and K beams to both accelerated and low energy experiments. The metal foil target Ta #3 operated from June to August, providing mainly beams of Li isotopes. Ta #3 currently holds the ISAC record for irradiation having received 27,362 μA h of proton beam, a total of 6.2×10^{20} protons.

Previously at ISAC, compound targets such as SiC, CaO and CaZrO$_3$ had been in the form of pressed powder pellets. The pellets (16 mm diameter, 1 to 2 mm thickness) were stacked inside the 18 mm diameter tantalum target container. The maximum operating proton beam current was limited by the target material's ability to dissipate the proton beam power. Due to the limited contact between target pellets and the inner wall of the target container, beam power deposited in the pellet stack first had to be radiated to the target container and subsequently, from the target container to the surroundings. At the operating temperatures of these target materials (1400–1600°C) radiative heat transfer is not highly efficient. Previously, the maximum operating proton current for pellet targets was 15 μA for a SiC pellet target and only 3 μA for a CaZrO$_3$ pellet target.

During 2002, higher proton beam current operation for carbide targets was achieved by replacing the target pellets with composite target foils consisting of a thin layer of metal carbide ($\sim$0.23 mm) on a supporting layer ($\sim$0.12 mm) of flexible exfoliated graphite foil. The composite foils were loaded into the target container such that good contact with the container wall was maintained allowing beam power to be transferred to the container by conduction rather than radiation. The graphite layer also increased the thermal conductivity of the composite foil allowing metal carbide targets to be treated in a manner analogous to metal foil targets.

Target foils were manufactured by slip casting mixtures of metal carbide powders with appropriate binders, plastisizers, dispersants and solvents. Methods for producing thin, evenly dispersed, compact layers of carbides using both aqueous and non-aqueous systems were developed for SiC, TiC and ZrC. Green densities of up to 65% were achieved for the cast carbides. Prior to on-line operation, the targets were conditioned by heating at operational temperature to decompose and volatilize the organic components and sinter the carbide layers.

The first silicon carbide composite foil target (SiC #3) consisting of 450 composite foils for a total of 18.9 g SiC/cm^2 operated at a maximum proton current of 30 μA, twice the beam current of the previous silicon carbide pellet target (29.9 g SiC/cm^2). A similar titanium carbide composite target (TiC #1) consisting of 590 foils operated at a maximum current of 40 μA for 22,475 μA h receiving a total of 5.1×10^{20} protons on target. A second silicon carbide composite target (SiC #4) operated with a maximum proton current of 45 μA (three times the previous maximum with pellets) operating for 19,397 μA h, a total of 4.4×10^{20} protons.

Yields of alkali beams from both composite foil and pressed pellet targets are presented in Table XLIII. For the sodium beams, the comparison is for silicon carbide target material in different forms. The yields are generally higher by an order of magnitude for the composite foil targets compared to the pressed pellet targets. This reflects the increased production and enhanced diffusion resulting from an increase in maximum beam intensity. Isotopic yields from composite foil and pellet targets operating at the same beam intensity are essentially the same. For the potassium yields, the composite TiC material is compared to a target of pressed pellets of CaZrO$_3$. While the CaZrO$_3$ target maximum beam current is $\leq 3\,\mu$A, the yields of short-lived ^{35}K and ^{36}K are comparable to those from the TiC composite target operating at a 40 μA proton current. This reflects the much higher production cross section of light K isotopes from Ca than from Ti. The higher proton flux on the TiC target does not sufficiently compensate for the difference in production. The high yields of neutron rich potassium isotopes from the TiC composite target are consistent with the higher production cross section from Ti.

Table XLIII. Comparison of yields from pressed pellet and composite foil targets.

Beam	Composite target	Yield (/s)	p^{++} (μA)	Pellet target	Yield (/s)	p^{++} (μA)
^{20}Na	SiC	2.6×10^8	46.3	SiC	3.4×10^7	15.4
^{21}Na	SiC	9.9×10^9	46.2	SiC	2.5×10^9	15.3
^{22}Na	SiC	4.8×10^{11}	45.0	SiC	2.0×10^{11}	15.1
^{24g}Na	SiC	6.8×10^{10}	45.0	SiC	7.0×10^9	10.5
^{24m}Na	SiC	1.7×10^8	30.6	SiC	1.3×10^7	10.5
^{25}Na	SiC	3.2×10^9	44.7	SiC	3.7×10^8	10.5
^{26}Na	SiC	3.2×10^7	45.4	SiC	5.2×10^6	10.5
^{26}Na	SiC	1.5×10^6	45.0	SiC	2.2×10^5	10.3
^{35}K	TiC	3.5×10^3	40.6	$CaZrO_3$	2.0×10^3	2.6
^{36}K	TiC	2.1×10^5	40.1	$CaZrO_3$	2.4×10^5	1.0
^{37}K	TiC	6.4×10^7	40.1	$CaZrO_3$	8.5×10^6	1.5
^{38g}K	TiC	1.8×10^{10}	40.1	$CaZrO_3$	7.4×10^8	1.1
^{38m}K	TiC	7.4×10^7	40.1	$CaZrO_3$	1.2×10^7	2.6
^{42}K	TiC	1.5×10^{11}	38.5		–	–
^{43}K	TiC	4.6×10^{10}	38.5		–	–
^{44}K	TiC	2.6×10^{10}	38.5		–	–
^{45}K	TiC	1.6×10^9	38.5		–	–

High Power Target Developments at ISAC

Existing target designs using foils of refractory material (Nb, Ta, etc.) can accommodate up to 40 μA beam intensities and the available intensities of many radionuclides seem to scale with the proton beam current. Production targets capable of withstanding proton beam intensities up to 100 μA without compromising the reliability and the yield of radioactive isotopes will be a future challenge. Several approaches to the dissipation of the power deposited in such targets by the proton beam have been investigated and a realistic solution for the removal of the heat from the target container seems possible. The development of a high power target is the subject of a development program at TRIUMF. In order to go beyond the current limitation one needs to efficiently cool the target. Over the past ten years several concepts were proposed but very few were developed and used satisfactorily on-line. Either the target is too difficult to produce and therefore too expensive, or the cooling is too efficient and the target material never gets to the ideal temperature for fast release of short half-life nuclides. Different schemes have been proposed to overcome these issues and it is clear that radiative cooling offers the simplest approach to cool the target material. If one can increase the effective emissivity of the target container one can increase the beam power deposited into the target. A thick target equipped with radial fins has been developed for this purpose at TRIUMF and the initial tests have been conducted.

Target fabrication

Instead of building a target using the diffusion bonding technique, we considered adding radial fins to a Ta tube. The fins are 55 × 55 mm cut out from a Ta foil sheet 380 μm thick. An undersized hole is punched in the centre and extruded to the tube diameter using a conical shaped tool. Then the fins are installed onto the tube from each side of the central block. Once the fins are installed we use a special tool to expand the Ta tube in order to improve the contact between the tube and the fins. In order to verify if we have a better contact, we measure the electrical resistance between the fins and the tube. We observed a reduction of the resistance by a factor of three across the contact area. The target is equipped with 90 fins in total. Figure 196 shows a photograph of the actual finned target.

Heating tests of the finned target

We ran several tests of the target using the ISAC target conditioning facility. The available power to heat the target comes from a 10 V, 1000 A dc supply. The current passing in the Ta tube directly heats the target. We measured the temperature using a pyrometer and thermocouples. The temperature versus power test has been performed for two types of target: without fins and with fins. The temperature was measured in the interior of the target and on the edge of the fins. Figure 197 shows the heating test results. The filled circles represent the data for the Ta target with no fins and no heat shields. The filled diamonds and the open

Fig. 196. Photograph of the target equipped with fins used for the heating test.

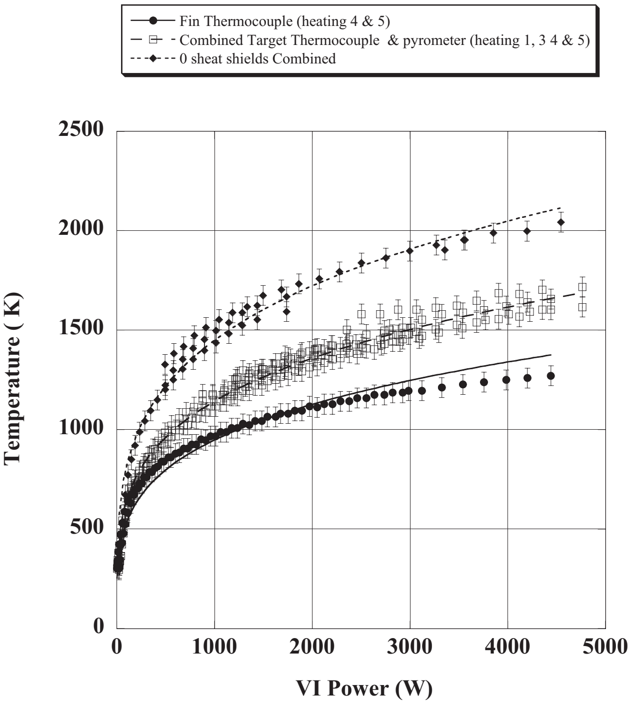


Fig. 197. Heating test of the finned target. The filled circles show the temperature of a Ta tube with no fins and heat shields around it. The filled diamonds show the temperature inside the Ta tube for the finned target. The open squares show the temperature on the target fins. The lines are a fit using the black body radiation law.

squares represent the temperature on the interior wall and on the edge of the fins, respectively.

We can fit the expression for T versus the input power and obtain the value of the emissivity for different targets. The emitting areas are 113.7 and 241.3 cm^2, respectively. We obtain an emissivity of 0.35 for the target without fins and heat shield, and we obtain an effective emissivity of 0.91 for the target equipped with fins.

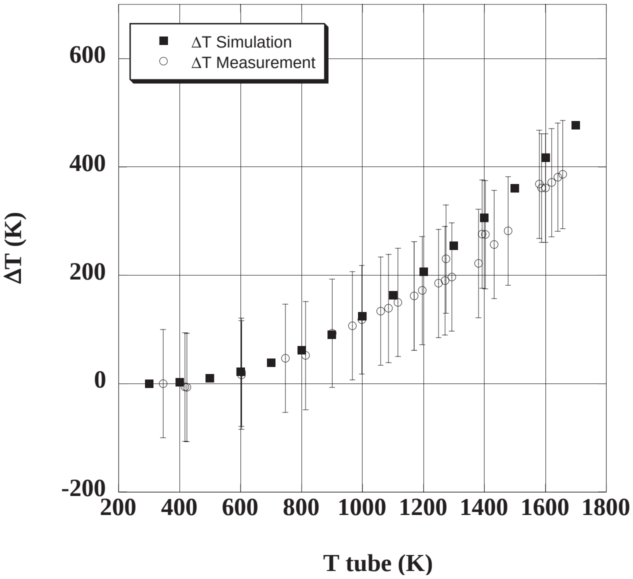


Fig. 198. Plot of the temperature difference ΔT between the target tube interior wall and the edge of the fins. The open circles are the measurements and the filled squares are the results of the simulation.

The results from the analyses using ANSYS® have been closely comparable to those from pyrometer and thermocouple readings when the target has been heated in a test scenario. Figure 198 shows the temperature difference (ΔT) between the target tube interior wall and the edge of the fins. The filled squares are the results of the simulation and the open circles are the measured temperature differences. As one can see, the ANSYS® simulation is in good agreement with the measurements.

In summary, we have tested a new concept for the fabrication of a target equipped with fins. The fins are fabricated from a square sheet of tantalum installed over a tantalum tube. During the fabrication process we make sure that the thermal contact between the fins and the Ta tube is optimum. We observe an improvement of the resistance across the contact area after the expansion of the Ta tube. The heating tests show that the thermal contact is very good and the simulations also show that we nearly reach a perfect contact between the tube and the fins.

With this target design we are confident that we can go up to the 100 μA proton beam intensity limit for operation on refractory target foils (Ta, Nb, Mo, etc.) on the condition that the contact between the foil and the Ta tube internal wall is very good. We noticed in our off-line tests that diffusion bonding between the Ta foils and the Ta tube occurred after heating the system at 2000°C for a period of 8 hours.

Before going on-line with such a target we need to test the concept off-line using the same amount of power, say 20 kW. An electron beam heating system is under development to test the target behaviour under such conditions.

Actinide Target Task Force

In March a task force was set up to study the radiation safety problems associated with operating actinide targets at ISAC. The task force prepared a report that both identified the safety issues and defined likely operational changes that would need to be instituted once such targets had been irradiated. The report also outlined a program of proof-of-principle testing that would try to answer issues such as the storage and migration of undesirable alpha-emitting radioactive species and the consequences of their release both on and off site. By year's end a conceptual design had been developed for a testing station that would allow bombardment of ISAC targets at low beam intensities and measurement of the radiological quantities of interest.

ISAC ION SOURCES

Electron Cyclotron Resonance (ECR) Source

The fabrication of a radiation hard ECR source for the ISAC radioactive beam facility has been completed. The ion source was installed in the ion source test stand (ISTS) to evaluate its performance. The source was first high voltage conditioned to the design value of 60 kV. Some weak points have been identified and corrected.

The source delivered a neon beam using helium as a supporting gas. A source ionization efficiency of 10% for Ne^{1+} beam was measured using a calibrated neon leak with leak rate of 1.4×10^{-6} atm cc/s. Figure 199 shows an M/Q scan. In the spectrum the $^{20}\mathrm{Ne}^{1+}$ and $^{22}\mathrm{Ne}^{1+}$ peaks are clearly seen well separated from the background contribution.

Beam emittance scans were also carried out at the ISTS with the new source. An emittance of $30\,\pi$ mm mrad was measured at 45 keV for a total beam current of 500 μA. The above results meet the source design and compare quite well with those obtained previously with the non-radiation-hard prototype source.

In December the ion source without the production target was installed in target module #3 for a dry test. The source was operated continuously during the whole month. Again some weak points showed up in the ion source and in part of the beam line downstream of the source. Operation and evaluation of the source will continue throughout January, 2003.

The source will be removed from target module #3 in February, 2003 to carry out some modifications and will be made ready for commissioning with radioactive beams by the middle of April, 2003.

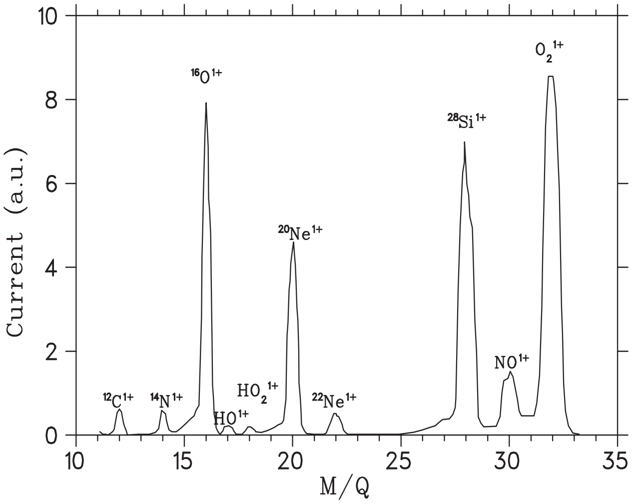


Fig. 199. An M/Q scan of a neon beam. Helium was used as a supporting gas. Two Ne peaks at M/Q = 20 and 22 are clearly seen. The other peaks arise from the residual gases, the silicon most likely coming from the quartz-made plasma chamber.

Off-Line Ion Source (OLIS)

OLIS supplied throughout the year beams of ^{21}Ne, ^{15}N, ^{24}Mg, and ^{13}C to the DRAGON and TUDA experiments as well as to other users in the low energy area using the 2.45 GHz microwave source. Some new beams, such as $^{12}\mathrm{C}^{2+}$ and $^{14}\mathrm{N}^{2+}$ were also delivered.

The source window of the 2.45 GHz microwave source was relocated. As a result of that the lifetime of the source increased; only minor maintenance work was needed within the three months running periods.

A new OLIS terminal has been constructed. It can now support simultaneously three different ion sources (Fig. 200). A surface ion source is being built and will be added to the new terminal in January, 2003. Four high current supplies, to power the three ovens and transfer tube of the surface source, and eight other devices were added to the high voltage rack. The new source will be commissioned in early 2003.

Plans to develop a high breed metal ion source are under way. With this additional source the new OLIS terminal will be producing a large variety of ions to satisfy the multiple experimental requests.

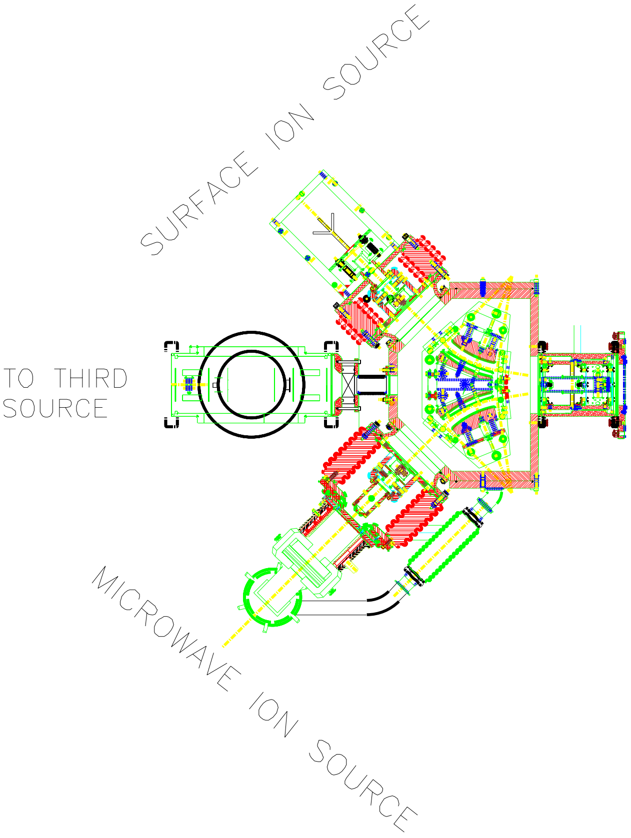


Fig. 200. The new OLIS terminal fitted with the surface and microwave ion sources. A high breed metal ion source will be developed in the near future and will be installed at the centre location of the new OLIS terminal.

Charge State Booster (CSB)

A charge state booster using the electron-cyclotron-resonance (ECR) technique has been developed at the Institute des Sciences Nucléaires (ISN) in Grenoble.

The CSB for TRIUMF, manufactured by PANTECHNIK (France) under license by ISN, was ordered in January and delivered to TRIUMF in November.

The 1^+ ion source test bench facility at TRIUMF is being extended to incorporate the CSB for tests and further development prior to its installation in the ISAC hall.

After detailed beam optical calculations the beam transport system has been designed, components have been ordered and their installation is under way. Completion is foreseen by the middle of June, 2003 with beam tests starting in July.

Figure 201 shows the layout of the CSB test facility.

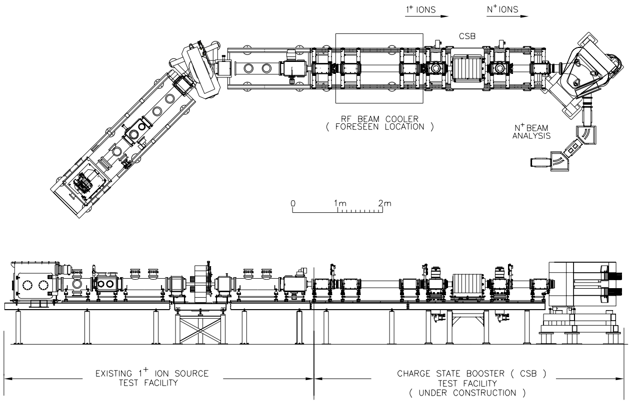


Fig. 201. The existing 1^+ ion source test stand (ISTS) and the charge state booster test facility now under construction. Provision has been made to enable the incorporation of an rf beam cooler in the CSB test bench facility.

Laser Ion Source (LIS)

Within the RIB development at ISAC a resonant laser ion source (TRILIS) is to be set up by 2005 to produce radioactive ion beams to augment the existing ion sources and their capabilities. For this, the position of a “laser ion source spectroscopist” was filled at the end of July. The resonant laser ion source, using multi-step resonant laser ionization, capitalizes on the potential for element selective, efficient photo-ionization, with the major parts of the LIS being located far away from the radioactive target ion source. The current sources are: the surface ion source (good for alkali and alkaline earth elements), and the ECR source (particularly good for noble gases). The resonant laser ion source is to supply beams of metals and transition elements that are otherwise difficult to obtain. The lasers required are tunable, high-power, high repetition rate, narrow bandwidth, and synchronizable pulsed lasers. 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 further step requires higher spectral energy density.

Current laser ion sources use either excimer- or copper-vapour-lasers, pumping pulsed dye-lasers. The excimer systems have inherently low repetition rates below 1 kHz and, hence, low efficiency due to their poor duty cycle. They are also rather expensive – with the development push going to far UV wavelengths for the semiconductor industries (193 nm), rendering them of increasingly limited use for pumping laser dyes. The efficient laser ion source at CERN ISOLDE uses copper-vapour-laser pumped dye-lasers with post amplification and frequency doubling and tripling. Copper-vapour-lasers emit high power, high repetition rate (about 10 kHz) laser lines in the green and yellow and are well suited for pumping dye-lasers. However, the copper-vapour laser technology is rather unreliable and out-dated and nowadays is being replaced by other lasers (main application in materials processing) as it is both expensive in installation and maintenance (e.g. the pump lasers at CERN are custom made Russian systems).

Therefore it was decided for the TRIUMF resonant laser ion source (TRILIS) to build on new, diode-pumped solid-state laser based technology. State-of-the-art pump laser technology, mainly frequency doubled YAG lasers, are ideal for pumping solid-state titanium sapphire (Ti:Sa) lasers. 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, namely the development of:

- new laser ionization schemes, as the wavelength range covered by the Ti:Sa lasers differs from that of the dye-laser systems,
- frequency-tripling for efficient laser excitation of elements such as Be,
- pulse-amplification of Ti:Sa lasers in the final ionization step, similar to that done in dye-lasers,
- improved ion optics and source design for the extraction of the laser generated ions and suppression of background ions (this work also has to be done at CERN-ISOLDE).

To facilitate the development work needed, a clean room grade laser laboratory was constructed adjacent to the ISAC conditioning station (ICB), by expanding and remodelling an existing storage area. These new installations were used for first tests and proof of principle measurements in November. The ICB was upgraded to allow laser access to the target ion source modules, such that development work and off-line tests for TRILIS can be accommodated without affecting the ISAC experimental schedule (Fig. 202). In parallel, floorspace in the TRINAT laser laboratory was cleared, and a laser table together with electrical and other utilities were installed to eventually accommodate the lasers for on-line TRILIS operation. Stable supports for laser-beam transport to the on-line target ion source module in the west target station have been built and installed. Pre-alignment of the laser beams into the on-line target station as well as modifications to the preseparator to accommodate a shuttered, laser grade optical window are under way during the 2002/2003 shutdown.

A state-of-the-art frequency doubled Nd:YAG laser system was purchased and installed in the off-line laser laboratory in the fall (Coherent Corona 75 W, 5 kHz–25 kHz repetition rate), together with a state-of-the-art pulsed and continuous laser wavelength meter (ATOS LM007). This wavelength meter is key to the precise wavelength determination for the resonant laser excitation. As a spin off, the new wavelength meter was also shared in the December polarized beam experiments.

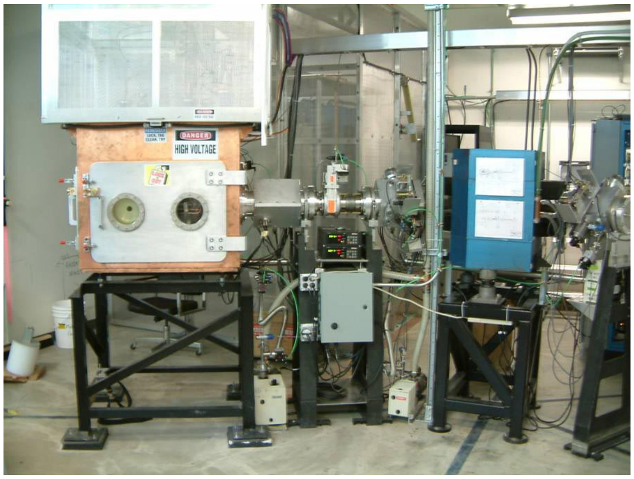


Fig. 202. The ISAC conditioning station (ICB) together with the adjacent laser laboratory (not shown) and the lasers under construction are the heart of the off-line TRILIS development. It allows optimum access to all components, lasers as well as the target ion source module and extraction optics.

Both instruments were successfully tested in a development/test run in November (just 3 months after project start), when the new off-line laser laboratory and the upgraded ICB were used for the first time (Fig. 203). In this test/development run three automated Ti:Sa laser systems were brought in from our collaborators at the University of Mainz (Dr. Klaus Wendt). These Ti:Sa lasers were operated to resonantly ionize Ca and Ga in ICB and learn about the necessary improvements in ion source and lasers.

The collaboration with the group of Dr. Klaus Wendt from the University of Mainz (Germany), a leader in the field of resonance ionization spectroscopy, was formalized. This group's unique Ti:Sa laser systems that are suitable for efficient resonant laser ionization, as shown by their use in plutonium trace detection, are to be copied for TRILIS. Presently there are no commercial Ti:Sa laser systems available that meet all the requirements for resonant laser ionization. The conditioning station was operated successfully with the help of the Mainz group. The Controls group upgraded the control interface continuously during these initial tests. Different biasing and electrode arrangements were tried in the conditioning station. Resonant laser ionization with a one step resonant, one step non-resonant excitation scheme ($1{+}1'$), using two frequency doubled Ti:Sa lasers, was performed on Ca and Ga with encouraging initial results. It was decided

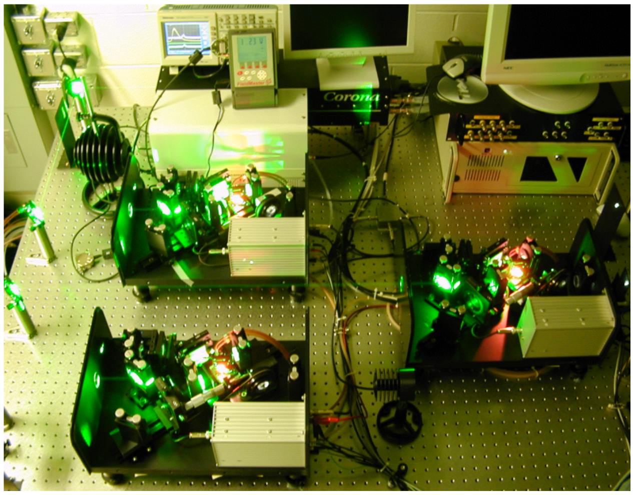


Fig. 203. First TRILIS development/test run in the new TRIUMF off-line laser laboratory adjacent to the ISAC conditioning station. Shown is the compact, state-of-the-art, laser hardware, with the new compact 75 W, 5 kHz–25 kHz repetition rate Corona pump laser (top), the ATOS lambda-meter (adjacent), and the three computer controlled Mainz University narrow bandwidth, tunable Ti:Sa lasers (centre, right and bottom). Not shown are the two Mainz frequency doubling units that were operated in this run as well. The proprietary Mainz Ti:Sa laser systems are now under construction at TRIUMF through our collaboration with the group of Dr. K. Wendt.

that in collaboration with the Mainz group, their proprietary laser systems would be re-built, installed and operated at TRIUMF. Fabrication of components for the lasers and requisition of optics and opto-mechanics for these lasers is under way with first operation of the TRIUMF-Mainz Ti:Sa lasers planned for spring, 2003.

The results from the initial off-line tests of the Mainz laser system and the conditioning station test stand are:

- an efficient TRILIS will have to include a target ion source module with optimized ion optics,
- the simple $(1+1')$ laser excitation for most elements has to be replaced by multi-step resonant laser excitation schemes (e.g. $2+1'$) for higher efficiency.
- the Mainz Ti:Sa lasers proved highly stable and rugged.

For on-line operation the lasers should be located close to the ISAC pre-separator magnet and target ion source, thus the ongoing preparations for an on-line laser laboratory in TRINAT. The overall outlook for 2003 is that the thrust will be towards building three Mainz-type Ti:Sa laser systems with automated controls, set up frequency doubling, as well as to develop, build and test off-line a prototype target-laser ion source module.

ISAC POLARIZER

Polarized beams of ^{8}Li (two β-NMR runs), ^{9}Li and ^{11}Li (one Expt. 903 run), and ^{20}Na, ^{21}Na, ^{26}Na and ^{28}Na (two Expt. 871 runs) were produced for a total of 6 weeks of experimental running time. Polarization was typically 50%, except during the last β-NMR run, when it was greater. The dual frequency Ti:sapphire laser was used for optical pumping during the first β-NMR run. A newly purchased Coherent 899-21 ring dye laser was used for all other runs. The dye laser was performing quite well by the end of the year, although the DCM dye used for pumping Li isotopes has a habit of precipitating out of solution. We are gradually learning how to handle it.

The dye laser frequency lock was upgraded using a new 300 MHz free-spectral-range spectrum analyzer for monitoring the dye laser frequency, in conjunction with a frequency-stabilized He-Ne reference laser. The new spectrum analyzer has higher precision than the original 2 GHz spectrum analyzer. The latter is still required for locking the Ti:sapphire laser and as a reference if the frequency lock (of any laser) is lost. Both spectrum analyzers were enclosed in temperature stabilized, hermetically sealed chambers, which reduced spectrum analyzer drifts by more than an order of magnitude. This eliminated out-of-range problems with the dc voltage offsets to the spectrum analyzer piezoelectric elements. It also eliminated laser frequency drift caused by nonlinearity in the element response.

Slight modifications to the sodium cell design cured a sodium vapour leak and improved the efficiency of the sodium recirculation. The sodium loss rate is now of order 1 mg/hour while operating the sodium reservoir at its maximum temperature of 450° C.

A neutral beam polarimeter was added to the end of the polarizer beam line, downstream of the 3-way bend B21. It measures the beam rate and longitudinal polarization of atoms that are not re-ionized in the helium cell, and which therefore travel straight through the bend. The beam line extension consists of a 5 cm diameter tube with a 5 cm diameter stopper foil inside. The foil has a 5 mm diameter central aperture to allow the laser beam to pass through. Beta particles pass through the tube wall, which is 50 μm thick near the foil, and into upstream and downstream beta detectors in air. Four large Helmholtz coils were added downstream of the helium cell, to preserve the polarization of the neutral beam. A small coil around the stopper foil produces a field of 100 Gs that helps preserve the polarization of the implanted atoms. The neutral beam polarimeter has been used by the β-NMR experimenters as a normalizing monitor for beam intensity and polarization. It is essential whenever the β-NMR spectrometer is used at low field, when the spectrometer cannot detect backward betas due to the very low solid angle of collection.

REMOTE HANDLING

Modules

This year six new modules for the east target station were built. One each of the exit-1, exit-2, entrance and dump modules, as well as two individual target modules, were constructed. Assembly of the shielding plugs, containment boxes, service ducts and top service caps was completed by Remote Handling technicians seconded to ISAC Engineering. Additional assistance was provided for assembly of the beam optics elements for the two exit modules.

Initially the TM #2 surface source target module was completed and installed for east station beam commissioning, followed directly by the TM #3 target for further development of the new ECR source in this module.

Remote Handling

Remote Handling hot cells activities were primarily in support of scheduled target exchanges for TM #1 in the west target station. Four target replacements were completed this year with differing targets installed as required by the experimental beam schedule.

Residual activity of spent targets varies greatly depending on material and μA h of operation but is documented for future reference. This year the SiC #2 target, removed at the end of February, measured at 1.75 R/h@$\frac{1}{2}$m.

At the end of May the SiC #3 target, measuring 4.93 R/h@$\frac{1}{2}$m, was removed due to premature failure caused by an electrical short between the ionizer and the outer conductor. Extensive cleaning was required to remove film and other deposits on the extraction column. At this time one containment box cover screw hole was re-tapped in the hot cell, and all box screws replaced as a preventative measure.

Damaged targets are now being systematically disassembled and inspected in the cell to evaluate failure modes. The SiC #2 target proton beam oven was broken in three separate places. SiC #3 target suffered an ionizer transfer tube failure at the weldment to the oven.

The Ta #3 target (28.3 R/h@$\frac{1}{2}$m) was removed in August, disassembled and inspected. It too had experienced a short between the ionizer and the outer conductor and required extensive cleaning. In October the TiC #1 (16 R/h@$\frac{1}{2}$m) was removed and inspected with no major deficiencies noted.

A new SiC #4 was installed during the August target removal. This was the first target to have the inside of the proton beam oven lined with TaC in an attempt to prevent chemical reactions between the target material the and tube wall; a failure mode previously noted during spent target inspection.

Spent targets are now routinely packaged in the hot cell and remotely transported to the spent target storage vault in the target hall. All targets used during the year are now in this storage facility.

Routine hot cell housekeeping required manipulator repairs, work on the tool port feed-throughs to the cell, maintenance of the dry-nitrogen purge system for the Pb-glass shielding windows and work on the module support turntable drive.

Target Hall

Installation continued on the east target station with services laid-in and connected for cooling, power, rf microwave, diagnostics, vacuum and safety interlocks. Pb shielding along the target hall south wall trench was installed for shielding of the active water system between ITE and the cooling package at the west end of the hall.

The RIB beam line between ITE and the preseparator magnet was completed and the ITWIV5 vacuum gate valve was removed from the beam line for adjustment. A new, cooled, proton beam window at the ITE vacuum tank was installed.

EAST TARGET STATION

In January, 2001, the decision was made to complete the east target station, to be operational by spring, 2002. This was not achieved until July, when target module 2 (TM #2) was installed and conditioning commenced. Stable beam was delivered in late August from TM #2 until the end of September, when TM #2 was removed and replaced with TM #3 which housed an ECR source. This was the first time an ECR source had been installed in a target station at TRIUMF. Stable beam commissioning commenced in late October and continued into 2003.

A detailed report, by work package, of the work necessary to bring the east target station into operation was presented in the 2001 Annual Report. The completion of this work in 2002 will be briefly described below.

Modules

East target station entrance and dump modules are mirror images of the west target station units. They do not embody any other design changes and were completed and installed late in 2001.

Exit 1 and exit 2 and the target module all utilized a completely redesigned shield plug and containment box assembly. Redesign was driven by the requirements of the target module, especially the housing of the ECR source which required five more service connections. Redesign also aimed at improving accessibility for servicing and for improved removal of the service tray and extraction column tray in the hot cell.

The east station exit modules also included redesigned optics in order to be compatible with the ECR source. This, coupled with diagnostics redesign due to the shield plug changes, resulted in basically redesigned exit modules. Installation of the optics and completion of the modules occurred in March and installation of both modules occurred in April. Leak checking and electrical continuity testing followed successfully.

TM #2 was the first module to have the new service connections to the extraction column tray in the containment box. This allows for the complete disconnection of services between the service tray and the extraction column tray such that either can be removed via the hot cell. To achieve this, there are 14 separable water/current junction blocks allowing for the separation of 24 copper service lines which operate at varying voltages – 4 junction blocks are designed to carry currents in excess of 500 A. Routing the 0.25 and 0.375 in. copper tubes with the required spacing to satisfy voltage isolation as well as clearances for tray removal proved to be a formidable challenge and is the main reason the schedule was missed. Due to the close proximity of many joints, soldering was difficult and various techniques had to be perfected. The end result was successful with high voltage checks up to 50 kV achieved to date.

TM #2 was installed in the east station (ITE) in July and delivered stable beam late in August. It was replaced by TM #3 (ECR source) early in October and it delivered stable beam early in November.

East Module Access Area (EMAA)

This is the zone above the modules and vacuum tank and below the 5 removable shield plugs. Experience with the operation of the west target station had indicated that a different approach was required with regard to the running of services in the MAA. The area in the WMAA became congested to the point that general maintenance activities were hindered. To correct this situation, in consultation with the target hall coordinator, a detailed design of the area was produced placing cables in cable trays, rerouting most services to maximize useable floor space, and redesigning the high voltage cage to produce a much neater entry of services to the target module and to allow easier removal. The work was completed during this report period and the results are commendable, as shown in Fig. 204. The west MAA will be reworked in similar fashion in the near future. The EMAA also houses the microwave equipment necessary to drive the ECR source. The power supply and controller are located in the electrical room but the magnetron, isolator and auto tuner are located on the south wall of the EMAA, and interface with the wave guide on the top of the ECR target module (TM #3). The EMAA was completed and operational in the summer.

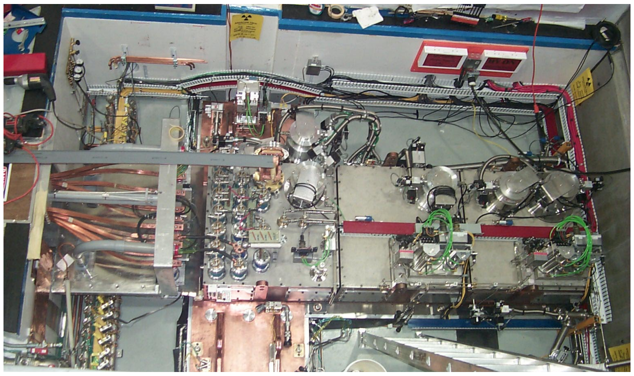


Fig. 204. The east module access area (EMAA).

Faraday Cage and High Voltage Chase

Advantage was taken of maintenance days and shutdown periods, during this report period, to complete the installation of power supplies and equipment into the east Faraday cage located in the electrical room adjacent to the target hall. Perhaps the most complex task was routing the ten 0.5 × 0.5 in. copper high current water-cooled conductors through the bends in the high voltage chase. These are supported by several insulator stands and terminate at a pedestal adjacent to the target module. Flexible cables make the transition from the pedestal to the target module feedthroughs. The chase is then enclosed by shielding blocks and the portion in the MAA is surrounded by the high voltage cage.

ISAC CONTROLS

Highlights of the year include the design and implementation of controls for several new sub-systems:

- Vacuum, optics and diagnostics controls for the east target station including support for an ECR source.
- Completion of controls for the target conditioning station.
- Controls for the ISAC-II cavity test set-up at BC Research.
- Control systems for a target evaporation station and the TIGRESS detector fill system.

During the year, control for 200 new devices was added to the ISAC control system, for a total of 2050 controlled devices.

The distribution of functionality among the EPICS IOCs and PLCs was adjusted in order to decouple different systems as much as possible. The system consists now of 15 IOCs and 8 PLCs.

As in the years before, the Electronics Development Group supplied the hardware support for the ISAC control system, both for design and maintenance.

New Systems

East target station

In order to comply with new specifications for completely independent operation of the east and west target stations, the existing hardware and software had to be reconfigured. One PLC and one VME crate were added to separate west target controls from preseparator and mass separator controls. Reconfiguring the EPICS software was fairly trivial, but the PLC ladder logic programs needed major surgery. At the same time, all ISAC PLCs were moved and consolidated to one cabinet in the bunker next to the control room.

For the east target station, an additional PLC and VME crate were added to the system. Ladder software and EPICS screens were developed interactively. IOC software and device control panels were generated automatically from the ISAC relational device database. Initially the system was commissioned with a surface ion source. Later in the year, hardware and software support for an ECR ion source was added.

Target conditioning station

Control for 25 optics and diagnostics devices was added to the target conditioning station with the usual complement of EPICS software and displays. Commissioning of the system is complete.

Ion source test stand

The ion source test stand was developed in 1996 as a prototype for the ISAC control system. This year it was upgraded for testing of an ECR ion source. The CAMAC I/O hardware was replaced with ISAC-standard VME hardware, which entailed re-wiring of the diagnostics breakout panel. At the same time, the ladder logic and EPICS software was upgraded to meet the ISAC standards. The test stand is now fully supported by the ISAC device database system.

ISAC-II superconducting cavity

At the BC Research location, the ISAC-II superconducting cavity was supplied with a PLC based vacuum control system and an EPICS system for operator interface and supervision of the rf control system.

In order to streamline the communication between EPICS and the rf system, the EPICS portable channel access server tool was ported to the Windows platform and implemented as a DLL. This makes the rf control system look and behave like an EPICS IOC and alleviates the need for a special protocol and a bridge-IOC.

For supervision of the BC Research systems from the TRIUMF site, a virtual private network was set up with the help of the TRIUMF networking group.

Other small systems

The PLC system for the mass separator high voltage area lockup was commissioned and integrated into EPICS.

At the target evaporator, a small PLC system (Modicon Momentum series) was taken over from a co-op student. It was reworked and an EPICS operator interface was implemented and commissioned.

For the TIGRESS detectors, an EPICS operator interface for a liquid nitrogen fill system was developed in collaboration with a co-op student, who implemented the underlying Modicon Momentum PLC system.

Functionality Enhancements

All CAN-bus loops and all stepper-motor devices were modified to allow bump-less reboots of IOCs. Each CAN loop was equipped with a monitor module, which takes over the IOC beacon for a programmable time and thus keeps the loop alive while the IOC reboots. The monitor module has a small LCD display, which allows simple diagnostics on the loop. ISAC stepper-motor devices unfortunately have no absolute position read-back and lose their step-count during a reboot. A software work-around was developed, which uses the IOC's non-volatile RAM.

For operator convenience, remote power cycling of VME crates and CAN loops is being implemented. In the first phase of this project, crates and loops in locked-up areas such as mass separator room and electrical services room were connected.

The OLIS IOC, being the earliest installation in the ISAC control system, used commercial VME I/O modules and old TRIUMF NIM current integrators. These were replaced by the standard, TRIUMF-designed VME modules. A diagnostics breakout panel was rewired, the ISAC device database was updated, and the IOC software was regenerated from the database.

For the laser controls of the ILE2 beam line, software was added to support a new dye laser and a new wave-meter. A wave-form replay utility was developed.

For DRAGON, more diagnostics controls were implemented. The NIM NMR modules were provided with signals for remote search range preset.

As a diagnostic help for the RF group, a temperature monitoring system was implemented. Work on a phase measuring system has started. A signal selection system was implemented. The GPIB part of this system is being worked on.

In support of laser tests at the target conditioning station, the fast EPICS binary archiver was installed and tested.

For the diagnostics group, driver and device support was developed for the Highland Technology v680 TDC module. A Motif based GUI for histogram plot was implemented, in order to overcome the plot limitations of the display manager.

For several Faraday cups on the mass separator and the ILT beam line, new current integrator modules were installed, which read lower currents than the VQSX ADC modules.

As a beam tuning help, a program was developed, which dynamically generates a display page with selection buttons for only those Faraday cups involved with the currently selected ion source and beam mode. The selected cup current is routed to meter widgets on the page.

The PLC ladder logic software was reviewed and received minor upgrades for consistency, to accommodate specification changes by the Vacuum group, and to keep track of operational hours for some devices.

System and Development Support

Two more Linux PCs were added to the operations console. This showed the limitations of using the console PCs as X-terminals since they overloaded the SUN display server. To remedy this situation, an EPICS system was built for Linux. Now the display applications run in native mode on Linux, while the SUN is used as an archive and alarm server. In order to resolve problems with the look-and-feel of the EPICS screens across various platforms, an X font server was installed. It is used by all X-servers on the Linux consoles, the development and production Sun workstations, and the Windows based development PCs. The Linux console PCs are managed by Chris Payne from ISAC Operations who, during shutdown periods, was again a valuable addition to the Controls group.

Two more production SUN workstations were added to the system. One serves the target conditioning station, the ion source test stand, the evaporator, and the TIGRESS detector fill system. The other one serves the ISAC-II cavity test at BC Research. Another SUN workstation was converted from a development machine to a production machine to alleviate congestion in serving displays to experiment groups.

Again this year, a considerable amount of time went into system maintenance on the development and production machines, especially into security enhancements, fire-wall improvements and support for the Linux consoles.

A new line of development was started by acquiring x86 based single-board computers on a PC 104 platform. They will be used as low-cost EPICS IOCs for special applications, e.g. small GPIB nodes, supervision of PLCs, etc. The manufacturer's vxWorks board support package was integrated with Tornado II and the BIOS was modified to allow a diskless boot of vxWorks.

More documentation, tutorial material and troubleshooting information was added to the ISAC controls Web site.

As a database exploration project, the ISAC controls asseting database was converted from Microsoft Access to the public domain database system PostgreSQL. This database is accessible by Web browser. The Web interface was implemented using the Perl DBI module.

Commissioning and Operation

After commissioning of the east target station early this year, the support of beam delivery became a priority. This was sometimes difficult as many scheduled maintenance days were used for beam tests with stable beam.

Implementing bump-less IOC reboots reduced the downtime due to controls considerably. The same can be said for the addition and reconfiguration of PLCs and IOCs. A balance, however, had to be achieved between cost and functionality. As a consequence, several of our IOCs operate with a memory load, which is higher than comfortable for extreme operating situations.

VACUUM

The vacuum systems of the cyclotron, cyclotron beam lines, ISAC-I targets, ISAC-I beam lines have been functioning well for beam production during the year.Vacuum problems encountered were dealt with in a timely manner and the impact on the beam production was negligible. The ISAC-I east target vacuum system was built and successfully commissioned.

Cyclotron Vacuum System

Three instances of problems occurred with the B20. These were all related to the regenerators on the 20 K stage.

A new Varian 551 turbo pump was installed on the cryoline connecting the B20 cryogenerator to the cyclotron. The pump replaced the original diffusion pump to shorten the turn around time during cryogenerator defrosts.

Beam Lines

A large vacuum leak occurred in the 2C4 line due to the beam induced melting of the indium seal. This seal was replaced. A number of vacuum leaks were diagnosed in beam line 1A. These are scheduled to be fixed during the spring shutdown. The rest of the group activities concentrated on routine MRO.

RF SYSTEMS

In 2002 the ISAC rf systems performed well with an overall reliability of about 94%. The major activities include:

- ISAC linac maintenance and operation.
- DTL power couplers protection.
- DTL fine tuner upgrade.
- Phase measuring system development.

RFQ

The RFQ operated quite reliably during the past year. The only trouble experienced was associated with malfunctioning of the ac switchgear system feeding the anode high voltage power supply. Both the conventional breaker and fast switchgear failed. The breaker contacts melted and welded together. The switchgear had difficulties due to transients in the control circuits. Both malfunctioning units were replaced. In order to provide a smooth start up for the system, a dedicated ramping circuit was developed. It is based on SCR elements and allows a slow voltage rise to prevent high inrush currents and very fast power cut off (8 ms compared to 24 ms in the mechanical switch), to reduce ignitron tube overloads.

For the RFQ structure a high power pulsing had been performed twice to reduce the build up of dark currents.

MEBT Rebuncher

Most of the problems with the rebuncher were triggered by unstable operation of the commercial rf amplifier, which could easily go into parasitic oscillations when loaded with an unmatched high-Q resonant load. Poor design of this amplifier made it difficult to reliably adjust or modify. An entirely new 35 MHz, 500 W amplifier was built and commissioned in March and has since operated very reliably.

DTL

DTL systems routinely operated mostly at about 4/9ths of full power (A/q $\approx$ 4) according to scheduled experiments. A lot of effort was dedicated to reliable operation of DTL rf amplifiers, couplers, tuners, troubleshooting and upgrade. During the winter shutdown all the DTL cavities, fine tuners and couplers were opened for inspection and assessed for problem areas (see corresponding sections below). Most of the tank inner surfaces were darkened and sometimes discoloured due to multipactoring. No spark traces were detected on rf structure elements. Similar to last year, soldering flux patches were observed, this time around the upstream nose cones of DTL tanks #3 and #4 (see Fig. 205). This is a manufacturing defect, which is very difficult to eliminate. Residuals were cleaned off the surface.

Fig. 205. Soldering flux patch in DTL tank #4.

Last spring a safety interlock for the DTL radiation protection cage entrance was commissioned. It allows access to the DTL cavities only when rf is below a predetermined radiation limit. RF cannot be turned on if this safety interlock is not engaged.

In 2001 we faced many interruptions caused by vacuum trips. Replacement of ion gauges, installation of screening grids and distancing the ion gauge from the cavity volume by means of extension pipes did not solve the problem. On the assumption that the problem was caused by a penetration of charged particles ionized and accelerated in the presence of an rf field, extension elbows were installed on all DTL ion gauges and the problem disappeared. Other DTL system interruptions were caused by water flow interlock trips. This was traced down to a grounding loop problem, which led to malfunctioning of the control boards and was subsequently fixed with proper grounding.

DTL amplifiers

All the DTL rf systems are energized by identical 106 MHz amplifiers based on an EIMAC 4CW25000B tube. Last year most of the tubes had reached 10000 hours of operation and a substantial degradation in their performance was observed. One tube showed a grid to cathode short, filament burnt in another one and 4 more aged, providing low cathode emission. Five tubes out of 8 tubes in operation had to be replaced. This triggered a detailed investigation on the tube performance. Two major conclusions were derived as a result.

1. Hairpin filament structure in a different tube type (4CW25000A) is almost insensitive to thermal deformation, while the tube is warming up, compared to the mesh filament structure (4CW25000B). So, application of a type-A tube dramatically cuts the downtime for system conditioning and reduces the probability of a thermal grid-to-filament short circuit.
2. Most of the tubes were running at slightly increased filament voltage, which is good for tube conditioning but not for operation. The supplier claims a 15% reduction in filament voltage should double the tube lifetime.

Based on these findings, we decided to gradually replace all B-type tubes in use with A-type tubes (4CW25000A). Also all filament transformers were replaced with new ones with proper voltage taps and all filament operational voltages were reduced by 15% from the nominal values.

Several amplifier trips due to insufficient water flow in the anode cooling circuit occurred due to a clogged pressure reducing valve with water impurities. In the September shutdown a dedicated filter was installed in the system.

DTL couplers

Due to the number of coupler window failures, infrared temperature sensors were installed on all power couplers to diagnose the problem in the early stages of deterioration. Indeed it helped to detect 4 more coupler deteriorations and save them from being destroyed. In DTL tank #2 a silver alloy evaporated from the coupling loop soldering joint (see Fig. 206) and spattered all the surfaces around including the ceramics (see Fig. 207). Three other couplers failed in DTL tank #5. Couplers were replaced with spare ones and an enhanced study was conducted in order to determine the cause of the trouble. A dedicated vacuum vessel was set up to test the couplers (see Fig. 208). A 106 MHz test amplifier provided rf power up to 8 kW.

Test studies brought us to a conclusion that coupler coating is triggered by a secondary electron emission discharge (multipactoring). In DTL tank #5 it happened during abnormal operation of a starting procedure when switching from pulse to cw mode causing excessive rf voltage. RF controls operational parameters were readjusted and failure never happened again. Buncher #2 coupling loop was copper plated to screen

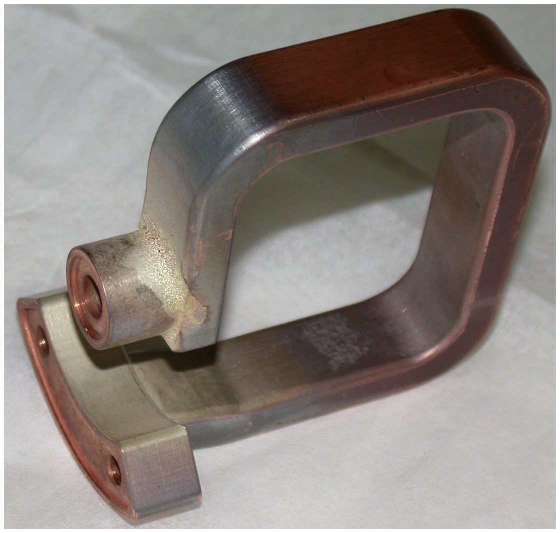


Fig. 206. Buncher #2 coupling loop with a failed soldering.

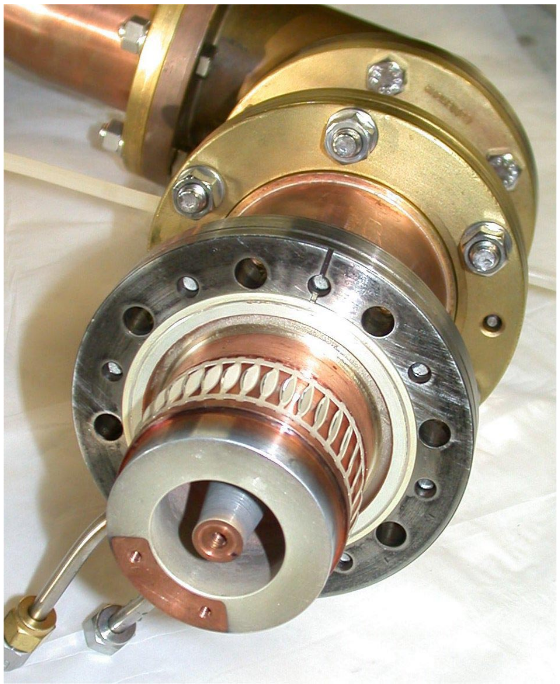


Fig. 207. Buncher #2 coupler – silver spattered.

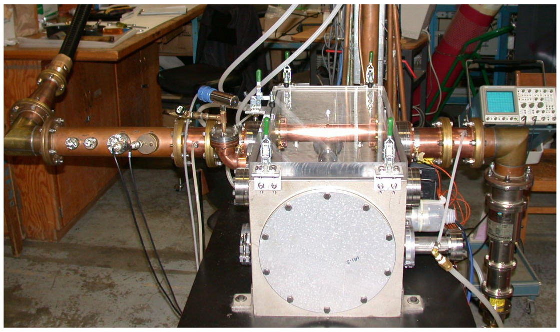


Fig. 208. DTL coupler test stand.

the brazing alloy from rf fields. All other coupling loops are scheduled to be copper plated as well during the next shutdown.

An easy and economical restorative solution has been found for the degraded couplers. It involves an abrasive removal of the coating by means of a sand blaster. With this procedure all 4 malfunctioning couplers were rebuilt to their original specifications.

DTL tuners

All DTL systems use capacitive tuners driven by identical drives. The weakest point of this drive appeared to be the rf fingerstock contacts between the moving copper shaft and a ground flange. During shutdown inspection almost all shafts were found scratched. The most damaged MEBT rebuncher tuner shaft is shown in Fig. 209. The reason for this failure is a constantly moving tuner, which operates in a feedback loop for frequency regulation. The fingerstock cannot stand that heavy load. Operating in vacuum without lubrication, they get worn and start scratching the copper shaft. These contacts serve to shield a stainless steel bellows from rf currents, which could result in excessive heat on the bellows. An extensive design review and bench tests were undertaken which led us to the conclusion that the fingerstock could be removed without causing excessive heat on the bellows. Bench tests showed that 25 W dissipated power caused a bellows temperature rise up to 100°C without cooling while application of air cooling allowed 100 W power dissipation with a moderate 40°C temperature rise. A full-scale test on DTL tank #5 confirmed our optimistic assumptions regarding operating the tuner without fingerstock. At a 20 kW power level the bellows temperature rose only by 6°C even without air-cooling. Following this positive outcome we removed the fingerstock from 4 more DTL operational tuners. Subsequently all the modified tuners were equipped with thermocouples to ensure our control over bellows temperature. A few months of operation didn't show any noticeable degradation in system performance. The rest of the tuners are scheduled for modification during the next shutdown.

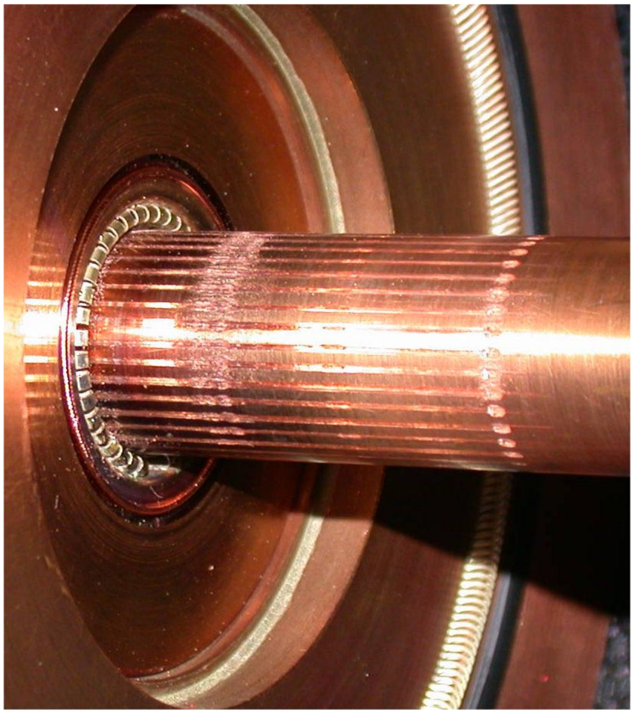


Fig. 209. Damaged MEBT rebuncher tuner shaft.

HEBT High Beta Buncher

The 35 MHz high beta buncher showed reliable operation last year, apart from one failure when a coarse tuner plate disintegrated from the shaft and shorted the rf spiral structure. The cause was traced to the wrong size of lock screw, which connects the plate on the shaft.

Phase Measuring System

An auxiliary phase measuring system has been developed for the ISAC rf system. It provides precise phase difference measurements between the reference rf source and each individual rf device. The need for this system comes from the operation of a multi-cavity variable energy linear accelerator, which dictates very high tolerance (fraction of degree) for rf phase stability and reproducibility. The set-up includes a frequency synthesizer, an rf switcher and a Hewlett Packard vector voltmeter (see Fig. 210). The synthesizer is excited by a 5.89 MHz ISAC rf controls reference signal and provides all ISAC rf system harmonics: 5.89, 11.78, 23.57, 35.36, 106.08 MHz with a very good stability (0.1°) with respect to the reference signal. An rf switcher combined in 6 NIM modules provides proper rf connection of the voltmeter to the desirable rf cavity and corresponding frequency multiple harmonics from the synthesizer. The SW221 chip is a basic element of the switcher. It provides 100% reproducible connection and very high isolation between channels (better than −75 dB). The vector voltmeter measures amplitudes and phase difference between 2 rf signals of the same frequency. Voltmeter phase resolution is about 0.1°. All the rf signals are canalized through semi-rigid phase stable cables in order to reduce temperature dependence and dielectric aging effect. The device is located in the DTL cage vicinity to make all feeding cables shorter and thus further reduce unwanted systematic errors. All hardware was tested and calibrated. An EPICS based control system for this device will be commissioned at the beginning of next year. In

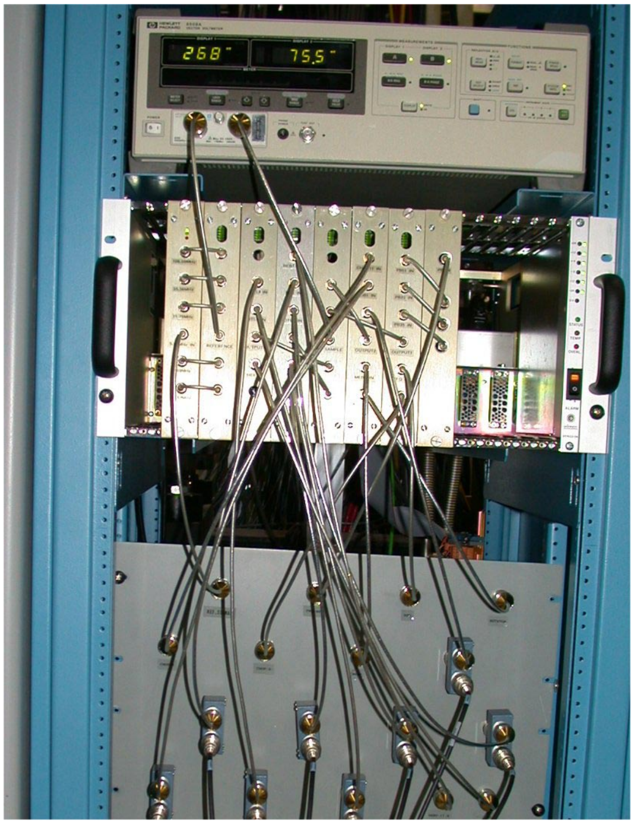


Fig. 210. Phase measuring set-up.

the manual mode this system has already helped us in troubleshooting beam instabilities.

RF Controls

Over the year the RF Controls group regularly provided routine tune up of the rf control system. Upgrade work had been done on the input circuits of the control modules in order to increase stability and reduce rf interference between subsystems.

A sufficient stock of spare modules has been built.

The rf controls system is operated by special software running on personal computers (PC) under Windows-95. Over time these PCs are becoming obsolete. During operation, we have intermittent software crashes due to PC hardware problems, many of them thermal in nature. To improve system reliability, 3 out of 6 operational PCs were replaced with newer units. The rest are scheduled for upgrade during next year.

BEAM DYNAMICS

The ISAC test stand is to be extended to test the charge state booster (CSB) for ISAC-II. Optics were designed to match into the CSB, leaving a 2 m long $-I$ transfer section open to allow for possible later testing of an RFQ cooler. After matching out, beam is directed through a 90° magnetic bend and two 45° electrostatic bends. The combination allows a mass resolution of 250 in spite of an energy spread of 2%. All optical elements are standard ISAC LE designs, except for the magnetic dipole, which was inherited from the decommissioned M8 beam line.

The following LE beam line sections were commissioned or re-commissioned: GPS, 8π, Osaka, new bender for the OLIS. All performed as designed, with settings close to theoretical values.

We began development of a graphical user interface (GUI) for beam envelope calculation. 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.

BEAM COMMISSIONING AND DEVELOPMENT

In 2002 the ISAC accelerator moved from commissioning and training to full beam delivery mode. No new equipment was commissioned during this period. Work instead consisted of operator training as well as standardizing tuning schemes and providing tuning support for new experimental set-ups.

Beam Delivery

Stable beams of $^{4}He^{1+}$, $^{12}C^{3+}$, $^{14}N^{4+}$, $^{20,21}Ne^{5+}$, and $^{24}Mg^{6+}$ were delivered to the two experimental facilities DRAGON and TUDA at various beam energies. Radioactive beams of $^{20,21}Na^{5+}$ were delivered to DRAGON during two different run periods.

A summary of the stable and radioactive beams delivered to experiments through to the end of 2002 is shown in Fig. 211.

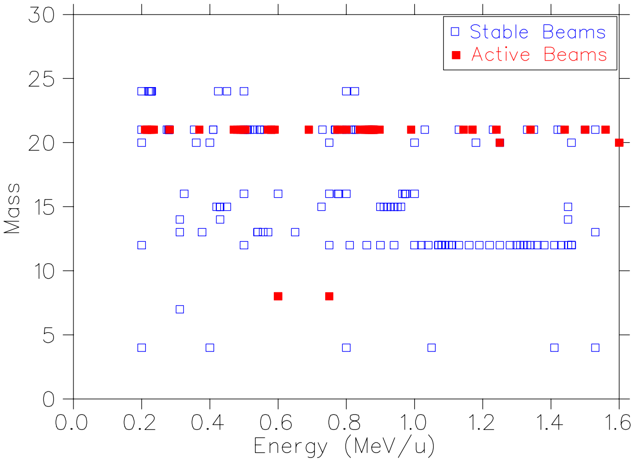


Fig. 211. A summary of stable and radioactive accelerated beams delivered to experiments through to the end of 2002.

Upgrades

The Prague magnet, a 90° analyzing magnet in HEBT, is used for measuring the energy and energy spread of the accelerated beam. The field is set by a Hall probe located on the magnet entrance. Due to the large energy range and A/q range of the delivered beams, the Hall probe has to accurately cover a wide field range. Initially the Hall probe was given two gain ranges. It was found that there was a small offset between the two ranges and so energy measurements at the transition zone were dependent on the gain range selected. A single gain range spanning the full field range has now been implemented.

ISAC DIAGNOSTICS

Fast Faraday Cups

The rf bunching and accelerating fields in ISAC gather the beam into short bunches whose length is measured by fast Faraday cups (FFC). At low beam currents their signal can be buried in noise but the averaging features of the development Tektronix TDS 820 6 GHz oscilloscope enhance the coherent beam related part. There are now several FFC in ISAC and a reconditioned Tektronix TDC8000 6 GHz sampling oscilloscope has been purchased and installed in the HEBT for their use. This oscilloscope can accommodate up to four dual input modules but since these are expensive, only one was purchased and instead a rf signal multiplexer was built. The development oscilloscope is presently on loan serving the MEBT FFC.

Control of the oscilloscopes and the remote display of their screens is performed by a LabVIEW program running on the Sunray control computer. The previous set-up used a National Instruments Ethernet to GPIB adapter with GPIB driver software in LabVIEW to communicate between the control room and the oscilloscope. The adaptors were replaced with units from Agilent that use the VXI-11 protocol of VISA 2.6 and this eliminated the need for the GPIB driver layer of software. The LabVIEW program was revised to take advantage of special features of the TDS 8000 that enhance the display.

The bunch shape at currents below the threshold of the FFC has been measured using a thin gold target to scatter ions into a silicon detector. Analogue nucleonics and a MCA have been used to acquire and display the data. The ISAC Electronics Development group has collaborated in writing an EPICS driver for a Highland VME TDC and this will allow the ISAC control system to display the bunch shape directly to the operators.

The geometry of this first detector used a rather backward scattering angle of 98° in order to observe a well-documented α-C resonance; the choice of angle was also constrained by neighbouring equipment. The data accumulated had almost no background but the count rate was slow and the permanent monitors now being drawn up will use a more forward angle of 30°. The targets have been damaged in the past by vacuum accidents. Flow restrictors have been fitted to both the venting and pump down lines and the new design will retract targets into a sleeve for further protection.

The Electronics group has also built a current integrator and digitizer that, with a small local 12 V power source, could be placed close to the electrical feedthrough of, for example, a Faraday cup in order to reduce the effect of any external pickup and improve the beam measuring sensitivity.

Our standard FFCs extend along the beam axis and are too long to fit into the narrow monitor boxes of the linear accelerator and bunchers. Argonne National Laboratory developed the concept of a FFC based on a stripline placed normal to the beam direction. We have designed and partially assembled such a monitor. It is formed from a copper plated ceramic board and the FOILTEMP program was used to investigate heating of the thin copper mesh that will shield the pickup electrode from the EM field of the approaching beam bunch. It will allow beam bunch shape measurement in the diagnostics boxes of the DTL or ISAC-II provided that a beam current of 10 to 50 enA is available.

Prague Magnet

An air-cooled 90° bending magnet, the Prague magnet, has been used as a spectrometer to commission the ISAC-I accelerators. The current from its power supply is stabilized, at all but the highest values, by a signal from a commercial Hall probe processed by TRIUMF-built electronics. The probe and module had been calibrated against an NMR in a different magnet and the system cross-calibrated against two well known nuclear resonances. The data available led to the belief that the system was linear. Nuclear physicists began to use this spectrometer to measure beam energies and incorporate the results into their analysis. The results accumulated over time implied that the resolution and reproducibility were not sufficiently accurate for their purpose.

The ISAC Electronics group modified the electronics to provide a single scale that spanned the operating range of the magnet and thus eliminated differences in offset between two scales. The probe and electronics were calibrated at finer intervals and a significant non-linearity discovered; it arose chiefly from the electronics. A different probe and a more linear module were obtained and installed in the magnet. The stability of the current from the power supply was measured using a DCCT. Data taken when the supply received its feedback signal from the Hall probe showed a just acceptable drift.

The magnetic field of the magnet has not been mapped in its entirety because of its shape. This ought to be done since the yoke goes into saturation and becomes sensibly warm at fields required by the more energetic heavier particles and it may be that portions of the iron behave differently from those where the probe is located. An alternative might be to calibrate the system over its momentum range using known nuclear reactions.

Other ISAC Diagnostics

ISAC has delivered beams to several types of experiments over the past two years. Several ion species, both stable and unstable, have been delivered at energies ranging from those emerging from the ion source terminal to ones accelerated by the RFQ and DTL. Diagnostic requirements were re-evaluated in the light of this operating experience and new priorities have been assigned. The top priority is an instrument to measure beam flux at cw currents from a few per second to 5 epA. This is followed closely by a) a device to measure the phase at each tank of the DTL at currents < 5 enA; b) modification of that equipment in HEBT which uses particle detectors or electron multipliers to measure the distribution in time of a low intensity beam bunch to (i) shorten the collection time and (ii) also give the distribution in space; c) installation of such a low intensity profile monitor in front of the MEBT chopper slits and d) elimination of the electrons created by field emission in the DTL that can mask signals from the beam.

A lot of effort early in the year went into equipping the new east production target for ISAC. Profile monitors 2A3M17 and 2A3M18 for the proton beam were installed in the east leg of 2A and also a new secondary emission harp profile 2A2M18 was installed upstream of the west target station. (This was used in the test of the VICA 96 cards described in the Engineering Physics section). A wire scanner and protect monitor were built and installed in the target entry module. Two harp profiles, a shutter monitor, collimators and a Faraday cup were installed in the exit modules leading to the preseparator region mimicking the arrangement on the west side. All were equipped with cables and signal processors, and connected to the control system and tested.

The standard target protection monitors derive their signal from electrons produced as protons pass through their plates. Ground planes are placed between biased plates and signal plates to intercept any leakage currents. A similar construction was used successfully in the manufacture of a quadrant halo plate monitor for the TUDA collaboration, although in this case ions stop on the plates.

The Faraday cup in the diagnostics box DB0 near the dispersed focal plane of the pre-separator magnet was damaged during a high current test of the stable beam from the ITE ECR source in September, 2001. A temporary repair was made while a new Faraday cup was being designed to permit higher beam power. The repair was done using a special glove box designed specifically for DB0 devices. It was a very useful learning experience in dealing with components contaminated by radioactive dust and ions. Absolute encoders were also installed for improved control of the DB0 slit and Faraday cup motions. The new Faraday cup will be installed in February, 2003. At the same time the DB0 slits will be replaced as an MRO exercise; in part to test the remote handling techniques that have been developed and in part to reduce the accumulated inventory of activation.

A second employee has been taught to lift and mount the 3–5 μg/cm^2 stripping foils used between the RFQ and DTL. A number of foils were prepared and loaded on the MEBT foil changing mechanism. Following the Beam Instrumentation Workshop at Brookhaven, the opportunity was taken to visit the BNL laboratories and shops manufacturing equipment for the electrostatic heavy ion pre-accelerator and the cryogenic synchrotron, RHIC. We were impressed by the stripping foil exchange mechanism designed by BNL; it is more reliable and easier to service with foils than the second hand NEC mechanism presently used in MEBT. Drawings have been obtained from BNL and their design principles will be used for any new foil or target changes required for ISAC-I or II.

ISAC-II

The components in each of the cryomodules being built for ISAC-II will have their alignment checked before installation. A system under development will attach quadrant stripline position monitors to each, solenoid and rf cavity. They will sense the field created when an rf signal travels down a wire stretched parallel to the axis of the module. This system, which will be a major project in the coming year, will be transferred from module to module as they are built.

General

We have purchased a turbo pump and a roughing pump with their necessary controls and gauges. A vacuum station will be set up in the probes lab and used initially for testing equipment before installation and, in the longer term, for various research and development projects.

Once again a significant amount of time has been consumed by routine maintenance work and other general activities; this was exacerbated by the illness of the MRO technician. Radiation damaged cables were replaced, modules replaced or repaired and the frequent failures of the 0865 300 V bias supplies has necessitated a program to modify them all. Advice is given regarding interpretation of signals to operators and experimenters and a talk on the Principle of Beam Instrumentation used by Nordion was given to a new group of AT operators.

Meetings

The Diagnostics group biweekly meeting notes are available electronically via the Operations CYCINFO information service on the site computer cluster (accessible also through the TRIUMF home page on the WWW). The winter cyclotron shutdown activities, including the report on the ISAC DB0 installation, are summarized in detail in the Diagnostics group meeting notes of May 24, 2002. The detailed fall shutdown report is included in the meeting notes of October 11, 2002.

EXPERIMENTAL SUPPORT

The Experimental Support group, which includes the Beam Lines group, is part of the Science Division and was responsible for the installation, alignment and maintenance of the experimental facilities at TRIUMF as well as support for the primary beam lines and maintenance, repair and operation of the secondary channels. As in 2001, the group supplied technical assistance to the existing experiments as well as technical support to ISAC. The Beam Lines group continued to provide alignment assistance to ISAC, Remote Handling and the RF group.

2A Beam Line

The beam line to the east target station was installed and aligned. The first 15 degree bender was moved to a second position. The 2A Wye magnet was installed in its place with steering magnets and "bunny" quads also installed and aligned. The Wye magnet can switch beam from the west target station to the east target station. The overall project took about 2 months.

β-NMR

A permanent telescope mount was placed after the GPS 2 alignment port to align the cryostat in the β-NMR experiment. This allowed the position of the sample to be checked without compromising the vacuum.

DRAGON

Two lead shielding frames in the DRAGON beam line were installed to protect personnel from X-rays emitted from the diagnostic boxes inside.

A DRAGON target analysis telescope was designed and installed. An Opti-Cal program was used to calculate the lenses required for focusing on the DRAGON gas target. The photograph obtained using an astronomical colour camera illustrated the hydrogen gas target beam glow.

GPS 2

A beam tube in the LEBT line was modified with glass view-ports to see the polarimeter without breaking vacuum.

Magnets

The old M8 bender magnet was rebuilt and installed in the off-line ion source test stand. The magnet needed new lifting lugs and the pole gaps were shimmed to meet the specifications for bending the beam into the analysis station after going through the charge state booster. The water manifolds and hoses were replaced as well as the thermo-switched interlocks. The magnet was field mapped and assembled on the stand and aligned in the test stand beam line.

CONVENTIONAL FACILITIES AND INFRASTRUCTURES

A number of construction projects were completed and a good number of maintenance activities carried out. Continuing engineering support was lent to ISAC Operations group, the Accelerator group, the Engineering group and the Science Division. General activities included attendance at regular progress and engineering meetings and participation in engineering design review. Dust accumulation continues to be a concern in the experimental hall, where a large number of electronic devices are housed. This problem has to be tackled once the construction of ISAC-II is complete.

Electrical Services

Engineering efforts focused on the experimental facilities, the target conditioning facility and the east target. Completed tasks included services for experiments like DRAGON, TUDA, 8π, the polarimeter, Osaka, the laser spectroscopy experiment, and other facilities like the laser ion source, the target evaporator, the 60 kV bias target conditioning system and upgrade to OLIS. About 40 installation orders were processed for ISAC alone. The majority of wall mounting transformers were retrofit with aircraft cables for seismic anchoring and the grounding around the LEBT was improved. The east target ion source HV terminal and grounding were commissioned in February.

Support to the Safety group continued with the installation of the tamper-proof conduit runs for the radiation monitoring systems and the HV interlock systems.

On the maintenance front, we had a couple of serious problems to address. The RFQ main relay started malfunctioning. As a result, the feeder breaker in MCC-T, the main power distribution centre, failed possibly due to overstress since the over-current protection function of the main RFQ relay had not been working reliably for some time. The breaker was replaced and the breaker-relay time coordination curves revisited. It was determined that the very high start-up (*in-rush*) current requirement of the RFQ input transformer together with a very fast trip function could not be satisfied by a standard industrial breaker or the relay. To limit the in-rush current a soft start device was considered as an addition to the existing RFQ line. The RF group took it upon themselves to install the soft start interface during the upcoming shutdown. One of the power supply cards of the experimental hall UPS failed. The failure revealed a mis-coordination between the UPS unit breaker and the feeder breaker. The latter will be replaced during the next shutdown. A replacement section for MCC-X was purchased and will also be replaced during the upcoming shutdown.

Mechanical Services

A large effort was spent on the completion of ISAC-I. The east target project included installation of cooling water, compressed air, vacuum, and air conditioning service spread over three areas: target hall, electrical room, and BL2A tunnel. New laser installations in room 104 and the experimental hall required ventilation and cooling water service. New water service was provided for the low-β buncher and new filters installed for various rf power supplies. Vacuum roughing lines were provided for GPS and β-NMR. Target lab jobs included water to the evaporator, and vacuum pump exhaust.

Development and MRO work included a new flow switch for the DRAGON hydrogen vent, new circulation pump for the DRAGON cooling package, more fresh air inlets (some to replace those covered up by ISAC-II links) for summers in the experimental hall, new chiller 1 refrigeration compressor, repairs to 8π, TUDA and TRINAT air conditioning, leaks of roof top units, non-active low conductivity water de-ionizer resin catcher, and festooning cable of experimental hall crane.

Various maintenance activities included the replacement of the Chiller #1 unit which failed the previous year, the repair of AHU #3 in the electrical room and regular servicing of the various air conditioning units and the target radiation exhaust system.

Engineering assistance was lent for calculations of gas escape rates in the solenoid helium vessel, and water flow rate through the ECR source.

The ISAC-I distributed digital control (DDC) was converted and integrated with the ISAC-II DDC. The new DDC system allows the operator to interface through EPICS. The conversion proceeded with most of the control systems replaced, installation of new outlets in the main control room and trailer V, and personnel training.

The temporary SCRF lab at BC Research required installation of clean room ventilation, an ultra-pure water supply system for the rinse, and nitrogen lines. Tie-ins for ISAC-II gas, compressed air, and various water systems were made in the existing ISAC-I lines.

ISAC PLANNING

This year the Planning group was involved in planning, scheduling, coordinating and expediting several sub-projects for both ISAC-I and ISAC-II.

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.

ISAC-I

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 to: the east target station that was installed in the winter shutdown; the ECR source (to be installed in TM #3 and tested with beam in November); expedited low energy experimental program that included the β-NMR and Osaka beam line.

East Target Station

This project received high priority and had to be fast-tracked for installation in the January shutdown. The project was broken down into 9 work packages and major highlights included: 2A beam line (2A3 beam line installed in winter shutdown); Faraday cage (most work done in winter shutdown and remainder completed by summer with limited access to electrical room due to ITW beam operation); target hall (included modification and commissioning of south hot cell and alignment components and water package shielding in March); controls (included 2A controls, target protect interlocks and RIB controls for vacuum system, beam optics and beam diagnostic systems completed in the winter shutdown).

The work on the modules required extensive Design Office and Machine Shop effort. Several design modifications were made for better manufacturability and remote handleability. Initially the plan was to make TM #2 and TM #3 interchangeable but later complications associated with installation of the ECR source and the microwave guide and generator excluded that provision. TM #3 was designated as the module for the ECR source at ITE, and TM #2 with surface source at either east or west target stations. Some of the major technical challenges that took longer than anticipated included accurate assembly and installation of 30 tubes and 14 water blocks in the containment box. Consequently the commissioning was delayed significantly as exit modules 1 and 2 were installed in April and TM #2 (with surface source) was installed in July, followed by leak checking, fixing water leaks, and high voltage checks by September. The ECR source was tested on the test stand by September. TM #2 was removed and TM #3 with the ECR source was installed in October, followed by checks and tests with stable beam in November.

Target Conditioning Box

An alternative conditioning system was designed and fabricated by January to expedite the process of changing and conditioning ISAC targets. Assembly continued until April due to lack of manpower.

Experimental Facilities

The Osaka beam line was installed and tested in October/November with new chamber and associated services. The 8π beam line with a simple chamber was commissioned with a test beam in December.

DRAGON and TUDA started commissioning with stable beam followed by RIB. Some of the major hardware items completed for DRAGON included: modular security fence with safety interlocks, service platform, lead shields for charge slits and mass slits diagnostic boxes, and universal alignment fixture.

ISAC-II

PERTs were prepared and monitored for all ISAC-II projects, and activities were coordinated and expedited to meet various milestones. Major milestones achieved for the medium β system included: commissioning tests on Nb cavity with rf controls in June, with mechanical prototype tuner in October, and with μ-metal in November, tuner development and final design released in November, order amplifiers in December, prototype solenoid ordered in October with delivery in March, 2003. Fabricated cavities at Ezanon progressed well with delivery in January, 2003, to be followed by chemical treatment at CERN by April, 2003. Extensive effort was spent in planning cryomodule engineering. The conceptual design was reviewed in November and three designers were allocated to complete the design of the tank, lid, LN_2 shield, liquid helium reservoir, frame and suspension system, intermodule zone, and jigs and fixture by March, 2003, fabricate and assemble by September, 2003, with an aim to do cold tests and test the cryomodule with rf in October, 2003. The refrigeration system is on critical path because specifications were delayed due to lack of appropriate manpower and information.

Work continued on high β beam dynamics, HEBT transfer line (layout, specifications and concept design of dipoles), and charge state booster (components ordered in February and received in November, design CSB stand in fall, modify analyzing magnet in December), with an aim to test the whole system on the test stand by October, 2003.

CONTRACT ADMINISTRATION

In the past year three contracts were awarded: E. Zanon S.p.A. of Italy manufactured 20 bulk niobium QWR sub-assemblies for the ISAC-II superconducting Linac. DANFYSIK A/S of Denmark manufactured 20 HEBT quadrupole magnets for the ISAC-II transfer line. Pantechnik of France supplied an electron cyclotron resonance ion source, “PHOENIX”, to be used as a charge state booster for ISAC-II.

Personnel Resources

ISAC-I

In 2002 the average monthly personnel effort for ISAC-I decreased by approximately 26 people per month to an average of 50.76 FTE people per month (see Fig. 212). In 2001 the FTE effort per month was 76.15 people. The total work effort expended on ISAC-I from the start of the project on January 1, 1996 to December 31, 2002 has been 473.52 years, based on a FTE work-month of 150 hours per person.

Figure 213 shows the FTE persons per month for the various sections of ISAC-I in 2002.

ISAC-II

The recording of work effort for ISAC-II started October 1, 2000 (see Fig. 214). 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. Figure 215 shows the FTE persons per month for the various sections of ISAC-II in 2002.

Figure 216 shows the FTE years of work effort for each section of ISAC-II since the project began on October 1, 2000 up to December 31, 2002.

The total work effort expended on ISAC-II from the start of the project on October 1, 2000 to December 31, 2002 has been 16.26 years, based on a FTE work-month of 150 hours per person.

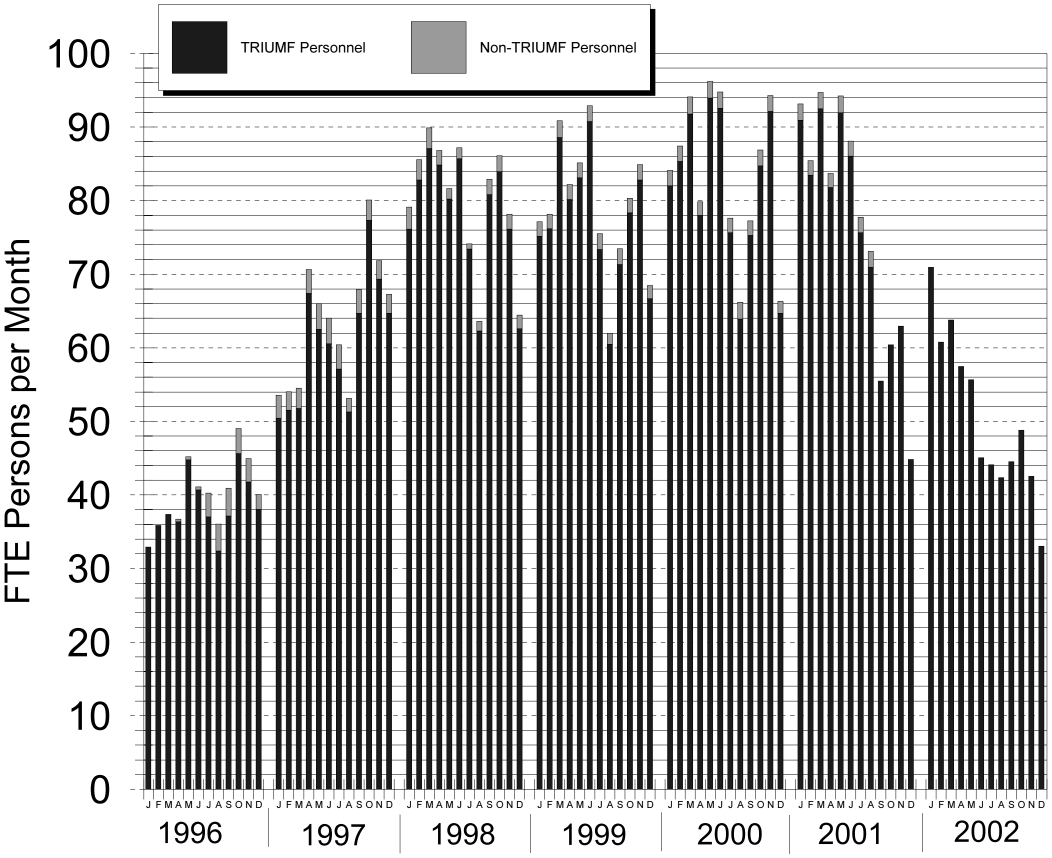


Fig. 212. ISAC-I monthly personnel effort, January 1, 1996 to December 31, 2002.

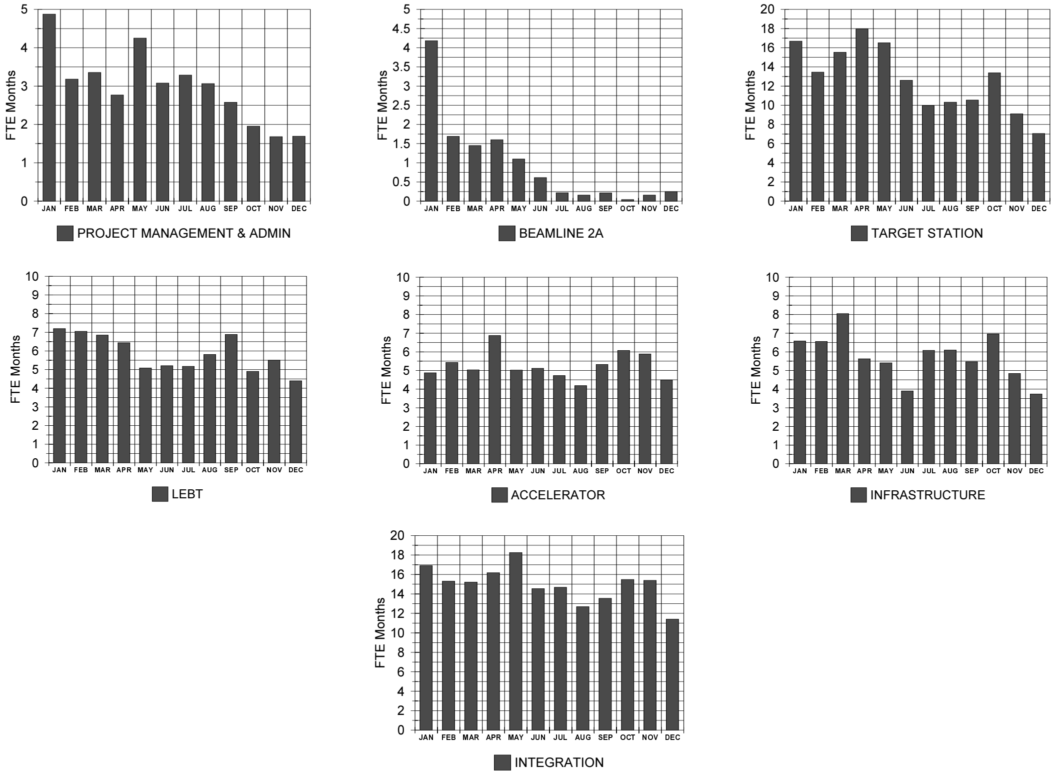


Fig. 213. ISAC-I monthly personnel effort, shown by section for 2002.

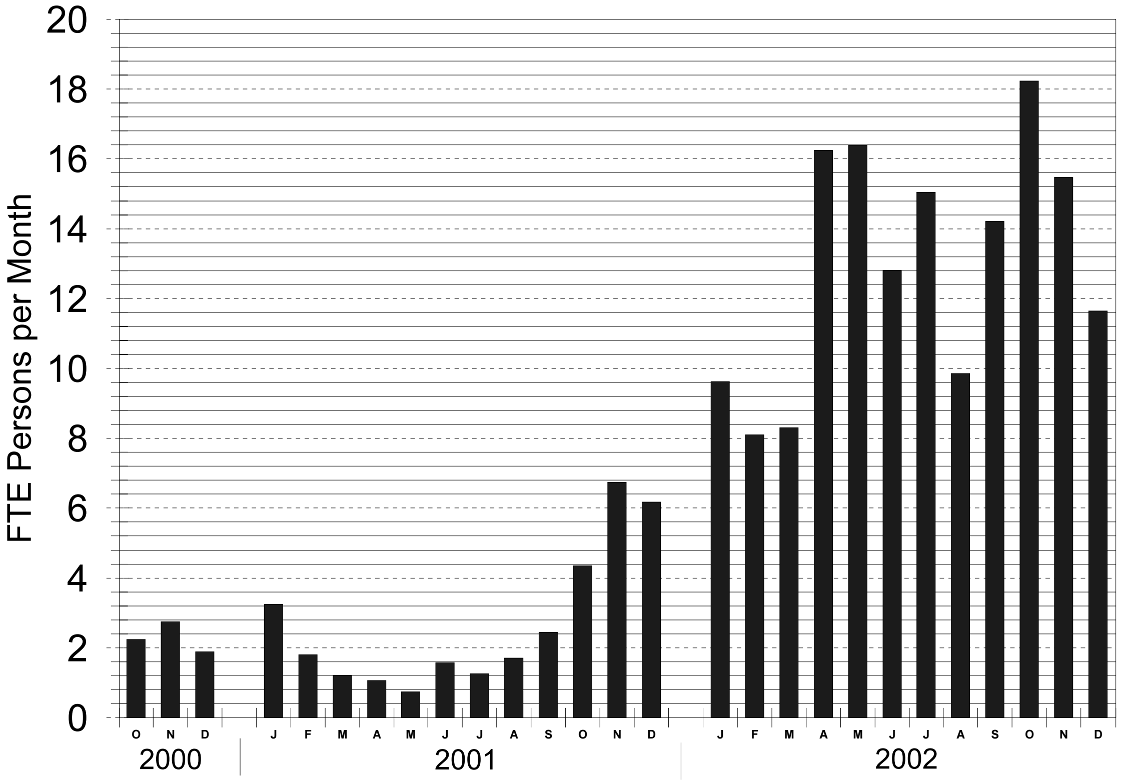


Fig. 214. ISAC-II monthly personnel effort, October 1, 2000 to December 31, 2002.

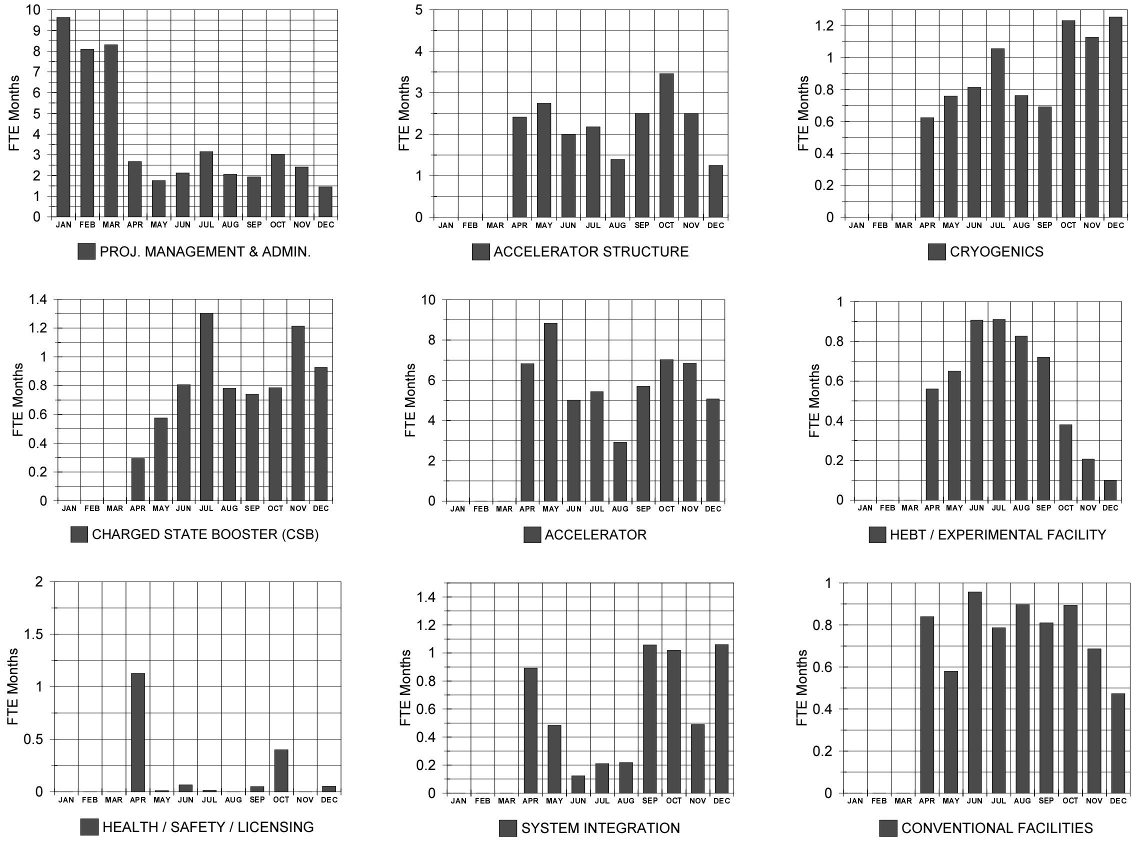


Fig. 215. ISAC-II monthly personnel effort, shown by section for 2002.

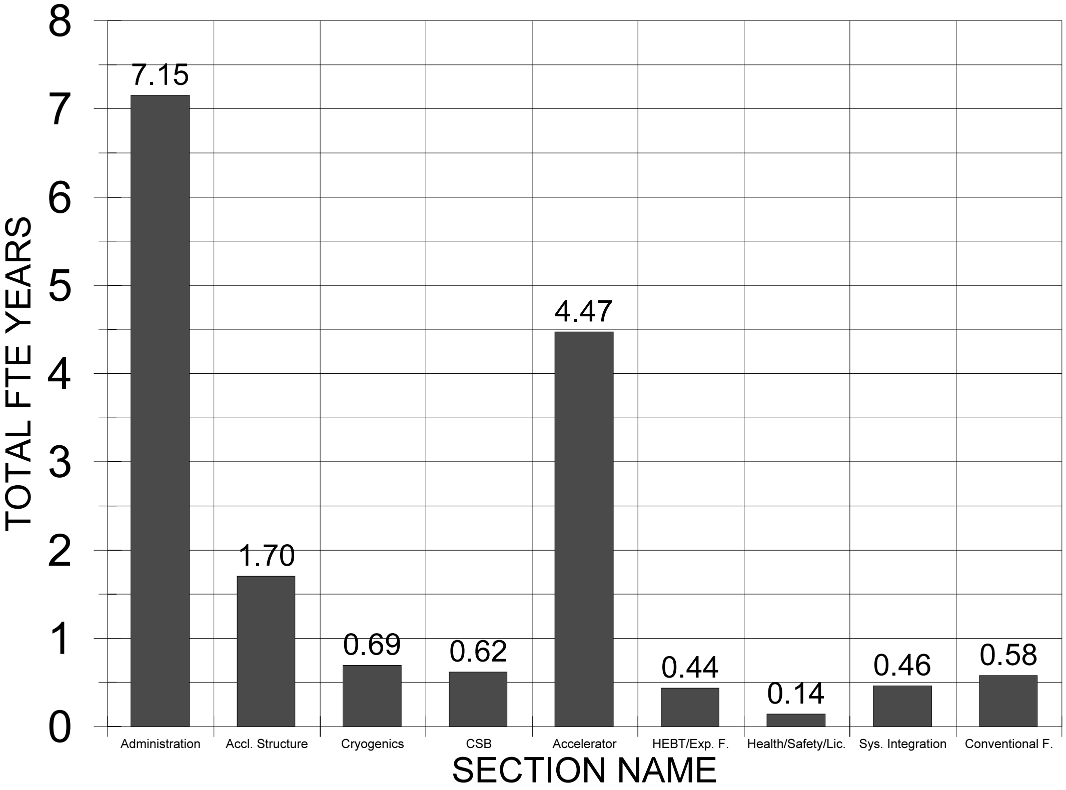


Fig. 216. ISAC-II total personnel effort, October 1, 2000 to December 31, 2002 shown by section.

ISAC-II CONVENTIONAL FACILITIES AND INFRASTRUCTURE

This was the year the ISAC-II laboratory was built. In the design of this laboratory we departed from the approach used in the design of previous buildings and gave the new building a more modern look. The new building has a soft contoured roof over the experimental hall and plenty of glass and architectural features in the office area. The new building is situated north of the ISAC-I experimental hall (see Fig. 217).

Fig. 217. A recent picture of the ISAC-II building. Landscaping is still in progress.

The facility is about 55,000 ft^2 set on two floors, with offices for approximately 90 staff, a clean room for the maintenance of the SCRF cavities, laboratories and technical shops in support of the experimental program and the accelerator.

Under the overall direction and guidance of UMA Management Services Ltd., the conventional facilities (the building portion) of the ISAC-II expansion project were divided into two main sequential construction packages:

- the site preparation package, and
- the main building package.

The site preparation package was tendered and awarded in December, 2001. This package included clearing, grubbing, bulk excavation and site servicing, and was issued ahead of the main building package for scheduling reasons.

Having been tendered and awarded the previous year, this year kicked off with the commencement of the fieldwork of the site preparation construction contract. The atmosphere at TRIUMF changed overnight as the heavy equipment required for the execution of the work, including approximately 600 separate truck trips, became a constant presence north of the existing site. This contract was completed at the end of February.

While site preparation was under way, the architect and the consulting engineers completed the specifications and drawings of the main building package. Pre-tender estimates confirmed that the project, as designed, was on budget. Therefore, also in January, the Ministry of Finance officials gave their approval for the tender of the main building package.

The main building package was the second major construction contract. This package was a general construction package and contained the balance of the work to complete the building. It was tendered in late January and throughout February. Tenders were received from pre-qualified general contractors and the successful tender was within budget. Upon receipt of approval to award from the Ministry of Advanced Education, the contract was awarded in March.

Construction work started on site in March in pursuit of an aggressive completion schedule. At the same time, we received the Building Permit issued by UBC, and Permission to Construct from the Canadian Nuclear Safety Commission. Construction continued to advance through the year and at the end of the year stood at 85% complete with Substantial Completion targeted for February 28, 2003.

Milestones achieved during the year include the first concrete pour of the accelerator vault on April 19 and the first structural steel column erected on June 24. The "*lights were turned on*" on January 2, 2003.

A major challenge was the sequencing of the construction due to the simultaneous construction of the nearby Nordion radioisotope laboratory addition. Despite the severely limited lay down space and the sharing of the construction site, both projects proceeded expeditiously, safely and harmoniously to completion. This speaks to the quality and motivation of the people involved at all levels! With careful management, we anticipate that the project will be completed within budget.

TRIUMF engineering staff provided continuing support to both UMA and the engineering consultants during the design stage and throughout the construction phase to ensure that the functional requirements established by TRIUMF were adequately installed. Staff attended weekly construction meetings and commissioning meetings, and participated daily in discussion to expedite construction activities and contractual issues.

With ISAC-II, we installed three capacitor banks for about 1,000 kvar. Capacitors operate to reduce the reactive power demand from the Hydro grid and therefore are a means for controlling the cost increases due to additional power demand. We also added two 40 kW UPS units to serve the ever increasing demand of battery-backed up quality power for better reliability of the data acquisition and computing services, safety systems and beam line controls.

The TRIUMF Data and Voice Communication groups have been preparing to move into the ISAC-II facility to start pulling cabling. Telephone and data services are required to be operational before staff can occupy offices and labs.

In addition, engineering support was lent to the CSB for the preliminary design of the test stand services and to the Refrigeration group in the preparation of the specification package. Preliminary studies started to determine possible configurations of the power supply room and services to the S-bend beam transport system.

ISAC-II ACCELERATOR DEVELOPMENT

In the past year the ISAC-II accelerator design and prototyping was advanced beyond the concept stage to development, design and fabrication. The key achievements were:

- Detailed beam dynamics including the addition of realistic electric and magnetic rf fields were completed. This led to the modification of the first eight medium beta cavities to improve performance. Analysis of the high beta section was completed for two cavity variants.
- An order was placed for twenty medium beta cavities with E. Zanon in Italy. Fabrication of four is now complete and they are ready for chemical polishing in CERN.
- Conceptual and detailed design of the medium beta cryomodule is now in an advanced stage.
- A SCRF lab was established and ten cold tests were performed in 2002. The tests concentrated on establishing cavity preparation and testing procedures, development of the rf controls, mechanical tuner and rf coupling loop as well as a variety of cryogenic tests.

Details of the various achievements are presented below.

Beam Dynamics Studies

Figure 218 shows a schematic for the ISAC-II linac indicating stage 1 and stage 2 installations. Detailed beam dynamics studies have concentrated on the first stage SC linac installation. The linac has been grouped into low, medium and high beta sections corresponding to cavities with design velocities of $\beta_o = 4.2\%$, $\beta_o = 5.7, 7.1\%$ and $\beta_o = 10.4\%$ respectively. The two cavity types in the mid beta section (Fig. 219), composed of eight $\beta_o = 5.7\%$ and twelve $\beta_o = 7.1\%$ cavities, are now being fabricated in industry. A prototype

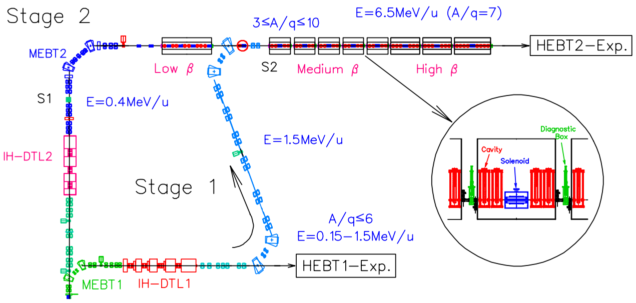
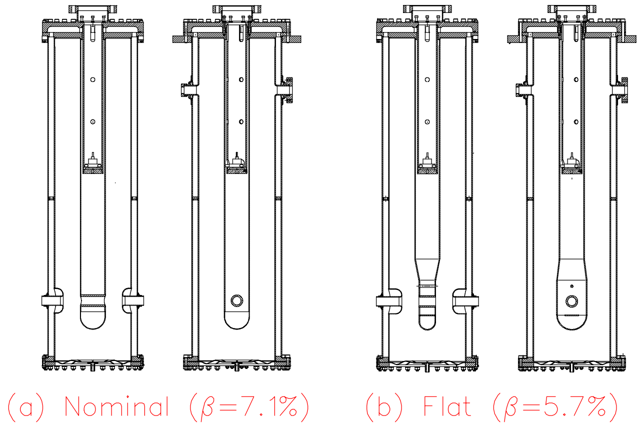


Fig. 218. Stage 1 and stage 2 of the ISAC-II expansion.



(a) Nominal (β=7.1%) (b) Flat (β=5.7%)

Fig. 219. The two medium beta cavities.

of the $\beta_o = 7.1\%$ cavity has been designed in a collaboration with INFN-LNL, and fabricated in Italy. The *flat* cavity, recently added to the design for improved beam dynamics (see below), borrows from the geometry of the low β cavities on the Piave accelerator at INFN-LNL.

Realistic field studies are now complete for the 10.5 m long medium beta section consisting of five cryomodules with four cavities and one 35 cm long superconducting solenoid in each. Two main asymmetries in the medium beta cavity fields are responsible for differences between a “simple cavity model” and “realistic field” simulations. Inherent in quarter wave cavities are both a vertical electric dipole field and a radial magnetic field that give velocity and phase dependent vertical kicks to the beam. The vertical steering can lead to loss of dynamic aperture and transverse emittance growth especially for multi-charge beams. The steering can be largely cancelled by displacing the cavity vertically so the electric focusing field compensates for the magnetic kick.

The cylindrical stem (Fig. 219a), while simplifying construction, produces an asymmetry in the transverse rf electric fields. The asymmetry leads to a mismatch between horizontal and vertical motion. The degree of mismatch is dependent on the magnitude of the asymmetry and on the relative strength of the defocusing rf with respect to the focusing optics in the lattice cell. In a quadrupole lattice the two planes are independent and different match conditions can be used to eliminate emittance growth. In a solenoidal lattice the beam is rotated periodically and a mismatch between transverse planes can lead to transverse emittance growth once the beam is delivered to a quadrupole transport system.

To reduce the effects of the focusing asymmetry we alter the original design by adding a new cavity geometry. In the flat cavity (Fig. 219b) the inner conductor is squeezed to 40 mm from 60 mm in the beam direction and the grounded beam ports are extended to maintain the original gap. The transverse deflections from the two cavity types are summarized in Fig. 220 over the operating velocity range required of the cavity for an accelerating gradient of 6 MV/m, an ion of $A/q = 3$, and a phase of $\phi_s = -30°$. The solid lines show the vertical and horizontal defocusing perturbations for a 1 mm displacement from the electrical axis. The dashed lines show the uncorrected, on-axis dipole steering components and the corrected components for cavities shifted down by 0.8 mm in the nominal case and 0.5 mm in the flat case with respect to the beam and solenoid axis.

Studies show that a small but worthwhile improvement in dynamic aperture is gained for light beams by replacing the first eight nominal cavities in the medium beta section with the flat cavities. Adding more than eight flat cavities reduces linac performance because of the reduced β_o.

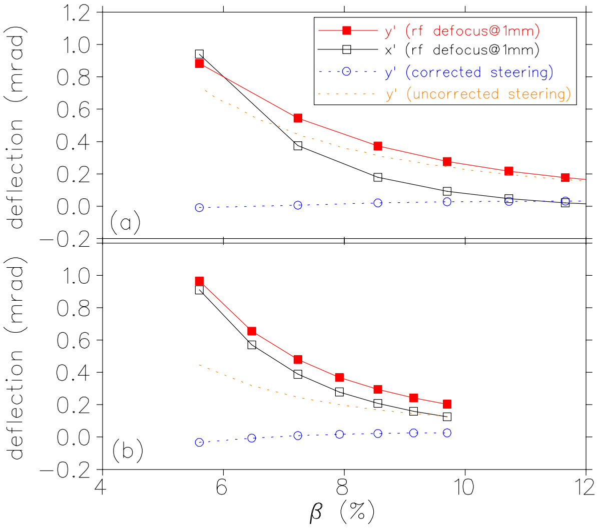


Fig. 220. Focusing and steering perturbations for the two medium beta cavities (a) nominal (b) flat as calculated in HFSS for $E_a = 6$ MV/m, $A/q = 3$, and $\phi_s = -30°$. The dashed lines are the uncorrected (on-axis) and corrected (displaced axis – (a) $\Delta y = 0.8$ mm, (b) $\Delta y = 0.5$ mm) vertical dipole perturbations. The solid lines are the vertical and horizontal defocusing perturbations for a 1 mm displacement from the electrical axis.

In an investigation of misalignment tolerances the realistic fields are used to generate velocity dependent linear matrix elements to speed the calculations. The beam centroid is tracked through the linac for multiple seeds of linac misalignments. For each seed linac, element positions are displaced randomly within a Gaussian distribution. The studies show that the solenoid is at least six times more sensitive to misalignment than the cavities. This assumes that the cavity errors are randomized within the error margin. If the cavity errors are systematic then the negative dynamic aperture is reduced. Since the difficulty of aligning any element is about the same, we can relax the alignment of the cavity by a factor of two with respect to the solenoid and make the engineer's job easier while not impacting the overall performance. The solenoid tolerance is chosen to give less than 20% reduction in the dynamic aperture. In Fig. 221 the single charge state beam centroid shift with steering correction for a randomized solenoid shift of $2\sigma = 200\ \mu$ and cavity shift of $2\sigma = 400\ \mu$ is superimposed on the envelope difference associated with a 20% and 40% reduction in dynamic aperture. The rms beam centre shift is within the 20% envelope.

High Beta Cavity

Beam dynamics studies with realistic fields were done to optimize the high beta cavity design. The cavity choice came down to two cavity variants. One variant has identical transverse dimensions to the medium beta cavity but is designed as a 141 MHz cavity by shortening the overall length. In the other variant the cavity frequency was kept at 106 MHz but the cavity transverse dimensions were scaled to increase the beta from 7.1% to 10.4%. The two cavity variants are shown in Fig. 222.

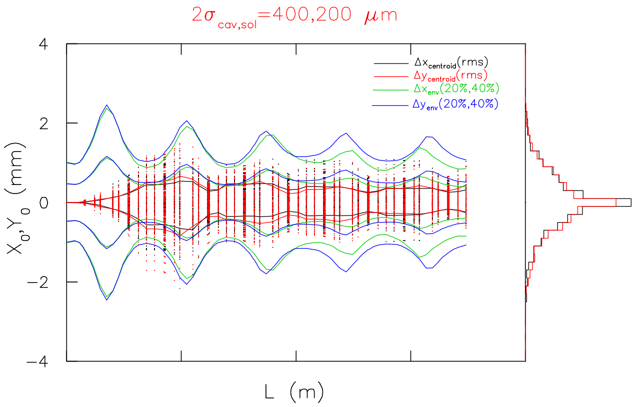
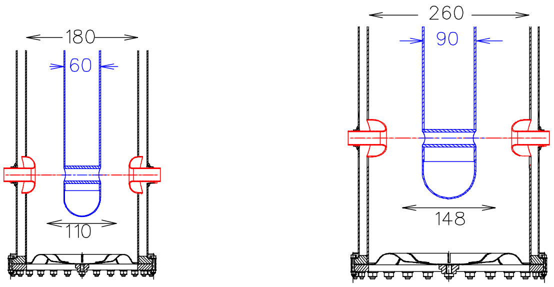


Fig. 221. The single charge state beam centroid shift with steering correction for a randomized solenoid shift of $2\sigma = 200\ \mu$ and cavity shift of $2\sigma = 400\ \mu$ is superimposed on the envelope difference associated with a 20% and 40% reduction in dynamic aperture.



(a) 141MHz Nominal (d) 106MHz Asymmetric B

Fig. 222. The two cavity variants for high beta beam dynamic studies.

Each cavity has transverse time varying electric and magnetic fields that account for rf defocusing and phase-dependent steering effects. The steering effect can be largely compensated for by shifting the cavity downward by ∼2 mm with respect to the beam axis. The quadrupole asymmetry noted in the previous section is somewhat larger in the high frequency case by virtue of the smaller inner conductor. The fields associated with the two cavity variants are displayed in Fig. 223.

Beam simulations of the two cavities were completed using the realistic three dimensional electromagnetic cavity fields. The high beta section was composed of three cryomodules with 6,6,8 cavities per module with the high frequency cavity and 4,4,6 cavities per module with the lower frequency cavity as shown in Fig. 224. Both cases use a medium beta section composed of eight flat and twelve round 106 MHz medium beta cavities.

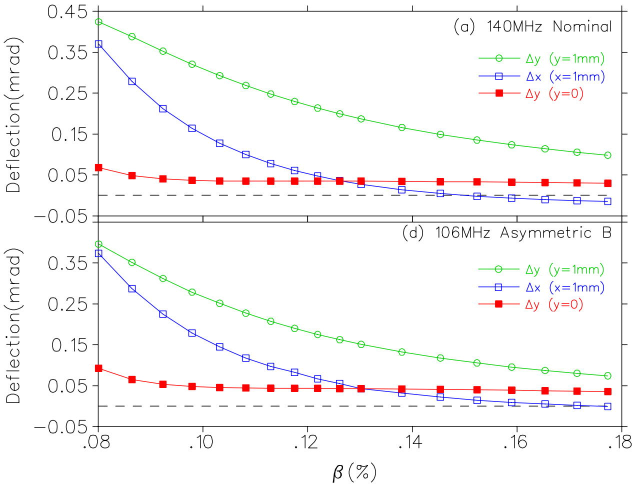


Fig. 223. Focusing and steering perturbations for the two high beta cavity design variants (a) 141 MHz (b) 106 MHz as calculated in HFSS for $E_a = 6$ MV/m, $A/q = 3$, and $\phi_s = -30°$. Shown are the corrected (displaced axis – (a) $\Delta y = xx$ mm, (b) $\Delta y = xx$ mm) vertical dipole perturbations, and the vertical and horizontal defocusing perturbations for a 1 mm displacement from the electrical axis.

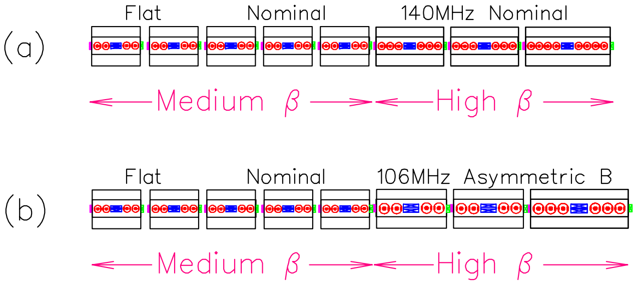


Fig. 224. The two linac variants used in the high beta beam dynamic studies; (a) twenty 141 MHz cavities (b) fourteen 106 MHz cavities.

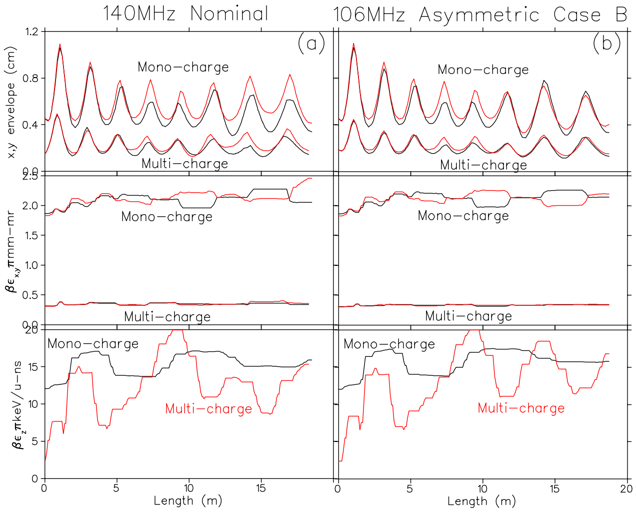


Fig. 225. The transverse beam envelopes and the transverse and longitudinal emittances as a function of longitudinal position along the medium and high beta sections for (a) the 140 MHz high beta variant and (b) the 106 MHz variant. In each case a single charge state beam with intial emittance of 1.8 πmm-mr and 12 πkeV/u-ns (ten times the expected emittances) is simulated. The large beam is used to characterize differences in the effective dynamic aperture of the two variants. Also shown are a multi-charge beam with initial emittances of 0.3 πmm-mr and 2. πkeV/u-ns.

A summary of the beam dynamics calculations is given in Fig. 225. Given are the transverse beam envelopes and the transverse and longitudinal emittances as a function of longitudinal position for the two different variants. In each case a single charge state beam with intial emittance of 1.8 πmm-mr and 12 πkeV/u-ns (ten times the expected emittances) is simulated. The large beam is used to characterize differences in the effective dynamic aperture of the two variants. Also shown are results for a multi-charge beam with initial emittances of 0.3 πmm-mr and 2. πkeV/u-ns. The reduced quadrupole asymmetry in the low frequency cavity results in a reduced envelope. However, the difference in the transverse emittance values is not large. Other considerations such as cost and schedule will be used to choose the cavity type.

Hardware

Work is ongoing on several fronts with the goal of realizing beam delivery in 2005. The first major milestone is the fabrication and cold test of a completed medium beta cryomodule in mid 2003. A summary of the present developments is given below.

Cryomodule design

A prototype of the medium beta cryomodule, shown in Fig. 226, is now in the design phase. The vacuum tank consists of a stainless steel rectangular box and lid. All services and feedthroughs are located on the lid. Unlike elliptical cavity systems, a common vacuum is shared between the thermal isolation space and the cavity/beam space. For this reason the vacuum system is completely oil free with a 340 l/s magnetically levitated turbo pump and scroll backing pump. Each cryomodule has independent gate valves at each end of the beam tubes to allow isolation of a cryomodule unit in case of failure. The initial assembly will be done in a clean room as will all subsequent servicing to the unit. The intermodule space consists of a slim diagnostic box and bellows. An $x-y$ steering magnet fits around the bellows.

A 190 l LHe reservoir and cavity/solenoid support frame is mounted from the lid from supports thermally anchored with LN2. Misalignment studies indicate that the solenoid and cavities must be aligned to a tolerance of ±200 μm and ±400 μm respectively. A position monitor using a guide wire carrying an rf signal and pick-ups installed on the devices is being developed for cold alignment. A cold shield is suspended in close proximity to the inner wall of the cryomodule vacuum space and is formed from copper sheet cooled by SS tubing flowing LN2. During nominal operation, a liquid nitrogen load of about 4 liquid l/h is estimated from heat radiation and conductivity load and from experience with our test cryostat. The rf coupling loop is thermally isolated from the cavity and anchored to LN2 through a separate heat exhange loop. Pre-cooling of components is done by delivering

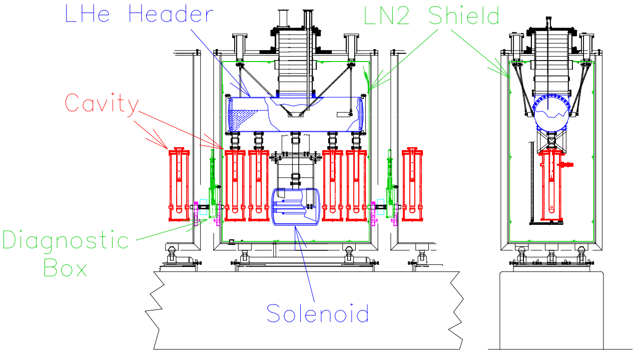


Fig. 226. Medium beta cryomodule for ISAC-II.

cold helium vapour to the bottom of each major component. Magnetic shielding in the form of high μ sheet is suspended between the warm wall and the cold shield.

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. Since the solenoid fringe field could affect the operation of the cavities, the magnets are equiped with active compensation using bucking coils. The operating field at the cavities is specified to be less than 0.1 T. The magnets are mounted in a liquid helium pressure vessel fed from the common helium header. Power leads run from the solenoid through the common helium header to feed-throughs at the top of the cryo-module. A contract has been let for five medium beta solenoids. A prototype medium beta solenoid is being fabricated for delivery in spring, 2003.

Cavities

The cavities are being fabricated at E. Zanon in Italy. Four cavities are now completed and await shipping to CERN for chemical polishing. The remaining sixteen cavities are scheduled for delivery by August, 2003.

SCRF Developments

A temporary superconducting rf test lab of $\sim$100 m^2 is set up in a space rented by TRIUMF in a neighbouring laboratory complex. The laboratory includes a test area with a sunken cryostat pit for high field rf testing, and clean areas for cavity assembly (Class 1000) and high pressure water rinsing (Class 100). In the high pressure rinse area an on-line treatment system delivers 20 l/min of 18 MΩ water at 2000 psi to a manual rinse unit. A prototype rf controls system using a self-excited loop architecture with digital signal processors is in development and has been used to successfully regulate a cold cavity in both self-excited and fixed frequency operation. Cold tests of the prototype cavity are ongoing at the rate of one a month.

Cavity tests

First cold tests were completed in April. Parallel developments of cavity performance, rf controls, cryogenic studies, cleaning procedures and mechanical tuners are ongoing. A summary plot of the measured cavity performance is given in Fig. 227. In initial tests, field emission reduced the Q sharply at field levels above 4 MV/m ($E_p \geq 20$ MV/m). High pressure water rinse (HPWR) treatments gave marked reductions in field emission. Helium conditioning at 4×10^{-5} torr for thirty minutes at 9 MV/m gave a further improvement so that we could push the cavity right out to the quench limit ($E_a \geq 9.5$ MV/m,$E_p \geq 48$ MV/m) without significant field emission. These initial tests matched earlier tests at Legnaro except that the measured Q values were lower by a factor of three. The original Legnaro data were finally duplicated after adding a mu-metal shield to reduce the surface resistance caused by trapped flux from the earth's magnetic field.

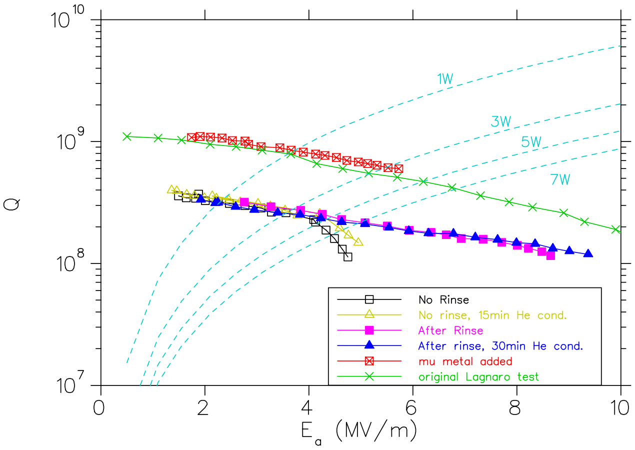


Fig. 227. Measured cavity performance during cold tests at TRIUMF.

RF controls

The ISAC-II prototype rf control system is based on the self-excited loop. It consists of two modules: an rf module and a DSP module, housed in a VXI mainframe. A pair of Motorola DSP56002 digital signal processors provide the low level amplitude, phase and tuning regulation. A special circuit is used to pulse through multipactoring. A rack mounted PC provides supervisory controls for these modules. An Apache HTTPD server running on the same PC acquires data from several GPIB-enabled instruments such as power meter, frequency counter, frequency synthesizer and a digital oscilloscope. These data and the computed Q and E_a values can be displayed and plotted in any Web browser. During the series of tests this year the controls system regulated the cavity in both self-excited and frequency locked mode. In one test the cavity frequency was detuned by 10 Hz by increasing the pressure in the helium space ($df/dp \simeq$1 Hz/torr) while overcoupling to produce a 10 Hz bandwidth. The control system managed to maintain lock both during the slow pressure change and when the pressure was suddenly released. Ongoing developments include optimizing the addition of a mechanical tuner to the control loop.

Tuner development

The mechanical tuner alters the resonant frequency of the cavity by deflection of a niobium tuning plate that encloses the cavity on the bottom high field end.

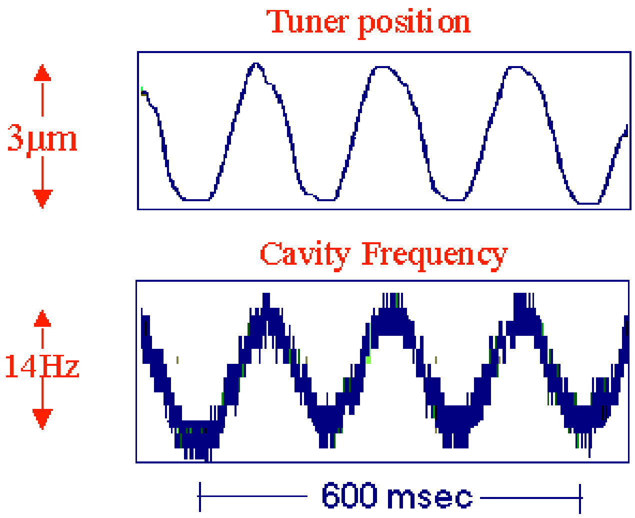


Fig. 228. The tuner position and cavity frequency with tuner driven at 5 Hz and amplitude of ±1.5 μm. The cavity frequency is modulated by ±7 Hz.

Presently a flat plate is being used but we are developing a plate spun with undulations and radial slots to allow a larger tuning range. The plates each give a tuning sensitivity of 7 Hz/μm. The "oil can" spun plate increases the tuning range from about 15 kHz to at least 40 kHz while significantly reducing cavity stresses due to plate distortion. A prototype mechanical tuner is now being tested. It consists of a lever mechanism acting directly on the centre of the cavity tuner plate through a zero backlash hinge and stiff rod connected through a bellows to a precision linear motor located on the top of the cryostat. The tuner is capable of both coarse (20 kHz) and fine (few Hz) frequency adjustments. Initial tests are promising. The tuner plate position has been modulated at mechanical drive frequencies of 0.1 Hz to 10 Hz and amplitudes of 1 μ to 6 μ corresponding to cavity frequency variations of ±5 Hz and ±30 Hz respectively. The self-excited frequency response matches the driving signal with no significant induced microphonics. Figure 228 shows both tuner position and cavity frequency for a 5 Hz, ±1.5 μm tuner variation.

In another study the cavity was phase locked while over coupled, generating a 20 Hz rf bandwidth, and the plate was dithered with a frequency of 8 Hz at ±1 μ without losing phase lock.

ISAC-II CRYOGENIC REFRIGERATION PROJECT

The ISAC-II cryogenic refrigeration workgroup was established early in 2002. The group was charged with preparing specifications and asking for tenders for a helium refrigeration and distribution system for the future ISAC-II superconducting linear accelerator. Since the ISAC-II linac will be installed in two phases, the helium refrigeration system will also be installed in two phases. Phase I will require a 500 W at 4.5 K class helium refrigerator combined with a cryogenic helium distribution system supplying the linac. The current design of the phase II linac will require extending the phase I helium distribution piping and adding another 500 W at 4.5 K class helium refrigerator. The reference schematic for the phase I refrigeration system is shown in Fig. 229. This design has evolved throughout the year after meetings and discussions with potential suppliers and other research laboratories operating similar systems.

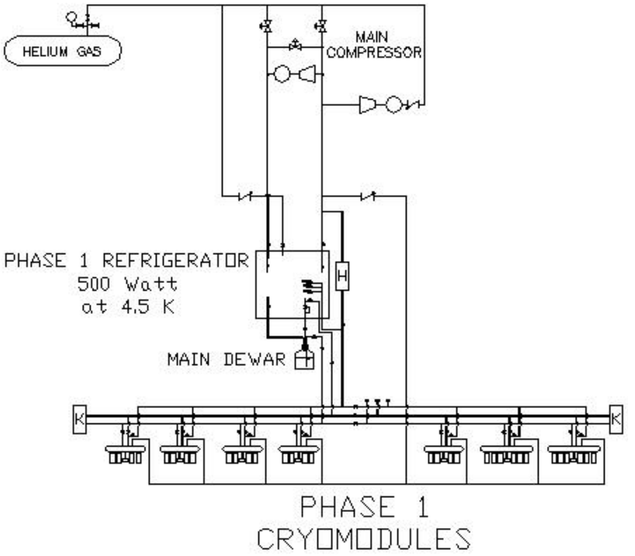


Fig. 229. Reference schematic for phase I refrigeration system.

In March, meetings were held at Argonne National Laboratory in Illinois. Argonne staff presented the helium refrigeration and distribution system used for the ATLAS linac. The feasibility of using a similar refrigeration system for the ISAC-II was discussed. The ATLAS linac injector cryostats are cooled with a series flow scheme with helium flowing from one cryostat into the next, and on through the remaining cryostats.

Subsequent to the Argonne meetings, the linac cooling methods used at other facilities such as Legnaro in Italy and NSC in India were investigated. Three main methods were considered: series cooling, parallel cooling and supercritical helium cooling for each cryomodule.

A paper titled "Overview of the Cryogenic System for the ISAC-II Superconducting Linac at TRIUMF" was presented to ICEC 19 in Grenoble, France in July. At the ICEC 19 conference several meetings were held with potential suppliers of the ISAC-II helium system. Among the many items discussed were the three cooling distribution methods, the capability of supplying a turn-key system, system sizing and cryogenic piping.

Discussions were also held with representatives from facilities operating cryogenic helium refrigerators such as BNL, NSC in India, CERN, Legnaro, Italy, and SRRC, Taiwan. As a result of the various discussions, it was decided to use the parallel flow distribution scheme in the reference design of the ISAC system. It was concluded that a properly designed parallel flow distribution system would offer better pressure stability and expansion capabilities.

In October an engineering design review of the medium beta cryomodule design and the helium refrigeration specification was held. The review committee included representation from Argonne National Laboratory, JLab and the University of Washington. Among the conclusions reached at the review were that the parallel flow distribution scheme seemed reasonable as long as pressure drops were controlled, and that detailed heat leak calculations should be performed.

Recent data obtained during cooldown tests of the superconducting test cavity have justified the suitability of a 500 W class helium refrigerator. The tendering package for the phase I helium refrigeration and distribution system will be released in March, 2003 with an expected commissioned date of October, 2004.

ISAC-II CRYOMODULES

This report period marked the commencement of the mechanical design of the medium β cryomodules, of which there will be five constructed and installed in the accelerator hall in ISAC-II as part of the superconducting linac.

The medium β cryomodule is a stainless steel vacuum tank housing five cryo elements: four quarter wave resonators and one 9 T solenoid all cooled to 4.2°K by liquid helium (see Fig. 230). The cryo elements will be supported by a rigid frame suspended from the vacuum tank lid by thin walled tubular struts with spherical ball ends at both ends to allow for thermal shrinkage during cool down. Positional accuracy of the cryo elements is crucial to the efficient operation of the accelerator, therefore it is imperative that the alignment of these elements relative to the vacuum tank be maintained for repetitive cool down cycles. The liquid helium inventory of 120 l is housed in a 16 in. diameter reservoir, partially filled and connected to the cryo elements by a 3 in. tube and bellows and bolted to the lid via a vertical tower in both the reservoir and lid, the top of which provides a platform for the cryogenic feed throughs, pressure relief valve and burst disk. The latter are provided to allow for perturbations in the operation of the LHe system and, in the event of a vacuum failure in the vacuum tank, to allow the escape of vapour produced by the rapid liquid He boil off. The vacuum tank is lined with 0.040 in. thick μ metal to negate magnetic field effects. Inside the μ metal is another liner which is a liquid nitrogen thermal barrier intercepting the heat load from the vacuum tank to the cryo elements. The μ metal liner is screwed to the tank wall and LN_2 liner is placed in the tank sitting on the floor and away from the μ metal by low conductivity stand-offs. The lid will also have a double liner and is 1.25 in. thick stainless steel plate with a central vertical tower matching up with the He reservoir as mentioned.

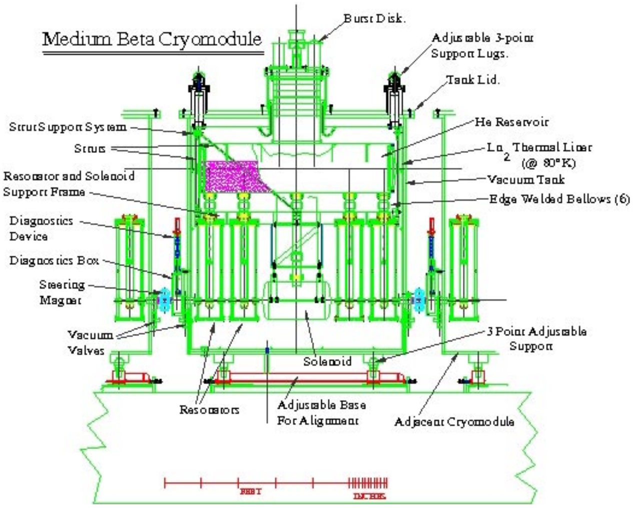


Fig. 230. Medium β cryomodule components.

Access to the cryo elements is achieved by lifting the lid off the vacuum tank, thus removing the contents of the tank except for the μ metal and LN_2 liners. The lid will also provide space for the many other feed throughs related to diagnostics, rf devices, resonator tuning motors, heaters, temperature detectors, alignment equipment feed throughs and suspension lugs.

Each medium β cryomodule will be delivered aligned internally with the tank beam ports (allowing for the internal thermal shrinkage). The lid will be dowelled to the tank and external tank targets will be provided to allow for correct alignment in the accelerator hall. The five cryomodules will sit on a special frame providing three-point mounts which allow for this alignment.

There is a ~30 cm gap between adjacent cryomodules allowing for a diagnostic box, two 2 in. valves, and a short piece of beam tube which is surrounded by a special vertical and horizontal steering magnet. The inter-modular zone is designed in such a way as to allow for removal of a cryomodule from the accelerator without venting the accelerator system. The cryomodule would come away with both beam ports sealed off by the valves, and at one end the diagnostic box, steering magnet and beam tube associated with that cryomodule would be attached to it. The removed cryomodule could be replaced by a section of beam tube to allow the linac to remain operational.