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NATIONAL RESEARCH COUNCIL OF CANADA

DECEMBER 2006

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.

CYCLOTRON OPERATIONS DIVISION

INTRODUCTION

Beam delivery for the year 2005 was quite successful with a total charge production of 722 mAh delivered to the high current proton lines (BL1A, BL2A and BL2C4). This was a 5% increase from last year, edging out the previous record of 720 mAh set in 2002. Of these, 434 mAh were delivered to BL1A for meson production and 130 mAh (20% more than last year) were delivered to BL2A for the production of radioactive ion beams (RIB) in ISAC. This was a record year for strontium-82 production in the 2C4 solid target facility (STF). A total of 55.0 Ci were produced from 158 mAh in 163 days compared with 48.5 Ci produced from 134.3 mAh in 137 days in 2004. Eleven natural rubidium targets were irradiated in 2005 compared with 9 targets in 2004. However, the cyclotron was available for only 86% of the scheduled time, down 6% from last year, mostly due to an rf resonator water leak.

A new BL2A tune, which produced the large spot sizes required by the ISAC high-current targets, was accomplished by the correction of an error in the program calculating the transfer matrices. The BL2A beam stability was greatly improved by a pulser-adjustment program, developed by the Controls group, that greatly reduced the number of spurious trips and significantly improved the quality of RIB production in ISAC. With this beam stabilization loop enabled, it was possible to extract 275 μA for 4 hours without encountering any problems. When the loop was disabled it was possible to extract 296 μA at a duty cycle of 97.3% for 2.4 hours with greater than 60% transmission and $\sim$1% tank spills without any thermal problems. This is a new high-current record for TRIUMF.

The annual downtime of 827 hours was almost double that of last year with rf problems costing 584 hours or 70% of the total. Most of this (508 hours) was due to a resonator water leak leaving the remaining 76 hours of rf downtime (about 2 hours per operational week) continuing the excellent behaviour of last year. The bulk (85%) of the remaining 244 hours of cyclotron downtime was more or less shared equally by the usual systems (beam lines, services, site power, beam trips, vacuum and power supplies).

During the winter shutdown the major beam line activities were various tasks on the 1AQ15 quadrupole triplet, the repair of vacuum leaks at 1AVA8 and the M15 slit drive, and the repair of an M9BQ3 shorted coil. The many other meson hall activities are covered in the Beam Production and Primary Beam Lines sections. An earlier decision had postponed the large M20 refurbishment work to 2006, but this did not offer much relief as some of the remaining tasks proved to be very difficult in terms of dose and time. For example, repair of the Q10/11 quadrupole doublet was not originally anticipated and it developed into a warm-cell operation.

When the lid was first raised, Safety surveyors found an area of the tank to be contaminated with ^{7}Be. Although not entirely understood, the evidence pointed to it being caused by an overheated extraction foil. Overheating may have resulted from higher beam densities associated with beam shadowing techniques or from the lower heat emissivity of the BeCu foil holder. A 3 m radius was flagged off inside of which respirators and additional protective clothing were required for any tank work. The same precautions were required for work on the extraction 1 probe when retracted from the tank.

Major tank activities included work on extraction probes, periscopes, slits, flags, wire ways, correction plates, vacuum pumps and gate valves. A four-year program of replacing the copper chore pads with fibreglass pads, which were protecting the cooling circuit bellows from vibrating, was completed. The details of these activities are covered in the appropriate group reports. Major work in the vault included the installation of additional safety railings, the inspection of trim- and harmonic-coil junction boxes and the replacement of the phase probe and all lower correction plate cables.

During start-up it became apparent that the vacuum was not as good as it should be and subsequent tests indicated a water leak in resonator 3U6 (quadrant 3, upper resonator 6). This caused a three week delay in the beam schedule while the repair was being made. Another surprise that came on start-up following the resonator repair was a high-temperature indication on resonator 3L1. Back-flushing efforts failed to dislodge whatever may have been restricting the coolant flow but, in mid May, some small perturbations in the resonator supply pressure that resulted from manual operation of the three-way valve after an rf trip apparently cleared the cooling channel and no subsequent problems occurred.

The major activity in the fall mini-shutdown was the work on the 1A triplet, which was completed ahead of time because of an early start, and the testing of various back-flushing techniques, where it was found that general chemical flushing was so successful that it was not necessary to dig down to isolate and flush the few individual coils known to overheat. This not only saved much time and dose, but held promise that any interventions required in the future would have similar savings.

To offset this good news, a CuALCW water leak was isolated to M20Q1. An additional week was required to uncover the area, repair a Hansen fitting, and recover it again. This still left BL1A available near the beginning of the start-up period as the preferred operational mode to tune the cyclotron and the least disruptive way to bring on the other proton lines. It is worthwhile to note that following the fall shutdown the cyclotron was available for 95% of the scheduled time.

Except for the 508 hours of downtime due to the resonator water leak, the upgrade activities described in the rf section of this report were responsible for the continued reliable operation of the rf system. Major activities included the overall refurbishment of the filament power supplies, a new stainless steel hairpin inductor design, increased energy discharge capacity of the HVPS varistor disks, commissioning of a high power rf coaxial switch to redirect rf power either to the cyclotron or a resistive load, and a complete overhaul of the transmission-line matching section. To complement this work, the RF Controls group made good progress in the high VSWR protection system, the spark detection/recovery system, the new HVPS crowbar system, and the rf booster control system.

A new intercepting probe for the TRIUMF cyclotron capable of measuring phase and time structure of the circulating beam was designed, manufactured, and installed in the tank during the winter shutdown. Signals from the tank nonintercepting capacitive phase probes were inspected and signals from all four probes are now equalized and exactly out of phase for each pair. New electronics that is capable of extracting reliable dc current information from a narrow band-width rf signal with the amplitude proportional to the beam intensity over a wide dynamic range was built for the BL2A capacitive probe.

The vacuum systems on the beam lines were made more reliable by upgrading to O-ring metal seals, replacing pumps and refurbishing gate valves. On the cyclotron side much MRO work was done, but the major activity was tracing down the water leak on the resonators that developed following the winter shutdown. The cyclotron vacuum/cryogenic system continued to operate well this year. The main beam downtime was due to B-20 electrical problems and inflector cryopump gate valve failure. These two problems will be addressed in next year's winter shutdown.

The cusp ion source, injection line, and inflector/deflector systems continued to operate well for the past year with uptime in excess of 99% of the scheduled time. The Prompt Radiation Safety Trip System was revised to include redundant Safety Critical Gamma and Neutron Monitors. The system was installed, tested and successfully commissioned in February and March. New 24-V power supplies for the ISIS interlock control system were purchased and installed. The restored first chamber of the 1 MeV test cyclotron has allowed testing of cusp ion sources by ISIS, Nordion and Dehnel Consulting. Dr. Yong-Seok Hwang, a visitor from the Department of Nuclear Engineering, Seoul National University in South Korea, completed an excellent study of the ion source characteristics.

The most significant new development by the Controls group was the work on beam stability for BL2A. This work resulted in an important improvement for ISAC. The Central Control System (CCS) ran well during 2005. As recorded by the Operations group, the loss of scheduled beam time due to CCS faults during the year was 3.4 hours. This low level of downtime was provided without compromising important hardware and software advances.

Operational Services, which includes Remote Handling, Magnet Power Supplies, Electrical Services and Mechanical Systems, continues to play a vital role in the reliable operation of the cyclotron. Their services extend to the whole TRIUMF site and are appreciated site wide.

BEAM PRODUCTION

Beam delivery for 2005 was good with a total charge production of 722 mAh delivered to the high current proton lines (1A, 2A and 2C4), up 5% from last year, to edge out the previous record of 720 mAh set in 2002. This success was achieved in spite of a lengthy start-up after the winter shutdown caused by a resonator water leak, and was in part due to record charge production for BL2A and BL2C4. The performance of the cyclotron remained strong, operating typically with a transmission above 60% and nominal tank spills about 1.5% of the centre region injected current. This was not as good as last year because of the cumulative effect of small vacuum leaks and a malfunctioning rf booster. ISIS and cyclotron beam developments combined with skilled tuning by operators were very helpful. Twelve weeks of shutdown left 6088 scheduled operational hours of which 5226 were delivered for an availability of 86%, down 6% from last year, mainly due to the rf resonator water leak. These totals, including 281 hours used for development and tuning, are shown in Fig. 248. The two-week periods preceding shutdowns were dedicated to lower-intensity operation, typically involving beam delivery to ISAC, with the proton irradiation facility (PIF) using BL1B and BL2C1 running in parallel. BL2C1 was also used at 74 μA for ocular melanoma treatments for nine patients during five proton therapy (PT) sessions.

As Fig. 249 shows, the total beam charge delivered to meson hall experiments along BL1A was 434 mAh or 84% of the scheduled amount, similar to last year,

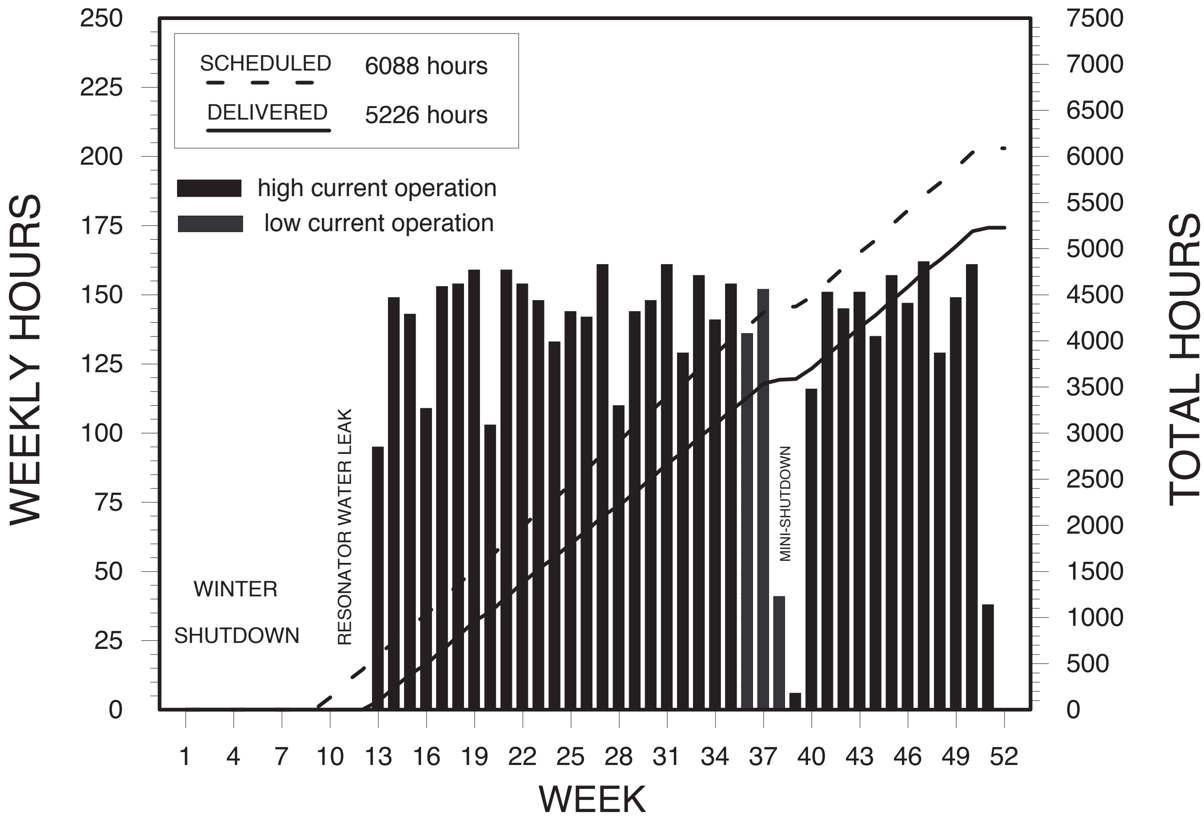

Fig. 248. Operational hours for 2005.

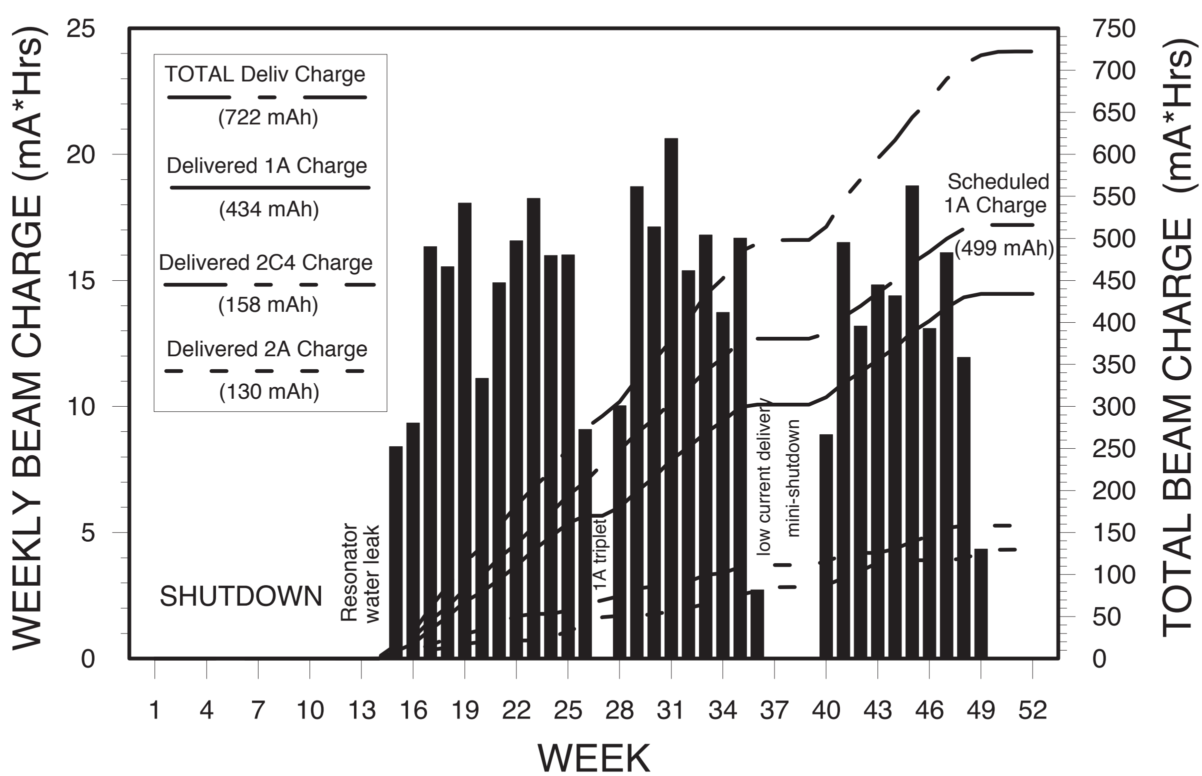

Fig. 249. Beam delivery for 2005.

because of the triplet cooling problems described below. In addition to the BL1A charge, there was a record 158 mAh delivered at 85 MeV to rubidium targets in the solid target facility (STF) in beam line 2C4 for the production of a radiopharmaceutical generator and another 130 mAh (20% more than last year) delivered to the two ISAC target stations for the production of radioactive ion beams (RIB).

The beam stability in BL2A was markedly improved by regulating the beam injected into the cyclotron via a feedback program between the extracted BL2A current and the ISIS pulser. Previously, this beam line had been subject to an unacceptable number of over-current trips, most of which were inherent in the method of stripper shadow-splitting of the internal beam for simultaneous 500 MeV 1A and 2A extraction. This led to instabilities in the intensities of the extracted beam, causing the average 2A beam current to be significantly reduced from the requested optimal values in order to decrease the frequency of over-current trips. On the other hand, BL1A and BL2C4 at normal operating average intensities could easily tolerate the increased fluctuations such a feedback mechanism would produce. Consequently, the pulser duty cycle could be varied to obtain the desired stability for ISAC without affecting the efficiency of beam production on 1A or 2C while at the same time producing a significant improvement of efficiency, quality and reliability of RIB production. The three proton lines sometimes exceeded a total extracted current of 230 μA, although 200 μA or less was more often the case for extended production periods, particularly when BL1A currents were limited to 100 μA because of the use of graphite targets at 1AT1 for the TWIST experiment.

The annual downtime of 827 hours (Fig. 250) was nearly double that of last year, with rf problems accounting for 584 hours or 70% of the total. Most of this (508 hours) was due to the resonator water leak, leaving the remaining 76 hours to rf on-line downtime (about 2 hours per operational week). This continued the excellent on-line performance of the rf system recorded last year. The bulk of the remaining downtime belonged (somewhat equally) to the usual systems: beam lines, services, site power, beam trips, vacuum and power supplies. Operational records and beam to experiments for the year are given in Tables XXIII and XXIV.

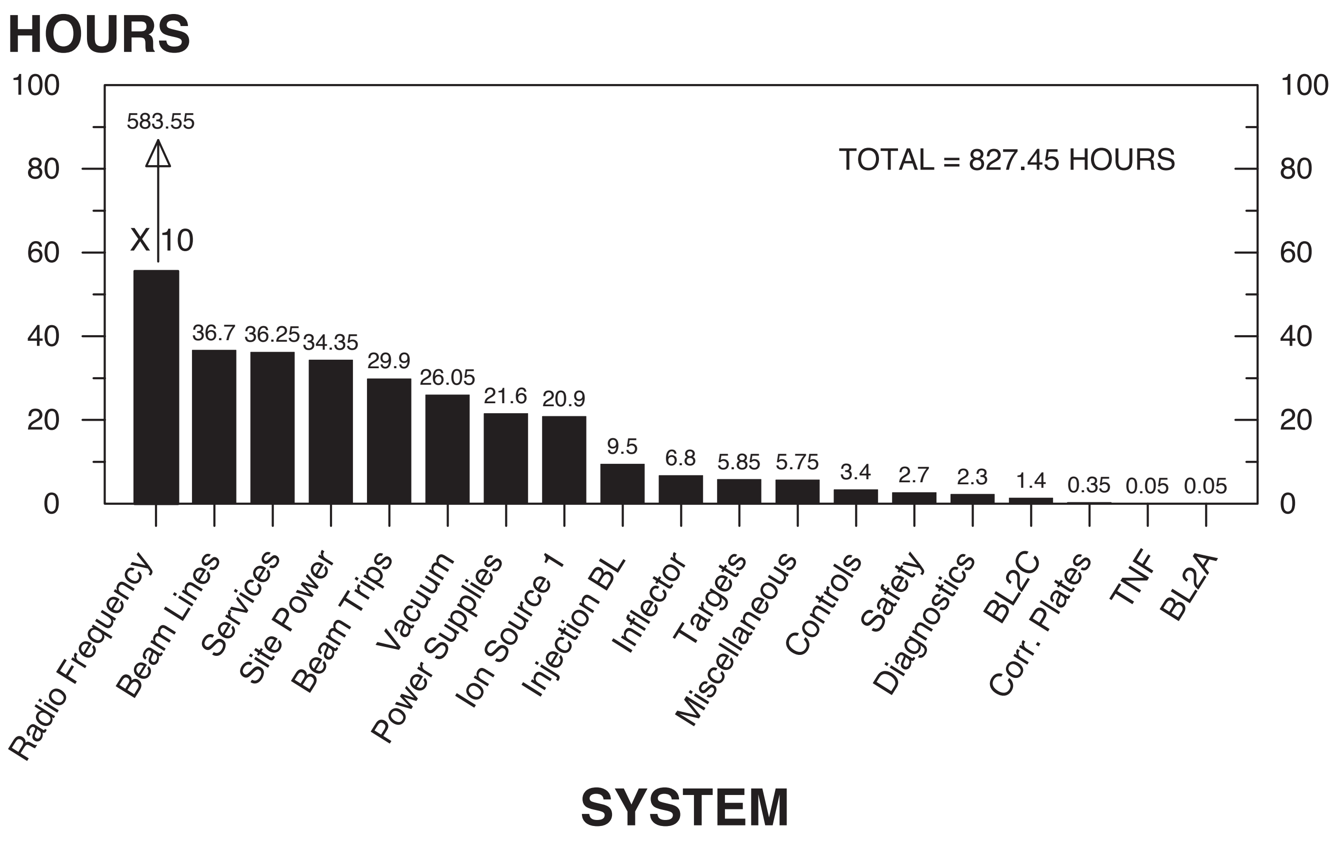

Fig. 250. Cyclotron downtime for 2005.

Table XXIII. Operational record for 2005.*

	Scheduled hours	Actual hours
Cyclotron off:		
Maintenance	470.0	439.10
Start-up	171.0	130.40
Shutdown	1,989.0	2,057.00
Other	0.0	5.50
Cyclotron downtime	0.0	827.45
Overhead	18.0	50.50
Totals	2,648.0	3,509.95
Cyclotron on:		
Development	117.0	130.50
Cyclotron tuning/training	465.0	150.95
Beam to experiments	5,506.0	4,944.60
Totals	6,088.0	5,226.05

Actual / Scheduled = 5,226.0 / 6,088.0 = 85.8% availability

	Scheduled hours	Actual hours
Beam to experiments:		
1A Production	4,282.0	3,884.40
1A Development/tuning	18.0	24.35
1A Down/open/no user	639.0	465.95
1B Production	434.0	22.30
1B Development/tuning	0.0	5.25
1B Down/open/no user	133.0	542.35
Total 1A+1B production	4,716.0	3,906.40
2A Production	4,580.0	3,669.95
2A Development/tuning	94.0	53.10
2A Down/open/no user	832.0	1,221.55
2C1 Production/tests	1,571.0	303.20
2C1 Development/tuning	0.0	9.60
2C1 Down/open/no user	423.0	1,223.70
2C4 Production/tests	3,407.0	2,926.85
2C4 Development/tuning	2.0	0.75
2C4 Down/open/no user	103.0	480.50
1A Beam charge (μA h)	515,840.0	434,105.00
2A Beam charge (μA h)	161,616.0	129,670.00
2C4 Beam charge (μA h)	194,130.0	158,283.00

* There was no BL4 production this year and the polarized source was not used.

Table XXIV. Beam to experiments for 2005.

			Scheduled		Delivered	
Experiment*	Channel	Schedule #	Hours	μA h	Hours	μA h
614	M13	107	2,579	335,270	2,259.30	267,757
614	M13	108	1,114	123,010	1,113.10	117,884
744	M9B	108	383	42,110	373.55	39,149
881	M15	107	66	8,580	61.75	6,318
891	M15	108	64	8,320	61.30	7,530
891	M20B	107	135	17,550	141.35	15,083
895	M15	108	69	8,970	68.65	9,019
895	M15	108	69	8,970	70.25	8,355
917	M20B	107	133	17,290	137.35	17,559
938	M15	107	287	37,310	242.45	31,862
938	M20B	108	283	32,290	280.55	31,012
939	M20B	108	173	22,490	176.30	20,943
944	M15	107	127	16,510	80.40	4,462
945	M20B	107	150	19,500	101.05	7,409
945	M20B	108	146	14,600	140.95	13,331
949	M9B	108	150	15,000	148.25	14,249
953	M20B	107	137	17,810	128.90	17,015
976	M15	107	92	11,960	96.00	11,990
976	M15	108	219	23,970	219.25	23,482
998	M20B	107	130	16,900	129.45	14,326
998	M15	107	130	16,900	129.45	14,326
999	M20B	107	141	18,330	129.90	14,634
1000	M15	108	142	14,200	147.35	14,173
1001	M20B	107	127	16,510	0.00	0
1001	M20B	108	127	16,510	132.30	15,564
1002	M15	107	137	17,810	0.00	0
1002	M15	108	156	15,600	148.45	14,666
1004	M15	108	146	14,600	140.95	13,331
1006	M20B	107	150	19,500	113.55	14,847
1006	M20B	108	156	15,600	148.45	14,666
1012	M9B	108	142	14,200	147.35	14,173
1013	M15	107	69	8,970	79.60	8,765
1013	M15	108	58	7,540	60.45	6,503
1015	M15	107	150	19,500	147.45	20,095
1018	M20B	107	137	17,810	116.70	12,930
1032	M15	107	141	18,330	129.90	14,634
1033	M20B	107	150	19,500	148.80	18,041
1035	M9B	107	287	37,310	242.45	31,862
1035	M9B	108	133	13,300	134.40	13,616
1038	M20B	107	150	19,500	147.45	20,095
1046	M15	108	133	13,300	134.40	13,616
1047	M15	108	58	7,540	62.05	7,209
1049	M20B	108	133	13,300	134.40	13,616
1050	M20B	108	142	14,200	147.35	14,173
9999	M9B	108	306	38,400	309.55	36,697
TBA15	M15	107	191	24,830	188.45	23,993
TBA20	M20B	107	150	19,500	147.10	18,424
ISAC†	2A2/3	107/108	4,580	161,616	3,669.95	129,670
ISOPROD	2C4	107/108	3,407	194,130	2,926.85	158,283
PIF	1B	107/108	434	0	22.30	0

Table XXIV (cont'd.)

Experiment*	Channel	Schedule #	Scheduled Hours	Scheduled μA h	Delivered Hours	Delivered μA h
PIF	2C1	107/108	1,229	0	281.20	0
PT	2C1	107/108	342	0	22.00	0

* See Appendix D for experiment title and spokesman.

† Total proton beam on ITW and ITE for all ISAC RIB experiments and tests.

Winter Shutdown

Shutdown activities got under way early in the new year with the removal of some 60 large shielding blocks from the meson hall in preparation for a number of BL1A activities. These included: repair of two water leaks, replacement of insulators, and back-flushing the triplet quadrupole 1AQ15; repair of vacuum leaks at gate valve 1AVA8 and at the M15 slit drive mechanism; maintenance of the 1AT1 and 1AT2 water packages and the T2 beam blockers; repair of thermal switches and water leaks at 1AQ9/10/11; replacement of monitors 1AM9 and 1AM8; repair of an M9BQ3 shorted coil and refurbishment of the 1A exhaust filter housing. An earlier decision had postponed the complex refurbishment of the M20 muon channel until 2006. However, this did not offer much relief because some of the remaining tasks proved to be both dose and time consuming. For example, repair of the 1AQ10/11 doublet was not originally anticipated; it developed into a warm-cell operation.

BL1A activities got under way while the cyclotron work was deliberately delayed for a few more weeks of cool-down. Before the lid was raised in mid January, the maintenance of jack station 7 in the cyclotron vault, as well as resonator draining and vacuum tests in preparation for rf chore-pad replacements, were taken care of.

When the lid was first raised surveyors found the tank to be contaminated in a fairly confined region around the west end of the south cryopanel and immediately below the 500 MeV extraction point for BL1A. Initial dry swipe readings of 500,000 cpm were reduced to less than 1000 cpm after two cleanings of the most contaminated surfaces. It was not considered worthwhile to decontaminate the rest of the limited area. Activity trailed off sharply within a metre but there were some associated high levels (~10,000 cpm) along the L arm of the extraction probe. The contaminant was found to be Be^7 and, although not entirely understood, evidence pointed to it being driven off overheated extraction foils before condensing on the colder surfaces below. This possibly, but not necessarily exclusively, involved one with a BeCu holder that was being tried for the first time. Overheating may have resulted from higher beam densities associated with beam-shadowing techniques or from the lower heat emissivity of the BeCu foil holder. Therefore it was decided to avoid the use of the latter until the problem was better understood. An area of 3 m radius was flagged off, inside of which respirators and additional protective clothing were required. The same precautions were implemented for work on the X1 probe when retracted from the tank.

Once the lid was up the following tank work took place: the Diagnostics group aligned the LE1 track and installed a new LE1 probe head; serviced extraction probe 2C; replaced both periscope prisms; rewired the NW periscope; emptied the foil buckets and loaded new foils in all three extraction probes; checked out slit and vertical flag drives; replaced the entire HE3 probe and performed commissioning tests. The RF group cleaned correction plate (CP) wire way insulators and installed new covers; realigned the CP2 upper tray; repaired broken insulators on the CP4 lower tray; replaced chore pads in LQ2, 3 and 4; performed centre region inspections; made hot arm tip adjustments to the #10 resonators and checked tank thermocouples. Operators drained and leak checked resonators; assisted with CP wire way work, tank inspections and periscope work, and checked the CP continuity. The Vacuum group repaired leaks at the south turbo backing valve and cryo-pump 2 gate valve; checked the 2A extraction probe housing thermocouple gauge and inspected the tank seal. The Remote Handling group installed and removed shadow shields, pumping port and spill-monitor covers and copper blockers in addition to assisting probes work, tank vacuuming, video inspections and safety surveys. Other work included inflector MRO and the adjustment of the position of a 2C exit horn copper blocker. One week after the tank work was finished (mid February), the lid was lowered for beam delivery to BL2A while the shutdown work continued on BL1A.

Work in the cyclotron vault included the installation of additional safety railings on the BL1A/2C overhead walkway and on the stairway to the tank lid; the inspection of trim and harmonic coil junction boxes;

the replacement of active filters; the replacement of phase probe cables and all lower correction plate cables; the preparations for a new 2C4 monitor; the replenishment of gas in the vault profile monitors; the replacement of 1VM2 signal wiring; maintenance on the rf transmission line (capacitor station 2 modifications, gasket replacement and leak repair at the coupling loop) and the replacement of O-rings in the vault beam lines.

Start-up

Several minor and one more important air leak (at the X2A gate valve) were dealt with during the cyclotron tank pump-down and bake-out but early in March it became apparent that the tank vacuum was not as good as it should be. Subsequent tests indicated a resonator water leak on the south side. Before raising the lid a quick check was made to confirm that beam could be tuned through the cyclotron. The resonators were then drained and further tests determined that the problem was in the cooling circuit in upper quadrant 3 (UQ3). The lid was then raised to pinpoint the exact location of the leak (through manual and remote leak-checking). This eventually led to the discovery of a bad weld partially hidden in a hot-arm cooling channel of a new-style resonator segment. The segment was then removed from the tank, repaired by replacing the faulty cooling panel and reinstalled. After recovery, injection took place and beam was quickly tuned through the machine at the end of March, about three weeks behind schedule. The extra dose incurred by this intervention was about 30 mSv, bringing the shutdown total to 168 mSv shared by 112 workers. This was consistent with other long and involved shutdowns in recent years with the various groups working closely with Safety, planning their work carefully and including the use of volunteers where possible.

Beam Schedule 107

Once the cyclotron had recovered, beam delivery got under way, first to BL2A and 2C1 and then, after the completion of shutdown activities there, to BL1A as well. One area of concern was an apparent blockage in the lines cooling the innermost section of the 3L1 resonator segment as evidenced by high temperature readings (130°C) for the electrode, skirt and rib thermocouples. Back flushing efforts had failed to dislodge whatever may have been restricting the flow but in mid May, small perturbations in the resonator water supply pressure caused by manual operation of the three-way valve (after an rf trip) cleared the cooling channel with no subsequent problems. The cyclotron availability for this schedule was only 82% of the 4360 scheduled hours largely due to the 508 hour turnover time for the resonator water leak. (Once running, the availability was a decent 93%.) The cyclotron itself fared reasonably well although several small air leaks (one in the vicinity of the extraction 1 gate valve, one at a tank feed-through and a third, eventually repaired, in the 2A vault section) kept the south side vacuum at roughly double its usual value. Also, the rf booster was not yet fully commissioned after undergoing a controls upgrade and was therefore not used. These two factors combined with the increased demand from ISAC, boosting the circulating current at times to 230 μA, resulted in a somewhat poorer transmission and higher spills than usual. Downtime averaged 10 hours a week for the 25 weeks of operation after the resonator repair, with a couple of copper active low conductivity water system leaks near the discharge side of one of the pumps as well as a premature B-20 change and a site UPS failure being the main interruptions in an otherwise fairly steady production period. In addition to the high intensity beams produced for the proton lines as discussed below, there was also low current delivery to BL2C1 for both PT (three sessions, six patients) and PIF (for two weeks) to provide some cool down at the end of the delivery period. BL2C1 currents were less than 7 nA while BL1B saw limited use at currents of less than 1 nA. The problem with tuning 2C1 at energies above 105 MeV remained unresolved in spite of the belief that a repositioned exit horn blocker would be the answer, so the users had to be content with 105 MeV and lower.

BL1A ran for 2624 hours or 88% of the scheduled time and received 302 mAh or 79% of the scheduled charge. The low numbers can be mainly attributed to overheating problems with the 1AQ14/15/16 triplet, which caused around 180 hours of 1A downtime as well as a day of cyclotron downtime over the course of three separate back flushing procedures. BL1A currents were kept somewhat lower than the 130 μA scheduled, partly as a conservative measure with respect to the cyclotron vacuum but primarily due to the BL1A triplet quadrupoles that were gradually detuned to successively lower values to keep them from overheating while the 1A beam current was correspondingly lowered to limit the associated beam spill. On the positive side, the 1A vacuum remained very good throughout the schedule, thanks in part to new style seals installed in 1AVA8 during the winter shutdown.

BL2A ran for 2684 hours or 78% of the scheduled time, at currents up to 65 μA for significantly extended runs that contributed the bulk of the 85 mAh total charge. Beam was generally available on demand. The lower availability reflects those times when RIB was not needed due to target problems or changeovers or tuning using stable beam from OLIS. This was the best performance BL2A has had so far both in charge and stability, thanks in part to the use of the pulser feedback program described above. However, tuning was still touchy at times due to the competing constraints of a larger beam size to ensure target longevity versus a smaller beam size to maintain cooler collimator temperatures.

BL2C4 ran for 2088 hours or 81% of the scheduled time receiving 111 mAh or 77% of the scheduled charge at currents around 60 μA. Delivery here requires that at least one other high current beam line is running so occasionally there was a holdup. However, the beam line and the STF ran quite well with one exception, namely the signs of a possible small target rupture as evidenced by cooling water conductivity, activity and krypton content as well as a slight excursion of an associated air monitor. There was no indication of a leak upon examination and processing in the Nordion hot cells although an anomaly in the target fabrication was noted. This process was reviewed before approval was given to resume operation.

Fall Shutdown

A cool-down prior to the fall shutdown was achieved by the scheduled early termination of BL1A (switching to 1B), a reduction in the current to BL2A and a switch from 2C4 to BL2C1 for low current PIF operation. The busy 1A triplet maintenance schedule got an early start due to early finish of BL1B operation. There was no requirement to raise the lid but there were plenty of jobs to fill the time allocation.

The Diagnostics group checked the water flow of the water-cooled probe, installed the new 2C4 harp monitor, gassed vault and 1A monitors and loaded extraction 1 foils. The Vacuum group leak-checked the 2A front end, replaced turbopump 2AVP1 and replaced O-rings at 2AVM1. The ISIS group checked out skimmer 3 and replaced cryo-pump 210. The Plant Services group rebuilt the south CuALCW pump. The RF group installed and tested the new hairpin in PA4 and checked the capacitor station 2 in the vault basement. The Controls group installed and tested a new UPS. The Remote Handling and Beam Lines groups continued the 1A triplet work and installed new flow meters. The Targets group worked on the 1AT1 and 1AT2 water packages and the Power Supplies group fixed a water leak in the main magnet power supply.

Most jobs proceeded as planned except for the 1A triplet work which was completed well ahead of schedule for two reasons. One was the early start as mentioned above. The other resulted from testing different back-flushing techniques and finding that general chemical flushing (straight water would not work) was so successful that it was not necessary to dig down and isolate and flush the few individual rogue circuits known to overheat. This not only saved time and dose but held promise that any such interventions required in the future would have similar savings. To offset this good news a CuALCW water leak up to 60 l/h was traced to M20Q1 and an additional week was required to uncover it, repair a Hansen fitting and cover up again. This still left BL1A available near the beginning of the start-up period to tune the cyclotron. This is the preferred mode for cyclotron tuning. It also provides the least disruptive way to bring on the other proton lines. So start-up was fairly smooth and beam production continued as described below.

Beam Schedule 108

The cyclotron availability for this period was 1648 hours or 95% of the 1728 scheduled hours, a very good finish for the last twelve weeks of the year. The average weekly downtime was halved to 5 hours, the bulk of which was fairly evenly distributed among the RF, ISIS and Services groups as well as site power disturbances. It should be noted that the rf behaved extremely well with an average weekly downtime of only 1.5 hours. The rf booster was eventually tested and ready for use but soon developed a water leak at its feed-through, rendering it inoperable for the remainder of the year. The previously degraded tank vacuum was further challenged by a growing air leak in the BL1V section that was beginning to seriously compromise cyclotron performance. The problem was located on a vacuum seal at the beam blocker and could be repaired (at a cost of 1.5 mSv) allowing the resumption of normal operation. The cyclotron tune was fairly good with a typical beam transmission of 62% and nominal tank spills around 1% of the total current extracted.

BL1A ran for 1260 hours or 97% of the scheduled time, at an average current of 105 μA for a total charge delivery of 132 mAh or an impressive 97% of that scheduled. However, the currents were for the most part kept reasonably low for a number of reasons. Not long after start-up the initial higher current was reduced to 100 μA due to the early use of a graphite target at 1AT1, when a misalignment on the newly installed, 4 mm low ladder precluded the use of beryllium targets there. The previous ladder was swapped back and currents were raised to 120 μA for two weeks before being reduced again to 100 μA for the final few weeks of the year's operation. The temperature of the troublesome circuit of 1AQ15 started to climb and would not have remained below the trip point much longer without requiring a back flush. By reducing its current and retuning BL1A the quadrupole remained usable until the end of the schedule.

BL2A ran for 986 hours or 88% of the scheduled time, at currents up to 70 μA during a significant extended run that delivered a record charge of 31.8 mAh accumulated on one of the SiC targets. The total delivered charge this quarter was 45 mAh, again aided by the use of the beam stabilization program. Tuning was made more difficult toward the end with the loss of the final scanning wire monitor but constraints on beam size were achieved using the halo monitor.

BL2C4 ran for 839 hours or 99.5% of the scheduled time receiving 47 mAh or 93% of the scheduled charge at currents around 60 μA. Some time was spent investigating a second suggested target blip which turned out to be related to water conductivity problems which were becoming somewhat chronic until some relief was obtained by changing the resin. Also, tunes toward the end of the year seemed to suffer a little from wider spots due to aging extraction foils.

BL2C1 was used for proton therapy (2 sessions, 3 patients) as well as for PIF experiments for a total of about 3 weeks of operation. The tuning problem at higher energies was resolved when a similar problem cropped up at lower energy. The problem had been caused by a shorted polarity switch in the combination magnet power supply. The switch was replaced restoring the ability to run the higher energy 116 MeV tune for PIF.

BL1B had been scheduled for PIF, however, during some tuning subsequent to 3 hours of initial operation at 225 MeV, there was difficulty finding the beam after a power glitch. In the process the extraction probe was dipped too low into the beam and was damaged and rendered unusable due to overheating, as confirmed during an inspection several days later. Independently the probe itself had already been scheduled to have most of the damaged parts replaced in the upcoming shutdown. PIF irradiations at higher energies (200 to 500 MeV) had to be suspended but some users were able to work at the lower energies offered by BL2C1.

Just before the Christmas holidays there was a two-day development shift after which most cyclotron systems were turned off. The year ended as it began with the removal of around 60 large shielding blocks from the meson hall in preparation for the next round of shutdown activities.

Apart from the many tasks associated with beam delivery and shutdown work, individual operators were again involved with several other important activities such as fire alarm and card access system improvements, site emergency planning, AutoCAD drawings, training, equipment repair, computer and console upgrades and maintenance, beam transport modelling, coordination of software improvements and more.

BEAM DEVELOPMENT

Cyclotron

Cyclotron beam development focused on increasing TRIUMF's extracted current for beam production from its existing level of $\approx$200 μA to $\sim$300 μA, on stabilizing the BL2A beam current extracted for ISAC, and on achieving/maintaining high quality tunes for routine operation.

In 2005 realignment work of the centre region correction plate was completed. Begun in 2002, this work was aimed at reducing beam-induced heating on the correction plate scrapers. The plates in upper quadrant 2 were surveyed, found to be tilted with respect to the median plane, and realigned. Afterward, while extracting 298 μA, all scraper temperatures stabilized below 50°C, only slightly above their ambient beam-off temperature of $\approx$40°C. This was a very important achievement in the effort toward reducing beam losses on indirectly cooled electrodes in the centre region, as required for the higher intensity beam goals of cyclotron refurbishment.

ISAC prefers to operate with currents close to, but not above, the target's limit. Thus small fluctuations in the extracted current may produce over-current trips. In order to avoid sudden changes of thermal load on the target, a slow ramp-up of the beam-pulser duty cycle is introduced delaying as much as two minutes the restoration of the required conditions of the primary beam. After this, the time required by the target to reach its stable production regime for RIB is normally at least as long. Fluctuations of the primary-beam current were substantially reduced by installing a BL2A/ion-source-pulser feedback loop. If the BL2A current increases, then the loop compensates for the increase by changing the setting of the pulser to decrease the duty cycle of the injected beam and vice versa. This loop is now being used for routine beam production and has significantly decreased the number of trips.

ISAC's proposed BL4N extraction line, which was based on an increased total cyclotron current requirement up to 400 μA, was removed from the 2005–2010 five-year plan because of budget reductions. As a result, in 2005, development concentrated on optimizing the tune for 300 μA needed as soon as ISAC begins operating with 100 μA. Much of this work was done at high equivalent currents with less than full duty cycle, because during most of the development shifts one or more of the extraction lines was unavailable for use as a beam dump. Still, valuable experience was obtained, and when the three high-intensity beam lines became available in October, TRIUMF's old *total* extracted current record of 275 μA set in 2002 was broken. 298 μA was extracted at 97.2% duty cycle for 2.4 hours with 60% cyclotron transmission. The duty cycle was then reduced so that the stabilization loop could be turned on, and 274 μA was extracted for 1.4 hours. As shown in Fig. 251 the extracted currents were fairly stable, and turning on the feedback loop improved the stability of the current delivered to BL2A. Although these results are promising, further refinements of the tune and/or the hardware may be required before we will be able to reliably deliver 300 μA to experiments for weeks or months at a time.

Development time was also used to diagnose and correct problems that arose during beam production. Routinely at the start of each development shift, a complete set of diagnostic scans is done and existing problems are corrected before proceeding with the scheduled development. Figure 252 shows one such problem that was corrected. The HE1 probe is scanned while the time-of-flight between cyclotron injection and extraction is recorded as a function of the HE1 radius.

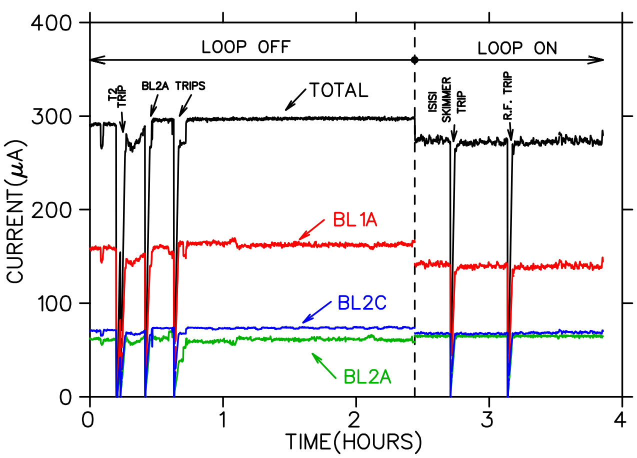

Fig. 251. Graph showing simultaneous extraction of high-intensity currents versus time with and without the BL2A pulser stabilization loop.

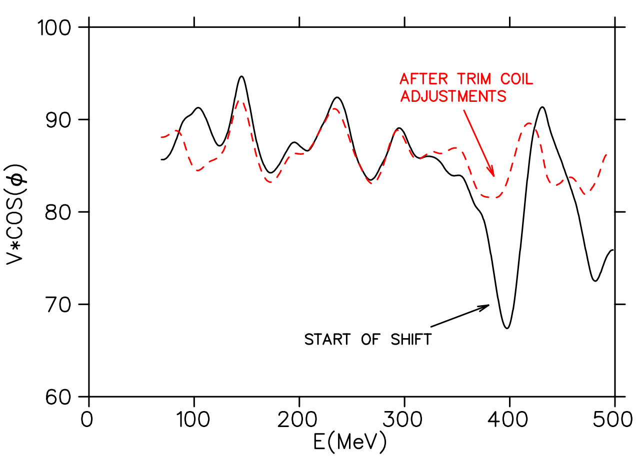

Fig. 252. HE1 $V\cos\phi$ scans showing how the isochronism was improved near 400 MeV by adjusting the trim coils.

This yields a measure of the product $V\cos\phi$. The dip near 400 MeV, indicating poor isochronism, was corrected by adjusting the trim coils.

The development time allocated to eliminate instabilities was particularly important. Early in 2005 an instability causing inflector trips was eliminated by adjusting the beam steering at the inflector entrance. In the fall a persistent intermittent instability causing BL1A target-protect monitor trips was eliminated by adjusting the centre region correction plates and trim coils. Although the solutions appear simple, problems such as these are often difficult to diagnose/solve and frequently require a large amount of development time.

Primary Beam Lines

In 2005, a new BL2A tune was developed for ISAC. The old tune produced a dense 1 mm × 2 mm spot which melted holes in the target. The new tune has been operational since April, 2005 and produces a less dense 12 mm spot ("size" being here defined as 4 times rms). It has successfully delivered 70 μA to ISAC's west target station over long periods of time. Post-mortem analysis revealed no localized melting of the target. A key factor in developing the new tunes was reported last year – the discovery of an incorrect description of the beam transport from the stripper foil through the fringe field of the cyclotron to the beam line. Since this discovery, we now achieve very good agreement between measured and calculated beam envelopes. This is shown in Fig. 253.

Spill-monitor trip limits are set at around 1 nA/m along the beam line. At highest current running, we are thus sensitive to halos at the 10^{-5} level. The observed spills are around this level and are consistent with large angle Rutherford scattering from the carbon extraction foil. In order to minimize the spills, the transfer matrix elements M_{12}, M_{16}, and M_{34} of the new tune between the stripping foil and the entrance of the ±15° dipole

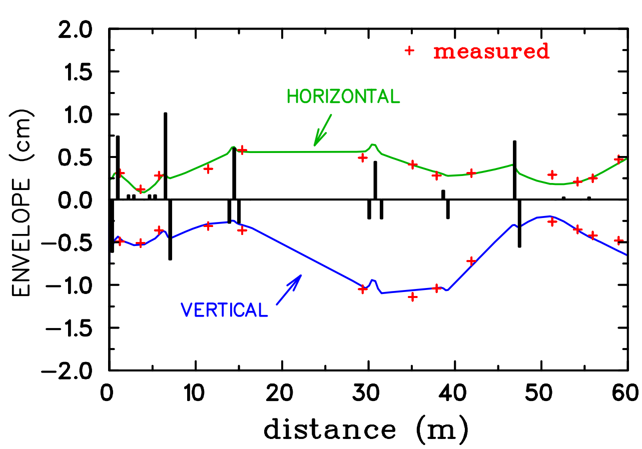

Fig. 253. Measured and calculated BL2A beam envelopes.

on BL2A were all made small because the beam pipe decreases from a diameter of 4 in. to one of 3 in. at the dipole entrance. Although this proved helpful, for high current it would be desirable to eliminate the halos by installing a collimator in the vault near the entrance of BL2A. Additional studies will be needed to determine feasibility and design configuration of the collimation.

Plans for 2006

Commissioning BL2A for 100 μA operation will be the primary goal of beam development during 2006. Cyclotron development will concentrate on stabilizing the extracted BL2A current and on identifying the sources of the instabilities, such as power supplies requiring additional regulation etc. while BL2A development will concentrate on finding tunes with acceptable spills that produce the required spot sizes on the targets.

As in previous years, some time will also be devoted to high-current tests and to maintaining/improving production tunes.

RADIO FREQUENCY SYSTEMS

RF Operation

The total cyclotron rf downtime for the year was 76 hours, excluding the 3 weeks required following the shutdown to find and repair a resonator water leak. Downtime due to sparking was reduced by a factor of two from that of the previous year, accumulating only 19 hours in total. Crowbars caused 13 hours of downtime with the remaining 44 hours caused by various hardware failures. These are described in detail below.

As in the previous year, a great deal of activity was devoted to enhancing overall reliability. A number of improvements were made in various areas from power amplifiers (PAs) to resonators.

Power Amplifiers

A thorough inspection and overhaul of most components in the PA cabinets took place during the shutdown. The replacement program for water-cooled filament adapters was completed for all PAs. All eight filament power supplies were overhauled. Of these, three older supplies were upgraded with new transformers because they were underrated for output voltage. All eight PA screen power supplies were overhauled as well.

Five spare 4CW250,000 tubes, three new, one rebuilt and one old, were tested in PA3 and PA4. All of them showed good and reliable performance. Input matching to all PAs was significantly improved.

Tube emission tests were performed in PA1, PA2 and PA4. The main conclusion drawn from the measurements is that there was no emission degradation for the entire tube lifetime in the PA operational regime in use.

The PA1 hairpin shorting plate showed very poor rf contact, which caused overheating. The original mechanical design was found to be deficient; eroded and deformed hairpin copper pipes did not allow proper rf contact to the shorting plate. As a temporary measure the rf contact was improved by using a 3 mm thick aluminum wire. At the same time, a new PA hairpin inductor prototype was designed, built and installed into PA4 (see Fig. 254). From an rf point of view this is a replica of the old inductor, although it features a stainless steel copper-plated body, improved anode contact electrodes, and a modified tuning (shorting) plate. This new unit has demonstrated excellent performance, but was found a bit too complicated to fabricate. An updated hairpin version was subsequently developed in which the expensive anode boxes were eliminated. The new design was optimized through extensive use of the HFSS 3D simulation package. Significant simplification of the structure and suppression of some parasitic rf modes were obtained. New hairpins are being fabricated and are scheduled for installation in 2006.

Anode HVPS

Many HVPS varistor disks were in bad condition and required a thorough cleaning and polishing. An entire circuit was upgraded. Each of four varistor stacks was expanded from 24 to 30 disks, increasing the total energy-discharge capacity by 25%.

The continuity test circuit for the tube cathode shunts was upgraded with test pulse generators installed for each PA tube. Many modifications were made to the crowbar driver front-end electronics, including crowbar triggering by Pearson current transformers and diagnostics added to detect the firing sequence of the crowbar elements. There is also a new crowbar counter that employs a binary output interface. All of these new signals are sent to the main control system for remote display and data logging. In

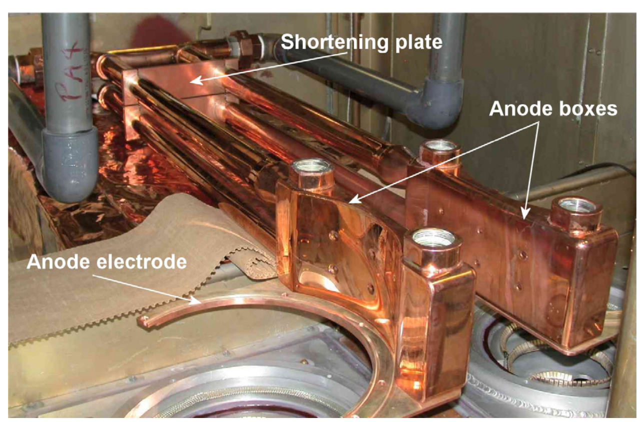

Fig. 254. New stainless steel hairpin inductor during installation in PA4.

addition, a signal from a HV resistive divider was added to the main control system for remote high-voltage reading, and a Hall-effect transducer was installed to measure the HVPS total output dc current.

RF Coaxial Switch

The rf amplifier system provides up to 1 MW of rf power at the output of combiner #3 and is connected to the cyclotron through a 9 in. transmission line. To simplify troubleshooting, a 4 port 9 in. coaxial switch has been installed at the output (see Fig. 255). This gives us the ability to redirect rf power to either the cyclotron or the dummy load. Originally rated to 700 kW, this switch was upgraded to carry 1.1 MW by adding water and air cooling. The switch is mounted on a stand which features height adjustment and permanently mounted casters for relocation. After one year of operation all movable rf finger contacts were inspected and found to be in very good condition.

Soda Solution Dummy Load

Our dummy load set-up was upgraded with a new 1 MW heat exchanger. A new conductivity sensor was also installed to aid in the monitoring of rf matching at the input port of the dummy load. The rf termination head received a new vertical stand (see Fig. 255), allowing easy adjustment of the height of the load and mobility required to connect it to either the rf switch port or any output of the PAs or combiners. The complete system was tested at 800 kW of rf power for a few hours.

Transmission line

A complete overhaul and cleaning of all spark and burn spots was made on the transmission-line matching section. Six new aluminum inner-conductor joint sleeves were installed. These replaced old copper ones that had failed in a few locations because of electrochemical corrosion (see Fig. 256). Also, eight new polypropylene disk spacers have replaced old unreliable insulators.

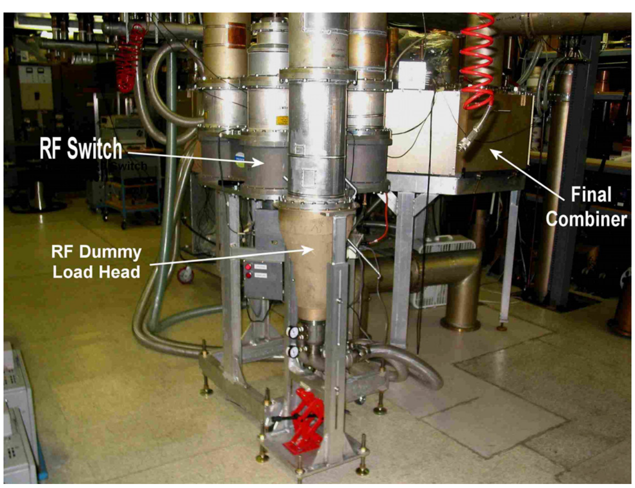

Fig. 255. RF switch installed into the system.

Fig. 256. Burnt spot at transmission line inner conductor joint.

New centre conductor “T” junctions were designed for capacitor stations 1 and 2. A set of fabrication drawings was issued with installation planned for 2006. The new design features simplified assembly, improved electrical contacts and rationalized cooling circuit inlets and outlets.

Cyclotron

The chore pad replacement program was completed. These protect the bellows of the resonator cooling circuits from excessive vibrations. In the winter shutdown the last 30 resonators in lower quadrants (LQs) 2, 3 and 4 were serviced. Most challenging was LQ3 because of significant radioactive contamination in this octant. Because of the contamination the use of respirators was necessary.

Thirty-two new correction plate (CP) HV cables were run from the power supplies to the tank lower feedthroughs and the old cables were removed from the vault basement. There was a plan to refurbish in-tank CP wire ways. However, during the shutdown it was decided to limit this intervention only to cleaning the ceramic insulators and covering them for protection against multipactor discharge (see Fig. 257).

We continued the alignment of the vertical position of the CP in order to reduce beam losses on the protective copper scraper and thus eliminate the overheating that had been observed in the past. During 2005 the set in upper quadrant #2 was raised by ~5 mm toward its nominal position. Reference measurements with respect to the median plane for the final locations of all CP scrapers are shown in Table XXV.

Fig. 257. Correction plate wire way insulators coated due to discharge.

Table XXV. Vertical coordinates (in mm) of the correction plate scrapers.

	LQ2	UQ2	LQ4	UQ4
Inner radius	−24.97	22.19	−22.74	26.54
Outer radius	−25.43	22.19	−23.94	30.06

The ceramic window of the coupling loop developed a vacuum leak at the end of 2004. Failed O-rings were replaced. At the same time damaged rf finger-stock contacts were repaired.

In the 2004 winter shutdown the hot arm tip (HAT) positions had been adjusted for resonator segments #10 in LQ2, UQ2, and UQ4, in order to compensate for misalignment of the corresponding ground arm tips. These lack remotely-controlled motors because of interference with the main magnet yoke. Following these adjustments no visible improvement was observed in the leakage field pattern. Instead they caused overheating of the attached resonator panels. Thus it was decided to return these resonators to their average vertical position in line with the rest of the HATs.

While the cyclotron was being pumped down following the shutdown, a water leak was detected in the tank volume. This was located on the copper skin of the 3U6 resonator facing the beam gap. The segment was removed from the tank for repair, which took place in the remote handling area. The entire skin of the failed 3U6 unit was replaced with a new type of resonator segment. The downtime incurred by this failure was about 3 weeks.

RF Booster

The rf booster was not used after the installation of a new rf control system during the 2005 winter shutdown because of its unsatisfactory performance. The anode blocking capacitor failed and was repaired twice before it was realized that there were deficiencies in both the new control system and the HVPS configuration. These deficiencies were corrected.

A high standing wave protection circuit was implemented in the control system. Trip points in the overcurrent protection circuit and 480 VAC breaker were readjusted. LC filtering and resistive current-limiting networks were modified. An SCR-based ramping/switching circuit was also fabricated and installed. In addition, a spark gap was installed in the PA to protect the blocking capacitor. These measures allowed a reduction of the energy dumped into a PA spark from 15000 J to ∼80 J.

RF Diagnostics

All 12 reverse power directional couplers installed on the 9 in. transmission line in the rf room were refurbished to accommodate higher coupling. This new requirement was set to satisfy the input capacity of the new high VSWR protection unit to resolve low level reverse power signals. The maximum coupling achievable was increased from −80 dB to −65 dB (−60 dB for the combiner waster loads).

The transmission line standing-wave protection unit was connected to the main rf system in a test mode in order to adjust the trip-point thresholds for all 12 reverse power signals from the rf room transmission line branches. Final commissioning of the system is scheduled for 2006.

The data acquisition system for PA dc voltages and currents was commissioned and calibrated. This system helps daily performance checkups, PA troubleshooting and tuning, and data archiving to monitor long-term trends. A number of tests were required to suppress rf interference for Hall-effect current transducers; eventually they were enclosed in aluminum shielding boxes. RF filters were installed for all power and signal leads connected to the sensors. More than fifty dc signals describing the PA status are now available through the control system.

RF Support

Activities of the RF group in ISAC are reported in the ISAC Section.

RADIO FREQUENCY CONTROLS

Cyclotron RF

Software and hardware to support the high VSWR protection system was installed and tested. Further adjustment to optimize trip points is required before the system can be fully commissioned. Further fine tuning of the spark detection/recovery system was completed. Debugging and testing of the new ISIS control computer and Firewire interface were completed. The new system replaced an earlier system that was obsolete and prone to failure.

A new crowbar design was implemented on the main HVPSU for the high power rf amplifier to the cyclotron. This new design uses Pearson coils for sensing overcurrent transient conditions. The previous design, which had been in use for the past 20 years or so, sensed overcurrent transients in the ground return resistor and was more prone to generating false crowbars because of noise on the ac supply from BC Hydro. Thus the new design results in less machine downtime and higher availability because fewer false alarms are generated by sensing the actual HV supply to the rf HPA.

RF Booster

The rf booster power amplifier was found to have major phase non-linearities, which interfered with normal operation of the IQ control system. As a result, a major redesign of the booster controls to a conventional amplitude/phase based system was undertaken. The resulting operating mode is similar to that used for the ISAC-II superconducting cavities. The booster is started in self-excited mode, then tuned to within 2 kHz or so of the fourth harmonic and amplitude/phase locked to the cyclotron reference. Although testing and commissioning were constrained to biweekly shutdowns, they were completed before hardware failures in the cavity tuning and transmission line forced a halt in operation until repairs could be made during a shutdown.

ISAC-I

A system was designed and implemented to permit pretuning of the RFQ. This is a necessary prerequisite for full turn-key operation of the system. The groundwork was also undertaken to begin replacement of the commercial tuning-motor drive systems with a more reliable in-house design. Design modifications to improve the stability of the rf systems of the DTL tanks and bunchers were implemented.

ISAC-II

A major effort – not unlike that of starting up a small manufacturing line – was required to produce the 20 rf control systems plus spares that this linac requires. The differing requirements of controlling superconducting cavities together with the obsolescence of a number of key components of the systems used previously forced a complete redesign of the rf control system to a very tight schedule.

A test system was developed to permit measurement of very low levels of microphonics in the superconducting cavities. Any microphonics would generate FM modulation of the cavity rf, so the test system consists of a low noise FM discriminator in which the output voltage varies according to the difference between the instantaneous frequency of the cavity rf and the reference rf.

Another system was developed to allow data collection, logging, and diagnostics from the operating cryomodules.

CYCLOTRON PROBES AND BEAM LINE DIAGNOSTICS

Probe Developments

Substantial progress was made on the high-energy probe (HE) refurbishment. The new HE1 replacement assembly was completed and commissioned in the laboratory. An endurance test of several thousand cycles was made to ensure that there were no problems related to extensive use, such as cable stretch, etc. The new HE1 head (Fig. 258) will provide 7 vertical fingers as opposed to the old probe head that provided 5 signals. The probe will be installed in the cyclotron in the coming winter shutdown (2006). Also, the HE3 probe was upgraded for improved mechanics and electronics as will be described below.

Fig. 258. Photograph of the HE1 probe head assembly.

The group now makes use of the site-standard, commercial design software program "Solid Works". New conceptual designs are modelled and developed using this tool, and then turned over to the Design Office for detailing.

A planned modification to the low-energy (LE) probe bearing subassembly for installation in the winter shutdown was abandoned due to interferences with an rf shield plate. The original recirculating ball-bearing system was cleaned up and reassembled. In the long-term, replacement of the segmented tracks with a continuous track, which is now feasible with modern machining tools, may be required. New LE probe heads were designed to lighten the load on the mechanics of the cantilevered head. Shown in Figs. 259 and 260 are the new heads that will be installed in the 2006 shutdown. Figure 259 shows the design model with the upper rf shield removed; Fig. 260 shows the main parts prior to final assembly. Thin insulating strips will be used initially to establish alignment and isolation of the segmented fingers.

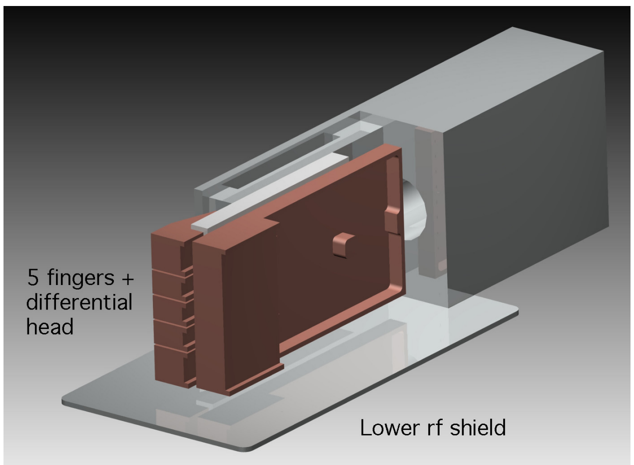

Fig. 259. Solid Works model of the LE probe head.

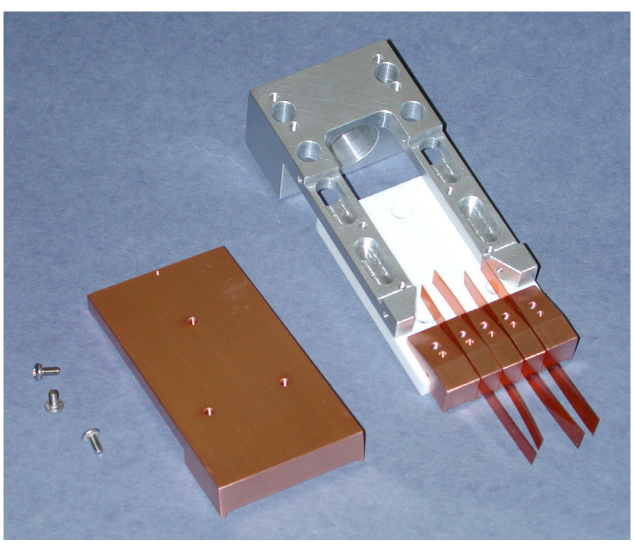

Fig. 260. Photograph of the LE probe head assembly.

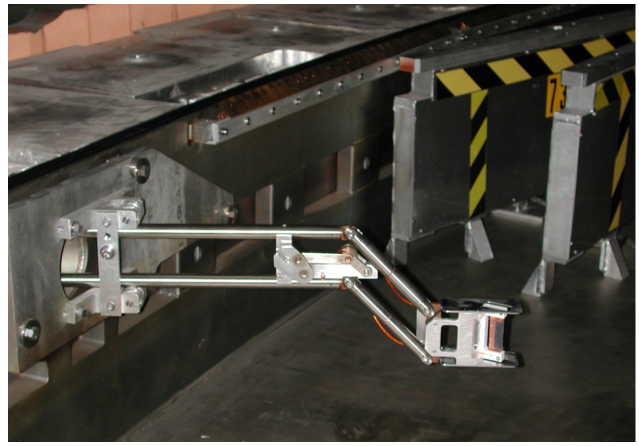

Fig. 261. The new wideband head in the cyclotron tank.

A new intercepting probe head for the TRIUMF cyclotron was designed, manufactured, and installed in the tank during the winter shutdown (see Fig. 261). Mounted with new signal cabling on the old HE4 assembly, in the HE3 location, this probe is capable of measuring phase and time structure of the circulating beam. The probe, described in last year's Annual Report, has an extended radial range and a newly developed rf strip-line pick-up for fast signal acquisition. New, semi-rigid cables were installed. It is expected to operate with an average current up to 500 nA and a bandwidth in excess of 1 GHz. The signals extracted from the probe are processed by a pair of diplexers in which low-frequency and high-frequency components are separated. The low-frequency signal is directed to our standard electronics for processing and provides both dc current and a time-of-flight signal with a rise time of ≤ 0.1 μs. No noticeable problems were found after one year of operation.

Several hours in two beam development shifts in May were dedicated to studies of the broadband functionality of the new probe. For the high-frequency outputs a signal-to-noise ratio of about 4 at 250 nA average current and 0.1% duty cycle was measured in the presence of rf noise from the cyclotron (see Fig. 262). Time-structure as short as 1 ns was resolved. Although the probe meets design specification and shows good performance, the signal-to-noise ratio is relatively low. An especially strong noise signal is induced in the probe by the cyclotron booster. Additional effort will be required to further filter out this noise.

In addition, signals from the existing tank non-intercepting capacitive phase probes were inspected. The replacement of cables performed during the shutdown produced positive results. Cables were adjusted for equal phase delay and amplitude attenuation so

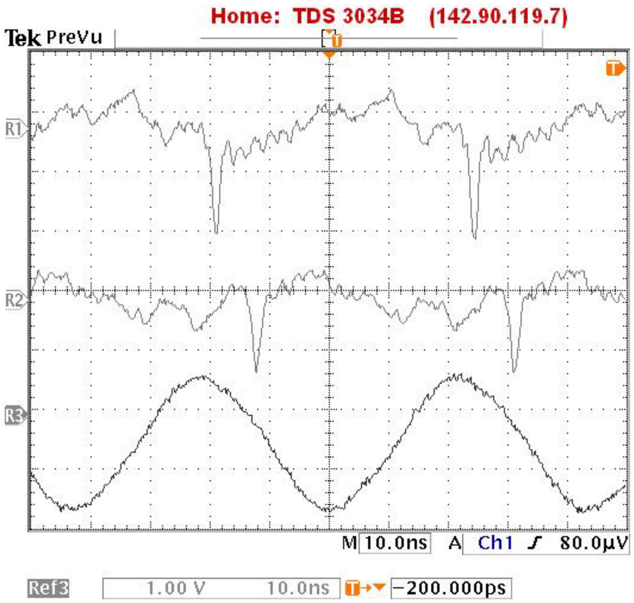

Fig. 262. Waveform of the signal from both high frequency outputs of the wideband probe (the two upper curves) and the rf sine wave (fundamental) measured with a 350 MHz scope. The horizontal scale is 10 ns/div.

that rf noise would approximately cancel and the signal from the beam would approximately double. Electronics for these phase probes are planned to be developed during 2006.

Probes MRO

The three extraction probes currently in use were inspected and found not to require servicing. The wiring of the NW periscope controls was replaced. New stock prisms were installed but they blackened quickly due to radiation damage. Two different sets of radiation-resistant prisms were procured; one of each will be installed in the 2006 shutdown.

The cyclotron probes use low-pass filters at the tank ports to block rf pick-up from being passed to the signal processing electronics. The filter design was optimized using OrCAD PSpice to provide the best rise time for the time-of-flight signal from the new HE1 probe.

A new, 24 V dc ferro-resonant power supply for the 264 level probes PIE box was assembled, installed in the rack, and commissioned.

A flow-rate problem of the water-cooled probe has also been investigated. Although no solution was found, analysis of its history shows the flow is slowing by about approximately 10–15% per year. Further investigations are necessary.

Beam Line Diagnostics Developments

During the spring it was verified that the prototype of the new pulse-shaper module for the cyclotron time-of-flight measurement from the beam line 1A capacitive probe was functioning well. A PCB layout was developed for the production version. The number of channels was increased to two. Logic signals for the start, stop, and duration of the beam macrostructure were also provided. The first production unit was assembled and installed during the September mini-shutdown.

Currently, the system provides an accurate measurement of the beam time-of-flight through the cyclotron by comparing the arrival time of the beam in BL1A with the injection time at the ISIS pulser. The data are now displayed on the operation 0 panel and are included in the shift log. As an alternative to using the rather qualitative oscilloscope display on the console, the digital data can now be used by the operators to accurately monitor and minimize the time-of-flight and consequently maintain good isochronous conditions in the cyclotron.

New electronics were built for the BL2A capacitive probe making it possible to reliably extract dc beam current information over a wide dynamic range from a narrow bandwidth rf signal with amplitude proportional to the beam intensity for currents as low as 50 nA. An advantage is that the average current can be monitored for any, even 100%, duty cycle. Therefore it does not require the extracted beam to show a pronounced beam-off interval in the micro-structure.

An indirect goal of the project was to develop expertise and hardware and software bases for “intelligent” front-ends that would be flexible enough to be widely used in different types of monitors with little or no modification. The approach selected is based on the Analog Devices mixed-signal ADSP 21992 processor. In the monitor that was developed, demodulation of the rf signal from the capacitive probe is provided by an Analog Devices AD8306 precision log detector capable of a dynamic range of 90 dB with analogue-to-digital conversion and temperature compensation performed by the DSP. The system was calibrated with a precision Marconi synthesizer and a look-up table was generated from the data and stored in the memory to correct for differential non-linearities of the detector. A digital low-pass filter was implemented to remove any residual modulation of the output signal of the log detector. Although there are several possible ways of reading the data from the DSP, a 16-bit digital I/O port was chosen because of the ease of interfacing with the cyclotron control system. A CAMAC TPG604 dual-input register card was installed for this purpose. The module will be installed in the winter shutdown of 2006.

A new multi-wire chamber monitor was designed for 2C4VM2. New cables and electronics were provided. The monitor boards were tested in the laboratory and the monitor was installed in the September mini-shutdown and tested with beam. Precision and resolution were found to be very good.

Beam Line Diagnostics MRO

All vault and standard beam line monitors were serviced during the shutdowns. Repairs were made to the following monitors: 1AM8 received a new gas pack, a spare unit was installed to repair a ferro-fluid vacuum leak on 1AM9, and new O-rings were installed on the signal feedthroughs for 1VM1.

The 0794 interlock-logic unit, part of the TNF protect system, was suspected of triggering false error messages. The problem was eventually found to be due to a faulty CAMAC input register.

On BL2A, actuator bellows of the ITW (ISAC target west) entrance monitor (wire scanner 2A2M19) developed a vacuum leak in the fall. It is scheduled for repair in the 2006 shutdown.

The ITE (ISAC target east) wire scanner 2A3M19 exhibited a high level of noise. On investigation, it was found that strong noise was generated during the scanner motion because of vibrations. After the mechanics had been adjusted the noise was slightly reduced. Then the speed was reduced from ∼0.6 s/swing to ∼2 s/swing and the signal-to-noise ratio improved to an acceptable level. Similarly, the 2AVM2, 2AVM6 and 2AM13 wire scanners were slowed down to 2 s of travel time in order to improve the resolution of measurements. It was also found that the wire-scanner software had errors in the geometric calculation of profile position. These were corrected.

Increases in proton beam power on the ISAC targets has resulted in damage to targets when the beam density was too high. In order to minimize the scattering upstream of the target, the original specifications for the target protect monitor intentionally excluded a total plate monitor required for density protection. Recent understanding of the beam line tune and target parameters indicates that scattering is not an issue, so a new target-protect monitor was designed and built to provide density protection against small beam spots with excessive power density. It will be installed in ITW during the 2006 winter shutdown. The ITE target protect monitor will be similarly upgraded in the 2007 shutdown.

The BL1A Čerenkov A and B monitors at the 1AT1 target were found to have been seriously damaged by radiation. The plastic of each monitor had turned brown and was replaced. Also, the photomultiplier tubes of monitors A and B had to be replaced. Both monitors are currently operating well, although signs of rapid deterioration of the light collection efficiency of the plastics is observed, indicating a rather high rate of radiation damage.

A noise problem manifested by the target protect monitors (2A2M20 and 2A3M20) at low duty cycles was investigated and was attributed to insufficient integration of the signal by QSX/W amplifiers. The original amplifiers had a low-pass filter up to 1kHz that was sensitive to the time structure of the proton beam. These amplifiers were replaced, for both east and west target stations, with QSX amplifiers with a 100 Hz low-pass filter.

VACUUM

Upgrades and Refurbishments

The vacuum system performed reasonably well during the year, despite the budget for new equipment being reduced to a bare minimum. Unreliable behaviour of the B-20 cryogenerators was the biggest problem and caused several emergency interventions and repairs. This worsening trend clearly showed that refurbishing the old units was now no longer sufficient and that the time for purchasing a new cryogenerator has come. It was recommended that a new, efficient, reliable modern unit be identified. This unit would meet the requirements for the majority of the vacuum-tank pumping; existing units would be used only as backups or spares. Several options for the replacement unit were investigated and a request for the 2006/2007 refurbishing budget was prepared.

In August, 2004 a new Vacuum and Cryogenics group was formed. The existing group was reorganized to include most vacuum and cryogenics responsibilities at TRIUMF. Substantial cryogenic activity took place for ISAC-II and is described elsewhere in this Annual Report.

MRO

Some vacuum problems related to air and water leaks into the cyclotron vacuum tank were experienced during the year. After the winter shutdown the ultimate vacuum of the tank failed to reach nominal levels (as measured by the north and south ion gauges of the tank). Changing the B-20 cryogenerator and defrosting the cryopanels did not correct the vacuum situation. Consequently, extensive leak checking was conducted using a leak detector connected directly to the backing line of the south turbo-pump. Only one air leak was detected. This leak, on a port on the bottom of the vacuum tank, was temporarily repaired and replacement of the port flange is scheduled for the winter shutdown. An investigation of the correlation between the pressure of the cooling water system and the pressure of the vacuum tank pointed to a water leak as the cause of the poor vacuum. This leak was eventually eliminated by the replacement of a resonator segment.

The cyclotron vacuum system continued to operate well for the remainder of the year. A B-20 electrical problem and the failure of the gate valve of the inflector cryopump contributed to most of the downtime. A B-20 electrical refurbishment is required; its installation and the commissioning of the new system is planned during the next winter shutdown.

A leak in the housing of the beam line 1A extraction probe was detected in September. This leak caused extra load on the cyclotron cryopanel system and thus increased tank pressure. However, the vacuum was acceptable for beam production and repair of the gate valve could be delayed until the upcoming winter shutdown.

Beam Line 1

The vacuum system of beam line 1 comprises the vacuum in beam line 1V in the cyclotron vault and in beam lines 1A and 1B external to the vault.

The vacuum system of BL1V operated well during the year except for a leak caused by radiation damage during beam tuning. The elastomer O-ring was replaced and its upgrade to a metal seal is scheduled.

During the winter shutdown the gate valve isolating target 1 from target 2 on beam line 1A was refurbished. The Buna-N gate seal was replaced and metal seals were installed on both sides of the valve. However, the Buna-N seal was damaged again by beam and will have to be replaced again during the 2006 shutdown.

One of the Leybold turbo-pumps on beam line 1A failed and was replaced. The backing pumps of the turbo-pumps and blower were serviced or replaced during the year. Replacement could be done during scheduled maintenance.

Beam line 2A

The vacuum system of beam line 2A had minor problems. A few O-rings damaged by beam were replaced. In 2006 some will be replaced with metal seals. A roughing pump in the vault section was removed from service and is scheduled to be repaired during the 2006 winter shutdown. A l/s turbo-pump failed and was replaced.

Beam line 2C

The turbo-pump on beam line 2C failed and it was necessary to operate by allowing the cyclotron vacuum to pump the beam line. The failed turbo-pump will be repaired during the 2006 winter shutdown.

ISIS

The cusp ion source, injection line, and inflector/deflector systems continued to operate well for the past year with uptime in excess of 99% of the scheduled time. Approximately one-half of the 37.2 hours of downtime was due to a failed insulator in the Einzel Lens and a vacuum leak. Although ISIS personnel were involved in other TRIUMF projects, high-priority extraordinary maintenance as well as a few important projects were undertaken during the past year.

General

The Prompt Radiation Safety Trip System has been revised to include redundant safety-critical gamma and neutron monitors. Each of these safety-critical trip functions requires three independent ISIS beam control devices. To provide the additional beam-control device functionality we designed a system of four high-voltage relays to service the four vertical-bend electrodes as well as two beam stops. Each trip function uses two high-voltage relays to switch two electrodes to ground potential and to insert a beam stop. The system was installed, tested and successfully commissioned in February and March.

Approximately fifty new power supplies for the vertical section of the beam line have been ordered as part of our refurbishing program. These supplies are of the same type as used in ISAC LEBT and will help reduce the overhead for spares. Last year we purchased two replacement supplies for the inflector/deflector; this year we have ordered two more as well as a spare with reversible polarity. It is anticipated that these supplies will be installed in 2006.

The 24 V power for the ISIS interlock control system was traditionally supplied from the Controls group through a UPS/converter system residing in ISIS. This unit is no longer serviceable and the Controls group now uses a site UPS feed for their system that does not have sufficient capacity to provide ISIS with the traditional requirements. Therefore we have purchased and installed our own 24 V power supplies for the interlock control system.

Ion Source

In order to provide the necessary ion source lifetime for the revised beam schedule (maintenance once every 2 weeks) we have changed the ion source filament diameter to 2 mm from 1.8 mm. This allows for continuous source operation between maintenance periods. Unexpected leaks in the ion source led to the discovery that an O-ring compression specification for the filament rod was incorrect. This was temporarily remedied, the drawing revised and new parts manufactured.

Injection Line

The injection line was leak-checked at the beginning of the winter shutdown. The most serious leak was found at the top of the vertical beam line. The leak is small and the decision was made not to institute a repair at this time as this would involve removal of the VR1 section of beam line. Other small leaks were found in the area immediately upstream of the vertical bend section. This area was disassembled; the related optics was removed and cleaned, reinstalled and aligned. Minor leaks in the pepper pot and chamber 127 were also repaired.

Inflector/Deflector

The inflector/deflector and the high-voltage feed insulators were serviced during the winter shutdown together with a complete replacement of the skimmer cabling. The system ran well for the entire schedule albeit with some sparking scan trips. Some development time, as well as on-line subtle tune changes, greatly reduced the number of sparks. Further investigation will take place in the winter shutdown when the inflector/deflector is removed from the cyclotron for servicing.

Development

We recently installed an adapter, gate valve, and standard 8 in. ISIS box frame (borrowed from the I3 beam line) at the end of the east-to-west section of the I1 beam line in preparation for the installation of an emittance scanner.

This year development was to focus on producing 300 to 350 μA-equivalent tunes at higher duty cycles with improved cyclotron beam losses. Because of other development demands and limited scheduled time for simultaneous extraction from three beam lines, only one shift was available for this work. However, some excellent results were achieved as described in greater detail in the Beam Development section of this Annual Report.

CRM

The restored first chamber of the 1 MeV cyclotron has allowed the testing of cusp ion sources by ISIS, Nordion, and Dehnel Consulting. Dr. Yong-Seok Hwang, from the Department of Nuclear Engineering, Seoul National University in South Korea, has completed an excellent study of our ion source characteristics as reported at the International Ion Source Conference in Caen, France.

ISAC

ISIS has provided assistance to a number of ISAC related activities during the past year. These include the assembly of the diagnostic boxes and some diagnostics devices for the transfer line from ISAC-I to ISAC-II. We have continued to provide mechanical effort toward the completion of the ISAC-II medium-beta cryomodules along with some of their diagnostics.

Standard optics chambers for the TITAN extension of LEBT and the TITAN beam line have been prepared. We continue to assist in this work as necessary.

PRIMARY BEAM LINES

It had been assumed that the major task in the winter shutdown would be the upgrade of the front end of the M20 muon channel. However, as a result of several problems that occurred on beam line 1A during the year it became necessary to address them first and, consequently, to postpone the refurbishing of the M20 channel. To this end, shielding blocks from the meson area were moved to an area near the machine shop and other shielding blocks were rearranged to allow shutdown access to the problem areas of the beam line.

Beam Line 1A

Winter shutdown

Magnet temperature trips had occurred at quadrupole 1AQ10 of the 1AQ10/11 doublet located between the 1AT1 and 1AT2 targets on beam line 1A. Further, both vacuum and water problems occurred intermittently at this location. These were the first problems tackled during the shutdown.

A video inspection showed corrosion on the 1AQ10 base plate from water leakage near the lower thermal switches and a broken spring eye on the south side of the 1AQ11 flange. It was hypothesized that because of water leakage in the area corrosion or rust were probably causing a short in the thermal switch circuit. Because repair of the magnet could not be done *in-situ* the doublet was moved to the remote handling warm cell.

With better access to the thermal switches, current leakage was confirmed from a lower thermal switch to the coil. Creative solutions were found for tooling to remove and reinstall and repair broken switches while maintaining the integrity of adjacent components. The broken flange spring on 1AQ11 was also replaced.

Significant effort and dose were required for this work; work in the warm cell alone required about 3.5 weeks to complete. The dose accumulated for this and other beam line work is given in the Remote Handling section of this Annual Report.

Repair of quadrupole 1AQ9 was another problem corrected during the shutdown. This quadrupole, which lies just downstream of the 1AT1 target, was used primarily to steer π^+ or π^- mesons into the M11 pion channel. Because of a thermal interlock problem in an inaccessible region it had been necessary to shut down 1AQ9. As a result there was an increase in beam spill at a vacuum valve between the 1AT1 and 1AT2 targets that caused radiation damage to the O-rings of the valve. Work to correct this 1AQ9 problem was the next job tackled.

When the bridge block covering 1AQ9 was removed a very fine coating of removable rust-like powder was found covering the quadrupole and surrounding services. Visual inspection of the underside of the bridge block indicated that the paint was disintegrating and settling on the magnet – a spallation phenomenon that had been observed in the M8 line during its decommissioning. Careful vacuuming of the material in the trench and magnet was performed allowing work to proceed in the area.

A faulty Hansen fitting was replaced to restore full water flow to the magnet. Repainting of the bridge block was accomplished using an epoxy paint.

Inspection of the thermal-switch lead junctions indicated significant corrosion that likely accounted for the indicated fault. A solution was devised whereby a premade chain of thermal switches would clip onto the return water line of each circuit of the magnet. This was done and confirmed by video inspection. Standard power tests confirmed the magnet to be operational.

As reported last year, magnet overtemperature problems in the 1AQ14/15/16 quadrupole triplet downstream of the 1AT2 target necessitated a retuning of the triplet to reduce the currents to the magnets. This resulted in the reduction of the extracted beam current in order to lower beam spills downstream of the triplet. Flushing of this triplet was the final job of the shutdown.

The area was accessed for the removal of the water insulators to individually flush each cooling circuit of the 1AQ15. Flushing results were similar to those reported last year. As a bench mark, the 1AQ16 magnet was exposed and one circuit was flushed. In comparison to 1AQ15 this circuit was very clean with no change in flow rate before and after flushing.

The shielding above the 1AQ12/13 quadrupole doublet was removed to inspect the area. No obvious problems were observed. Video inspections of the crumbling block on the upstream side of 1AT2 monument showed no further disintegration of the block. Vacuum leak checking in the exposed area discovered leaks only on monitor 1AM9. The beam line was vented to replace 1AM9 and to remove valve 1AVA8 which was transported to the remote handling warm cell where the transition flange O-rings were replaced with Helico-Flex metal seals. The O-rings on the valve gate and air cylinder were also replaced and the valve was reinstalled in the beam line.

Beam production

BL1A performed well until late May when 1AQ14 experienced magnet temperature trips. Again the beam line had to be retuned to reduce the current in the magnet. In late June the 1AQ15 water temperatures climbed to the point where the magnet current had to be reduced thereby reducing the beam current. Measurements on one circuit of 1AQ15 revealed a factor of 3 reduction in flow rate. After flushing with water and air 90% of the flow rate was recovered. A chelating agent, which was purchased with the intent to flush the coils, was used in an unscheduled intervention in early July. It was mixed according the manufacturer's specifications and, when pumped through the circuits, it was found that the return filter was clogged with an undissolved abrasive used in the chemical agent. Chemical flushing was aborted and the circuit was rinsed with water for a number of hours. Flow measurements indicated a further 10% improvement. Similar results were obtained for a circuit of 1AQ14. A thermocouple was added to the 1AQ15 magnet for remote temperature monitoring. Temperature measurements on 1AQ16 confirmed the magnet was operating normally.

After the July intervention the chelating agent was tested in our lab to ascertain an appropriate mixture ratio to water. The manufacturer states 6 ounces per gallon; our findings show that 3 grams per gallon are sufficient to clean copper and to remain in solution.

September mini-shutdown and beam production

In the September mini-shutdown the temperatures of the coil circuits were measured for all three magnets of the BL1A triplet. As expected, some circuits of the 1AQ14 and 1AQ15 magnets were running at elevated temperatures. All three magnets were treated with the chelating agent for 4 hours with notable improvements in water flow for 1AQ14 and 1AQ15. In addition, the existing float flow meters were replaced with Proteus paddle-wheel sensors.

After the mini-shutdown the beam line could be run at the nominal tune parameters.

Beam Line 2A

Beam intensity fluctuations at ISAC targets had been a problem. A constant beam intensity is imperative in order that a constant temperature be maintained at a target. Because fluctuation of the beam intensity in BL1A is not important at the level of a few per cent, a scheme has been implemented to keep fluctuations in the beam intensity in BL2A constant within a fraction of 1% at any BL2A current. Further details are given elsewhere in this Annual Report.

Another problem with beam delivery to the BL2A targets was corrected this year. The original tune of the beam line provided a ±2 mm beam spot at the target. This proved to be too small and holes were drilled through several targets. A revised tune was developed to produce a beam spot ∼1 cm in diameter.

In the course of this development an error in the program that calculated the vertical portion of the extraction matrix through the cyclotron extraction field was found and corrected. (See the Beam Development section for further details.)

BL2A was surveyed and O-rings were replaced in high radiation field locations during the shutdown. During the year five radiation damaged O-rings were replaced in scheduled maintenance days. The metal seals installed this shutdown at 1AVA8 will provide a test case and, if successful, the BL2A O-rings will be replaced with metal seals starting in 2007.

Beam Line 2C

2005 was a record year for the production of strontium-82 from the 2C4 solid target facility (STF), which was scheduled for 146 days. On 2C1, 35 days were scheduled for proton therapy (PT) and 36 days for experiments at the proton irradiation facility (PIF).

On 2C4 55.0 Ci of ^{82}Sr were produced from 156.9 mAh of beam compared with 48.5 Ci from 134.3 mAh in 2004. Eleven natural rubidium targets were irradiated compared with nine targets in 2004. The make rate of 0.35 mCi/μA-h remained constant with beam currents of 55–60 μA and irradiations of approximately 20 days. The beam intensity could be maintained at 55–60 μA because of the improved manufacturing of extraction strippers and of the larger acceptance of the 2C4 beam line resulting from the realignment of the STF (see last year's Annual Report). One of the improved, 0.200 in. wide graphite-brush strippers was used for 75 mA/h. In previous years the accumulated charge on an extraction stripper was limited to $\sim$50 mA/h and strippers were replaced as a precautionary measure during short cyclotron openings.

No work was done on the STF target assembly during the winter shutdown because of the anticipated replacement with an upgraded STF and to limit personnel dose. On the STF water package the ball valves were replaced with globe valves and a metering valve was installed on the water line for the ion exchange column to achieve better regulation of water flow and of the water column height. Also, the 2C4 split plate monitor was replaced with a harp monitor and new cabling and electronics were installed. This monitor now provides more accurate beam position data at the entrance of 2C4 downstream of the switching magnet.

By the fall the design of an upgraded STF was completed. All major mechanical components for the target water vessel and the target insertion were in hand. A mock-up and assembly of the STF had been set up in the proton hall and on the proton hall roof to check reliability and installation procedures. The water-cooled double window at the end of the 2C4 beam pipe had to be redesigned because the window proved to be difficult to manufacture and did not meet water pressure specifications. The 2C4 beam pipe and diagnostics vacuum chamber were also redesigned to accommodate a scanning wire monitor and a new target protect (halo) monitor. Components were being manufactured for installation in 2006. By year-end, designs for the water package and the PLC based control system had been completed and most parts had been ordered.

On 2C1, nine patients were treated during five proton therapy sessions. PIF operation was partially compromised because energies above 108 MeV could not be extracted, although the 2C extraction system had previously been working from 65 MeV to 120 MeV. During a winter shutdown assessment no blockages could be observed in the 2C exit horn. Later in the fall it was discovered that the 2C combination magnet polarity switch was shorted for magnet settings above 96 MeV and that the exit horn intercepted beam when the extraction probe was tuned above 108 MeV. Once discovered, the fault was easily repaired.

CONTROLS

2005 was an active year for the Controls group. There were new developments and a large component of maintenance. Perhaps the most significant of the new developments was the work on beam stability for Beam Line 2A, which resulted in an important improvement to the beam current stability. After being given cyclotron development time to test and refine the software, closed loop feedback on the ISIS pulser was commissioned. This software now offers Operations a new tool for providing stable proton beam on 2A with less downtime for radioactive ion beam production.

The Central Control System (CCS) ran well during 2005. The loss of scheduled beam time due to CCS faults during the year, as recorded by the Operations group, was 3.4 hours. This low level of downtime was provided without compromising important hardware and software advances.

A number of tasks had been scheduled for 2005 and those projects progressed as anticipated. These included decommissioning the DSSI disk system in the Production Cluster, continuing to replace old terminal servers, changing cyclotron device numbering from octal to decimal, and introducing Itanium based computers into the OpenVMS clusters. Some of these jobs are described in further detail below.

Central Control System Facilities

Developing software to provide beam-current stability on beam line 2A was a major beam achievment. For maximum RIB target production, it is desirable to run the beam current very close to the over-current trip set-point. Minor drifts or noise in the beam current may lead to the beam being shut off and the associated downtime. An application has been developed and commissioned to monitor the extracted beam current as measured by the extraction foil and use the ISIS pulser to quickly stabilize the current on beam line 2A where stability is critical (at the expense of some instability in the simultaneously extracted beam line 1A beam, which is quite acceptable). Development and testing time were difficult to obtain but once granted, the software was refined and put into production. Display changes and reassignments on the operator's console were also made. Beam production with the stability program enabled is now a normal operating condition.

Among the larger tasks was the investigation of a new line of HP computers called Integrity Servers. These were explored for their potential use in running OpenVMS in the CCS. They use Intel 64-bit Itanium chips instead of the Alpha chips which are more commonly associated with OpenVMS. In 2004 an Integrity Server RX 2600 was borrowed from HP and set up for testing. The unit was later purchased and integrated into the CCS, although not initially at a production level. A significant amount of the software infrastructure from the manufacturers was originally at the beta-test or field-test level (OpenVMS FT 8.2, Multinet 5.1, and DMQ T5.01) but during 2005 these have been replaced by production releases.

Within the TRIUMF-written control-system software there have been a number of developments. A low-level software driver was adapted to the new hardware platform and then enhanced to support multiprocessor computers. This software driver allows access to cyclotron devices. All of the device tables and support routines have also been ported. By the end of 2005 almost all CCS software applications had been ported. Some porting issues arose but, in general, applications just need to be recompiled and relinked. During the last part of this year's beam delivery the displays on the cyclotron's main console were running in production mode on one of these Itanium based machines.

The mini-shutdown in September was a busy time. One of the most important events was the final decommissioning of the old DSSI disk system from the Production Cluster. This disk system had run well for many years but had been replaced by a fibre channel raid system (a storage area network). The mini-shutdown provided the first opportunity with sufficient time to remove this disk hardware. The phasing out of the DSSI disk storage equipment on the Production Cluster was an ongoing job for more than 1 year (the DSSI system on the Development Cluster was already decommissioned). The labour intensive part of this task was moving the files to the newer fibre channel disk system, reorganizing the files, and removing old and obsolete files. This large reorganizing job was finally completed during the second quarter. The disks were dismounted in software but will not be physically disconnected and removed until the next shutdown in 2006. During 2006 the fibre channel disk system will be expanded to meet the increasing requirements for disk space.

A major effort went into supporting the new ISIS safety trip devices that were introduced for the upgraded prompt radiation hazard system scheme. This project involves high-voltage relays at the vertical bends in ISIS together with a variety of other equipment. Numerous hardware and software changes were required in the CCS. New devices were defined, displays were developed, scans configured, and messages set up. Because these changes involve personnel safety and are essential for cyclotron operation, the work was of high priority.

Support was provided to the RF group in a number of areas. One example was a development involving their vector voltmeters, a multiplexer, and a number of related signals. Device definitions, logging, and display pages were developed. This was quite an involved task. Another example was the creation of a scan to check that the rf booster is detuned when not in use. In still another development, the two existing X Window terminals in the rf console were replaced by a multi-headed display computer, which provides better performance. An RFinfo display panel was developed which makes it easy to insert information from the display page into the RF group's electronic log (elog). This Web-based elog facility was ported from the version being used by ISAC and was made available to cyclotron groups as their needs arose. The RF group was the first to start using this facility as supported by the Controls group.

There were serious problems with the site UPS and the decision was made to move CCS equipment off that UPS. This later led to the problem of moving all of that equipment back to UPS. Some disruption was experienced but these procedures went relatively smoothly. A new site UPS will be installed during the 2006 shutdown and it is hoped that this will remove these power system issues.

During 2005 one of the development cluster computers shut itself down a number of times. The problem was traced to a faulty network interface. Replacing the motherboard rectified the problem, but during the interaction with HP support services a new network configuration was suggested. This new configuration was set up, tested, and determined to be a significant improvement. It uses two network ports on each computer (the Alphas and Itaniums each have 2 connections) with each connection going to a separate Ethernet switch and, in fact, to separate networks. There are multiple benefits. Without any software reconfiguration, OpenVMS clustering immediately senses multiple networks and uses them to provide increased performance and redundancy. The original hardware failure now will not cause a system crash. In addition, our display computers are also configured in this manner, something that is not possible for the aging X Window terminals. The Operator display pages run using X Window displays over the DECNET protocol and DECNET will dynamically switch over to the other network if a network failure occurs. As a result, the overall performance improved, the computer/cluster/X Window display reliability increased, and the network bandwidth doubled.

More display computers were installed during this quarter. The aging VXT X Window terminals are slowly being phased out. A new display computer was installed in the rf console and another in the main console of the cyclotron. Additional display computers will be installed during the next year.

There were a number of CCS hardware-related activities during the year of which a sample are reported here. For hardware diagnostics another computer was purchased and configured in the development cluster. This provides more capacity to do on-line diagnostics and testing. In an effort to replace some of the older CAMAC crates, six crates were updated. In the ongoing task of the installation of new crate-diagnostic equipment, more power monitors were added. The control-system-specific UPS hardware saw the 7.5 kW unit upgraded to 10 kW. A number of 24 V systems were standardized and received new 24 V supplies and cabling. A variety of hardware faults occurred although none caused major downtime. There were problems with input gates, dicons, fans, power supplies, power monitors, X Window terminals, and the like.

The year ended with a flurry of activities related to projects planned for the upcoming shutdown. These were dominated by those related to the solid target facility upgrade.

Secondary Beam Lines

Increased use of secondary beam lines controls and the limitations of the existing microprocessor have led to the need to expand the computing power. After taking measurements and considering the options, it has been decided to break the existing CAMAC serial highway into two highways and have a microprocessor drive each branch. These changes may be done in the 2006 shutdown if time and parts delivery allow.

Diagnostics for the secondary beam line system have been enhanced through the development of an on-line crate-monitoring program.

Security on the secondary beam line servers has been tightened.

Other Systems

A request from Nordion for beam-related data was received. An application was developed that returns data to the caller via the Web server.

Support continued for the Vacuum group's test stand. Devices were configured in the device database and added to the logging stream. In addition, a new XTPAGE was developed to display the data.

Proton therapy received some attention. An aging terminal server was replaced with a new unit. This included changing the software support from the LAT protocol to TCPIP.

The proton irradiation facility had numerous users during 2005 and several requests for new functionality were handled.

A request from the PET facility to have real-time access to the data from air monitor 27 was met by allowing the trending data to be displayed locally.

OPERATIONAL SERVICES

Remote Handling

Cyclotron servicing

The Remote Handling winter shutdown activities for the cyclotron included the usual interim removal and storage of copper blockers, tank peripheral personnel shadow shield installation, remote vacuum cleaning, as well as video and tank seal inspections. In addition the 2C extraction probe and the LE2 low-energy diagnostics probe were both removed for servicing and reinstalled.

A new photographic documentation of the cyclotron tank was begun with quadrants 1, 2 and 4 completed and quadrant 3 nearly completed. This will provide valuable information on critical in-tank details.

Toward the end of the shutdown a leak was located in the Upper Quadrant 3 resonator cooling system. Remote leak checking with helium was performed to narrow this down to the upper #6 resonator segment in this quadrant. The segment was remotely removed from the tank using the resonator handling trolley and moved to the Remote Handling building basement. The leak was pinpointed in the ground panel and the panel replaced.

Routine inspection and maintenance were also performed on the cyclotron elevating system. The elevating jacks and worm gear reducers at station 8 were replaced with original units. Station 7 was removed and replaced with spare units. These components will be rebuilt for installation during the next shutdown.

As part of the overall refurbishing program, sourcing began for new counters to replace the original 35 year-old plastic counters that are rapidly deteriorating due to radiation damage.

Hot cells and targets

In the winter shutdown routine maintenance of the 1AT1 and 1AT2 cooling packages was performed. Both packages were drained and refilled and the ion-exchange resin was replaced, as was the target, collimator and, at 1AT1, the M15 permanent-magnet cooling circuit filters. Also at 1AT1, the rubber pneumatic air line hoses supplying the target profile monitor were replumbed with radiation-hard, 1/4 in. diameter copper tubing. At 1AT2, similar rubber hoses supplying the target profile monitor as well as M9 and M20 beam blockers were replumbed with copper tube. The P1A and P2A transducers (target cooling-water pressure, supply and return) were moved from the cooling package into the beam line 1A access tunnel.

The old M8 medical beam line blocker solenoid valve and air line were removed. The M9 beam-blocker vacuum seal, centre shaft and radiation damaged micro-switch wiring were replaced in the hot cell.

At mid-year the demineralizer water-flow transducer for the 1AT2 cooling package was replaced because of rotor and axle wear. The 1AT1-Mark2 target was transferred to the hot cell in preparation for the scheduled installation of graphite targets. The spare M20Q1 cooling-water jumpers were transferred from storage in the east hot cell to the warm cell where they were radiation surveyed to permit safe manual replacement of the sealing O-rings. In the beam line, the M20 beam-blocker height-position micro-switch actuator was realigned.

Developments on the graphite target included a jig redesign and new parts for more accurate placement of graphite material onto the cooled Saddle, new brazed and machined graphite segments and the first segment soft-soldered onto a saddle.

At the 2C hot cell, a total of nine rubidium production targets were installed and removed. One target, which had a cracked weld and elevated radiation levels, prompted removal of an unused target from the cell for comparison to determine a cause for weld failure. Also, the 2C cooling package was routinely inspected, serviced and adjusted as required. The demineralizer was exchanged to increase flow for optimized resistivity, and the conductivity cell was replaced. Continued Remote Handling input was given to the solid target facility redesign project.

Beam lines

Winter shutdown began with remote removal of the 1AQ10/11 quadrupole doublet from beam line 1A and its transport to the hot cell facility. The personnel access shielding wall in the warm cell was utilized for hands-on access to replace faulty Klixon thermal-switches and to repair wiring on 1AQ10. A cracked ceramic circuit insulator on 1AQ10 was replaced, and a corroded and broken compression spring on the indium vacuum joint of 1AQ11 was also manually replaced. Total personnel exposure for the 1AQ10/11 work was recorded at 8.02 mSv.

At the end of January the 1AQ9 magnet, which lies downstream of T1 target, was uncovered. An open thermal-switch circuit preventing operation of the magnet was repaired by installing an ingenious “clip-on” style redundant thermal-switch wiring to bypass the open circuit. A water leak required replacement of the quick-disconnect coupling fittings. Opportunity was taken to repaint the iron shield block situated over the magnet. Personnel exposure for the 1AQ9 repair was 3.07 mSv.

General inspection and vacuum leak checking were performed in the 1AQ12/13 area and in the 1AVAW2-to-1AT2 beam line section. Video inspection was completed on a crumbling concrete block in this area in anticipation of its future replacement. This inspection work recorded 0.51 mSv in total.

The 1AVA8 vacuum gate valve was removed and transported to the warm cell where it was rebuilt with radiation hard metal seals replacing rubber O-rings. A broken vacuum flange compression spring on the assembly was also replaced. Assistance was given with the replacement of damaged rubber O-rings in the beam line. The total exposure for 1AVA8 work was 3.01 mSv.

To complete the shutdown, the 1AQ14/15/16 triplet at 1AT2 was uncovered, a solder repair made to a joint on 1AQ15, and a slow drip water leak at another circuit examined. Finally all flow rates of its cooling circuits were individually measured, the circuits pressure flushed and rates remeasured. The 1AQ16 magnet also had one circuit flushed and measured. Personnel exposure for the work was 3.72 mSv.

In May, after the shutdown, the magnets of the BL1A triplet underwent a second series of back- and pressure-flushing to improve deteriorating cooling flows. The 1AQ15 quadrupole, because of its higher operating current, was compromised by over-temperature tripping, limiting beam line 1A operating currents. Further temperature “warning” trips from 1AQ14 instigated a universal pressure back-flush of both magnets again in June. This was completed by access to TNF south without the removal of any shielding blocks.

During early July elevated temperature trips once again required independent coil flushing of 1AQ14 circuit 1 and 1AQ15 circuits 5 and 11. Beam line shielding was removed for local access and chemical (Phoenix Cu) and air/water flushes were performed on the individual circuits. A thermocouple was mounted on the 1AQ14 circuit 1 to monitor future temperature rise versus thermal switch trips. In late July a cooling water conductivity meter was installed on the 1AQ15 cooling return line to learn more detail regarding the constantly deteriorating cooling flow blockage.

In mid August the 1AQ14 and 1AQ15 quadrupoles were once again universally back-flushed from the TNF south area on two maintenance days that occurred in consecutive weeks.

Finally, during the September mini-shutdown the triplet was universally flushed with the chemical solution at elevated pressures and temperatures. Significant improvement was noted in the individual magnet flow rates at this time. During this same shutdown a water leak in the M20Q1 magnet required shielding block removal for access. A leaking rubber seal ring on a quick-disconnect water coupling was observed. The entire cooling line was replaced with a refurbished spare.

Other significant work was the design of the beam line vacuum box and services for the replacement M20Q1/Q2 magnet assembly scheduled for installation in 2006. An investigation also began on possible revisions to the 1AQ14/15/16 triplet magnet cooling services. Alternatives to the bellows/insulators that limit pressure boost of the cooling system are being evaluated.

Magnet Power Supplies

The year started with shutdown activities, one of which was the inspection of power supplies and employing corrective action as required. The brushes of the variable-voltage transformers were replaced. In the rectifier cabinet of the main magnet supply the torque of the heat sink of the rectifier clamp was verified and hoses were replaced.

A major project was the modification of the trim and harmonic power supplies for bay 1. These were rewired to bring them up to the required standards of the electrical code. Work proceeded to ready the power supplies for the rewiring of the trim and harmonic supplies in rack 3. This will be done in the winter 2006 shutdown.

Assistance was provided to resolve the over-temperature problems that had occurred with the beam line 1A quadrupole triplet.

In ISAC, power supplies were installed and commissioned for the components of the beam line from ISAC-I to ISAC-II. The power supplies for the magnetic elements of the medium-beta accelerator (SCB) were procured as were those for the beam line in the accelerator vault of ISAC-II (SEBT).

A new polarity switch controller was designed and implemented for the SCB and SEBT.

The group performed normal MRO activities throughout the year as well as providing experimental support when required.

The group leader was involved in the coordination of the winter and fall shutdown activities. In addition, he was involved in the coordination of the activities of the various service groups involved in the installation of the components of the vault section of ISAC-II.

Electrical Services

It was a relatively quiet year on the site maintenance front. The only major exception was the failure of the main UPS unit. However, on the construction front we were extremely busy building the ISAC-II laboratory infrastructures. The ISAC work is covered in a separate section.

In all, about 43 entries of various importance were logged in the engineering logbook. Of these, 28 belonged to ISAC. Major site-related jobs completed include replacement of an existing 5 kVA UPS with a 10 kVA unit in the control room, refurbishment of the ac distribution for the trim harmonics bay 3, the TR13 radiation exhaust, and UPS to the rf room to service controls critical to the reliability of the rf system.

Continuing engineering support was provided to TRIUMF users, Nordion and the ATG group. Major changes were introduced by the government regarding safety regulations following the passage of a new Safety Standards Act last year. One of the most significant of these that affected TRIUMF was the change from an annual permit to an annual operating permit. Under the new regime our electrical permit no longer covers electrical installations and equipment approval. Equipment approval is mandated to external agencies or to a special certification program that is administered by the newly created BC Safety Authority. This program has started but their policies are still evolving.

Design of the refurbishment of the rf ac distribution was started and good progress has been made. Existing drawings were updated to reflect reality and the single-line diagram was updated with future additions and rationalized. The proposed design includes a three-level breaker distribution to allow maintenance intervention on a single group of devices without shutting down the whole unit. As this is a large project, it was decided that it was more efficient to prepare the specifications and contract the engineering work to industry. The new distribution is planned for installation in the winter 2007 shutdown.

Typical maintenance activities included servicing lighting systems, motors and associated controls, air conditioning controls, panel boards and transformers, high-voltage switchgear, breakers and capacitor banks, and the fire alarm system. The annual inspection of the fire alarm system was carried out during the shutdown. Some problems with the ISAC-II fire alarm system that were related to electro-magnetic interference were eventually solved by inserting isolator modules on the various addressable lines.

After many problems the main UPS unit eventually died. Following an extensive search for the best options a decision was made late in the year to install the replacement UPS in early January, 2006. The new unit design is an N+1, "hot-swappable" model with significantly better reliability and better diagnostics and monitoring functions. Four 10 kVA modules are continuously on-line to supply our 40 kVA load and one 10 kVA unit is in "hot" stand-by mode, ready to take the load should one of the operating modules fail. The other significant advantage is that the failed module can be replaced without shutting down the UPS.

Power delivery

Power delivery continued to be reliable and without major unscheduled outages.

Coordination with Powertech Labs Inc. continued on a regular basis. It is important to acknowledge the excellent cooperation of the staff of Powertech Labs who worked closely with our operation staff to minimize the impact of the activities of the high voltage laboratory on our experimental program. In February, UBC replaced the metering units of the South Campus substation.

For the first time in five years the monthly averaged, peak-power demand took a turn downward, dropping by 1.8% from 7,560 kVA to 7,426 kVA (Fig. 263). The annual maximum peak demand, reached in December (8,957 kVA), was a mere 0.5% higher than the previous year. The electricity consumption also bucked the previous trend, decreasing a good 5% from 58.4 GWh to 55.5 GWh (Fig. 264). The largest monthly consumption was recorded in August (6.0 GWh) and was approximately 3.4% less than last year's maximum. These declines are indicative of longer maintenance activities on site.

The power factor (PF) averaged over the calendar year improved a mere 0.3% to 96.7% (Fig. 265). The average load duration – the indicator of how well we use our power demand – dropped a significant 6.2% to 82.7% (Fig. 266). The drop is primarily the result of the February and March start-up activities.

It may be of interest to compare this year's consumption figures to those of the year 2000. The power demand has increased 10.2% while the electricity consumption has been more contained with a 4.4%

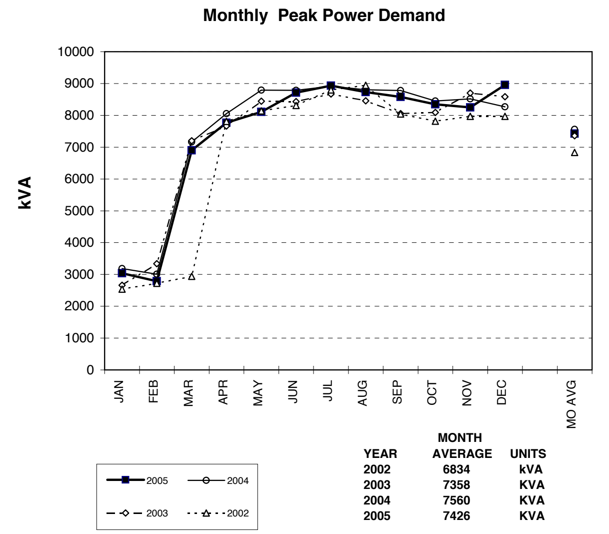

Fig. 263. Monthly peak power demand – four year comparison.

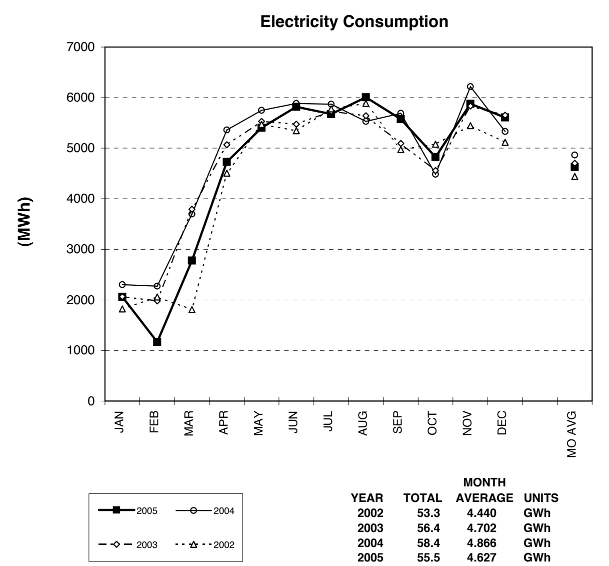

Fig. 264. Electricity consumption – four year comparison.

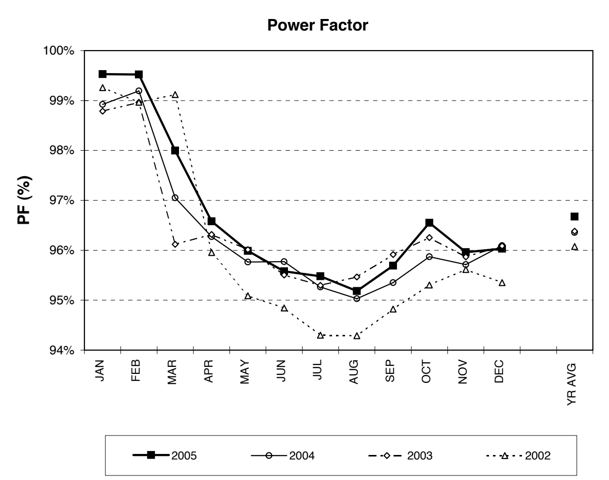

Fig. 265. Electrical system power factor – four year comparison.

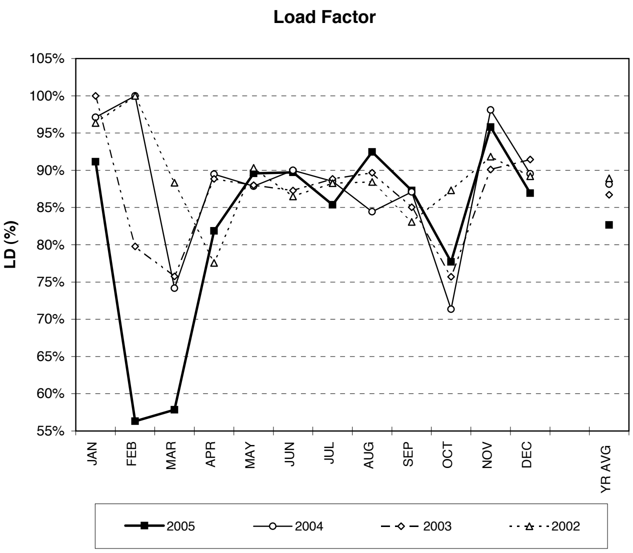

Fig. 266. Electrical system load duration – four year comparison.

increase. Despite the difference in demand versus consumption increase, the power factor edged up slightly by 0.7%. This improvement can be attributed to the addition of the capacitor banks in ISAC.

Mechanical Systems

The largest project during the last year was the demolition of the existing BL1A exhaust HEPA filter housing and the installation of a new filter rack system. Impressive in size, it is out of sight to most people because it is down the stairs of the south TNF. The old polyflo instrument tubing was replaced with copper tubing. The second largest job was the new nuclear ventilation system of the TR13 hot cell.

A new heat exchanger for the rf dummy load was installed and new check valves were installed on an amplifier cooling circuit. Deficiencies observed in the annual fire sprinkler inspection were repaired. Other sprinkler work was the installation of a new pressure switch and the repair of a leak in the chemistry annex. The failure of a fire sprinkler in the main office building prompted a random inspection of other heads (although they have a nominal minimum lifespan of 50 years).

After the winter shutdown assistance was given in the flushing of the resonators. Vibration in the CuALCW pump led to cracks in a discharge piping weld. This problem was immediately addressed by installing a vibration-isolation spool and, later, by a pump overhaul. A portable deionized-water resistivity meter was provided to the Beam Lines group to aid in their investigation of the cooling problems of the BL1A quadrupole triplet. A dissolved oxygen sensor was also provided so that additional data could be obtained.

Other activities included the installation of a new cooling fan in the Machine Shop boiler room, the start of the extension of the CuLCW system into the main office building from the new underground connection, and the fabrication and installation of new manifolds for cooling water for the M9 meson channel and for the M9 vacuum system. New air conditioning was provided for the Thaumaturgy room and the AHU-1 of the main office building was overhauled. A new exhaust system for the kitchen fume hood was also installed. The sink and hot water tank in the MHESA basement darkroom were relocated.

A design review was held for a new M20 VA1 valve lifting jig. Engineering assistance was provided for a new fume hood and related speed-up of fan AH5 for the CP42 vault and to the ISAC-II warm helium piping job. Cost estimates were provided for the air conditioning of the top floor of MHESA and for a new router room. The latter was eventually relocated to the proton hall and the air conditioning job was begun with completion expected in the new year.

In ISAC construction of water, air and vacuum piping continued for the transfer line from ISAC-I to ISAC-II and in the accelerator vault. A new, dry vacuum pump exhaust line was run from ISAC-II to the nuclear ventilation system of ISAC-I. The air conditioning programming of room 242 was modified to avoid a deadband situation. A concept design and cost estimate was provided for air conditioning the proposed ATLAS computer centre. An upgraded transfer pump for deionized water was installed. The oxygen deficiency system was put in service and underwent some development.

Maintenance was provided for building services: air conditioning, piping, and the new DDC. A new air compressor was installed on the ISAC-II dry (duo-action) sprinkler system, and a compressed air line in room 164 was relocated to allow for cryogenic piping.