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**FOR PARTICLE AND NUCLEAR PHYSICS**

OPERATED AS A JOINT VENTURE

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DECEMBER 2003

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# CYCLOTRON OPERATIONS DIVISION

## INTRODUCTION

During 2002 the cyclotron was available for ∼90% of the hours scheduled, a satisfactory result considering a few problems that arose at the end of the winter shutdown and during the first part of the beam production schedule. The total number of available hours was 4,845, exceeding that achieved in 2001 and almost equaling the ∼5,000 hours achieved in 2000. For high-intensity beams, 2002 was a record year. The total beam charge delivered at 500 MeV was 594 mAh, of which 517 mAh were delivered to BL1A for meson production and 77 mAh were delivered to BL2A for RIB production. Approximately 125 mAh were delivered at 85 MeV to rubidium targets in beam line 2C4 for the production of $^{82}$Sr that is used for medical diagnostics. The total beam charge extracted was 20% greater than that produced in previous years. The total beam current extracted and available for experiments increased from 220 $\mu$A to 250 $\mu$A. During development shifts a total average current of 280 $\mu$A was achieved, 20 $\mu$A shy of our 300 $\mu$A goal for ISAC-I. This 280 $\mu$A limit corresponded to the total maximum intensity accepted by the extraction beam lines (170 $\mu$A in BL1A, 40 $\mu$A in BL2A, and 70 $\mu$A in 2C4).

The 90% availability of the cyclotron was lower than the 92.4% achieved in 2001. The main cause was a period of frequent rf sparking that lasted until the September shutdown. The resulting rf downtime in the first weeks of beam operation was three times higher than that in a similar period following the 2001 shutdown. The effect of frequent rf sparking and of corresponding beam interruptions is rather disruptive for the production of the radioactive ion beams that is critically dependent on stable operating temperatures of the RIB targets. Sparking could have been cured by retuning the position of ground-arm-tips through their remote control system. However, that system was malfunctioning and could not be used. A refurbished control system had been planned, but was not yet available because of other site priorities. Priorities were readdressed; the new system was constructed and was installed during the one week shutdown in September. The rf sparking rate following that shutdown was reduced by a factor of 2.5.

The highlights during the winter shutdown were the repair of several water leaks on BL1A and refurbishing modifications around 1AT2. The total loss of cooling water had reached the rate of 74 l/h at the end of the beam production period in December, 2001. Leaks were repaired on the quadrupole triplet in the extremely active area downstream of 1AT2 and on the first quadrupole and first dipole of the M20 meson beam line. The triplet leak appeared in an easily accessible position on a soldered joint on a cooling-water pipe. This was repaired promptly without high-dose exposure. There were a few other leaks that were more difficult to repair. Other work in the 1AT2 area included the removal of the M8 meson channel, and the refurbishing of the shielding structure south of and above the triplet. Shielding was configured in a manner that would ease replacement of the triplet that is scheduled for the 2003 winter shutdown. A few crumbling concrete shielding blocks were replaced by new units. The 1AT2 area refurbishing effort required close, efficient collaboration between the Remote Handling, Beam Lines, Plant, and Safety groups. This was key to the completion of this delicate operation that was concluded successfully on schedule in mid-April.

In May, during the high-intensity beam production, BL1A was plagued by a substantial water leak in the coils of the M11 septum. Attempts to repair the leak with a special "colloidal solution" in the coolant failed. As soon as it was realized that *ad hoc* repairs were not feasible, it was decided to let the leak grow in a controlled fashion to ∼80 l/h. This occurred at the end of July at which time beam delivery to M11 was discontinued. Installation of a new septum is planned for winter, 2005.

The total average intensity extracted from the cyclotron had never exceeded a maximum of ∼220 $\mu$A, despite several attempts to obtain higher values using the combined maximum-current capabilities of BL1A and BL2C4. The reasons for this limit were analyzed and were traced to thermal problems caused by beam losses in the centre region. The following improvements were introduced during the winter shutdown.

1. A water-cooled copper absorber was installed inside the first quarter-turn orbit to absorb radial beam losses caused by ions not matching the cyclotron rf phase acceptance.
2. The centre region correction plates, showing evidence of beam damage and found to be vertically misaligned, were carefully realigned so that they would no longer protrude into the beam volume intended to be available for acceleration.
3. The back edge of an rf contact, found to be protruding vertically into the beam volume, was also adequately tailored.

Over-temperature problems at ∼220 $\mu$A disappeared after the shutdown and improved high-intensity conditions were immediately achieved. This was in part due to the above centre region modifications and in part to an improved beam tune that had been established in the ion source/injection line systems. Cyclotron transmission from axial injection to extraction could be increased above 60%, implying good beam matching through the centre region, for all beam intensities up to 325 $\mu$A total. The following results were recorded.

On July 16 a record 250 $\mu$A at 100% duty cycle were extracted with good transmission over a 2 hour period. Two weeks later a record 275 $\mu$A at 100% duty cycle were extracted over 3 hours with better than 60% transmission. The extracted beams appeared to be reasonably stable (see Fig. 181). On the same day, 300 $\mu$A were extracted over 2 hours at 90% duty cycle with good transmission. This was followed by 325 $\mu$A (75% duty cycle, 60% transmission) and 350 $\mu$A (40% duty cycle, 57% transmission). On subsequent development shifts in August, September, October and November the 300 $\mu$A tune was reproduced easily. We failed, however, to reproduce the 350 $\mu$A tune. The cause was traced to the rf voltage on the dees being actually lower (by about 10%) than indicated by the rf PA system. After recalibration of the rf we easily reproduced the 350 $\mu$A at 10% duty cycle and greater than 60% transmission in the last development shifts before Christmas. In addition, we obtained 380 $\mu$A also at 10% duty cycle and better than 60% transmission. We believe that 400 $\mu$A cw are now well within reach.

The next goal will be to demonstrate 400 $\mu$A with 60–70% duty cycle, good transmission, and reasonable stability over a period of several hours. To demonstrate operation at 100% duty cycle, additional beam dump capacity will be required. For this we are studying the possibilities of increasing the capability of beam line 1A to accept up to 200 $\mu$A at 500 MeV and of installing a dedicated beam dump in the vault that would allow simultaneous extraction of another 200 $\mu$A at a lower energy (70–85 MeV).

In conclusion, the results achieved indicate that the cyclotron can now be refurbished to operate reliably and stably at total currents up to 400 $\mu$A. This is 100 $\mu$A in excess of the previous goal set for simultaneous 1A, 2C4, and ISAC operation. It is now conceivable to extract an additional ~100 $\mu$A from a fourth high-intensity beam line (for instance, beam line 4V North) to feed a separate target and to provide a second simultaneous beam of radioactive ions for ISAC users. Part of the high-intensity beam for ISAC may have to be extracted at lower energy, i.e. 450 MeV, to avoid electromagnetic stripping between 450 and 500 MeV and thus keep beam losses in the cyclotron within reasonable limits. This scenario is now being considered for the next five-year development plan for the laboratory.

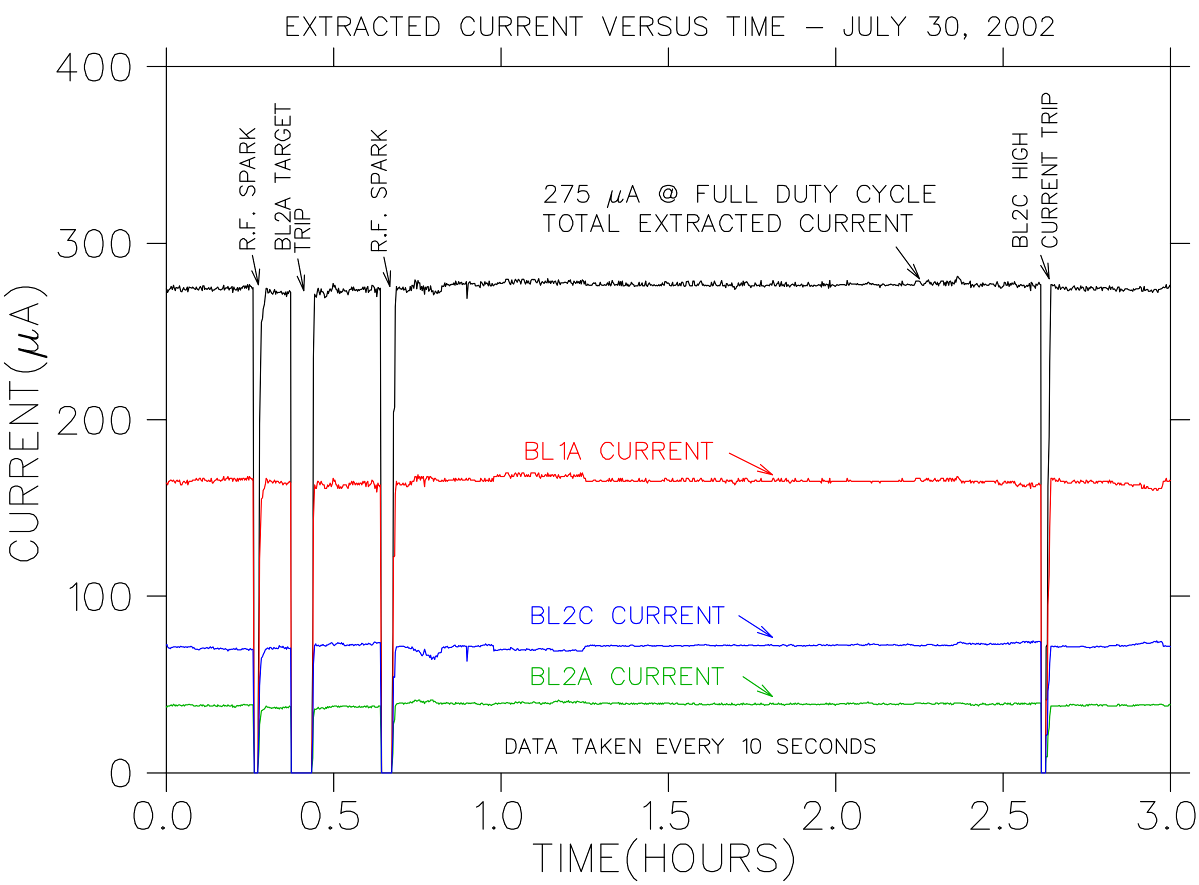



Fig. 181. Beam currents extracted at 100% duty cycle over a three hour period.

Cyclotron refurbishments continued according to the program initiated in year 2000. For the 1AT2 area, the work mentioned above represents only the first phase of the total refurbishing action required. During the 2003 shutdown, we will replace the 1AQ14/15/16 triplet and complete the replacement of adjacent crumbling shielding blocks. The 1AT2 area is given the highest priority because it is the weakest link in the reliable production of high-intensity proton beams.

High priority was also given to the refurbishment of the rf resonator and amplifier systems because historically these have been a major cause of cyclotron downtime. In addition to the centre region improvements described above, metallic pads that were originally applied as vibration dampers to the bellows of the cooling circuit are being replaced with fibreglass units. Occasionally over the years the metallic dampers have caused arcing situations leading to water leaks, the repair of which has required interruption of beam production for two to three weeks each time. The plan is to gradually change these metallic dampers wherever possible. RF diagnostics are being upgraded with improved multiplexing and first-event counters.

Significant progress was achieved on the rf amplifier system. A new waster load was tested at about 500 kW. Two rebuilt combiners were tested at full power and the first one was installed for operation before the year end. Two more combiners are planned for installation in 2003 and 2004. In 2004 we will be able to switch the whole rf amplifier system to the waster load for off-line tests and repair. The goal is to achieve by the 2005 shutdown a rf generator that, in emergencies, can operate with two amplifiers instead of four. Thus, in case of failure, a partial system may be used until repairs can be made during scheduled maintenance.

The refurbishing work on probes and diagnostics was limited by insufficient budget and personnel resources. The group was also heavily involved in the production of diagnostics devices for ISAC. However, a milestone was achieved when it was demonstrated that gas-filled multi-wire chamber monitors can be replaced by lower sensitivity secondary-emission multiwire harps that can operate in a vacuum. In high radiation areas, gas-filled monitors require frequent maintenance for seal replacement, therefore causing dose exposure problems. A new electronic system was designed that makes the readout of the harp wires more sensitive by two orders of magnitude, thus making the secondary-emission harps preferable for radiation environments. For the cyclotron, a refurbished high-energy probe was designed; this probe is more functional, reliable, and precise than the present ones. Construction and assembly of this probe are planned for 2003.

Refurbishment of the cyclotron central control system (CCS) was also limited by budget restrictions. However, progress was achieved by installing a new fibre-channel storage system in the cluster to provide superior performance and reliability. Tape back-up systems were upgraded to high-density drives, and two obsolete production computers were replaced with Alpha units. New LCD monitors have improved console displays in the Control Room, the RF Room, and the Proton Therapy Control Room. Controls integration with beam diagnostics during operation and development shifts was well organized and very helpful.

Finally, a major effort was undertaken to improve the reliability of the safety system that protects against prompt radiation hazards. In response to requests from the CNSC, a study group and an action group were created to study, recommend, and implement improvements. By the end of 2002 almost all of the suggested improvements and actions were completed. These included shielding improvements and the implementation of two separate, parallel systems (a gamma monitoring system and a neutron monitoring system) to interrupt beam in case of radiation in non-exclusion areas. Other improvements included modifications to minimize the risk of tampering with the safety systems, routine periodic testing to verify the functioning of safety-critical devices, and the introduction of additional redundancy. This resulted in the safety systems satisfying the stringent requirement that the probability of serious accidents be less than $10^{-5}$ per year. It should be stressed that the present safety record of TRIUMF for prompt radiation hazard is very good because no significant problems have been encountered over the (more than) 25 year life of the project. However, it is reassuring to have established that our system is also in line with the prescribed minimum-risk guidelines. Recommended improvements will be completed during the 2004 shutdown with the completion of the restructuring of the safety-critical gamma and neutron monitoring systems such that they become completely independent and without the possibility of a common-mode failure.

In conclusion, the cyclotron is still operating (after 28 years from first beam) at the familiar 90% level of availability. As a result of recent developments and refurbishments, the system can now be expanded to provide an increase of at least 30% in output beam current. This additional output may be used to construct a second, parallel source of exotic ions for the scientific program.

## BEAM PRODUCTION

Beam delivery for 2002 was again quite successful with 500 MeV charge production up 20% from the previous year. Cyclotron performance continued to be enhanced by the use of the rf booster, which was on during most of the high-current running, partly to satisfy the occasional demand for 2 ns pulse-width beam but also to improve the cyclotron transmission (typically between 62% and 66%) and reduce the measured tank beam spill (usually below 2.5 $\mu$A). Sixteen weeks of shutdown left 5,386 scheduled operational hours of which 4,845 were achieved for an average availability of 90%. These totals include 288 hours used for development and tuning and, as shown in Fig. 182, were split roughly 5:1 between scheduled high-current beam production and lower intensity operation. For the latter, the proton irradiation facility (PIF, using BL1B and BL2C1) usually ran in parallel with BL2A. BL2C1 was also used at 74 MeV for ocular melanoma treatments for nine patients during four proton therapy (PT) sessions. Again this year there was no BL4 operation and no polarized source operation except for a viability test of the latter for a few hours.

As Fig. 183 shows, the total beam charge delivered to meson hall experiments along BL1A was 517 mAh or 96% of the 538 scheduled, one of the best results for the past ten years. The average current delivered to BL1A was 135 $\mu$A. In addition to this, there were 126 mAh delivered at 85 MeV to rubidium targets in the solid target facility (STF) in beam line 2C4 for the production of radiopharmaceutical generators. Another 77 mAh, twice the charge of the previous year, was delivered to the west target station in BL2A2 for the production of radioactive ion beams (RIB) for experiments in ISAC. The total current extracted to the three high-current beam lines was normally around 210 $\mu$A, but was pushed to 230 $\mu$A for some shorter production periods. The higher currents were possible because of the continuing development efforts.

The annual downtime of 484 hours (Fig. 184) was a little above average with the rf responsible for the greatest share of this time (47%), followed by power supply problems (10%), and power failures (9%). RF downtime, chiefly from sparking, was tamed considerably in the latter part of the year, dropping from 8 hours per week in the first beam schedule to 3 hours per week in the second beam schedule. The operational record and beam to experiments for 2002 are given in Tables XIX and XX.

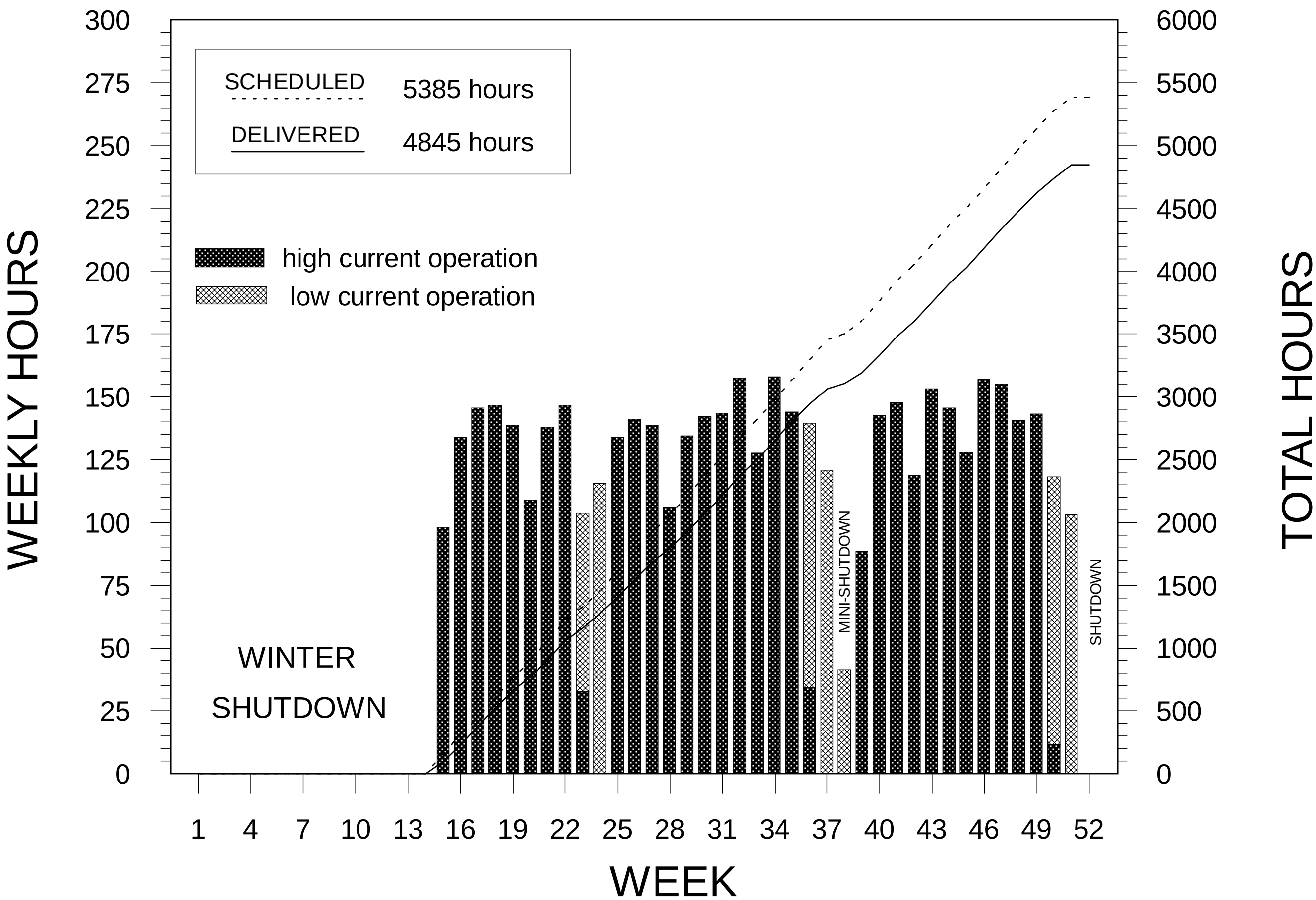



Fig. 182. Operational hours for 2002.

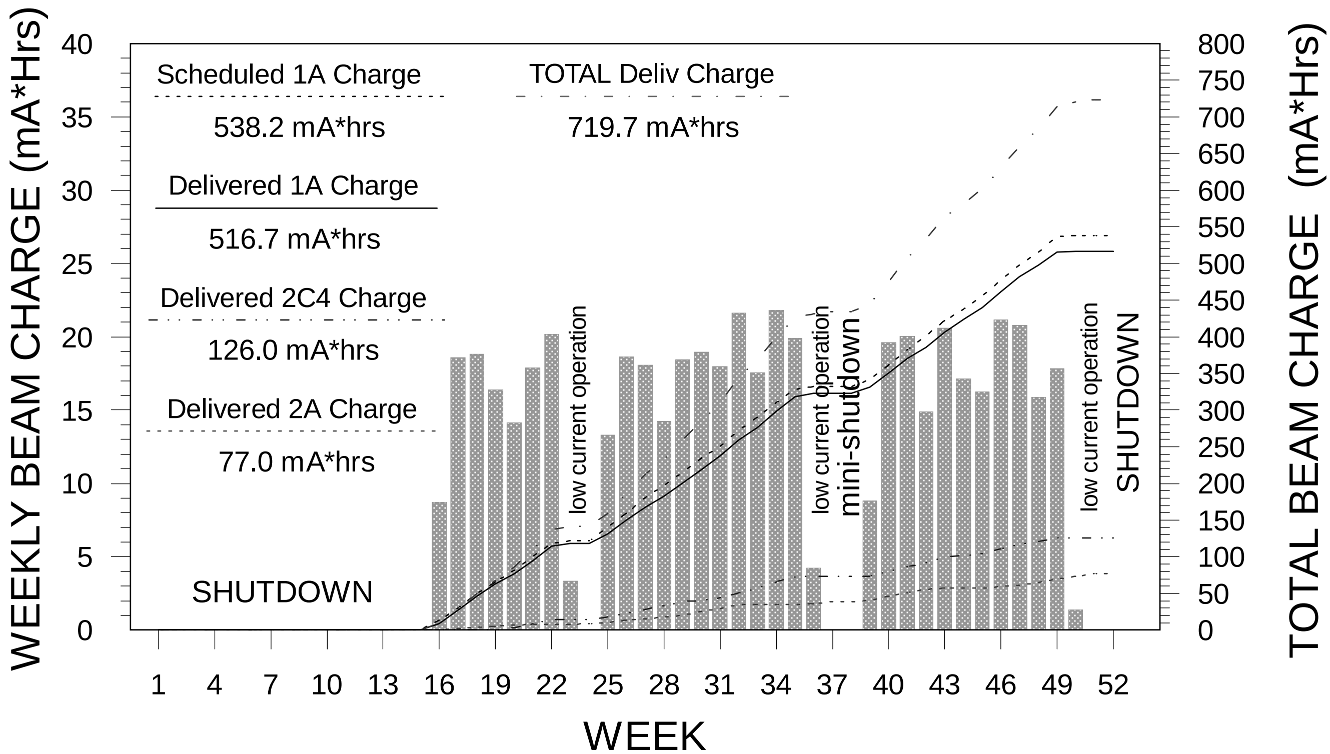



Fig. 183. Beam delivery for 2002.

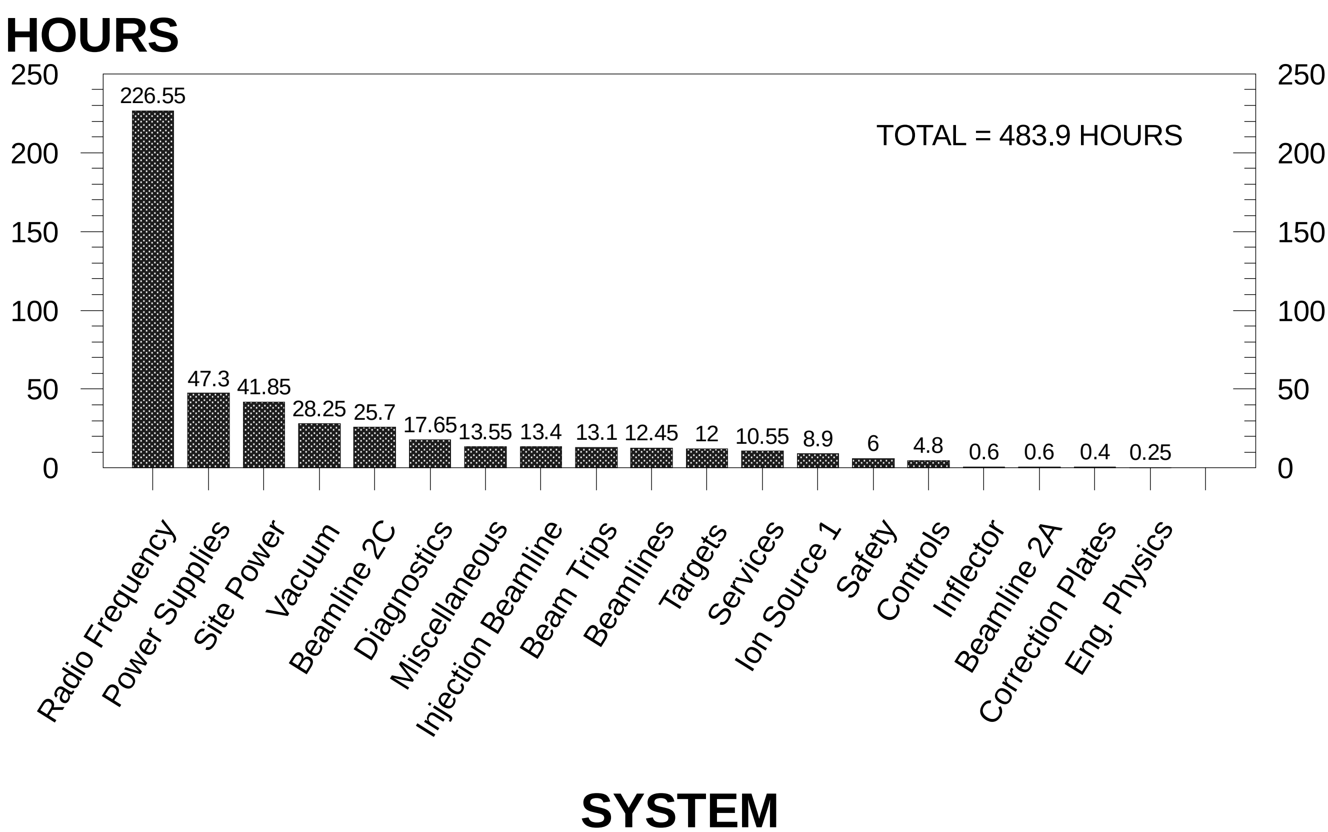



Fig. 184. Cyclotron downtime for 2002.

Table XIX. Operational record for 2002.*

| | Scheduled hours | Actual hours |
|---|---|---|
| Cyclotron off: | | |
| Maintenance | 454.0 | 485.20 |
| Startup | 243.0 | 210.05 |
| Shutdown | 2,562.0 | 2,560.00 |
| Other | 18.0 | 25.60 |
| | | |
| Cyclotron downtime | 0.0 | 483.90 |
| Overhead | 73.5 | 126.05 |
| | | |
| Totals | 3,350.5 | 3,890.80 |
| | | |
| Cyclotron on: | | |
| Development | 174.0 | 125.00 |
| Cyclotron tuning | 419.0 | 162.75 |
| Beam to experiments | 4,792.0 | 4,557.45 |
| | | |
| Totals | 5,385.5 | 4,845.20 |
| Actual/Scheduled = 4845.2/5385.5 = 90.0% availability | | |
| Beam to experiments: | | |
| 1A Production | 4,007.0 | 3,834.40 |
| 1A Development/tuning | 0.0 | 17.35 |
| 1A Down/open/no user | 266.5 | 268.50 |
| | | |
| 1B Production | 323.0 | 63.10 |
| 1B Development/tuning | 0.0 | 3.75 |
| 1B Down/open/no user | 196.0 | 370.35 |
| | | |
| Total 1A+1B production | 4,330.0 | 3,897.50 |
| | | |
| 2A2 Production | 3,820.5 | 2,868.50 |
| 2A2 Development/tuning | 0.0 | 24.00 |
| 2A2 Down/open/no user | 972.0 | 1,664.95 |
| | | |
| 2C1 Production/tests | 617.5 | 155.05 |
| 2C1 Development/tuning | 0.0 | 5.45 |
| 2C1 Down/open/no user | 604.0 | 913.85 |
| | | |
| 2C4 Production/tests | 3,346.0 | 2,811.00 |
| 2C4 Development/tuning | 0.0 | 9.05 |
| 2C4 Down/open/no user | 225.0 | 663.05 |
| | | |
| 1A Beam charge ($\mu$Ah) | 538,160.0 | 516,704.00 |
| 2A Beam charge ($\mu$Ah) | 96,582.0 | 76,973.00 |
| 2C4 Beam charge ($\mu$Ah) | 147,810.0 | 125,987.00 |

* There was no BL4 production this year and the polarized source (I4) was not used.

Table XX. Beam to experiments for 2002.

| | | Scheduled | | Delivered | |
|---|---|---|---|---|---|
| Experiment * | Channel | h | $\mu$A h | h | $\mu$A h |
| 614 | M13 | 3332.0 | 456650 | 3212.15 | 434579 |
| 768 | M15 | 148.0 | 19470 | 133.00 | 18099 |
| 775 | M20 | 127.0 | 17550 | 107.95 | 13766 |
| 782 | M15 | 119.0 | 15470 | 111.50 | 15261 |
| 791 | M15 | 447.5 | 60695 | 415.90 | 53033 |
| 814 | M15 | 127.0 | 16740 | 107.95 | 14703 |
| 814 | M20 | 127.0 | 17780 | 134.80 | 18725 |
| 822 | M11 | 1182.5 | 159415 | 1098.90 | 151652 |
| 822 | M15 | 208.0 | 28890 | 189.15 | 25026 |
| 834 | M20 | 265.0 | 35700 | 237.60 | 32403 |
| 842 | M9 | 146.5 | 19505 | 141.95 | 19819 |
| 843 | M20 | 69.0 | 9660 | 69.20 | 9614 |
| 846 | M15 | 127.0 | 17780 | 129.25 | 17566 |
| 846 | M20 | 127.0 | 16740 | 107.95 | 14703 |
| 847 | M15 | 392.0 | 52110 | 416.10 | 47532 |
| 848 | M15 | 127.0 | 17780 | 137.75 | 19578 |
| 848 | M20 | 162.0 | 22680 | 173.10 | 24560 |
| 865 | M15 | 150.0 | 21000 | 150.20 | 20882 |
| 877 | M9 | 127.0 | 16740 | 107.95 | 14703 |
| 883 | M20 | 254.0 | 34290 | 285.60 | 31049 |
| 888 | M9 | 193.5 | 25155 | 160.35 | 18501 |
| 890 | M20 | 127.0 | 16510 | 126.25 | 16226 |
| 891 | M15 | 342.5 | 45675 | 329.95 | 44612 |
| 891 | M20 | 119.0 | 15470 | 111.50 | 15261 |
| 894 | M15 | 115.0 | 16100 | 109.00 | 13595 |
| 894 | M20 | 127.0 | 17780 | 136.10 | 18484 |
| 895 | M15 | 277.0 | 38780 | 284.25 | 38531 |
| 895 | M20 | 81.0 | 11340 | 73.75 | 10213 |
| 898 | M20 | 138.0 | 15410 | 117.55 | 14728 |
| 912 | M15 | 150.0 | 21000 | 138.50 | 18059 |
| 912 | M20 | 219.0 | 30660 | 214.00 | 27144 |
| 914 | M15 | 150.0 | 21000 | 144.55 | 21018 |
| 915 | M15 | 127.0 | 17780 | 136.10 | 18484 |
| 916 | M20 | 343.5 | 46155 | 292.40 | 36499 |
| 917 | M15 | 128.0 | 17920 | 131.05 | 18018 |
| 917 | M20 | 271.0 | 37940 | 265.70 | 39474 |
| 918 | M15 | 121.0 | 16940 | 121.15 | 18456 |
| 930 | M9 | 638.0 | 85360 | 606.80 | 82645 |
| 931 | M15 | 138.0 | 17940 | 113.45 | 15007 |
| 931 | M20 | 115.0 | 16100 | 114.85 | 15900 |
| 932 | M9 | 277.0 | 38780 | 285.00 | 39607 |
| 933 | M20 | 150.0 | 19500 | 145.15 | 18683 |
| 934 | M20 | 148.0 | 19470 | 133.00 | 18099 |
| 935 | M9 | 546.0 | 74960 | 506.65 | 71339 |
| 936 | M15 | 150.0 | 21000 | 132.05 | 17998 |
| 937 | M20 | 146.5 | 19505 | 141.95 | 19819 |

Table XX (cont'd.)

| Experiment * | Channel | Scheduled h | Scheduled μA h | Delivered h | Delivered μA h |
|---|---|---|---|---|---|
| 938 | M20 | 11.0 | 1540 | 11.75 | 1387 |
| 939 | M20 | 277.0 | 38780 | 267.75 | 35625 |
| 940 | M20 | 300.0 | 42000 | 304.00 | 40726 |
| 942 | M20 | 128.0 | 17920 | 131.05 | 18018 |
| 943 | M9 | 254.0 | 35560 | 273.85 | 38062 |
| 943 | M15 | 138.0 | 15410 | 117.55 | 14728 |
| 944 | M15 | 150.0 | 21000 | 154.55 | 20920 |
| G∅ | M9 | 115.0 | 16100 | 109.00 | 13595 |
| ISAC RIB† | 2A2 | 3820.5 | 96582 | 2868.50 | 76973 |
| ISOPROD | 2C4 | 3346.0 | 147810 | 2811.00 | 125987 |
| PIF | 2C1 | 557.5 | 0 | 138.85 | 0 |
| PIF | 1B | 323.0 | 0 | 63.10 | 0 |
| P.THERAPY | 2C1 | 60.0 | 0 | 16.20 | 0 |

* See Appendix D for experiment title and spokesman.

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

**Winter Shutdown**

BL1A shutdown activities began in early January with the removal of many shielding blocks from the meson hall to a temporary storage location by the Machine Shop. The original work schedule slipped a little at first because of an unanticipated need to quickly put together two shipments of radioactive waste for disposal and then later from obstacles encountered along the way (welded steel shielding, additional water leaks, new crumbling blocks). The extent and complexity of some of the BL1A tasks, most of them in high radiation fields, resulted in some higher than usual doses for a few workers. Three each received between 5 and 7 mSv of a total summed shutdown dose of 150 mSv that was distributed among 110 workers.

Jobs undertaken in the meson hall by the Remote Handling (RH), Beam Lines (BL), Vacuum, and Diagnostics groups included removal of the front-end elements of the M8 channel; replacement and reconfiguration of shielding (new shielding was designed to fill the M8 void as well as to replace some crumbling blocks); *in situ* repair of three separate water leaks on the 1A triplet; repair of M20Q1 and M20B1 water leaks; a rebuild of the troublesome M13 beam blocker; maintenance of the 1AT1 and 1AT2 targets and their water packages; repair of 1AM8 and 1AM10 monitors; the repair of vacuum leaks at 1AVA8 and M13VA1; and the replacement of the air cylinders of 1AWVA2.

In the vault the cyclotron lid was raised toward the end of January. Radiation fields were about 10% higher than last year (as predicted from the previous beam delivery schedule). As much as possible, remote-handling equipment was used to minimize personnel dose exposure. Apart from the usual heavy schedule of routine diagnostics MRO (including work on the extraction and pop-in probes), a lot of time was spent doing centre region work where, fortunately, the fields were reasonably tolerable. This included the installation of a water-cooled beam absorber in LQ1's detachable quadrant (to help maintain cool centre region temperatures during higher intensity injection); the repair, relocation, and addition of several thermocouples, and the refurbishment of Q1 and Q3 correction plates. At the tank periphery, work included blanking off the unused centring probe feedthroughs and the tricky job of replacing the seals on the gate valve of extraction 1.

There was also a large number of additional jobs and MRO work around the site, not the least of which was the construction and installation of the BL2A3 leg and east target station to eventually provide continuing RIB to ISAC during changeovers of the west target.

**Beam Schedule 101**

Although the first week of production saw quite a bit of downtime with the site UPS and excessive rf sparking, the performance for these 24 weeks was not too unreasonable with a cyclotron availability of

89%. Other problems included a vacuum failure of the ferrofluidic seals of the 2C extraction probe. These were replaced during a week (originally high current) rescheduled for septum magnet repairs (see below). Downtime totalled 367 hrs with rf being responsible for 190 hours (52%). Power supplies, site power, and vacuum problems (chiefly with the power supply of the main magnet (MMPS), UPS and B-20, respectively) accounted for another 98 hours or 27% of the total downtime.

BL1A usually ran 140 $\mu$A to Be targets at 1AT1 and 1AT2, but saw currents as high as 168 $\mu$A during some development shifts. The charge delivered was 322 mAh or 93% of that scheduled. There were minor meson-hall problems, that included continuing intermittent trouble with the M13 beam blocker, but the main setback lay with the septum magnet. In the middle of May, it developed a rapidly growing water leak that prompted an exploratory investigation to see if it could be easily repaired. When it became apparent this was not possible, the water was valved off while an alternative *in situ* repair was pursued. Experts came in mid-June to inject a special sealant into the cooling lines, but on the first two attempts the patch failed as soon as the septum was powered. The third and final attempt saw the septum briefly fully powered immediately after the cooling lines were infused with an injection of the epoxy-clay matrix sealant. This allowed the sealant to penetrate and more thoroughly block the crack that had presumably opened under the strain of the huge electromagnetic forces when the magnet was powered. The septum was back in operation following pressure and power tests a week after this final repair attempt, but started to leak slowly after a few days. Five weeks later at the end of July the water was turned off for good after the leak had steadily grown to about 80 l/h, leaving M11 high and dry. The leaking water was well contained, ultimately draining into the active sump. Toward the end of the high-intensity period there was also a failure of the X1 current read-back for which the front-end BL1A toroid signal was substituted.

BL2A took currents from 5 to 45 $\mu$A on two different targets (Ta and TiC), running for 1,727 hours or 70% of its scheduled time and receiving 39 mAh or 76% of its scheduled charge. Target trouble and ISAC energy changes were the chief sources of off-time. BL2C4 got off to a slow start because of target float problems but went on to irradiate two rubidium targets for processing by Nordion, running for 1,688 hours or 80% of its scheduled time and receiving 39 mAh or 82% of its scheduled charge. Currents averaged about 43 $\mu$A. There were no problems with the corrective steering magnet that continued to be used to compensate for a slightly misaligned STF, but there was some anxiety when it was found that only one of the three new foils was suitable for prolonged high-intensity beam – the other two were found to be somewhat deformed with little or no beam on them. In addition to the above, there were three PT sessions (BL2C1/74 MeV) during which 6 patients were treated and three PIF runs, one at the beginning using 2C1 only (70 and 116 MeV) and the others in June and September using BL1B as well (500, 350 and 200 MeV). The latter provided some cool-down (along with the following PT run) prior to the one-week maintenance period starting mid-September. BL2C1 currents were 5 nA or less and BL1B currents less than 1 nA. There were also three development shifts that utilized 92% of their scheduled 48 hours to improve 300+ $\mu$A equivalent tunes with as much as 275 $\mu$A total extracted down the three high-current proton lines. Some time was also allotted for OPS training during which operators had time to practice machine and beam line tuning and calibrations or to continue with development work.

**Fall Mini-Shutdown**

This week for extended maintenance work had a reasonably ambitious schedule. BL1 work started when PIF finished in 1B; vault work started a week later once PT had finished. The total shutdown dose was under 5 mSv with no one exceeding 1 mSv. Some of the group's jobs were: Diagnostics MRO (extraction probes 1 and 2A, beam line monitors including 1AM8, fast shutter); Beam lines (repair M13BB and installation of a slit box in M13 F2, removal of 1BBB2 latch mechanism and repair 1BBB3 vacuum leak); Power supplies (MMPS relay and hose MRO, and repair of radiation-damaged feedback wiring of the main magnet); Vacuum (tank cryopump MRO, installation of a turbo pump on cryoline and swap B-20, extensive beam line leak checking, change 2A O-rings near 2AVM1); Services (install new rf room water filter, compressor MRO, ISIS LCW pump MRO, Al ALCW system control valve MRO) and rf (investigate sparking, install and test new combiners, build new GAT control software, check out ISIS rf pickup from tank).

The vault was ready in time for tuning up the cyclotron as scheduled but extraction down BL1A was delayed one day to accommodate last minute work. There were a few lingering details from the shutdown affecting subsequent operation: the M13 beam-blocker worked fine as a blocker, but lost its dual purpose as a beam line gate valve; M20Q1 developed a 1 l/h water leak; and a 1AQ9 over-temperature fault was not found along accessible interlock wiring. Therefore it would be necessary to uncover that quadrupole to determine the exact cause of the fault. In the meantime 1A would have to remain tuned with 1AQ9 off – not a serious issue because it works in concert with the septum to provide M11 beam. Finally, 1BBB3 needed to be removed to repair a leaking bellows. This made it necessary to run with the 1B area secured until the blocker was fixed. Because the lid was not raised, there was no opportunity to replace the two dud X2C foils. A viewing through the periscope indicated the whiskers were not nicely aligned in the two suspected foils and that the heavily used one remained looking fairly good. After the usual target scans and radiation surveys, the beam intensity was increased over the next two days so that BL1A and BL2A2 were receiving their nominal currents. A few days later 2C4 was slowly brought up to 40 $\mu$A.

**Beam Schedule 102**

A Thanksgiving Day failure of the motor driving the main magnet booster pump, an earlier power bump, and later problems with the BL2C vacuum were the chief downtime events in an otherwise productive schedule. The new rf ground-arm-tip (GAT) control system allowed the resonators to be fine-tuned to reduce considerably both leakage and sparking, and was the main contributor to a reduction in downtime from 15 hours per week in the previous beam schedule to 9 hours per week in the latest one. Downtime totalled 117 hrs with rf being responsible for (only) 31% or 37 hours. BL2C vacuum problems accounted for another 25 hours or 21%. For these 13 weeks the cyclotron was available for 1,740 hours or 92% of the scheduled time (1,882 hours), and delivered as much as 230 $\mu$A total to the three operating high-current proton lines before ending the schedule with two weeks of low-current production for PIF and 2A only. Again the rf booster was on most of the time helping to maintain a decent cyclotron tune. Three development shifts focused mainly on high-current extraction ($\sim$350 $\mu$A equivalent) and made progress in extending those good tunes to the higher-intensity domain. Probe scans done during the last development shift found that the rf dee voltage was 5 to 10 kV lower than its read-back value (as well as compared to previous scans). This helped to explain some high-current-development limitations and probably also contributed to the lower spark rate.

BL1A ran for 1,453 hours or 97% of its scheduled time, receiving 194 mAh or 94% of its scheduled charge. The current was normally around 135–140 $\mu$A, but was lower toward the end of the run because of a vacuum leak in the 1AT2 area. The M11 channel remained out of commission because of the septum failure and the M9 channel saw little use because of an SCS fridge failure. Water leaks were again a concern as a 1 l/h drip from M20Q1 grew to a 10 l/h spray. Other leaks developed in M13Q5 ($\sim$2 l/h) and M13B1 ($\sim$5 l/h). In mid-November the 1AT2 Be target was determined to be disintegrating after years of use and a new one was selected. BL1A high-current operation wound down in early December, followed by a two-week, low-current schedule that initiated the cool-down period prior to the winter shutdown. This included a very limited amount of BL1B operation for PIF experimenters for whom the 1BBB3 beam blocker had been repaired and reinstalled in October.

BL2A2 ran for 1,166 hours or 85% of its scheduled time, receiving 38 mAh or 83% of its scheduled charge. There was no proton beam during a two-week ITW target change but 45 $\mu$A delivery continued up to the end of the beam schedule as 2A became the sole high intensity user for the last few weeks of beam delivery. There were two instances, a few hours apart, when an output glitch in the 2AVB1 dipole power supply (traced to the local/remote electronics and since repaired) caused not only the 2A tunnel BSMs to alarm but also tripped the ISAC Safety-Critical BSMs and NMs on the ground floor above the electrical room. This was further investigated and quantified during a beam development-shift and found to be non-hazardous should similar events recur.

There were also improvements in the X2A software to eliminate R-Z reproducibility problems that have caused radiation trips in the past. Apart from such spurious trips and some power bumps that were particularly hard on 2A2 because of a faulty UPS unit, beam production was reasonably steady for the scheduled period. However, RIB production from the ITW dropped 2 to 3 orders of magnitude toward the end of the running period before the target somehow rejuvenated itself in the last hour of operation.

BL2C4 ran for 1,126 hours or 90% of its scheduled time, receiving 52 mAh or 89% of its scheduled charge for an average delivery of 46 $\mu$A. Most of the 2C4 specific downtime was due to two vacuum leaks, the first in a sliding seal where the corrective steering magnet was installed last year and the second at the indium seal just after the fast valve. The latter occurred a few days before the start of the PIF run for which the 2C1 line was heavily subscribed and therefore required immediate attention. Radiation fields in the area were fairly intense and there were significant space constraints. Some cool-down time was scheduled, and remote handling and beam line experts were involved as well as volunteers in the successful repair that cost about 10 mSv total dose. It was assumed that the faulty and aging extraction foils were responsible for compromised tunes that gave rise first to somewhat elevated collimator temperatures and eventually to some beam glitches that overheated the vacuum seal. BL2C1 was used for PT (3 patients one session, the other session cancelled) as well as for PIF experimenters at 70 and 116 MeV. As with all of the other PT sessions this year, the high-intensity source was on-line so the ISIS pepper pot was required to limit the injected beam current during times of patient treatments.

Most cyclotron systems were turned off by the weekend before Christmas just as holidays and the winter shutdown were beginning. The year then ended as it had begun with the removal of about six dozen large 1A shielding blocks to temporary storage by the machine shop as preparations were made for the next stage of BL1A and meson channel refurbishment and repair.

Apart from the many tasks associated with beam delivery, operators were involved with fire alarm system expansion, card access system installation, Autocad drawings, training and documentation improvements, equipment repair, computer upgrades and maintenance, beam transport modelling, etc., as well as actively helping out with many shutdown jobs, particularly in the areas of remote handling and diagnostics.

## CYCLOTRON DEVELOPMENT

### Centre Region Upgrade

During the winter 2002 shutdown a great deal of effort was dedicated to improving the cyclotron centre region. Problems were being caused by excessive beam losses on uncooled surfaces in the first few turns. Radial beam losses on the vertical walls of the centre-region rf resonator quadrants were overheating the attached stainless steel reinforcing ribs. At high beam intensities the rib temperature rose above 120°C, triggering protection trips. To solve this problem a water-cooled beam absorber was installed immediately after the injection gap to intercept a large portion of the beam that had previously been hitting the quadrant walls. To install the absorber, the centre region detachable quadrant 1 (Q1) was removed from the cyclotron. Figure 185 shows a centre region view looking towards Q1 before the beam absorber installation. The beam absorber attached to the vertical wall of Q1 is shown in Fig. 186.

Next the quadrant 1 correction plates (CP) (see Fig. 187) were removed from the tank. A detailed inspection of the plates showed a number of deficiencies:

1. The upper tray, which houses the plates, was bent 0.3 in. down toward the median plane of the cyclotron.
2. Evidence of the beam hitting plate 5, one of the plates closest to the median plane, was observed (see Fig. 187).
3. The plates had been made from thin stainless-steel sheet and required realignment.
4. A few ceramic insulators were cracked and/or broken.
5. Some of the insulators near plates exposed to the beam were spattered with metal.

Repairs were made during the shutdown. All damaged insulators were replaced, and the plates were straightened and reassembled. The correction-plate trays were reinstalled and realigned to specifications.

Fig. 185. View into Q1 from slightly above the median plane. The correction plate assembly is on the left.

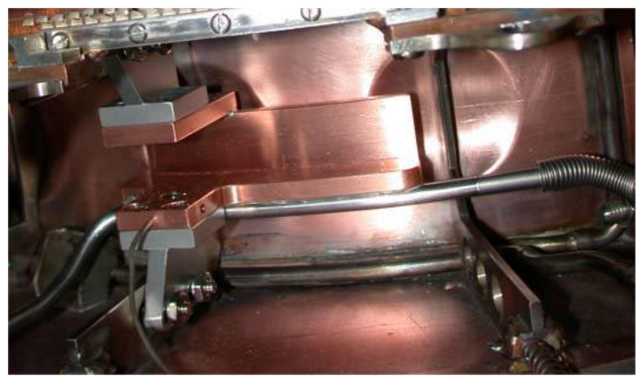


Fig. 186. Cooled beam absorber installed in Q1.

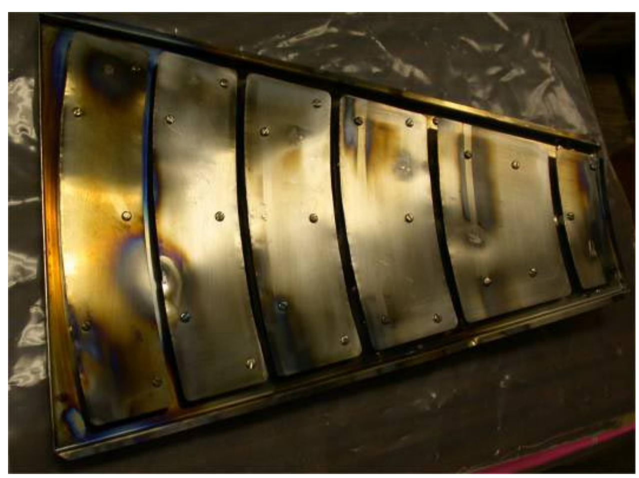


Fig. 187. Q1 correction plates. Notice beam damage spot on the left.

Fig. 188. Protruding M-foil, damaged by beam.

Because similar problems in quadrant 3 were suspected, those plates were also realigned. However, complete servicing had to be postponed until the next shutdown because of time limitations and dose constraints.

Then it was found that the M-foil, designed to provide a good rf connection between adjacent resonators (see right-hand side of Fig. 185), was sticking up into the dee gap. There it was exposed to the beam that caused melting (see Fig. 188). To prevent this from happening again, the excess foil material was trimmed away. Finally, to improve temperature monitoring in the centre region, four new thermocouples were installed and two old thermocouples were relocated.

Observations after the shutdown with the beam back on showed a dramatic decrease in centre region heating. Figures 189 and 190 show the temperature response of the Q1 stainless-steel ribs to rf power and to beam currents of about 200 $\mu$A before and after the installation of the beam absorber. Before shutdown the beam losses heated this rib to about 100°C. After shutdown the beam did not affect it, and the 8°C temperature rise was caused by rf losses only.

## BEAM DEVELOPMENT

### Cyclotron Beam Dynamics Development

The 2002 cyclotron beam dynamics activities focused on increasing the current extracted from the cyclotron. By 2005 it is anticipated that the ISAC target stations will be operating with target currents of 100 $\mu$A. If a second, independent ISAC target facility is eventually constructed, the current requirements of ISAC would increase to 200 $\mu$A. In order to produce these beams without decreasing the beam available to non-ISAC users, the maximum extracted beam from TRIUMF would have to increase from ~200 $\mu$A to 300 or 400 $\mu$A. During the past year cyclotron beam dynamics studies have focused on extracting 300 $\mu$A

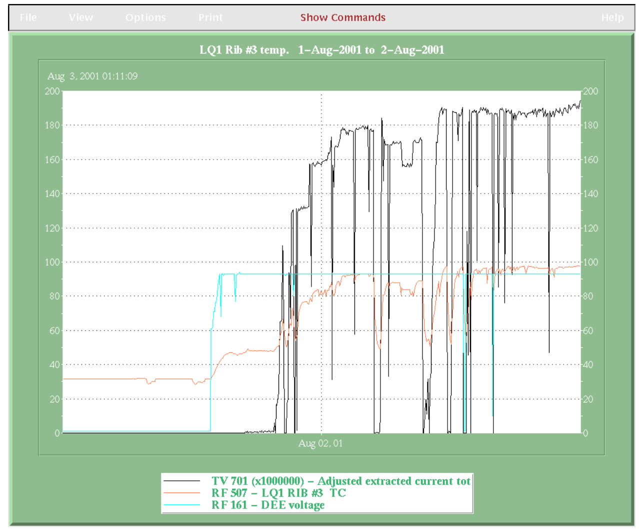



Fig. 189. Temperature response of the Q1 stainless steel ribs to rf power and to beam currents of about 200 $\mu$A before the installation of the beam absorber.

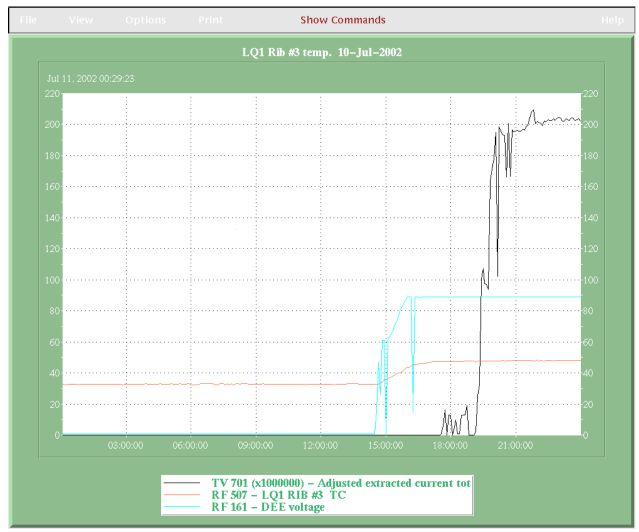



Fig. 190. Temperature response of the Q1 stainless steel ribs to rf power and to beam currents of about 200 $\mu$A after the installation of the beam absorber.

reliably and stably, and on demonstrating the feasibility of 400 $\mu$A extraction.

At the end of 2001, two major roadblocks to 300 $\mu$A extraction had been identified. First, at high current levels radial beam losses on the vertical walls of the centre region rf resonator quadrants were causing overheating. Second, cyclotron transmission at 300 $\mu$A equivalent current appeared to be limited to 50%, substantially lower than the 63% transmission typically obtained with 200 $\mu$A production tunes and the 62% that had been obtained with a 250 $\mu$A development tune. Both of these obstacles were overcome during 2002. In addition, equivalent currents as high as 380 $\mu$A at 10% duty cycle were eventually extracted with greater than 60% cyclotron transmission.

The rf quadrant heating problem was eliminated by the installation of the water-cooled beam stopper to intercept most of the beam that previously was being lost on the quadrant walls. This device was installed during the 2002 winter shutdown and successfully tested with beam after operations resumed. The heating problem was completely eliminated, and the stopper had no discernible effect on the cyclotron transmission to extraction.

After devoting several development shifts to improve the ISIS/cyclotron tunes, on July 30 we extracted 275 $\mu$A at 100% duty cycle with 62% cyclotron transmission for three hours. We were then able to increase the equivalent current extracted to 300 $\mu$A at 90% duty cycle with 61.5% cyclotron transmission for a period of 2 hours, and deliver it to experimenters. The reduction in duty cycle was dictated by the 270 $\mu$A combined current limit on the external beam lines. No thermal problems were encountered, and the beam ran quite stably during this period. We then went on to extract 325 $\mu$A equivalent current at 75% duty cycle and 60% cyclotron transmission, and 350 $\mu$A equivalent current at 40% duty cycle and 57% cyclotron transmission for periods of approximately 1/2 hour each. Operation at 350 $\mu$A appears to be an achievable goal, although some additional centre-region cooling may be required for operation at full duty cycle.

Subsequent beam development shifts were devoted to duplicating and refining the above tunes. Initially it was found that the 300 $\mu$A results could be duplicated on a regular basis; however, it was impossible to duplicate the 350 $\mu$A results. Above 300 $\mu$A, increases in the ion-source current were accompanied by decreases in transmission, preventing an increase in the extracted current. The reason for this is still not completely understood, but part of the problem appeared to be insufficient rf dee voltage. The phase acceptance of the cyclotron increases as the rf voltage is increased, and higher phase acceptances, and hence higher rf voltages, are required at the higher currents where the bunching efficiencies are lower. An analysis of the rf power input to the dees and of the beam's time of flight as measured on high-energy probe HE2 indicated that the actual rf voltage varied throughout 2002, possibly due to the large amount of rf tuning required to reduce sparking. During much of the year, the actual rf voltage was several per cent lower than the voltage being displayed in the control room. Once this was discovered, the rf power was increased to raise the actual rf voltage to $\sim$90 kV, its nominal value prior to 2002. On December 20, after re-optimizing the centre-region correction plates and trim coils, we were able to extract 380 $\mu$A equivalent current at 10% duty cycle with 64% cyclotron transmission. An attempt to raise the duty cycle at this current level was thwarted by lack of rf power – a problem that has now been solved. Although this initial result appears promising, additional work will have to be done on this tune in order to reduce the ISIS/tank spills to levels that would allow operation at full duty cycle.

It is anticipated that cyclotron beam dynamics for 2003 will continue to concentrate on high-current development. Emphasis will be placed on refining and understanding the behaviour of the high current tunes at increased duty cycles. Major goals will be reproducibility and stability.

### ISIS Beam Dynamics Development

The high-intensity CUSP ion source and injection line continued to operate well for the past year. The major development activity undertaken was trying to model its optics better. The beam profiles were measured periodically, with 13 wire scanners along the beam line. As an example, Fig. 191 shows the $2\sigma$ beam widths measured for dc currents of 345 and 575 $\mu$A. It can be seen that the beam widths all stay within 0.4 in. diameter, except near the cyclotron where the beam is bunched, resulting in strong space charge. In the horizontal periodic section, the beam is seen to be well-matched, because it is of quite uniform size.

Comparison of the two currents in the figure shows the effect of space charge on the beam. Because it uses the space-charge-loaded equations of motion of the second moments of the beam, the computer code TRANSOPTR can be used to determine the magnitude of the space charge neutralization, if any. Three wire scanners in the horizontal periodic section were used to measure the horizontal and vertical rms beam sizes for a number of different settings of the periodic section quadrupole strength at a beam current of 686 $\mu$A.

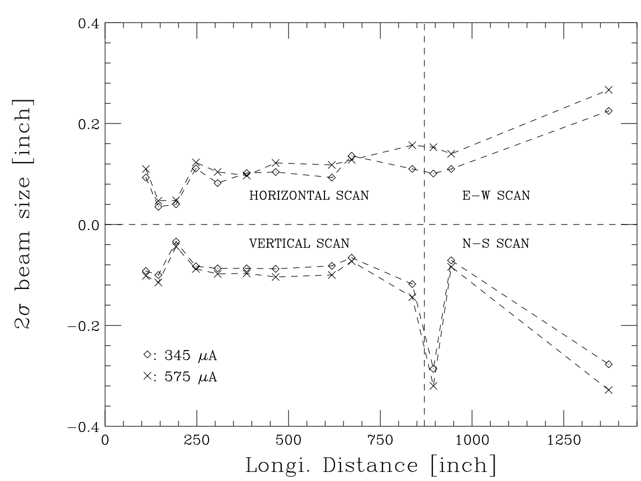



Fig. 191. The $2\sigma$ beam sizes in ISIS measured for dc currents 345 and 575 $\mu$A. The data points are the measurements. The dashed line is only intended to guide the eye.

These sizes were used in fitting the initial beam parameters and the effective current. In this way, it was found that the (4 rms) beam emittance is $4.3\,\pi$mm-mrad (i.e. $0.11\,\pi$mm-mrad normalized) in both planes, and the effective beam current is $580 \pm 70\,\mu$A. The size of the error is related to the fact that even at $686\,\mu$A, the effect of space charge is to increase the matched 2 rms beam size by only 0.5 mm, from 2.3 mm to 2.8 mm.

Our conclusion is that there is little, if any, neutralization.

## RADIO FREQUENCY SYSTEMS

### RF Operation

The total rf downtime for the year was 226 hours, 25% higher than last year. Although 80% of this downtime was charged to a combination of sparking and crowbars, it is really the recovery from those events that caused most of the downtime. In the September shutdown a new ground-arm-tip control system was installed and an extensive program of resonator-tip tuning was carried out. Also, in the rf control system, the timing sequence for spark recovery was changed and a software problem was discovered and fixed. As a result the rf downtime was reduced from 8 hrs/wk before the shutdown to 3 hrs/wk after the shutdown. Further work will be done in the January, 2003 shutdown to better diagnose the sparking problem.

Impurities in the LCW cooling system blocked the filter in the line feeding the rf room. The filter was replaced with a finer filter and has been operating reliably since September. Ground-loop interference, which caused unstable performance in the resonator water-pressure regulating system, was investigated and remedied.

### RF Refurbishing

A substantial effort was dedicated to rf refurbishing. A 500 kW resistive load was commissioned during the winter shutdown. It is an essential tool for the high-power tests of the rf combiners and for troubleshooting the amplifier system. During the September shutdown, rf combiner #1 was tested to a power level of 460 kW and installed into the rf system. It operated reliably for the rest of the beam run. RF combiner #2 was tested to full power as well and is ready for installation in the next shutdown. All 3 operational combiners were retuned to best matching and isolation values. This reduced the VSWR from 1.3 to 1.15 in transmission-line interconnections within rf room and isolation of the ports from −30 db to −70 db. Two directional couplers were incorporated in the IPA output transmission line to allow tuning for better matching to the rf splitter and easier system troubleshooting. Three water-cooled capacitor stations, which are part of the transmission line matching section, are very difficult to service, especially when a water leak occurs. It was decided to improve their design. An upgraded set of drawings was issued and all the parts were manufactured for installation during the next shutdown. The major improvements were the installation of quick-disconnect water connection, quick-disconnect capacitor electrical connections and the addition of flow interlocks in the cooling system. A multiplexing and diagnostic system was developed that provides first-event detection from as many as 24 voltage pickup probes along the rf power-feed chain. It is a very useful tool for troubleshooting during sparking and rf trips. The system is scheduled for commissioning in spring, 2003.

### Cyclotron RF Control

The ground-arm-tip (GAT) motor controller has a long history of unreliable operation. There has been a bug in the system from the beginning that, under some circumstances, will cause all resonator tips to move to maximum travel when only one resonator was selected to move. Several modifications have been made by several people, but this problem was never resolved. As a consequence, movement of the resonator GATs has been kept to a minimum. In an attempt to reduce the sparking rate, which became serious this year, it became evident that we required a more reliable GAT controller.

The GAT motor controller was replaced with a PC-based system. This work was done in collaboration with Jan Miszczak of Warsaw University. With this new system, the GAT motors are energized only during adjustment while under software feedback control. This improves the reliability of the motors and of the power elements in the controller circuits. The relevant data of the GATs and their drive system are stored and retrieved in a relational database. In addition to local control, the system is also connected to the site-wide Ethernet, and the GAT positions can be accessed via an Apache server running in the system.

### RF Support

The RF group was also involved in the following major projects in ISAC-I, which are reported in the ISAC section.

1. Maintenance and operation of the ISAC linac.
2. Development of a phase measuring system for the whole ISAC rf system.
3. DTL fine tuner upgrade.
4. DTL power coupler protection and restoration.

## CYCLOTRON PROBES

In the fall of this year, we bade a fond farewell to George Mackenzie. "Congratulations on a long and distinguished career! It has been a pleasure working with you; thank you for all of your help. Now, enjoy your retirement!".

In addition to normal MRO activities and ISAC work, there were a number of major repair jobs completed this year. Good progress was made on the HE probe refurbishment design. The majority of the replacement standard beam line monitor-box gas packages have been prepared for installation; some of these were installed. This year, non-routine repairs were done on the following devices: EX1, 2C1 fast shutter, 2CVM1 MWIC and the ISAC IMS:DB0 Faraday cup.

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

### Probes MRO

Extraction probe EX1 was removed for routine service in February. The L-arm latch-pin design was changed to the same style as used at EX4. It was removed again in September to repair a short circuit on the beam-current pick-up that occurred at the end of beam schedule 101. A very small piece of aluminum swarf was found to have caused the short; new track insulators were installed. The drive tapes and cables were replaced, and the ball-screw disassembled and cleaned.

The air solenoid valve for PIP#4 was replaced and a proper speed control was installed. The valves for the other PIPs will be serviced in future shutdowns.

The ferrofluidic feedthroughs (f/t) were removed from the two decommissioned dee-gap centring probes; blank off flanges were installed. The planned inspection of the slits and flags f/ts was not done this year, but will be done in January, 2003.

### Monitor MRO

All vault and standard beam line monitors were serviced during the shutdowns. The monitor refurbishment program was essentially completed. All mechanical assemblies have been built. Monitors 1VM4.6, 1AM6, and 1AM7 were replaced, and replacement of the remaining monitors will begin in January, 2003. New scanning wire monitors were installed in beam line 2C4 and 2C5. The 2CVM1 MWIC was serviced for the first time since its installation: the air solenoids were replaced.

As with all MWIC monitors close to the cyclotron, the gas package seals are susceptible to radiation damage. With the advent of new higher-gain electronics, it is now feasible to operate these devices without gas amplification. Consequently, 2CVM1 was modified to run without gas. It is planned to modify monitors 1VM1, 1VM2, 4VM1, and 4VM2 to use the same advantage and eliminate the need for semi-annual replacement of gas package seals.

The 2C fast shutter seized during operation in late August and was temporarily repaired to permit operation to 2C1 until the scheduled shutdown in September. The assembly was inspected during the shutdown, and found to be in satisfactory condition. A few design improvements have been made to facilitate maintenance, and a spare is being manufactured.

The 1AM8 monitor gas seals leaked due to radiation damage after only six months of operation. A recent service modification has left a shorter park distance from the beam elevation. This monitor becomes another candidate for use without gas. 1AM10 became stuck when a nylon spacer became radiation damaged. The spacer material was changed to brass. 1AM8 and 1AM10 will be refurbished when time permits.

A new MWIC was provided for use of PIF experiments in beam line 2C1/1B.

## VACUUM AND ENGINEERING PHYSICS

### Vacuum

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

The ISAC-I east target vacuum system was built and successfully commissioned.

In the cyclotron three instances of problems occurred with the B-20. These were all related to the regenerators on the 20K stage. A new Varian 551 turbo pump was installed on the cryoline connecting B-20 cryogenerator to the cyclotron. This pump replaced the original diffusion pump to shorten the turn-around time during cryogenerator defrosts.

In the beam line vacuum system a large vacuum leak occurred in the 2C4 line because of beam-induced melting of the indium seal caused by an anomalous beam configuration that, in turn, was caused by a deteriorating stripping foil. This seal was replaced. A number of vacuum leaks were diagnosed in beam line 1A. These are scheduled to be fixed during the spring shutdown.

The rest of the group activities concentrated on routine MRO.

### Engineering Physics

The Engineering Physics group leader retired this year. In light of this event, some of the group's responsibilities have been assigned to other groups. The correction plates are now serviced by the RF group and responsibility for the inflector/deflector has been moved to the ISIS Group. Manpower for most of these tasks has been allotted from the Engineering Physics Group on an as-required basis. The target development and MRO, as well as the secondary channel front end and TNF MRO responsibilities, now fall under the Primary Beam Lines coordinator.

During the past year the RF group has serviced two sets of correction plates from the cyclotron tank. The other two sets of plates will be serviced during the winter, 2003 shutdown. The inflector/deflector was inspected during the shutdown and was deemed to be serviceable without any intervention. Servicing for the inflector/deflector is now scheduled for the winter, 2003 shutdown.

The TNF system caused a minor inconvenience during the startup last spring because of a known, but inaccessible, vacuum leak. After the vacuum interlock set-point was adjusted and beam was delivered, a gradual improvement in the leak rate was noticed – in accordance with past experience.

During the last high current running period, two beryllium targets, one on each of the 1AT1 and 1AT2 target ladders, showed evidence of deterioration as the secondary-channel count-rates decreased. In both instances, the target ladder held a second beryllium target that was put into service within a few minutes. The failed targets have been in service since 1997 and will be replaced during the winter shutdown.

### ISIS

The CUSP ion source and injection line continued to operate well for the past year with only minor down time due to a failed turbo pump. As in the past few years, there were no major projects undertaken because most ISIS personnel were involved in other TRIUMF projects.

Last year we reported the successful effort to extract 700 $\mu$A of $H^-$ current from the ion source. This beam, although with slightly larger emittance, was successfully transported to the cyclotron and used for 300 $\mu$A, 500 MeV, reduced duty cycle (50%) development tests. The transmission through the cyclotron at this current was approximately 48% rather than the usual 63% for typical 230 $\mu$A operation.

Work this year entailed producing a broad ISIS tune at the 300 $\mu$A equivalent extracted current level at better than 60% cyclotron transmission. This tune was developed and frozen to eliminate the use of many of the 120 variable beam-control elements in ISIS. Only a few ion source parameters, the bunchers (variable depending on beam current), and two quadrupoles and steering elements used to match into the cyclotron were available for tuning. In fact, these last elements were also frozen toward the latter part of the year forcing better cyclotron centre-region tunes. This work is described in more detail in the following section.

## BEAM DEVELOPMENT

### Cyclotron Beam Dynamics Development

The upgrade of the optically-pumped polarized ion source that was started last year has been completed. The new ECR rf power supply, the biased sodium-vapour jet ionizer, and the ionizer solenoid were installed. The ion source delivered 15 $\mu$A unpolarized to the cyclotron using the standard ISIS tune with 8 $\mu$A extracted from the cyclotron. Off-line tests later in the year produced 40 $\mu$A at injection (greater than 21 $\mu$A extracted equivalent). Further tests produced 50 $\mu$A to a beam stop in the horizontal section of ISIS. In all cases the laser system to measure thickness of the alkali target was not available and therefore conservative temperatures were used in both ionizer cells.

These results, coupled with the fact that the extraction optics were not optimized, suggest that the performance of the source can still be improved with further development. The ion source has met the required goal to provide useful polarized beam intensities of 10 $\mu$A that can be used for ISAC lower-intensity beam production in parallel with users requiring polarized beam. (Lower intensity is normally recommended during a three-week period before scheduled shutdowns.) In addition, the source can be used as a lower-intensity (20 $\mu$A) backup for cyclotron beam production in the event of a major failure of the I1 CUSP-source system.

## PRIMARY BEAM LINES

By the end of the last running period of 2001 water leaks had been identified in the triplet as well as in the front-end of the M20 channel downstream of the 1AT2 target region. Because the total water loss from these leaks amounted to $\sim$80 l/hour, it was necessary to find and fix them. This was in addition to the decommissioning of the M8 (pion therapy) channel that had already been planned for the 2002 shutdown, the latter being a continuation of the refurbishing program for the primary beam lines.

Work began with the removal of the shielding over the M8 beam line to allow access to the M8 triplet and second dipole M8B2. Electrical, cooling and diagnostic services were disconnected and the vacuum seal separated. M8B2 was removed first and bagged. The triplet was disconnected from the first dipole of the channel, its exposed beam pipe bagged (because of contamination), and placed in a temporary bunker.

Services to the remaining two elements, M8B1 and M8Q1, of the (M8) channel were removed, and then the elements themselves. The radiation level on the mezzanine above was reduced to $110\,\mu$Sv/hr by installing a new iron shielding block and a new iron suitcase block.

At this point a problem developed in the plans for replacement shielding. Because the M8 channel accepted beam at a forward angle of 30° directly above the primary proton beam, a number of specially shaped shielding blocks had been installed. It was expected that these could be replaced with regular blocks, of which a number had been made. However, it was found that two support blocks had been welded to the 1AT2 target monolith. Consequently, several modifications to the new shielding were required.

The M8-1AT2 flange was sealed with a blanking plate. Four scrapings of the flange face were required before a vacuum seal was successfully obtained. With this operation completed, the M8 channel was successfully decommissioned.

In preparation for work on the 1AQ14/15/16 triplet downstream of the 1AT2 target, shielding over the triplet was removed. A major water leak was found on the return line of 1AQ15. This was cleaned of rust and repaired by welding a solder patch in place. Another leak was found in the supply header to a coil of 1AQ16. Although small (a leak rate of 1–2 drops/s), attempts to tighten the connection were unsuccessful because of a lack of space between the shielding wall and the fitting. The insulator itself was replaced but the small leak remained. After running cooling water overnight it was found that the leak rate had not increased and it was decided to leave the leak rather than expose personnel to further radiation dose.

Electrical shorts in 1AQ15 were found to be caused by an oxidation build-up on the pyrotenax cap insulators and were probably caused by moisture from the large water leak found at that quadrupole. Emery cloth was used to remove the oxidation from those connections that were accessible, resulting in an adequate resistance to allow operation. In addition the trip, warn, and common leads from the magnet's thermocouples were resoldered.

Other problems were encountered with the interlock wiring of the quadrupoles. These were repaired after much troubleshooting had been done. During the troubleshooting it was discovered that a vertical, heavy concrete shielding block near the 1AM10 monitor had disintegrated. Rubble from it had accumulated on the triplet main-header water lines and had displaced them. The debris was removed to reduce any stress on the water lines.

With these repairs completed there remained a water leak of $\sim$3 l/hr that could be attributed to the triplet. After relocating some shielding, a camera was used to visually locate the leak. The leak, found on the supply header-cap of 1AQ14, was repaired.

With the completion of the triplet repairs, iron shielding was replaced in the area and shielding was rearranged to allow the work that had been delayed on the M20 channel to proceed. Water was restored to M20Q1 and M20B1 and visual leak checking began. Leaks at both Hansen fittings of M20Q1 and at a solder joint on a coil of M20B1 were observed. The Hansen O-ring sealed fittings of the quadrupole were replaced with spare jumper hoses and the dipole leak was repaired by applying a clamp to the leaking solder joint. Two other similar clamps had been used at other leaks on the dipole. The rubber gaskets of the clamp that was accessible were replaced; however, those of the second were too difficult to reach and were left undisturbed. Water was restored and no indication of further leaks was found.

After restoring the shielding of M20 and from 1AT2 to monitor 1AM10, attention turned to other areas. The window valve upstream of the 1AT2 target had been working improperly and a vacuum leak had been found in the region of the 1AQ10/11 quadrupole doublet downstream of the 1AT1 target. A leak was found in the indium seal between the rotary collimator and 1AQ10. The faulty ring was cleanly removed and a replacement ring was made and installed.

When shielding over the window valve was removed it was found that the air cylinders were leaking badly. The cylinders were removed, new cylinders were installed, and the window valve was tested numerous times with no complications. Shielding over the area was then replaced.

In work around the 1AT1 target, the M13 beam blocker/gate valve assembly was removed, repaired, reinstalled, and the shielding over the area restored. The front end of the M11 channel was opened up to repair the jaws assembly and to locate and repair the last major vacuum leak.

This three-month long shutdown required a lot of planning and arduous work. Many times personnel were required to use their ingenuity when it was found that things were not as they were supposed to be. All of this work was successfully completed despite the high-radiation environment of the work areas. Those involved in the planning and execution of this refurbishment project are to be congratulated for a job well done.

Things ran well until the middle of May when water was found on the floor of the beam line 1A tunnel. By May 22 the leak rate had increased to 15 l/hr. The

M11 septum was identified as the source of the leak; when the area was uncovered it was not possible to find its location. However, with the use of mirrors and a video camera it was possible to see water falling from somewhere above.

It was decided to try a high-technology stop-leak process. One week of high-intensity running was cancelled and a PIF run instituted in order to provide a cool-down period. On June 13 the first infusion of an epoxy-clay matrix sealant was made. Following one day of air curing, a pressure test with water gave some indication of a leak and was confirmed when the septum was powered to 3,000 A. A second infusion followed by a longer curing period gave the same results. It was felt that the high electromagnetic fields of the septum were forcing the crack open.

One more infusion was attempted. This time the septum was briefly, but fully, powered immediately following the injection of the sealant. After a one week curing period the water was slowly turned on. At full water pressure and full power (3,850 A) there was no sign of a leak. On July 1 a leak rate of 2 l/hr was noted and by July 8 this had increased to 35 l/hr. The septum was valved off when not required by the M11 channel experimenters. By the end of July the leak had increased to 80 l/hr. At this time the septum was considered to be unrepairable and its power and water were turned off.

In mid September there was a short, one-week shutdown. The M13 beam blocker was repaired and a slit box installed at the second focus of the channel. To prevent the beam blocker from hanging up, the latch mechanism of the 1BBB2 was removed. The 1B beam blocker 3 was removed and its bellows repaired after which the blocker was reinstalled.

In the January shutdown of 2003 it is planned to replace the 1AQ14/15/16 triplet on beam line 1A. Three 8 in. bore, radiation-hard quadrupoles, nominally identical to those presently installed, were found on the vault roof of the cyclotron. One of these was found to have a shorted coil, so another, shorter quadrupole was substituted for it.

In order that services be accessible from the top of the magnets, their orientation was changed from horizontal to vertical. Water services were changed so that each quadrupole has its own cooling circuit rather than the parallel feed from a single header that had been used previously. The new electrical and water services were installed on these quadrupoles and each was field mapped. They were then installed on a dummy track and aligned. During the January, 2003 shutdown their alignment will be compared with that of the existing triplet and any required corrections made before the new triplet is installed in the beam line.

In addition to the above, the Beam Lines group was involved with other MRO and site activities. The filters of the active cooling system were changed and a new slit assembly for M13 installed. Interlock problems at 1AQ9 were investigated, the M15 separator serviced, and the M20 window changed. A window assembly was installed for Expt. 614 and assistance given for installation and alignment of the solenoid for the TWIST experiment.

In ISAC related work, beam line 2A was reconfigured for the installation of the new east target. Alignment support for both the east and west targets and their modules, as well as in the experimental areas, was given. Ongoing support for the DRAGON experiment continued.

In all, it was a busy year for both the Beam Lines and the Remote Handling groups. That the work load was completed successfully and on time is a tribute to the dedication and cooperation of these personnel.

**Beam Line 2C**

This year the major use of the 2C beam time continued to be the production of the radioisotope $^{32}$Sr in the solid-target facility (STF) on beam line 2C. Operating time increased from 107 days in 2001 to 148 days in 2002. The beam line ran very well on limited support with the only significant downtimes arising from a vacuum leak at the 2C4 steering magnet in November and one between the 2C fast valve and the quadrupole triplet in December. The dose was increased from 81.14 mAh and a yield of 31.12 Ci in 2001 to 123.35 mAh and a yield of 45.08 Ci on 2002. There were eight natural rubidium targets irradiated this year compared with five targets the previous year. The last target irradiated was not processed because it received a small dose of only 609 $\mu$Ah. This irradiation was terminated because of the vacuum leak between the 2C fast valve and the quadrupole triplet.

The beam extraction foil that is used for isotope production is a 0.250 in. wide curtain of 0.001 in. diameter pyrolytic graphite fibres. Two foils had been loaded in 2001 and one had failed during the run. Thus one foil was pushed to 75.77 mAh, which is 80% of the total 2001 dose and is about 50% higher than the dose on any previous foil. Three foils were loaded in 2002 to share the dose, but two of the foils split, creating a beam halo that could not be tuned out of the beam. Of the total dose this year, 116.26 mAh were put on the good foil and 8.29 mAh and 22 $\mu$Ah on the split foils. The tuning difficulties and the large beam halo contributed to the vacuum leaks in the beam line, and the (known) misalignment of the STF makes high-current operation very sensitive to the beam halo. Splitting of the foils will be investigated in the 2003 shutdown and the STF misalignment will be corrected in the 2004 shutdown. An upgrade of the 2C diagnostics in the 2003 shutdown will also assist in tuning.

The target-handling apparatus in the 2C STF hot cell was repaired and another manipulator was added there. The resin can on the STF was modified to facilitate replacing the resin and the STF conductivity meter was repaired. A jig was built for the STF target assemblies and all of the target assemblies were repaired and realigned or disposed of. All of the long overdue maintenance was done with the assistance of the Remote Handling group.

There were 36 days scheduled for proton therapy on 2C1 and 33 days were scheduled in the proton irradiation facility (PIF) on that beam line.

## PROMPT RADIATION HAZARD

### Introduction

Prompt radiation is produced only while an accelerator is in operation and hence, if required, can be rapidly terminated by interlocks that shut off the beam. In the present context it consists of a mixture of the many different particles that are produced when high-energy protons from the 500 MeV cyclotron interact with any type of material. Of this prompt radiation, high-energy neutrons are the most penetrating. At TRIUMF the safety systems that protect against this hazard have functioned for over 25 years without a failure leading to a significant exposure from prompt radiation.

As a result from the Canadian Nuclear Safety Commission (CNSC) we evaluated "the reliability of the engineered safety systems to provide a timely response under fault conditions must be under fault conditions". The purpose was to establish that the safety systems are sufficiently reliable in turning off the proton beam in response to high beam loss so as to reduce the probability of serious radiation exposures to anyone outside the shielding to well below significant levels ($< 10^{-5}$/year). The "Prompt Radiation Hazards Study Group" was formed to address the question of reliability of the safety systems and to formulate a response to the CNSC. The study group investigated the status of the safety systems and identified 11 action items that could be implemented to guarantee the desired reliability. Later this number was expanded to 15 items by the CNSC.

### Immediate Action Group

A "Prompt Radiation Hazard Immediate Action Group" was appointed in March, 2000 to implement the actions that had been identified. The group proceeded to address these issues and also examined the overall rationalization of the safety system. Before the end of 2002 this work had been largely completed. In several cases progress had been driven beyond the original mandate.

### Work Accomplished

To examine all of the work that has been done would be too long for this report, but a short summary is possible.

A policy has been developed that specifies the maximum dose-rate levels outside shielding due to prompt radiation. This policy applies to both normal and abnormal beam-loss conditions of the licensed proton-beam current.

The active machine protection and active personnel protection systems are now treated as separate systems. The existing radiation monitoring has been reconfigured into two independent "safety-critical" radiation safety systems, one using $\gamma$-ray detectors and one, neutron detectors. However, both systems trip the same set of beam control devices to shut off the beam. Reliability requirements have been established and testing to verify that these requirements are met is now routinely done. Operator training is being updated to include training on the new safety system configurations and on the calibration and testing requirements.

The above two systems have been examined for ways to reduce their vulnerability to tampering. A number of improvements have been implemented. The monitoring and trip components have been evaluated for single point-of-failure mechanisms and changes have been made to reduce vulnerability to common failure modes. One remaining change is being actively pursued.

A policy has been established that defines the action to be followed when there is a malfunction of some part of the safety systems and that specifies the conditions and measures to be taken to allow continuing operation of the accelerator or beam line for a limited time until repairs have been completed. Improvements to the documentation describing the safety systems have been completed. A system of configuration control for safety-critical beam control devices has been established.

The definition of an "initiating event", that is, an event that could lead to a substantial prompt radiation exposure outside the shielding should the active safety-critical not respond, has been given a precise definition. This was required in order to be able both to clearly identify such events and to count them for the purpose of verifying the safety system reliability in terms of the probability of potential accidents.

The reliability of the pepper pot, a device used to restrict beam current during low-intensity operating configurations, has been re-evaluated and the device once again found to be safe.

### Work Arising

The remaining issue, one that arose from the immediate action items as a very desirable enhancement, was to make the beam-trip configurations for each of the gamma and neutron monitoring systems completely separate and redundant. A concept has been proposed and has been accepted. An engineering design is now being developed. Implementation is planned for the winter, 2004 shutdown.

## CONTROLS

The Central Control System (CCS) continued to run well throughout 2002 and was responsible for only 4.8 hours of beam downtime as recorded by the Operations group. This is 2.7 hours less than the previous year. The major part of the downtime was due to hardware failures. Considering the size of the CCS and the age of many of its components, the downtime is minimal. The CCS runs reliably, performs well, and is flexible in meeting new needs. However, because of the many old components, there is serious concern about maintainability of some items. As a result, the importance of refurbishing is considered to be of the highest priority.

The goals set for this year were largely attained. These include continuing to replace the existing secondary beam line controls, phasing out VAX with Alpha machines, replacing the DSSI disk systems with fibre channel disk systems, and starting to replace the aging PC-based ISIS wire scanner system.

### CCS Facilities

The major applications such as XTpage (cyclotron display pages), Xstrip (trending package) and Scan (machine protections scans) have received numerous enhancements and new features. Constant modifications and additions to XTpage have been made to keep pace with changes in various systems such as safety, vacuum, and beam lines, and for requirements of the Operations group. Purchase of the source code for the commercial XRT/graph widget, which is used by applications including Xstrip, has made changes and bug fixes much easier. For the Scan application, new keywords have been added to better handle data-acquisition error conditions (hardware failures). Scan also has new features tailored for Operations use. The DOSE program that the Safety group uses to keep track of dosimeter records was successfully ported to the Controls clusters, as anticipated in the previous year.

On the refurbishing front, a new fibre-channel storage has been installed in the Production Cluster to phase out the old DSSI disk storage system. Together with the existing fibre-channel system in the Development Cluster, they provide superior performance and reliability. Continued effort has been made to move file structures from the old disks to the new one. So far, three old disks have been retired in the Development Cluster. In addition, two new fibre-channel disks for the Safety DOSE data storage have been installed, one for each cluster. For the PC Servers Cluster, the fibre-channel hardware has been purchased and will be installed next year.

The tape backup systems in both Production and Development Cluster have been upgraded to high density SuperDLT drives. This provides needed capacity and performance. The backup procedure has been improved to make the incremental backup automatic.

The Production node CCSCS3 has been replaced with a faster Alpha (617 MHz DS10), and the VAX that was used as Diagnostics node DEVDG0 in Development Cluster has been phased out and replaced by a 466 MHz DS10.

New LCD monitors have been installed in locations such as the control room, the rf room, and the proton therapy control room. They were favourably received, in part for their non-susceptibility to stray magnetic fields, slightly larger screens, and light weight. In the next year we plan to replace the old X Window terminal system using VXT terminals and Infoservers with a higher-performance system. The old system has run extremely well for more than 10 years, but is much slower than required. Further, the VXTs do not support secure connections.

To prepare phasing out the last VAX, called DEVBN1, most of its unique functionalities have been ported to DEVBN2 (an Alpha CPU). We plan to remove this last VAX node in the next year.

### Secondary Beam Lines

The replacement of the secondary beam line control systems with a new EPICS based system has progressed well. To date, two beam line systems, M13 (TWIST) and M20, have been converted. The M13 control system has been used in production mode. It provides the same functionality as the old system and new features such as finer steering of the beam. The M20 system has been fully converted and is ready for field testing. The M9B and M15 systems and a multiplet tuning program to facilitate $\mu$SR tuning are all planned to be done next year. Documentation has been compiled and is available in the Secondary Beam Lines Web site under the CCS home page.

The new EPICS system uses two Sunblade 100s, one for production and the other for development. The latter doubles up as a “hot spare” in case of a failure of the production computer. The usefulness of this configuration was demonstrated when the system disk of the production computer crashed and a switch-over to the development computer was performed.

Additional measures have been taken to improve system reliability. These include setting up a tape drive for routine backup and installing a firewall for the front-end processor (input/output controller). In the area of diagnostics, programs have been developed to facilitate the investigation of faults.

### Other Systems

A new system to control and readout data from the VME based electronics for the multi-wire chamber monitors in beam line 2A has been installed. It includes a PC running Windows 2000 for acquiring data from the VME module. This system integrates seamlessly with existing display and control of monitors in other beam lines. Controls have also been provided for the new 2A3 beam line. These include various scans and display pages.

For the proton therapy facility, UPS has been provided as planned and made available to the CAMAC crate, terminal server, and a display terminal. This ensures the equipment is protected from power disturbance. The dose and error-log printers, which were rather older models, were upgraded to more modern units. During the next year the proton therapy computer will be upgraded to a DS10 and the existing computer will be freed up to act as a spare for the beam line 2C CPU.

### Miscellaneous

Work has begun on a replacement for the old PC-based ISIS wire scanner system. Display page and device controls are in place and preliminary tests have been completed successfully. Unlike the old system, the new system will allow widely distributed remote control using an X Window interface. It will provide display of statistical parameters together with new features such as saving and restoring scan sets. Further enhancements are planned for next year.

To maintain the CCS software in an up-to-date status, upgrades have been performed on Oracle (to version 9i) and Multinet (version 4.4). An upgrade of VMS to 7.3-1 is planned for next year.

## OPERATIONAL SERVICES

### Remote Handling

#### Cyclotron servicing

The winter shutdown presented an uneventful routine of copper blocker and shadow-shield handling, along with video and radiation surveys. The 2C extraction probe was removed remotely for service and replaced at the end of shutdown. Once again, other than routine maintenance, major servicing on the cyclotron elevating system was postponed because of conflicting ISAC work loads.

#### Beam line servicing

Major beam line refurbishment began in the 1AT2 area this year with removal of the decommissioned M8 pion therapy beam line. All M8 components from the 1AT2 target station downstream were disconnected and removed from the line; the large elements were stored for future-service evaluation. The vacuum flange joint to 1AT2 was cleaned and blanked off.

Miscellaneous parts were packaged for disposal at a radiation waste facility. Low-level activity steel shielding of unique and unusable configuration as well as water-damaged crumbling concrete shielding blocks removed from the beam line also were packaged and transported to the off-site radiation waste disposal facility. Over 32 tons of new concrete and 100 tons of new steel shielding blocks were installed to replace the original components and unique shielding in the area.

Work in the area uncovered a number of water leaks on the beam line 1A triplet magnet assembly. A steady increase in water loss as well as resultant electrical ground faults from this unit had threatened continued operation of the beam line prior to the scheduled shutdown. A water leak at a silver-solder joint on a 1AQ15 cooling header was repaired with a patch soldered *in situ*. A water leak at a ceramic insulator fitting on 1AQ16 required removal of adjacent shielding to allow proper access. Water erosion at the fitting joint due to a long term leak prevented an absolute repair. Even after replacement of the insulator a small leak persisted (1 drop every 2 s). Yet a third leak at a seal plug on a 1AQ14 header was fixed with a replacement plug and metal washer. Pyrotenax coil insulators on 1AQ15 were hand cleaned to remove oxidization products.

Thermal-switch interlock wiring on the triplet assembly was found to be damaged and required rewiring to enable power supply interlocks. Faulty radiation beam-spill monitors in the area also required replacement.

During the shutdown, shielding over the M20 beam line front end was removed to access other known water leaks. Quick disconnect, rubber O-ring sealed fittings on M20Q1 were found to be leaking and were replaced with spare jumper hoses. A new leak on M20B1 was found at a split at a copper coil termination. This is now the third of three identical splits in coil terminations, and is not solder-repairable. A specialized design of rubber clamp was installed to stop this leak. At this time the rubber seal in the one similar, accessible clamp on another coil was also replaced.

A concrete core sample through the meson hall floor adjacent to 1AT2 was drilled and removed at the beginning of the shutdown by outside contractors. The sample is required for information in preparing the TRIUMF Safety decommissioning report.

Miscellaneous beam lines work required replacement of the pneumatic actuator cylinders on the 1AWVA2 window valve between 1AT1 and 1AT2, and an indium vacuum seal on the rotary collimator-to-1AQ10 magnet. The horizontal 12 in. diameter indium metal seal on the 2CVBB1/M1 monitor was replaced.

In May a serious water leak developed on the M11 septum magnet. After removal of shielding in the area, we used closed circuit television in an unsuccessful attempt to locate the actual source of the leak.

In December a vacuum leak in the cyclotron vault at the 2CVF2/2CVQ1 joint required replacement. Initial installation of the beam line had not left sufficient clearance for free removal of the indium carrier ring. The 2CQ1/2/3 quadrupole triplet was permanently relocated approximately 1 cm downstream to improve future access to the joint.

### Hot cells and targets

Routine production target maintenance for the year required removal and exchange of the 1AT1 and 1AT2 targets, measurement confirmation of target elevation, resin can exchange at both 1AT1 and 1AT2 cooling packages, replacement of the water flow transducer for collimator "A", and repair of a damaged water return line at 1AT2 package during M8 beam line removal.

Beam lines support saw the replacement of the M20Q1 water quick-disconnect fitting O-rings in the warm cell, and the rebuilding of the spool and pilot valve in one of two beam line 1A air-pressure amplifier units. The storage pit was also prepared toward the end of the year for scheduled 1AM10 monitor removal.

Throughout the year assistance was given to 2C hot cells operation with the retrieval of a misplaced target holder, the repair of the target-flipper mechanism, the replacement of a rubidium target, service maintenance on a pivoting-tong manipulator, and help with the design and drawings for a floating-target jig. A resin can at the 2C cooling package was prepared and exchanged, and a water-outlet fitting replaced. Later in the year a standard 1AT1/1AT2 resin can was adapted and installed at the 2C cooling package, and the package conductivity meter was replaced.

The Safety group was assisted in the design and detailed drawings for a portable neutron source flask, and the addition of 3/4 in. thick aluminum back-up plate for the industrial trash compactor.

## Magnet Power Supplies

2002 saw the installation of beam line select switches to enable future beam delivery to the east target station for ISAC.

Many water leaks were encountered in the old M8 power supplies, which were installed for DRAGON. These were repaired as they arose and a decision was taken to replace the power supplies for MD1, MD2, Q9, Q10, SX3, and SX4. Replacement supplies were purchased for installation and commissioning during the spring shutdown, 2003.

Water leaks in the remaining 20–30 year old supplies, which were part of the original TRIUMF installation, continue to be a problem. This is being addressed by the installation of new heat sinks, which should provide better service.

The main cyclotron magnet power supply exhibited signs of instability. This was traced to radiation damage to wiring that had been installed on the cyclotron lid in the early days of power supply commissioning. The wiring provides feedback from trim coil 54 to stabilize the magnetic field. The cable, type 8451, exhibits the characteristic that the insulation turns to powder. A portion of this cable was replaced and further inspection of this type of cable used in the vault is scheduled for the spring, 2003 shutdown.

Further work was done to ensure stability and reproducibility of the M13 power supplies. This was done in conjunction with the Controls group and the Electronics Shop.

Water leaks in the hosing of the main magnet supply indicated that the silicon hoses were reaching the end of their practical lifetime. They were installed in 1982. New hoses will be installed during the spring shutdown, 2003.

Other activities involved provision of experimental support and as normal MRO.

Shutdown coordination was provided for the PCB transformer replacement, the removal of the M8 beam line, and other activities.

## Electrical Services

### Electrical systems

About 40 engineering and installation work-orders were completed in support of site requirements, including the cyclotron and the experimental program. Among them worth noting are the cooling tower variable-speed drives, UPS power to the proton therapy facility, services for the rf waster load, interlocks for the data acquisition system for Expt. 614, the upgrade of the fire alarm system, extension of the emergency power capacity in the main office building required for the new Card Access system, and site lighting improvements.

However, the ISAC project continued to be an important focus of the engineering efforts. Work on those projects will be covered in the ISAC report. In addition, continuing engineering support was provided to Nordion for the new TR30-2 radioisotope production facility project and to the ATG group for maintaining the operating facility.

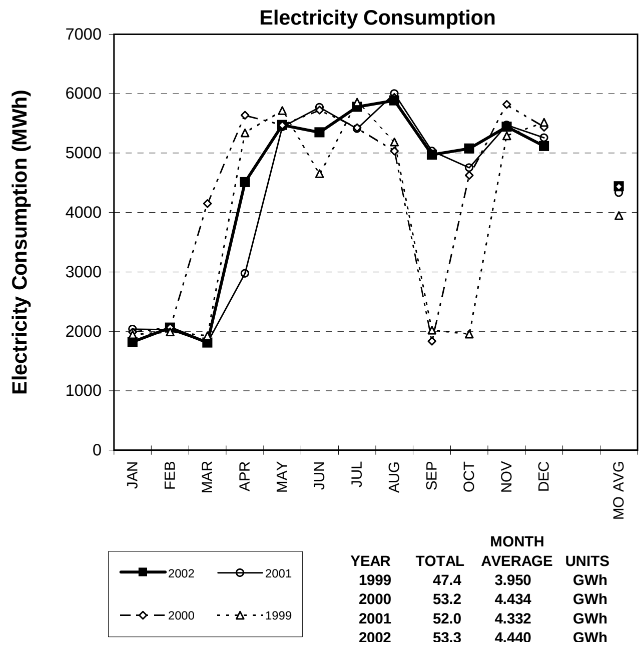
TRIUMF uses two types of light fixtures: fluorescent and high discharge (mostly metal halide). Because of advances in lighting technology, we investigated the possibility of significant Hydro savings through replacement of existing lighting by more efficient units. The study indicated that we could save about $60,000 per year in electricity consumption. If approved by BC Hydro, this program would be eligible for some funding under the Power Smart incentive program.

Maintenance-based activities formed the bulk of the work of the Electrical Services group. Approximately 200 calls were answered and completed with an additional 20 carried forward to 2003. Typical maintenance activities included servicing lighting systems, motors, air-conditioning controls, panel boards and transformers, high-voltage switchgear, breakers, and capacitor banks. In addition, the maintenance of the approximately 10,000 fixtures of site lighting continued to keep the crew very busy throughout the year. Ground water has found its way into the conduit housing the 15 kV cable feeding the main office building. The cable still appears to be in fair condition, but it was determined prudent to replace it next spring. Work commenced on the variable-speed control for the cooling tower motors. We plan to put the new system in service by February, 2003.

The electrical crew saw its number decrease when the apprentice quit early in the summer. This placed additional burden on an already understaffed group. The addition of ISAC-II buildings will not make things easier. The service continuity and reliability may suffer if the staffing level does not match the increased workload.

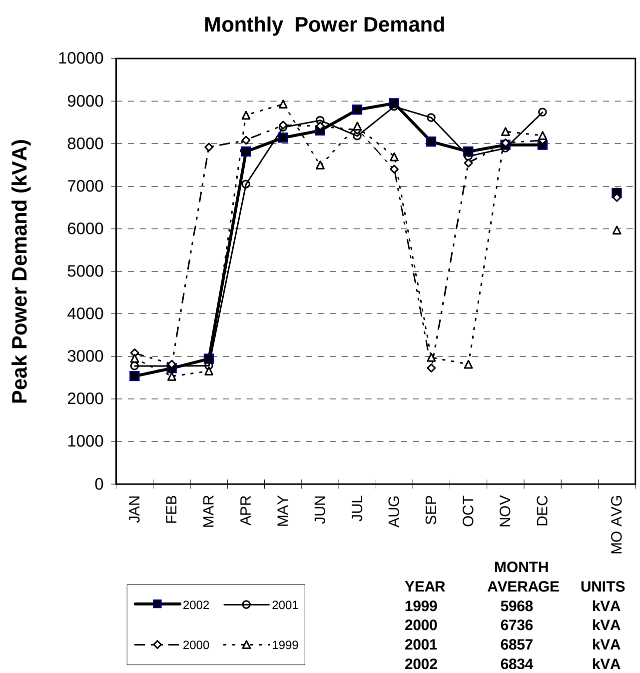
**Power delivery**

This was a relatively smooth year with only one outage. The current power management program has been administered manually. With the addition of ISAC-I, ISAC-II, and the TR30-2, we began exploring ways to network the power monitoring and ground-fault alarming for better efficiency and response. The monthly averaged peak power demand remained essentially unchanged (6,834 kVA). However, the maximum peak demand increased by 1% to 8,944 kVA and was reached in August (Fig. 192). Electricity consumption inched up by about 2.5% to 53.3 GWh (Fig. 193). The largest consumption also occurred in August (5.89 GWh). The power factor (PF), averaged over the calendar year, remained unchanged at 96.1% (Fig. 194). However, the PF of a typical production month decreased slightly.




| YEAR | TOTAL | MONTH AVERAGE | UNITS |
|---|---|---|---|
| 1999 | 47.4 | 3.950 | GWh |
| 2000 | 53.2 | 4.434 | GWh |
| 2001 | 52.0 | 4.332 | GWh |
| 2002 | 53.3 | 4.440 | GWh |

Fig. 192. Electrical system power demand – four year comparison.




| YEAR | MONTH AVERAGE | UNITS |
|---|---|---|
| 1999 | 5968 | kVA |
| 2000 | 6736 | kVA |
| 2001 | 6857 | kVA |
| 2002 | 6834 | kVA |

Fig. 193. Electrical system energy consumption – four year comparison.

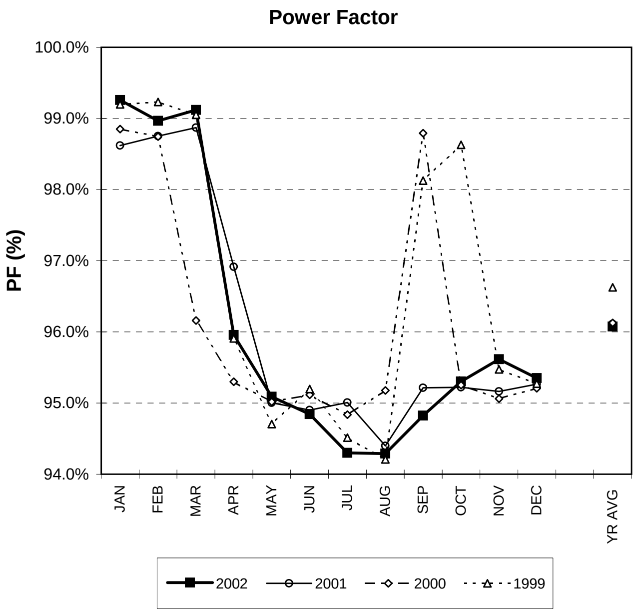



Fig. 194. Electrical system power factor – four year comparison.

**Mechanical Services**

The majority of effort at TRIUMF can be roughly divided up into two areas of activity: provision of new or maintenance of existing services piping, and heating, ventilation, and air conditioning (HVAC). New piping service jobs included the rf dummy load and CERN kicker magnet, while upgrades included M15 and M20 vacuum pump exhausts, M9 rf separator, M11 and M15 water manifolds, and a new filter for cooling water in the rf room. A large number of MRO jobs were completed. Typical examples would be the repair of leaks in the main magnet power supply and in the Machine Shop hot water system, and the replacement of failed valves. Work was started to replace one of the original perimeter ground-water drainage sump pumps along with connecting piping. Orders were issued for the supply of speed controls for eight of the fourteen cooling tower fans. The completion of this job in the next year will see better rf stability because of better regulated water temperature, and reduced maintenance and power consumption.

New HVAC services were provided to trailer A, PH extension room 204, trailer Gg room 30, and PH extension shower room. An exhaust system was provided for the new TR13 fume hood. A large effort was made in maintenance of existing site HVAC equipment. The list comprised a large fraction of the total inventory: MOB air handling units 1 (a complete overhaul) and 8, board room, trailer Gg, medical annex, ISIS clean room, both service annex machines, telephone exchange room, ATLAS clean room, chemistry annex computer room, and various Buffalo units. A new BL1A exhaust fan was installed.

Annual inspections and deficiency correction were completed for the site fire sprinklers and lifting equipment.

The air compressor formerly known as MRS has been rehabilitated and put to use as a site backup machine. The area around it has been cleared, and a new NOMONOX (breathable air quality) treatment system installed.

Engineering assistance in various areas was provided to Nordion for their new building project.

The Plant group welcomed the addition of technician Rob Walker.