# TRIUMF

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**FOR PARTICLE AND NUCLEAR PHYSICS**

OPERATED AS A JOINT VENTURE

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UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

DECEMBER 2004

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# CYCLOTRON OPERATIONS DIVISION

## INTRODUCTION

During 2003 the cyclotron was available for ∼88% of the hours scheduled, despite the unexpected problems encountered. However, the total number of available hours was 5176, exceeding the 4845 hours available in 2002. The total beam charge delivered at 500 MeV was 533 mAh of which 450 mAh were delivered to BL1A for meson production and 83 mAh were delivered to BL2A for RIB production. Beam was delivered for the first time down BL2A3 to the east target station (ITE) of ISAC. Approximately 117 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 88% availability of the cyclotron was 2% lower than last year and the total downtime was 200 hours higher than average, due primarily to the problems with the inflector that forced an unscheduled lid-up in May. The low beam-charge delivery to BL1A was mainly caused by a water leak in one of the targets in the triplet assembly that forced us to run with a low average current for a while. A large water leak at an insulator on a quadrupole magnet (1AQ15) caused further reduction in the beam-charge delivery.

During the development shifts, two high current milestones were reached. A record-setting peak current of 420 $\mu$A was extracted at 25% duty cycle with 63% cyclotron transmission and a peak current of 370 $\mu$A at 50% duty cycle was extracted for ∼3 hours with good stability and with a cyclotron transmission greater than 62%.

During the winter shutdown, the major beam line activities were the replacement of the chronically leaking BL1 triplet, replacement of crumbling blocks around the 1AT2 target, and replacement of shielding blocks to accommodate the new triplet. A number of water and vacuum leaks were repaired along with plenty of routine maintenance work. A chronological detailed description is presented in the Primary Beam Lines section. The major vault and tank activities include work on the extraction probes, slits, periscopes, correction plates, thermocouples, rf voltage probes, ground-arm-tip measurements, transmission line modifications, new tank ion gauges, and new inner and outer tank vacuum seals.

In the fall mini-shutdown, a decision was made to raise the lid to replace the water-cooled probe (WCP) that had failed earlier and to exchange the 2C extraction foils. In the meson hall, water leaks were repaired at the 1A triplet and M9Q5, and electrical connectors at M9Q1, which had melted and caused the M9 line to be shut down, were replaced. As well as tank and beam line activities, the support groups were also very busy in their own respective areas.

RF downtime was similar to last year but it is worthwhile noting that only 20% of the downtime was due to sparking compared to 80% last year. Although most of this improvement in the sparking rate is due to the new ground-arm-tip control system that was installed in the September, 2002 shutdown, it was further improved this year by modifications to the software in the rf control system.

The major hardware failures were a 250 kW resistive load, damage to the transmission line, water leaks in the high-voltage power supply, and the failure of the 250 kW power tubes. Improvements in interlock protection circuitry, water cooling circuits, and reliability are being addressed to minimize hardware failure. During the winter shutdown the major activity was an extensive program to improve readings of the cyclotron voltage probes.

In the rf refurbishing program a second new combiner was installed. It operated reliably during the past year. A third new combiner was tested to 500 kW into a resistive load and will be installed in the winter shutdown next year. An upgrade to one of three capacitor stations in the matching section of the transmission line allows for faster replacement time, thus reducing the radiation dose for this job. The remaining two will be installed in the shutdown next year. A multiplexing and diagnostic system was built that provides first-event detection from as many as 24 monitoring points when rf sparking occurs.

In the Probes and Diagnostics group, progress was made on the refurbishment of the HE probe that included some prototyping of the probe-head mechanics. Several of the refurbished monitors were installed and a number of other monitor improvements were made.

The Vacuum group encountered a few problems with the B-20 cryogenerators related to lead loss in the 20 K regenerator, leaks in the helium gas plumbing, and the malfunction of the lubrication delay device. Despite these problems, downtime due to the vacuum and cryogenic systems was minimal. BL1A was upgraded to accept Varian turbo pumps, which involved a large amount of re-cabling and leak checking.

In ISIS, two new CUSP ion source bodies were built for use in the I1 terminal, the old wire-scanner PC-based data acquisition and display system was replaced, and four new sets of motor-driven variable-aperture slits were designed and built. The ISIS group is responsible for the inflector/deflector system and was very busy during the lid-up intervention in May for repairs.

The Controls group completed the new ISIS wire-scanner system controls, the rf spark first-event detector system controls, the phase out of the last VAX computer, the decommissioning of one of two DSSI disk systems, the implementation of a wireless infrastructure and its initial applications, and software upgrades.

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

The work for "Safety-Critical Monitoring for Prompt Radiation Hazards" continued this year. Five pairs of safety-critical neutron and gamma monitors were installed around the proton hall. Eight safety-critical detector trips occurred during the year. A report, written for each event, included an estimate of the maximum radiation field outside of the shielding (at licensed beam current) had the beam not been tripped off and a record of whether the radiation field exceeded 50 mSv/h. A review meeting on the Conceptual Design of the Cyclotron Beam Trip and Prohibit System was held and the design concept was approved following some recommended changes in the documentation

## BEAM PRODUCTION

Beam delivery for the year was reasonably successful although total charge production was down 10% from last year's record. Cyclotron performance continued to be enhanced by the use of the rf booster which was on during much of the high current operation, partly to satisfy the occasional demand for 2 ns pulse-width beam but also to improve the cyclotron transmission (typically close to 65%) and reduce the measured tank beam spill (usually below 2.5 $\mu$A). Thirteen weeks of shutdown left 5878 scheduled operational hours of which 5176 were achieved for an availability of 88%, 2% less than last year. These totals include 231 hours used for development and tuning and, as shown in Fig. 227, were split roughly 4:1 between high-current beam production and lower-intensity operation. The latter usually involved beam delivery to ISAC with the proton irradiation facility (PIF) using BL1B and BL2C1 running in parallel. BL2C1 was also used at 74 MeV for ocular melanoma treatments for nine patients during five proton therapy (PT) sessions. These PT sessions, with the high intensity source online, required the use of the ISIS pepperpot to limit the injected beam current during patient treatment times. Again this year there was no BL4 operation and no polarized source operation.

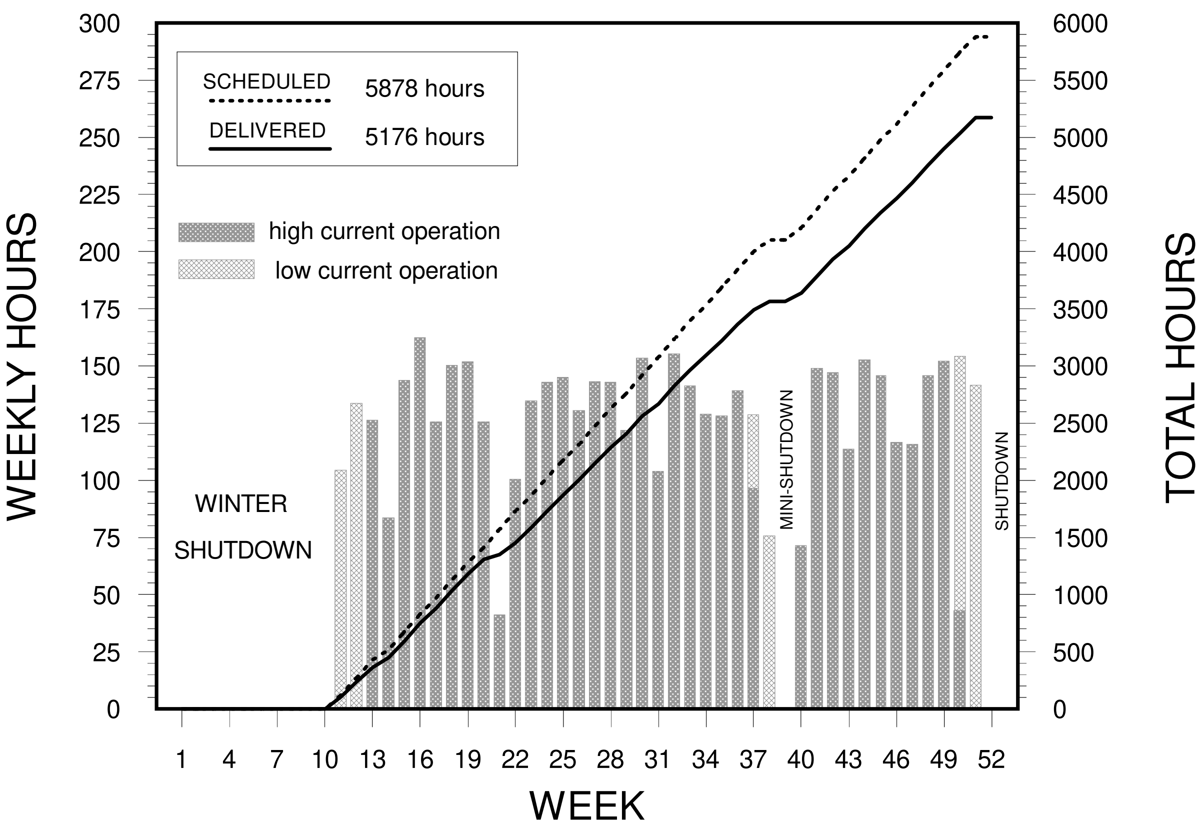


Fig. 227. Operational hours for 2003.

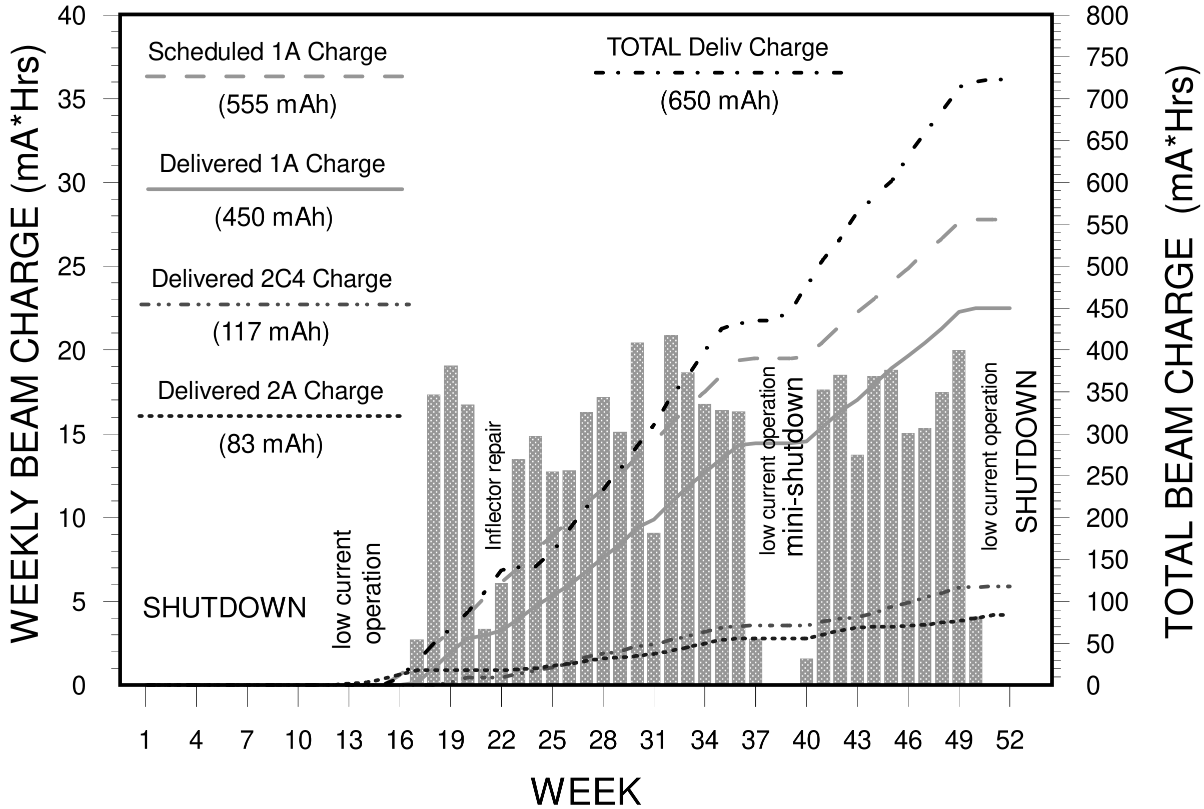


Fig. 228. Beam delivery for 2003.

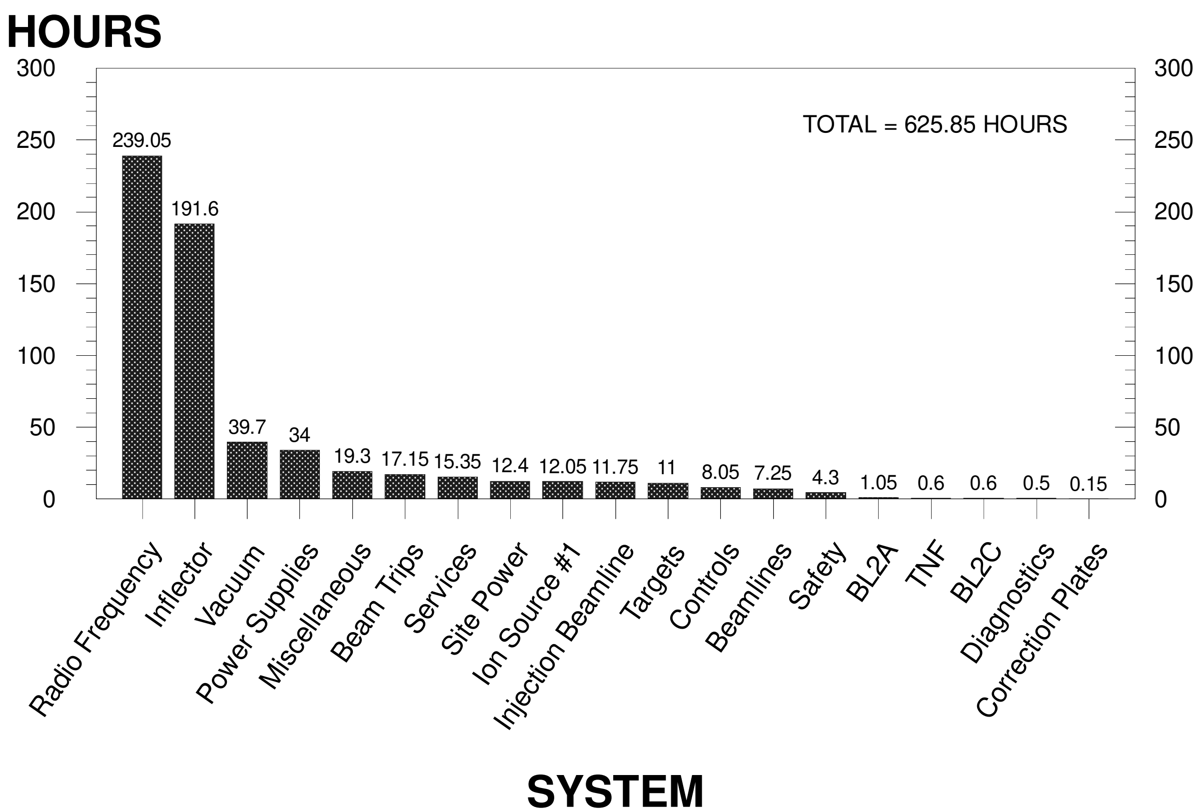


Fig. 229. Cyclotron downtime for 2003.

Table XXIII. Operational record for 2003.*

| | Scheduled hours | Actual hours |
|---|---|---|
| Cyclotron off: | | |
| Startup | 163.0 | 131.10 |
| Shutdown | 2081.0 | 2104.90 |
| Other | 0.0 | 0.00 |
| Cyclotron downtime | 0.0 | 625.85 |
| Overhead | 31.0 | 84.60 |
| Totals | 2858.5 | 3562.65 |
| Cyclotron on: | | |
| Development | 180.0 | 120.60 |
| Cyclotron tuning | 473.0 | 110.70 |
| Beam to experiments | 5224.5 | 4945.05 |
| Totals | 5877.5 | 5176.35 |
| Actual/Scheduled = 5176.35/ 5877.5 = 88.1% availability | | |
| Beam to experiments: | | |
| 1A Production | 4167.5 | 3677.60 |
| 1A Development/tuning | 127.0 | 40.20 |
| 1A Down/open/no user | 549.0 | 836.80 |
| 1B Production | 323.0 | 74.40 |
| 1B Development/tuning | 0.0 | 8.25 |
| 1B Down/open/no user | 58.0 | 307.80 |
| Total 1A+1B production | 4490.5 | 3752.00 |
| 2A Production | 4627.5 | 2963.95 |
| 2A Development/tuning | 0.0 | 25.95 |
| 2A Down/open/no user | 597.0 | 1955.15 |
| 2C1 Production/tests | 1247.0 | 201.50 |
| 2C1 Development/tuning | 0.0 | 3.20 |
| 2C1 Down/open/no user | 899.0 | 1499.40 |
| 2C4 Production/tests | 3055.5 | 2731.50 |
| 2C4 Development/tuning | 0.0 | 21.35 |
| 2C4 Down/open/no user | 23.0 | 488.10 |
| 1A Beam charge ($\mu$Ah) | 555360.0 | 449495.00 |
| 2A Beam charge ($\mu$Ah) | 119300.0 | 83352.00 |
| 2C4 Beam charge ($\mu$Ah) | 143935.0 | 117379.00 |

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

Table XXIV. Beam to experiments for 2003.

| | | | Scheduled | | Delivered | |
|---|---|---|---|---|---|---|
| Experiment* | Channel | Schedule # | Hours | μAh | Hours | μAh |
| 614 | M13 | 103 | 2746.0 | 377785 | 2412.10 | 286410 |
| 614 | M13 | 104 | 1317.5 | 165435 | 1265.50 | 157937 |
| 744 | M9B | 103 | 677.0 | 94780 | 659.75 | 81933 |
| 768 | M15 | 103 | 150.0 | 21000 | 154.05 | 20862 |
| 782 | M15 | 103 | 101.0 | 14140 | 95.00 | 13007 |
| 782 | M15 | 104 | 148.5 | 19305 | 131.15 | 16741 |
| 791 | M20B | 103 | 127.0 | 17320 | 119.90 | 15966 |
| 842 | M9B | 104 | 254.0 | 33020 | 224.50 | 29269 |
| 843 | M20B | 103 | 150.0 | 21000 | 87.30 | 1918 |
| 843 | M20B | 104 | 81.0 | 10530 | 81.65 | 10538 |
| 844 | M15 | 103 | 277.0 | 38780 | 273.00 | 24018 |
| 847 | M15 | 103 | 150.0 | 21000 | 87.30 | 11918 |
| 847 | M20B | 103 | 150.0 | 21000 | 154.05 | 20862 |
| 851 | M20B | 104 | 127.0 | 16510 | 129.85 | 17412 |
| 875 | M20B | 103 | 423.0 | 56480 | 355.45 | 40958 |
| 877 | M9B | 103 | 150.0 | 19270 | 108.10 | 13563 |
| 877 | M9B | 104 | 150.0 | 19500 | 150.75 | 19198 |
| 883 | M20B | 103 | 150.0 | 21000 | 137.60 | 16933 |
| 883 | M20B | 104 | 117.0 | 15210 | 113.45 | 14808 |
| 895 | M15 | 103 | 150.0 | 21000 | 141.60 | 18653 |
| 898 | M20B | 104 | 148.5 | 19305 | 131.15 | 16741 |
| 912 | M20B | 103 | 127.0 | 17780 | 116.05 | 15116 |
| 915 | M15 | 104 | 94.0 | 6380 | 91.80 | 6411 |
| 916 | M15 | 103 | 150.0 | 19270 | 108.10 | 13563 |
| 917 | M20B | 103 | 273.0 | 38220 | 269.65 | 36711 |
| 917 | M20B | 104 | 127.0 | 16510 | 98.75 | 13413 |
| 931 | M15 | 104 | 127.0 | 16510 | 125.75 | 15856 |
| 932 | M9B | 103 | 127.0 | 17320 | 119.90 | 15966 |
| 938 | M15 | 103 | 277.0 | 38780 | 274.05 | 30106 |
| 938 | M15 | 104 | 127.0 | 16510 | 129.85 | 17412 |
| 939 | M20B | 103 | 265.0 | 33645 | 237.25 | 29837 |
| 939 | M20B | 104 | 244.0 | 25880 | 239.35 | 25142 |
| 941 | M20B | 103 | 127.0 | 17780 | 119.55 | 14850 |
| 942 | M15 | 104 | 117.0 | 15210 | 113.45 | 14808 |
| 942 | M20B | 103 | 127.0 | 17780 | 135.75 | 10822 |
| 943 | M9B | 103 | 681.0 | 95340 | 550.45 | 60138 |
| 944 | M15 | 103 | 150.0 | 21000 | 137.60 | 16933 |
| 944 | M20B | 104 | 150.0 | 21000 | 137.25 | 13196 |
| 949 | M9B | 103 | 127.0 | 16510 | 121.40 | 15540 |
| 945 | M20B | 103 | 150.0 | 21000 | 137.25 | 13196 |
| 949 | M9B | 103 | 115.0 | 14375 | 129.15 | 16274 |
| 949 | M9B | 104 | 127.0 | 16510 | 129.85 | 17412 |
| 950 | M15 | 103 | 250.0 | 35000 | 246.20 | 25332 |
| 951 | M15 | 103 | 127.0 | 17320 | 119.90 | 15966 |
| 953 | M20B | 103 | 254.0 | 35560 | 122.25 | 11976 |
| 953 | M15 | 104 | 150.0 | 19500 | 155.05 | 19827 |
| 958 | M15 | 103 | 273.0 | 36980 | 283.55 | 36970 |
| 959 | M15 | 103 | 115.0 | 14375 | 129.15 | 16274 |

Table XXIV (cont'd.)

| | | | Scheduled | | Delivered | |
|---|---|---|---|---|---|---|
| Experiment* | Channel | Schedule # | Hours | $\mu$Ah | Hours | $\mu$Ah |
| 960 | M15 | 103 | 127.0 | 16510 | 75.90 | 4468 |
| 960 | M15 | 104 | 150.0 | 19500 | 147.55 | 18731 |
| 962 | M20B | 103 | 150.0 | 21000 | 154.50 | 15256 |
| 963 | M15 | 103 | 127.0 | 17780 | 131.90 | 17996 |
| 963 | M20B | 103 | 273.0 | 38220 | 265.55 | 32009 |
| 965 | M15 | 103 | 127.0 | 17780 | 116.05 | 15116 |
| 965 | M15 | 104 | 127.0 | 16510 | 98.75 | 13413 |
| 968 | M9B | 104 | 148.5 | 19305 | 131.15 | 16741 |
| 969 | M15 | 103 | 172.0 | 24080 | 42.75 | 5708 |
| 969 | M20B | 104 | 150.0 | 19500 | 155.05 | 19827 |
| 974 | M15 | 104 | 150.0 | 19500 | 150.75 | 19198 |
| 975 | M15 | 104 | 69.0 | 8970 | 63.00 | 7922 |
| 977 | M15 | 104 | 58.0 | 7540 | 58.40 | 7618 |
| 978 | M20B | 104 | 69.0 | 8970 | 69.10 | 8660 |
| 981 | M20B | 104 | 127.0 | 16510 | 125.75 | 15856 |
| ISAC† | 2A | both | 4627.5 | 119300 | 2963.95 | 83352 |
| ISOPROD | 2C4 | both | 3055.5 | 143935 | 2731.50 | 117379 |
| PIF | 1B | both | 323.0 | 0 | 74.40 | 0 |
| PIF | 2C1 | both | 815.0 | 0 | 184.70 | 0 |
| P.THERAPY | 2C1 | both | 432.0 | 0 | 16.80 | 0 |

* See Appendix D for experiment title and spokesman.

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

As Fig. 228 shows, the total beam charge delivered to meson hall experiments along BL1A was 450 mAh or 81% of the scheduled amount. This relatively poor outcome is a result of running with an average delivered current to beam line 1A of only 122 $\mu$A (for reasons described later) at the above reduced availability (88%). In addition to the BL1A charge, there were 117 mAh delivered at 85 MeV to rubidium targets in the solid target facility (STF) in beam line 2C4 for the production of radiopharmaceutical generators, about the same as last year. There were another 83 mAh, 8% more than last year's record, delivered to the two target stations in BL2A for the production of radioactive ion beams (RIB) for experiments in ISAC. A total extracted current exceeding 210 $\mu$A was sometimes shared by the three proton lines although 200 $\mu$A was more normal for extended production periods.

The annual downtime of 626 hours (Fig. 229) was about 200 hours higher than average mainly due to problems with the inflector (191.6 hours or 30.6% of the total). RF downtime was similar to last year at 239 hours (38%). Vacuum and power supply problems were distant runners-up, accounting for 6% and 5% respectively. RF downtime arose from various faults but it is noteworthy that sparking, tamed considerably by software improvements late last year, played a relatively minor role at 20% of the total rf downtime or about 1 hour per week. The operational record and beam to experiments for the year are given in Tables XXIII and XXIV.

**Winter Shutdown**

For BL1A the winter shutdown was as long and involved as the previous year. Cyclotron work, however, was scheduled to finish a month earlier in order to deliver beam to PT, PIF and ISAC while activities in the meson hall continued. The main project there was the sorely needed replacement of the old and chronically leaking 1A triplet with a new one of a more serviceable design. This huge installation job began last year with the removal of interfering, defunct M8 front-end elements and involved rerouted services and custom shielding changes. Several crumbling shielding blocks in the area were also replaced and a number of water and vacuum leaks were repaired. These, as well as a plethora of more routine maintenance work, left no time and dose remaining to remove the M11 septum, so that job that was postponed a year.

In the vault, the cyclotron lid was cycled briefly in early January in order to remove the highly radioactive copper beam blockers prior to some jack maintenance work. The lid was up most of February for diagnostics, rf and engineering physics systems maintenance. Diagnostics tasks included work on the extraction probes, slits, and periscopes while engineering physics systems maintenance involved correction plate and thermocouple repairs. The long list of rf jobs included voltage probe maintenance, resonator bellows chore pad replacement, ground-arm measurements, unplanned resonator repairs, centre region inspections, and transmission line modifications. The Vacuum group installed four new tank ion gauges (for rf) as well as replaced the tank inner and outer vacuum seals, one of the higher dose jobs, with the aid of a team of volunteers. Vault work finished as scheduled several weeks ahead of meson hall work so that beam to other proton lines started a few weeks prior to BL1A startup. The extent and complexity of the meson hall work, much of it involving very high radiation fields, resulted in some higher than usual doses that contributed to a total shutdown dose of 186 mSv distributed among 123 workers.

**Beam Schedule 103**

The cyclotron was started up in mid-March to deliver beam to PT and then PIF (both via BL2C1) before being joined by BL2A2 for delivery to ISAC toward the end of that month. A moderate amount of rf sparking as the high voltage settled, and some combiner and transmission line problems slowed things down a little at the start. Some undedicated time in the schedule offered the opportunity for a few days of maintenance in early April to improve rf stability, do a B20 defrost, fix a main magnet power supply leak, and fix monitor 2CVM1. When BL1A started in mid-April the downstream spills were unacceptably high. After some analysis it was realized that the rewiring done for the new, rotated quadrupole triplet had changed the direction of its associated asymmetric steering to a state incompatible with the sense of the quadrupoles. The triplet was uncovered and the problem corrected although some additional steering power was required to achieve the traditional beam tune. BL1A was running close to full intensity by the end of April, about ten days later than scheduled.

Although the startup period was beset with the above problems, the lower cyclotron availability (87%) for this beam schedule was due primarily to problems experienced with the inflector during the last half of May. The primary fault turned out to be a darkened insulator which, at the normal operating voltage, caused excessive current draw on the positive power supply of the inflector. An initial attempt to run asymmetrically helped somewhat for a while, but it was soon decided that the lid needed to be raised to fix the problem. The actual repairs were completed quickly with a reasonably low dose (6.5 mSv) but the overhead resulted in a turnaround time of nearly a week. There was also another difficulty with the inflector that resulted in numerous exit skimmer trips and forced a temporary reduction in beam currents. The quality of the injected beam seems to have been a contributing factor but a bad cable or connection was the chief suspect. All told, the inflector was responsible for 190 hours or 40% of the total downtime for this schedule with the rf a reasonably close second at 148 hours or 31%. Currents were reduced somewhat during recovery from the inflector failure and subsequent 1AT2 target problems (described below).

Normal high current operation was under way by mid-July when a small tank vacuum leak developed at the water-cooled probe (WCP). The vertical flag was used instead to define the cyclotron off. The WCP was disabled in the OUT position and a vacuum pump attached to reduce the size of the leak. Because there was some suggestion that the rf booster was involved in initiating the leak (it turned out not to be), it was left off for the remainder of the schedule. The lack of the booster and the somewhat increased tank pressure resulted in slightly higher tank spills than normal although the cyclotron transmission remained well above 60%.

Apart from the high-current proton lines, which are discussed below, there was beam delivery to BL2C1 for both PT (four sessions, six patients) and PIF (four sessions totalling about twelve days). PIF also ran in BL1B for five days at the end of the beam production schedule (at 500, 350 and 200 MeV) as part of a two week, lower-current run scheduled to provide some cooldown prior to the fall shutdown. (BL2C1 currents were less than 5 nA, BL1B currents less than 1 nA.)

BL1A ran for 2412 hours or 85% of its scheduled time, receiving 289 mAh or 74% of its scheduled charge. The initial tuning problems associated with the triplet replacement job were finally sorted out and normal operation resumed ten days late. The current was as high as 140 $\mu$A before the inflector problems but afterward was kept around 100 $\mu$A largely because of problems at 1AT2. There, one of the targets developed a very small water leak in early June, apparently (on subsequent examination) because the beam was too low on the target. Other targets were deliberately positioned 3–4 mm low with reasonable beam-spot sizes and centring when yet another leak developed. This time the age of the target was suspected to be the cause. Once the target problems were identified, including difficulties with the target motor control system, the current was raised toward 130 $\mu$A. Then there was a large water leak at an insulator on a quadrupole magnet (1AQ15) that was fixed during an emergency three-day repair in August. This held until the last few days of BL1A operation when the triplet leak again started a climb to 12 l/hr before beam was shut off.

The meson channels were fully subscribed with the following exceptions. M9 saw limited use because its first quadrupole developed an open circuit in July due to a bad power connection. Its repair would have to wait for the fall shutdown. M11 remained unusable as a meson channel because of the broken septum; it did, however, see limited use as a source of electrons for detector tests.

BL2A ran for 2050 hours or only 60% of its scheduled time, receiving 55 mAh of charge. A beam current of up to 50 $\mu$A was delivered to the first ITW target although one of 30 $\mu$A was more common on subsequent targets. Beam was delivered for the first time down BL2A3 to the east target station (ITE) of ISAC. Little charge was accumulated during the initial scheduled run because of uncertainties about the performance of the ECR source being tested there. After switching back to ITW, production was fairly steady until the last three weeks of the schedule when a required target change was held up because of a vacuum problem with the replacement target assembly. There was a reduction in the number of spurious BL2A beamspill monitor trips after a change to a more fully-intercepting extraction foil that was closely radially shadowed by the BL1 extraction foil.

BL2C4 ran for 1699 hours or 81% of its scheduled time, receiving 71 mAh or 70% of its scheduled charge. There was little BL2C4 downtime *per se*; rather the line remained idle during some of the lower injected current periods (BL1A startup problems, inflector troubles, BL2A-only times) until a reasonable running split could be obtained. The restored front-end wire monitor 2CVM1 was used to correct the tune before the first production run – the previous beam tune was found to be steered far to the right, accounting for the melted indium seal last year. Beam delivery was generally good but during the last month of operation there was difficulty in maintaining a tune that kept the collimator temperature from climbing toward warning levels. It was thought that the extraction foils were to blame, but when they were examined during shutdown only one of the three foils appeared obviously worn out. The other two had fine separations visible between the whiskers but otherwise appeared normal. If this was caused by a combination of a slightly broadened foil together with a decreased beam aperture due to the kink in the beam line, it was suggested that the problem might be alleviated by using a somewhat narrower (0.200 in.) foil.

**Fall Mini-Shutdown**

Because of extended maintenance work, the fall mini-shutdown had a very ambitious schedule. It was decided to raise the lid to replace the WCP and exchange the BL2C extraction foils after an initial assessment of turnover time and dose cost deemed it reasonable. The shutdown was advanced several days by chopping the last bit of the ISAC schedule, which was somewhat moot because of target problems anyway. This left PIF as sole user for the last nine days after high current ended and allowed for some significant cooldown time, enough to reduce the residual cyclotron fields (with the south-side shadow shields in place) to tolerable levels, about 50% higher than last spring. This allowed the WCP replacement and the BL2C4 foil exchange to proceed. Meanwhile, meson hall shutdown work was able to get under way a few days earlier than vault work because BL1A became accessible as soon as PIF was finished with BL1B. The main jobs in the meson hall were to repair water leaks at the BL1A triplet and M9Q5, replace the electrical connections at M9Q1, and repair a small air leak at the M20 beam blocker. The final total shutdown dose for the fall mini-shutdown was 28 mSv distributed among 47 workers.

**Beam Schedule 104**

Cyclotron availability for this quarter improved to 91%, slightly better than the long term average of 90%. The leaking water-cooled probe was replaced in the fall shutdown with the result that tank spills were a little lower with the return to normal tank vacuum conditions. The rf booster was also able to be turned back on to help keep the cyclotron transmission around 65%. Total downtime was 147 hours of which 86 hours were caused by rf system failures (mostly HVPS and PA problems) while another 14 hours were caused by power supply failures. In addition to the high-current proton lines discussed below, there was beam delivery to BL2C1 for both proton therapy (one session, three patients) and proton irradiation facility experiments (two sessions, about a week each). PIF also ran in BL1B for a week at the end of the beam production schedule and there was some use of the neutron irradiation facility at TNF while BL1A was operating.

BL1A ran for 1266 hours or 96% of its scheduled time, receiving 160 mAh or 97% of its scheduled charge for an average current of 130 $\mu$A. The current was capable of going higher (and indeed did during a high current development shift) but was not pushed as there was no overwhelming demand. Triplet water-leak repairs in the fall shutdown held tight with no new ones arising there. The M9 channel saw some use after repairs were made to the power connections of its first quadrupole, but did suffer a couple of large water leaks in some downstream elements. The M20Q1-1AT2 vacuum leak was a constant concern as it wandered up and down depending, apparently, on the flange temperature (beam heating versus CuALCW cooling). There were suggestions of another leak in the 1AT2 volume that needs to be investigated during the M20Q1 seal repair in the 2004 winter shutdown. There were no more target problems at 1AT2 as the target was kept 3–4 mm "low" all of the time. However, there was a two-week period of elevated BL1A tunnel air activity that seemed to be caused by a small CuALCW system water leak at the 1AT2 water-package plumbing that seeped through the shielding blocks into the BL1A tunnel. The readings often hovered around the warning level but eventually settled back to normal values (about half of warning) after the leak was repaired.

BL2A ran for 914 hours or only 74% of its scheduled time and received 28 mAh for an average current of around 30 $\mu$A. Things went fairly well when BL2A was on the air but the beam was turned off for two five-day stretches to repair target vacuum leaks caused by HV sparking. That accounted for virtually all of the downtime on this beam line. The schedule finished as the year began with BL2A the sole high-current user while PIF ran nanoamperes in parallel.

BL2C4 ran for 1032 hours or 106% of its scheduled time, receiving 46 mAh or 111% of its scheduled charge. The main reason for the high percentages was the turnover of unused BL2C1 (PT) time to BL2C4. New foils from the mini-shutdown helped achieve an average extracted current of 45 $\mu$A without collimator heating problems. A 0.200 in. foil tested at the end of the year looked promising for future operation as it helped maintain even cooler (10° less) collimator temperatures than obtained with the new 0.250 in. foils. There is a plan to straighten out the STF in the 2004 winter shutdown so as, hopefully, to dispense with the corrective steering magnet introduced two years ago. A dose study estimates the whole job to cost around 15 mSv.

Most cyclotron systems were turned off following a two day development shift over the weekend before Christmas. Before the end of the year about six dozen large BL1A shielding blocks were removed to temporary storage near the machine shop in preparation for the next round of BL1A and meson channel refurbishments and repair. These include repair of the 1AT2 area vacuum leaks (particularly M20Q1), replacement of the 1AM10 crumbling block, and the possible removal of the M11 septum magnet. In the vault there is the STF realignment work. The cyclotron lid is being raised for the usual tank MRO work on correction plates, probes, thermocouples, resonators, and inflector.

Apart from the many tasks associated with beam delivery, various operators were again very involved with fire alarm system improvements, card access system installation and implementation, AUTOCAD drawings, training, equipment repair, computer and console upgrades and maintenance, beam transport modelling, coordination of software improvements, etc., as well as actively helping out with many shutdown jobs.

## BEAM DEVELOPMENT

### Cyclotron Beam Development

High current beam development work, aimed at increasing TRIUMF's extracted current from the present level of $\approx$200 $\mu$A to $\approx$300 $\mu$A continued in 2003. The higher currents will be required in 2007 when ISAC is scheduled to start operating with 100 $\mu$A and $\approx$400 $\mu$A which will be required in 2009 if TRIUMF goes ahead with its plan to build an additional independent 100 $\mu$A target facility for ISAC.

Two high current milestones were reached. In July a record setting peak current of 420 $\mu$A was extracted at 25% duty cycle with 63% cyclotron transmission. In October, as shown in Fig. 230, a peak current of 370 $\mu$A at 50% duty cycle was extracted for $\approx$3 hours with good stability and with a cyclotron transmission greater than 62%.

Each of TRIUMF's centre region quadrants contains electrostatic correction plates for vertical steering. Figure 231 shows how each upper and lower set of plates is mounted on a tray fastened to the dees. Vertical beam scrapers have been attached to the leading edges of the trays. As shown in Fig. 232, the thermocouples, mounted on the upstream side of the

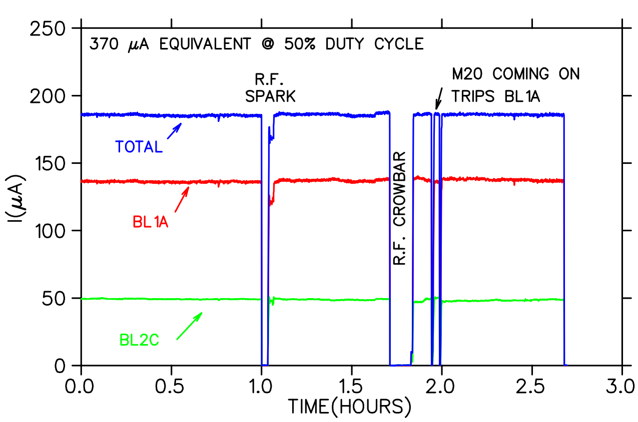


Fig. 230. 380 $\mu$A peak current at 50% duty cycle.

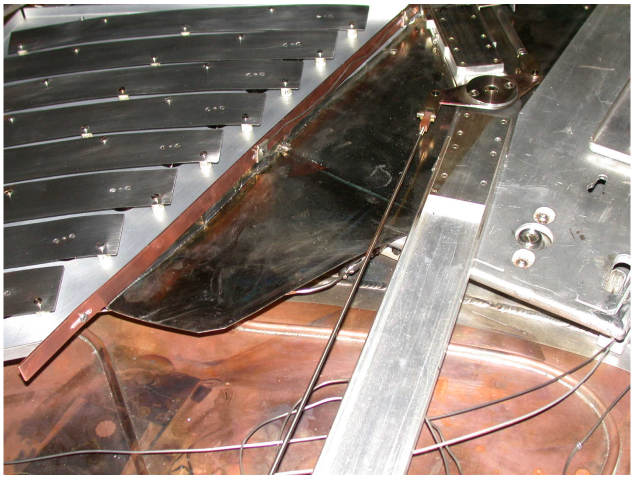

Fig. 231. Quadrant 4 lower correction plates showing the beam scraper and thermocouples.

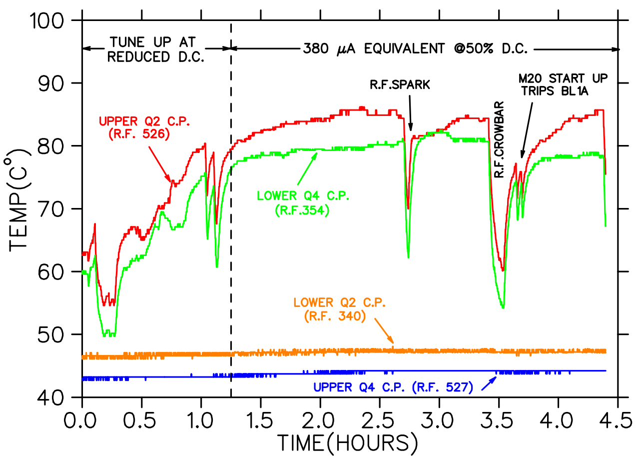


Fig. 232. Quadrant 2 and 4 correction plate thermocouple readings versus time with 380 $\mu$A peak current at 50% duty cycle.

scrapers, show that the beam heats up the upper scraper in quadrant 4 and the lower scraper in quadrant 2. The other scrapers remain cool. Some beam development time was devoted to trying to understand this phenomenon, and it is now thought to be caused by misalignments of the trays. These will be corrected in 2004. In addition, the thermocouples will be moved from the upstream to the downstream side of the scrapers to make sure that they are measuring the scrapers' temperature and not just responding to direct hits by the stray beam. Hopefully these measures will solve the problem.

Two new devices were installed during 2003 to assist with high current development. A pair of movable energy-limiting slits were installed in the dispersive plane at the centre of the ISIS vertical bend. Within the cyclotron a high resolution head with five vertical fingers was installed on low energy probe LE1. Both were tested successfully.

## 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 to further model its optics better. An experiment with beam was made to clarify the polarities of some quadrupoles in the downstream portion of the vertical section where the wiring is not conveniently accessible. It was found that there are three consecutive quadrupoles with the same polarity. This is an error; fixing it should result in a better match to the cyclotron.

An experiment was performed to determine the initial beam parameters (radius, divergence and emittance) at the exit of the 300 kV acceleration tube. The initial beam should be axially symmetric. Although this was not the case, the reasons are unknown.

The horizontal and vertical profiles were measured with a wire scanner for a number of different settings of the upstream quadrupole strength at beam currents of 400 and 660 $\mu$A. The rms sizes were used in the beam optics calculations with TRANSOPTR to fit the initial beam parameters.

Using these initial beam parameters and the actual operational voltage settings of all the quadrupoles, we calculated the ISIS beam envelopes for a current of 520 $\mu$A. The result is shown in Fig. 233, where the measured beam sizes are plotted as well for comparison. One can see that in the horizontal section the calculated beam envelopes are in good agreement with the measured beam sizes and it is well matched, whereas the vertical section is obviously mismatched. This unmatched beam may be responsible for the observed

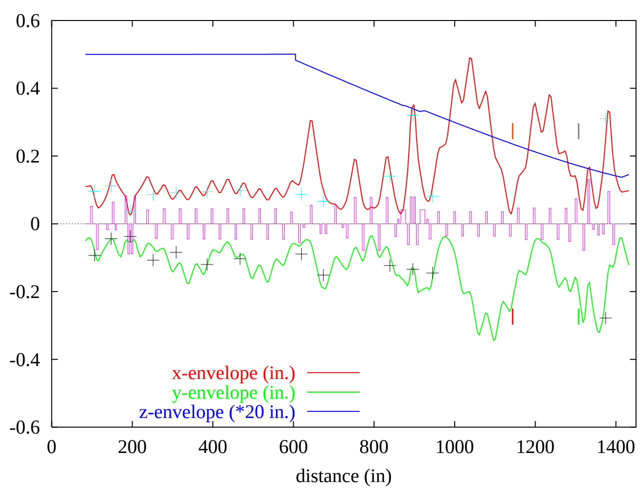


Fig. 233. Calculated beam envelopes in ISIS using the initial beam parameters inferred from a fit of rms sizes versus quadrupole setting, and the actual operational voltage settings of all the quads. The plus marks represent the measured beam sizes. The beam current is 520 $\mu$A. The vertical bars occurring at 1144 in. and 1308 in. represent two collimators.

spills often occurring in the vertical section, although the beam size still stays within the aperture of the two collimators in this section.

### BL1 Beam Dynamics Development

The operational tune of beam line 1A is known to differ from the theoretical tune by ∼10%. Experiments were therefore performed to determine the effective length of the quadrupoles. The main result is that the effective length is 10–15% less than the length calculated from the field map. The discrepancy is under investigation.

## RADIO FREQUENCY SYSTEMS

### RF Operation

The total rf downtime for the year was 234 hours. Although at the level of the previous year, the contribution of different factors has dramatically changed; for example, the downtime due to sparking was reduced to 48 hours from about 170. This was achieved with two major activities: an extensive program of resonator tuning using a new ground-arm-tip control system that was installed at the end of 2002, and an upgrade of the rf control system in which the timing sequence for spark recovery was changed to allow a fast recovery of the system following a spark.

A detailed weekly downtime chart is shown in Fig. 234. Bars on the histogram represent the accumulated number of hours over a one week period that were lost while the system recovered from a specific failure. The failures are grouped into four categories: sparks, high voltage power supply (HVPS) crowbars, rf self-excited (out of driven (OOD)) mode, and other, which represents unique hardware failures. It is obvious that the largest part of the downtime (∼62%) was attributed to unpredictable failures of major hardware (the Other category). Among these was the failure of a resistor in the 250 kW waster. This caused heavy sparking in the transmission line and substantial damage to it (see Fig. 235). On another occasion, damage to the transmission line was triggered by parasitic-mode excitations in the rf combiner. Both failures demonstrated a deficiency in protection of the system against a high standing wave ratio (VSWR) in the transmission line. Interlock circuitry is being developed that triggers rf drive cutoff in the case of high VSWR.

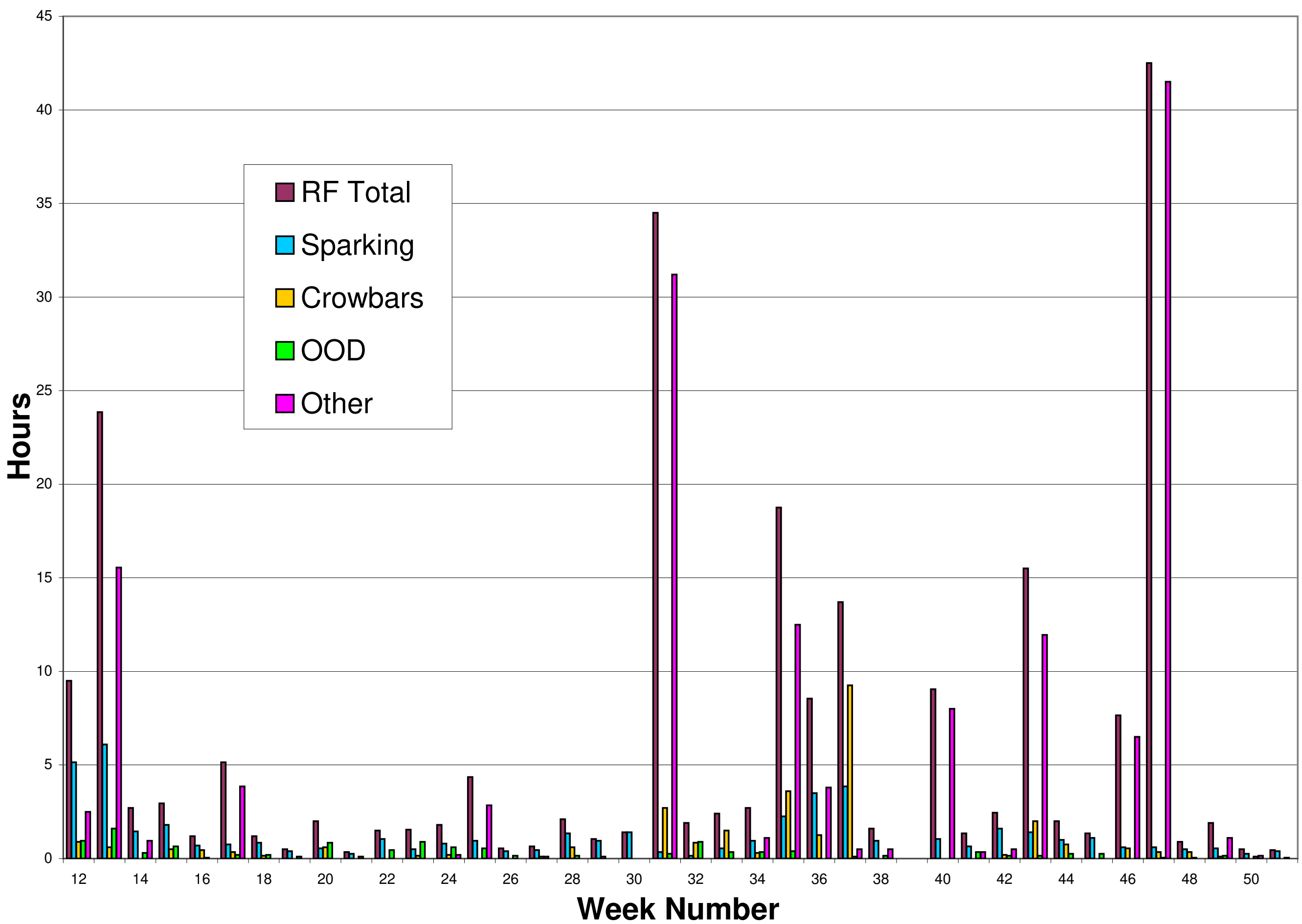


Fig. 234. 2003 rf system downtime.

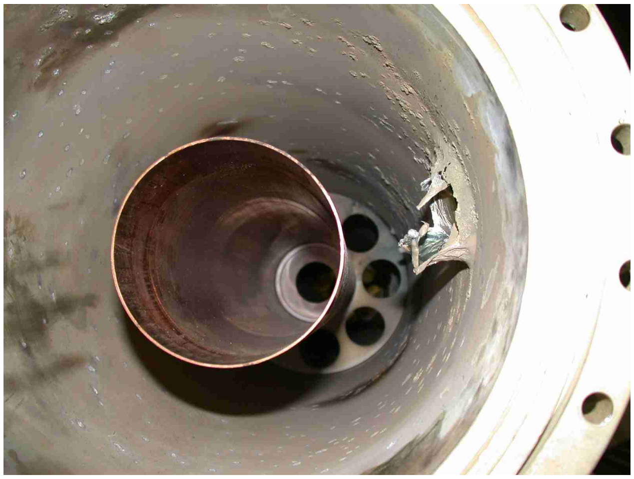

Fig. 235. Spark-damaged 9 in. transmission line.

Another series of failures was associated with HVPS water leaks. HVPS crowbars caused pressure bursts in the cooling line of the high power resistors which, in turn, caused subsequent damage to the plastic hosing. One of the floods caused damage to electronic circuitry in the HVPS. An improved cooling circuit was designed and is to be implemented next shutdown.

Over the year, two of the 4CW250000 power tubes failed. Their replacement and conditioning caused about 25 hours of downtime. While troubleshooting these failures, it was found that the tube protection circuit associated with the crowbar firing schematics had a few deficiencies in its design. Thus when running power amplifier (PA) number 3 without tube protection a screen power supply, a tube cathode shunt, and some crowbar firing-circuit components were burnt. A new approach to the crowbar firing circuitry is being developed to improve the reliability of the system.

During the winter shutdown an extensive program was carried out to improve reading of the cyclotron voltage probes. There are 64 probes installed at every resonator ground-arm panel (excluding resonators number 1 and 10). Six broken voltage probes were repaired and the readings of all 64 probes were recalibrated. This involved measurements of the capacitance of the pickups and the positions of the resonators ground-arm-tips (GAT) and hot-arm tips (HAT), fixing the 20 Db attenuators, and calibration of the adjustable rectifiers (64 channels). GAT positions were measured directly in the rf gap using a special tool (see Fig. 236). This operation was very delicate and associated with a personnel radiation exposure of 3.62 mSv for the ∼150 measurements. Apart from the distance calibration, we were able to identify a few spots of damage to the resonator panels caused by rf breakdowns (see Fig. 237) and parasitic rf currents across adjacent panel junctions. Problems were observed between resonators number 3 and 4 in quadrants 2 and 3. Eroded surfaces were polished and bent finger contacts were straightened to fix this problem.

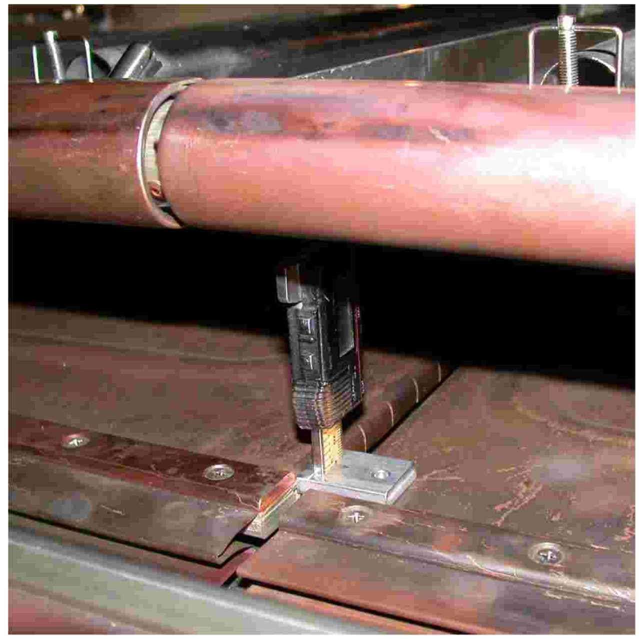

Fig. 236. Ground-arm-tip position measurement.

Fig. 237. UQ2 resonator number 3 spark damaged panel.

Other shutdown activities in the cyclotron tank included:

- maintenance cleaning and insulator replacement of the centre region correction plates in quadrants 2 and 4;
- relocation of the two centre region thermocouples RF516 and RF107;
- relocation of two thermocouples from LQ2 resonator 2 to LQ2 resonator 1 for monitoring the resonator strong-back temperature;
- installation of four new thermocouples on LQ1 resonator 1, LQ3 resonator 1, and LQ3 resonator 2 strong backs;

- assessment and repair (where possible) of failed thermocouples RF543, RF406, RF507, RF303, RF323, and RF345;
- 1U2, 2L2, 3U2 GAT manual adjustment;
- continuation of the program of the replacement of copper chore pads with the fibreglass ones for another 20 resonators in the upper octant numbers 1 and 2.

In addition, all four rf power amplifiers (PA) were carefully retuned. This resulted in an increase of the overall PA efficiency to ∼60% from ∼50%. A remote, PC control interface for a LECROY digital scope was developed that allows instant data logging. This helped us in the spark diagnostics and in the debugging of the new control system during its upgrade.

**RF Refurbishing**

A substantial effort was dedicated to the rf refurbishing program. In the winter shutdown, rf combiner number 2 was installed. It has operated reliably during the past year. RF combiner number 3 was tested to a power of ∼500 kW and is being prepared for installation in the forthcoming shutdown. A new layout of the rf room for the power combining was developed that incorporates a new 900 kW rf switch. This set-up will allow a fast switch to the 50 Ω dummy load for PA fine tune-up and troubleshooting.

An upgrade to a fast replaceable capacitor station number 2 was implemented in the matching section of the transmission line (see Fig. 238). A major modification of the cooling circuit for all the capacitor stations that will provide higher reliability and serviceability was included. New capacitor stations numbers 1 and 3 were prepared for installation during the next shutdown.

Fig. 238. New capacitor station number 2.

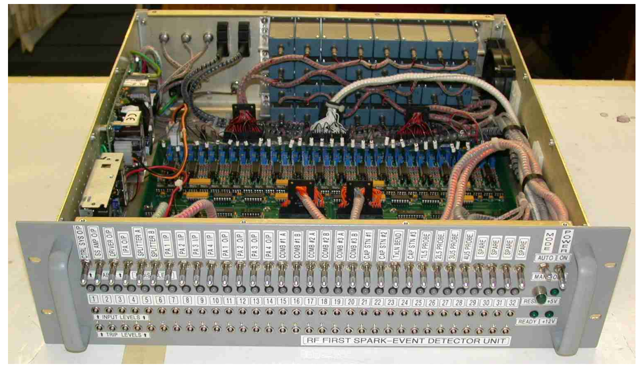


Fig. 239. First-event rf spark detector unit.

A multiplexing and diagnostic system was built that provides a first-event detection from as many as 24 voltage pickups when rf sparking occurs. It has proved to be an essential tool for troubleshooting the rf system. A view of the electronic module is shown in Fig. 239.

With the help of a student, one more automatic system was developed that switches rf signals from all of the transmission-line directional couplers (32 channels) to a Hewlett Packard vector voltmeter that is linked to the main control system via a GPIB interface. This device opens the possibility of monitoring the performance of the rf system; it also provides data logging. Another student was involved in simulations of the cyclotron electrodynamics using the HFSS program. A detailed three-dimensional model of the resonator structure was created. This work is ongoing and is aimed at obtaining a better understanding of how the rf modes are excited and, eventually, to suppress cyclotron sparking. A set of four additional ion gauges was installed in the cyclotron tank. These will allow local vacuum monitoring and are expected to be useful instruments in the troubleshooting of rf breakdown.

**RF Support**

The RF group was also dedicated to the following major ISAC projects (details are reported in the ISAC section):

- operation and maintenance of the ISAC Linacs;
- development of the RFQ HVPS soft-start circuit;
- upgrade of the DTL tuners and couplers;
- development of ISAC-I rf amplifier remote controls;
- set-up of the SCRF laboratory;
- design, test, and characterization of the SCRF cavities and accessories;
- development of a cryomodule alignment (WPM) system;
- development of an ISAC-II transfer-line rebuncher system.

## RADIO FREQUENCY CONTROLS

In conjunction with the RF group the RF Controls group has performed tests with the goal of reducing rf downtime in the main cyclotron. By ignoring some of the smaller sparks and using a more aggressive recovery of rf voltage on the larger ones, the rf downtime has been reduced significantly.

The rf control system of the booster has been upgraded using the VXI standard. This provides better performance in voltage and phase regulation as well as a configuration that is easy to upgrade. Better communications and data logging are also incorporated into the new system. The new system has been tested and is ready for commissioning.

The rf control system for the superconducting rf cavity has been tested with the fast tuner-feedback control. Amplitude and phase regulations have also been tested. A procedure for conditioning the superconducting cavity has been developed that allows a new cavity to be powered within minutes rather than the hours required previously.

## PROBES AND DIAGNOSTICS MECHANICAL MRO

In addition to normal MRO activities and ISAC work, more progress was made on the HE probe refurbishment, including some prototyping of the probehead mechanics. Several of the refurbished monitors were installed, and a number of other monitor improvements were made. This year, non-routine repairs were made on the following devices: water-cooled probe, SE periscope, and the ISAC IMS:DB0 slit and Faraday cup.

For more details, the Diagnostics group 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 are summarized in detail in the Diagnostics group meeting notes of April 11, 2003. The fall shutdown report is included in the meeting notes of October 10, 2003.

### Probes MRO

The extraction probes for beam lines 2A and 2C were removed for routine service in the winter shutdown. The low- and high-energy probes were inspected *in situ* and a new five-finger head was installed on LE1. The vertical drive screws were replaced on the SE periscope; square threaded screws were replaced with standard ACME threads. The SE periscope prism was replaced during the September shutdown when the lid was raised to replace the water-cooled probe, which had developed a vacuum leak in the retraction bellows during the summer operation. Dose limitations did not permit replacement of the NW periscope prism, which will be serviced in the 2004 winter shutdown. The PIP3 vertical drive screw was cleaned and relubricated during the September shutdown.

The ferrofluidic feedthroughs (f/t) for slits H3 and H4 and the vertical flag were inspected during the winter shutdown and found to be in good condition.

### Monitor MRO

All vault and standard beam line monitors were serviced during the shutdowns. Refurbished monitors were installed at 1BM5 and 1BM5.5. Monitors 1VM1, 1VM2, and 2CVM1 were modified to work without gas; they now use the new VME signal processing system. New signal and HT wiring was installed for 2CVM1. Monitor 2AM10 was re-aligned. A spare 1AM9 monitor was manufactured and lifting hardware was mounted on the box lid to facilitate handling during service.

### ISAC Diagnostics

The IMS:DB0 slits were changed during the winter shutdown and a slit drive misalignment was fixed. The Faraday cup was replaced during the September shutdown. New absolute encoders were commissioned. They should solve deficiencies in the reliability of software control of the slit and Faraday cup positions.

A number of foils were prepared and loaded on the MEBT stripper.

## CYCLOTRON VACUUM AND CRYOGENICS

The cyclotron vacuum/cryogenics system worked well during the year. There were a few problems with the B-20 cryogenerators. These were related to lead loss in the 20 K regenerator, leaks in the helium gas plumbing that had developed over the years due to vibration, the failure of a seal ring, and the malfunction of the lubrication delay device. There was little impact on beam production because of the timely and efficient work of the Vacuum group on cryogenerator repairs.

Cyclotron cryopumps were maintained and serviced regularly throughout the year. Leak checks of the turbo-pumps backing system were conducted during the winter shutdown. One leak was detected on an oil lubricant canister of the north turbo pump. The canister was replaced.

The inflector box was leak checked in May.

The main seals of the cyclotron were replaced during the winter shutdown. A decision to install new seals was based on noticeable vacuum changes in the tank that were correlated with the main cyclotron magnet tuning on or off.

Four new ion gauges were installed on the cyclotron. They were located in the four quadrants of the cyclotron tank so as to provide better vacuum mapping. These gauges are used by the rf group for diagnostic purposes.

A TRIUMF vacuum workshop took place on September 29. The main questions discussed were the status of the cyclotron vacuum controls and their possible refurbishment, the cyclotron vacuum status and possible improvements, the status of the ISAC vacuum, and the beam line vacuum.

The Vacuum group looks after maintenance and repair of the leak detectors. Because the older detectors require more and more attention with time, we are proceeding with a program to replace them. Four new leak detectors arrived on site this year.

**Beam Line Vacuum**

In preparation for the upgrade of BL1A to accept Varian turbo pumps and gauges, eleven cables were installed to connect the vacuum rack on the meson hall mezzanine to the 1A tunnel. Adapter pieces were designed and manufactured for the Varian turbo pumps, which will be installed in the BL1A tunnel. Turbo pump 11 was replaced after a failure. No spares are available for the old pumps. A leaking indium seal was replaced in the BL1A vault section, the controller for the Leybold turbo was repaired, and two controllers for interlocks summary and gate valves were refurbished and made ready as spares. A few leaks in the area of M20Q1 and triplet were diagnosed and scheduled for repair during the spring, 2004 shutdown.

A few leaks located on BL1B were fixed during the spring, 2003 shutdown. Since then the beam line vacuum has been good and is performing well.

Beam line 2A performed well during the year with an average vacuum level of $4.0\times10^{-7}$ torr. A few leaks developed in the vault section because of radiation damage and these were repaired by replacing O-rings. A roughing pump in the ISAC-I tunnel is showing signs of wear; it is scheduled to be replaced during the spring shutdown of 2004. One of the turbo pump controllers was refurbished and is back in operation.

The vacuum system of BL2C worked well throughout the year. The BL2C radiation-hard valve and its nitrogen supply have been repaired.

The vault section of BL4 is kept under high vacuum to protect the cyclotron vacuum. It performed well during the year. The backing pump for the turbo in this section was refurbished.

A few repairs in the 1AT2 area were made. An automatic venting for the 1AT2 blower has been installed. Additional remote helium lines with manifolds for remote helium leak checking were traced in 1AT2.

The turbo pump backing valve of the M9 channel has been repaired. Leak checks were done on the M13 beam line following repairs. A convectron gauge was installed on beam line M13; this gauge replaced an old thermocouple gauge.

**Vacuum and Cryogenics Support**

The Vacuum group has been involved in ISAC-I and ISAC-II in major projects related to SC Linac development, leak checking, the installation of vacuum equipment and mechanical assemblies, the design of cryogenic systems, the production of vacuum and cryogenic diagrams, testing the SC solenoid, etc.

**ISIS**

The CUSP ion source and injection line continued to operate well for the past year with only minor downtime that was caused by a failed control module. Although many ISIS personnel were involved in other TRIUMF projects, a few significant projects were undertaken during the past year.

Two new CUSP ion source bodies were built for use in the ISAC-I terminal, one of which was installed and commissioned in March. This source ran successfully through December of this year. The second source will replace the first source for commissioning in March, 2004.

In conjunction with the Controls group, the old wire scanner PC-based data acquisition and display system has been replaced with a new system that allows distributed remote control using X Windows. The save and restore scan functions allow on-line profile and statistical parameter comparisons. The system has been commissioned and has been particularly useful for beam development work.

Four new sets of motor driven variable aperture slits have been designed and built. Three of these sets are variable aperture in both the $x$- and $y$-directions; the fourth assembly is in the $y$-direction only. Two sets of slits will be installed into the first common periodic section of the ISIS beam line to define the emittance of the beam injected into the cyclotron. The third assembly will replace the existing 5:1 slits and will provide enhanced beam current control. These devices will be installed in the winter, 2004 shutdown. The fourth set of slits ($y$-direction only) was installed in the September shutdown and has been successfully commissioned. They reside between the two 45° vertical bend elements to limit the dispersive energy tails of the beam from reaching the cyclotron.

The inflector/deflector system experienced a series of failures during the last week of May and the first week of June and accounted for 175 hours of downtime. The inflector/deflector was serviced during the winter shutdown and ran well for 10 weeks at which time a high voltage insulator failed, requiring a lid-up intervention for repair. A high voltage cable breakdown as well as poor connections slowed the repair effort. After the insulator replacement and attachment of the spare high voltage cable the system ran well for the balance of the year.

Last year we reported the successful effort to produce a broad ISIS tune at the 300 $\mu$A equivalent extracted current level at better than 60% cyclotron transmission. This year we made significant progress toward demonstrating the feasibility of 400 $\mu$A operation. In July we achieved 412 $\mu$A equivalent extracted current at 25% duty cycle. Although both the ISIS and cyclotron transmissions were good, the tank spills inside the cyclotron were a factor of 4–5 higher compared with nominal operating parameters. Later in the year we achieved a 370 $\mu$A equivalent tune (185 $\mu$A extracted at 50% duty cycle) with nominal transmissions and tank spills that were only 25% higher than the extrapolated nominal operating value. This work is described in greater detail in the Beam Development section of this report.

## PRIMARY BEAM LINES

The year began with a three-month shutdown in which it was planned to replace the quadrupole triplet downstream of the 1AT2 target, repair water and vacuum leaks in the front-end of the M20 channel, and replace some of the crumbling concrete shielding blocks. In addition to these, normal MRO activities were undertaken.

The shutdown began with vacuum repairs upstream of the 1AT2 target. O-rings were replaced on the window valve upstream of the target, on monitor 1AM9, and in another valve downstream.

The highly active, iron bridge-blocks that required removal in order to gain access to the triplet and M20 areas were craned to a temporary bunker to expose the M20Q1/Q2 quadrupoles. The leak in M20Q1, previously measured to be ∼10 l/hr, was located in an insulator. After loose contamination had been vacuumed from the magnet, the insulator was replaced. The Hansen O-rings were found to be leaking and they were replaced. During this work a ground fault showed up on this quadrupole, remaining when the magnet was electrically isolated from its power supply. It is suspected that water damage to the insulation of the pyrotenax has occurred, leading to a chemical reaction that is causing a battery effect. Although this ground fault could not be repaired, the magnet can be run from an isolated supply as long as another fault does not occur.

After 20 years in a radiation environment the cooling hoses of M20Q2 had become rigid and brittle and had begun to leak. These too were replaced.

A vacuum leak was found on the top plate of a box between quadrupole M20Q2 and dipole M20B1. A new O-ring was installed. Leak checking showed that a small leak remained. It was so small that it was felt that the radiation dose required to diagnose it was not justified. All three magnets were powered and no trips occurred in an overnight run. The shielding blocks were reinstalled and MRO work concluded in the 1AT2 area.

The 1AS1 scraper downstream of the 1AQ14/15/16 triplet was removed, bagged, and placed in the bunker. The location and arrangement of the power supply terminations to the triplet were verified. With some difficulty (and with a bit of persuasion) the triplet was removed, bagged, and taken to the remote handling warm cell where alignment measurements could be taken.

Contamination of the beam line vacuum system was prevented by blanking it off at collimator B, which lies immediately upstream of the triplet, and keeping the beam line under vacuum. All services for the triplet that were attached to the trench blocks were removed. Work began to replace the crumbling blocks under the 1AT2 water package.

Earlier, the water lines and cabling had been disconnected from the water package and the package itself had been moved from its operational location. A number of shielding blocks were removed from the trench and the trench cleared of debris and all obsolete services. The two crumbling shielding blocks supporting the water package were removed. As more blocks were being removed the hand-stacked wall that separated the M8 treatment room and the beam line 1A blocks began to shift. Although this wall was in no immediate danger of collapsing, a plywood retaining wall was built to prevent any blocks from falling into the 1A tunnel. Removal of a crumbling tunnel block provided a view of other crumbling blocks. Some were in worse condition than that of the block removed; it was necessary to jackhammer one in order to remove it.

Following replacement of the crumbling blocks, preparation for the installation of the new triplet began. The 1AT2 water package was returned to its normal location and water, diagnostic, and electrical connections were restored. New cabling was added for the new flow meters and other diagnostic equipment that had been added to the assembly. The plywood retaining wall was removed and the beam line trench was cleared of debris and vacuumed. Two special wall blocks supporting the cooling lines to the triplet were installed and the water lines craned in. Flexible copper lines running the length of the water lines were installed. These lines will become part of a new remote leak-checking package. Assembly of the electrical buss bars was begun.

The new triplet was moved to the warm cell where its vacuum box was aligned to that of the old triplet.

Some modification of the triplet stand was required to meet the alignment requirements. Asymmetric steering was connected to the outer quadrupoles of the triplet. The triplet was lowered into the beam line trench, a temporary rubber seal was inserted at the joint between collimator B and the triplet, and the beam line was pumped down. The joint was found leak tight. Measurements were made to ensure the alignment of the electrical leads, the vacuum joint was broken, and the triplet was removed.

The scraper was moved to the warm cell where a substantial amount of indium was scraped from the flange that connects it to the triplet. Buss bars were installed in the trench, supports for the water lines were added, and the triplet was returned to the trench. New interlock cables and water connections were connected. In the new configuration the quadrupoles have individual copper and stainless cooling lines, flow meters, control valves, and upgraded fittings for back-flushing. A water test showed a small leak and attempts to resolder the connection failed. The leak finally was sealed successfully by applying epoxy.

The scraper was craned into position and indium rings were installed in all vacuum joints. A leak check of the system found it vacuum tight, although a small leak was observed in the connection between the 1AT2 target and the M20 channel. Bridge blocks were installed and all magnets were examined for water leaks; none were found. A test at full power for 1.5 hours showed no ground faults or temperature warnings. The next layer of shielding was added and a power test over the weekend showed no problems. The remaining shielding was added so that beam delivery could begin.

Shortly after beam delivery began it was found that an error had been made in the wiring of the asymmetric steering of the triplet. The triplet area was opened again and the steering problem corrected with little loss of beam time.

In addition to the above, the Beam Lines group was involved in servicing the active water filter systems, repairing the M9B solenoid, upgrading the beam blocker and diagnostics for the TWIST experiment, and repairing vacuum leaks in their area.

In early July the first quadrupole of the M9 channel, M9Q1, had developed an open circuit that rendered the channel inoperable. Inspection at that time found that the power connections from the magnet power supply had melted. It was planned to replace the six connections to M9Q1 and, if necessary, the four connections to M9Q2 in the September shutdown.

In early August a water leak was detected in the centre quadrupole of the new triplet. The area was again opened and the insulator replaced. It was noted that two other insulators had small leaks. Because no insulators were available they were not replaced. By early September the leak rate had increased to $\sim$12 l/hr. The area was opened again during the September shutdown. The two damaged insulators were found to be leaking badly. All eight insulators on the supply side of 1AQ15 were replaced with insulators that had been made in the machine shop. A similar repair was made to an insulator on 1AQ14. No leaks were observed when the water supply was turned on.

Inspection of the M9 channel in September prompted the decision to replace all power connections to these quadrupoles. Cabling was replaced and an electrical continuity check ensured that each connection was isolated from the others and from the service stand. O-rings in the Hansen connectors were replaced. Ten new power cables were prepared and positioned remotely. Shielding was replaced and the vacuum system restarted. A substantial leak was found and isolated to a feed-through for a convection gauge. This was repaired *in situ*; no other vacuum leaks were found. All work was completed as scheduled before the shutdown.

The Beam Lines group was also involved in assessing the upgrade of the M13 beam-blocker. A new window valve assembly was installed at the downstream end of the M20 separator and a new booster pump was installed in the triplet cooling system.

In non-shutdown activities throughout the year the Beam Lines group replaced the hosing of the 1VQ4/5/6 quadrupoles and repaired water leaks in 4VQ1 and vacuum leaks at 2CQ4. A flow switch was installed on a steering magnet on beam line 2C4, leaking fittings repaired on 1AQ8, and problems were sorted out with interlock wiring on M9B1 and M13Q4. A gate valve was installed in M13, hosing was replaced on quadrupoles M9BQ9/10/11, and water leaks repaired on M20BQ11.

In addition to ongoing support of experimenters for TWIST, DRAGON, TUDA, HEBT, and $\beta$NMR, the Beam Lines group was involved in alignment measurements of the triplet in the hot cell, cyclotron probe *in situ* measurements, and ISAC-II beam line/floor measurements. They also took part in the measurements of the sag of the roof beams in the cyclotron vault, total station reliability and limitations investigations, and MRO of existing survey devices and equipment.

The majority of the work during these shutdowns was done by members of the Beam Lines and Remote Handling groups. Because of their dedication the work was completed on schedule despite the many unforeseen problems that were encountered.

### Beam Line 2C

The production of the radioisotope $^{82}$Sr in the solid target facility (STF) on 2C4 continued to be the major user of 2C beam time. Operating time was increased from 149 days in 2002 to 170 days in 2003. The beam line ran very well on limited support with no interruptions due to beam line or target failures. The dose was decreased slightly from 123.35 mAh with a yield of 45.80 Ci in 2002, to 116.1 mAh with a yield of 41.66 Ci in 2003. Eight natural rubidium targets were irradiated in 2003, the same number as in 2002. However, to meet isotope demands, all of the 2003 targets were processed with better optimization of the dose and target processing.

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. Because the foils were splitting after extended operation, different assembly techniques were tested during isotope production. Unfortunately, positive results were not achieved. An emergency cyclotron lid-up in September allowed the Diagnostics group to load another set of foils. A 0.2 in. wide foil was tested for 7820 $\mu$Ah of isotope production at a beam current of 50 $\mu$A. The beam spot was approximately 10% smaller than that of the wider foil, making beam tuning much less sensitive to the beam halo. No damage was observed on the rubidium target window. Operation in 2000 with a 0.1 in. wide foil had burnt a small hole in the target window because of a higher beam density. The test of 0.2 in. wide foils will continue to higher currents in 2004.

The Diagnostics group rebuilt the profile monitor, 2CMWIR01, and repaired the actuator of the blade scanner monitor, 2CSWM04, in the 2003 shutdown. The operating diagnostics facilitated the correction of a chronic misalignment problem at the front end of the beam line. The beam was routinely too close to the vacuum pipe wall and it destroyed the O-ring upstream of 2CQ1 in December.

Considerable time was spent preparing for correction of the solid target facility (STF) misalignment in 2C4 and repair of the STF limit switches in the 2004 shutdown. Two alignment jigs that can be used remotely were designed and built. Consideration of an upgrade of the STF to increase isotope production will go ahead in the 2004 shutdown.

There were 35 days scheduled for proton therapy on 2C1 and 40 days scheduled in the proton irradiation facility (PIF) on 2C1.

## PROMPT RADIATION HAZARD

### Safety-Critical Devices

In response to questions from the Canadian Nuclear Safety Commission, a review of prompt radiation at TRIUMF was initiated several years ago. A number of recommendations came out of that review. Work on those recommendations, and subsequent developments, has progressed well during the year.

Five pairs of safety-critical neutron and gamma monitors were installed around the proton hall. This completes the installation of monitors for the existing beam lines. In addition to these hardware changes, a series of operational procedures were drafted to describe the appropriate response to safety-critical monitor trips. The procedures require each trip event to be documented.

Eight safety-critical detector trips occurred during the year. A report, written for each event, included an estimate of the maximum radiation field outside of the shielding (at licensed beam current) had the beam not been tripped off and a record of whether or not that radiation field exceeded 50 mSv/h.

In response to another recommendation, the Safety Systems group convened a Conceptual Design Review for a redesigned beam trip/beam inhibit system. Proposals for both an interim and a final configuration were approved. An interim proposal will be implemented during the 2004 shutdown. This interim configuration will have three existing ISIS safety beam control devices terminating beam for all categories of safety trips (gamma, neutron, emergency, and access). The final proposal cannot be implemented until several ISIS electrostatic elements are re-engineered for use as safety beam control devices. This re-engineering is scheduled to be completed during the 2005 shutdown. When this work is completed the safety-critical gamma and neutron monitoring beam trip systems will be totally independent of each other. One set of three beam control devices will terminate beam for safety-critical gamma monitor trips and another set of three devices will terminate beam for safety-critical neutron monitor trips. The trip functionality of each set of safety beam control devices is tested weekly to demonstrate their reliability.

## CONTROLS

The Central Control System (CCS) ran well during 2003. Operation of the CCS remains reliable and requirements for cyclotron operation, developments, experimental use, and other users were fulfilled as needed. To meet this year's new requirements, functionality was added in numerous areas.

Despite being a good year, there were some problems. The loss of scheduled beam time because of CCS faults was recorded by the Operations group as 8.7 hours. This is up somewhat from previous years but it is still a minor contributor to overall cyclotron downtime. The faults that result in downtime continue to be largely caused by unpredictable hardware failures such as power supply problems. A new hardware diagnostic module has been developed and its deployment may help to detect some issues before downtime occurs.

The goals set for this year were mostly attained. These included such items as the completion of the new ISIS wire-scanner system controls, the rf spark (first event) detector system controls, the phaseout of the last VAX computer, the decommissioning of one of two DSSI disk systems, the implementation of a wireless infrastructure and its initial applications, and software upgrades. In addition, there were numerous changes made in areas where unforeseen requirements arose. The Controls group remains extremely busy meeting new requirements and maintaining a reliable system.

**CCS Facilities**

The ISIS wire scanner system was completed and commissioned during 2003. This set-up provides a much more flexible interface to ISIS wire scanners and the data they provide than did the previous system.

The wireless Ethernet infrastructure used by Controls has been expanded and reorganized to meet new needs. These changes have been made to support developments in the use of monitoring and control of cyclotron devices using wireless, handheld devices. Initially, wireless notebook computers were used but this has evolved to the use of Personal Digital Assistants (PDAs). PDAs are usually employed as a repository for phone numbers and to-do lists but new models now support Web browsers and X Window displays. The first application was a Web-based program that allows the Operations group to do their weekly testing of the safety-critical monitors. This new set-up shortens the time required for testing while it also reduces the staff needed for the testing. More developments in the next year should see PDAs being used as important diagnostic tools.

Support was added in the CCS for the new ISIS slits. Slits are important beam control devices but the old unit did not operate as desired. The new system is expected to be commissioned at the end of the 2004 shutdown.

A system for detecting low voltage in the rf system (often caused by sparks) has been developed and deployed. It has multiple voltage detectors and the capability to identify the first location to detect a voltage drop. This “first event” or spark detector is still being debugged, but the software and hardware to monitor the detector system and to display the data have been developed and commissioned for the CCS. Further work will be done in 2004 as the spark detector system is fine tuned.

Another project was started to support rf developments. This system is for multiplexing rf signals and comparing their amplitudes and phases using a vector voltmeter. Software and hardware developments commenced during the year and should be completed in 2004. This system will automate the recording of these values, which now is done manually. In addition, this system will provide the trending information that is currently unavailable.

A replacement for the aging X Window terminals is being pursued. The old system of VXT 2000 X Window terminals has run very well, providing good functionality while requiring very little software management. Approximately 50 of these terminals are in use. Unfortunately, because this equipment is more than 10 years old, it is slow compared to more modern hardware and it lacks certain functionalities. The hardware components are failing frequently due to age. A candidate set-up has been configured in hardware and the software is under development. It should support simple management, secure connections, and multi-headed displays. One or more new X Window display stations should be deployed in 2004.

Within the CCS infrastructure there were a number of hardware developments. The DSSI disk-storage system in the development cluster of computers has been phased out. During this process all of the disk files were moved to a new storage system. As part of the move, a reorganization and cleanup were done. The new set-up has a much better directory/file organization and its performance is significantly better. Although clearly worth the effort, phasing out the old system was a larger task than anticipated and took longer to complete. The same procedure has been started for the DSSI system of the Production Cluster, but there are fewer files and the organization is now fully determined. This task should be completed during 2004.

Another network switch was added, providing 24 more ports and reflecting the ever expanding need for network connections. Changes to the computers included memory enhancements and a swap of CPUs to provide a faster CPU for one of the production computers. Within the main console, the old 17 in. CRTs are being phased out and replaced by 18 in. LCD monitors. The LCD monitors provide a particular bonus because, unlike the CRTs, the fringe field of the main magnet does not adversely affect them.

Of the many other developments only two more will be cited here. The last of the VAX computers in the CCS was decommissioned. OpenVMS continues to be used successfully and is now running exclusively on Alpha computers. OpenVMS was upgraded to version 7.3-1 during the year and will likely be upgraded early in the new year to the recently released 7.3-2. With the port of the VMS to the IA64 architecture, VMS may be seen running on PCs in the CCS in the future. The last example of infrastructural developments is the removal of old terminal servers and their replacement by a new generation of hardware. More terminal servers may be replaced during the next year.

In addition to the development of new applications, many of the existing applications received enhancements. Examples of programs that received changes are XTpages, Xsoftwatch, Xstrip, and the Safety Panels. In another area, a significant start has been made on allowing the device numbering system to move from octal to decimal. Within the CCS, cyclotron devices are identified by a system ID and a device number (often called the thumb-wheel number). This change will permit much larger device tables, but it does mean work on some applications and modifications to device selection lever-wheels. The change to decimal device numbering should be completed during 2004.

### Secondary Beam Lines

Progress on the new secondary beam line controls continues to go well. The controls for M15, M20, M9A, and M9B have been implemented and there is ongoing effort for testing and commissioning these beam lines. M11 and M9 solenoid crates have been added to the CAMAC serial highway. A multiplet tuning application has been developed for M15 and M20 and the EPICS version has been upgraded to R3.13.8.

### Other Systems

Support for the proton therapy facility is continuing. During 2003 the computer handling the operator interface was upgraded as expected to a DS10 and the previous computer was freed up to act as a spare for the beam line 2C CPU. To improve the quality of the operator displays, one of the CRTs in the proton therapy control room was changed to an LCD monitor.

There has been increased activity in the neutron irradiation facility (NIF) and to support this work a special display page was developed. Functionalities such as charge timers have been added.

## OPERATIONAL SERVICES

### Remote Handling

#### ISAC

Remote Handling technicians began assembly work of the shield plug, service cap, and containment box for target module #4 (TM4). Hot cell activities for the year included four scheduled target changes for TM1, the installation of new targets on TM2 and TM3 modules, and the replacement of steering plate assembly in TM1. Specialized handling equipment was designed, built, installed, and used to exchange a damaged manipulator at the south hot cell.

#### Cyclotron servicing

The winter shutdown was dedicated to the usual routine of Cu-blocker and shadow shield handling, along with video and radiation surveys. The 2C extraction probe was removed remotely and replaced for the Diagnostics group during its annual service. A pair of screw jacks at station #4 of the cyclotron elevating system were routinely exchanged for servicing.

#### Beam lines servicing

During the winter shutdown (January through March, 2003) the new replacement beam line 1A triplet magnet (Q14/15/16) assembly was installed downstream of the T2 target. The previous triplet assembly was removed from the beam line, bagged, and transferred to the active equipment storage pit. Shielding blocks to the south of the beam line trench at the triplet location were removed to replace water damaged crumbling blocks in the area beneath the former M8 beam line and to create a chase for the triplet cooling services to the beam line 1A tunnel. Electrical power conductors were extended in the beam line trench from the previous location beneath the triplet to buss connections along the north wall. The new triplet was installed, guide fixtures aligned for future remote positioning, and the vacuum beam tube was connected, pumped and leak checked. Water cooling connections, utilizing a radiation-hard metal seal coupling recently designed by the Remote Handling group, were made up and the power buss links remotely connected. The magnets were fully power tested prior to, and after, installation of the first cover layer of steel shielding.

A fairly large job at the M20 beam line front end required repair of cooling-water leaks at the M20Q1 quick-connect fittings and replacement of a cracked ceramic insulator. The M20Q1 magnet was disconnected and investigated to determine the cause of ground fault in one of the coils. During the M20Q1 work a water leak was created at M20Q2 by disturbing and cracking a rubber cooling supply hose. This required replacement of the hose.

Other shutdown jobs included: repair of separate vacuum/air leaks at the M20 jaws box, the 1AWVA2 window valve, and at the 1AVA8 valve. The tentatively scheduled rejuvenation work for the M20 beam line front end continued throughout the year, taking a more intensive approach of a major refurbishment of the M20B1 magnet as well as replacement of the M20Q1/Q2 magnets, stand and vacuum box. The removal of the failed M11 septum magnet for failure mode examination, scheduled for the winter shutdown, 2004, prompted the issue that M11 experimenters are still able to gather some limited data from operation of the beam line without powering the septum magnet. This ability would be totally lost with installation of the straight-through beam line 1A septum bypass vacuum beam tube. Design began in November for modifications to the bypass to provide an M11 take-off leg.

This beam tube would replace the septum magnet with a comparable septum-Y vacuum box.

**Hot cells and targets**

Annual target station cooling package maintenance was performed during the winter shutdown. The 1AT2 cooling head was rewired for an electrical upgrade and both 1AT1 and 1AT2 cooling package flow meters were measured and recalibrated. A leak in the T2-Mk1 target required the metal C-seals to be replaced. The beam profile monitor on T2-Mk1 was also replaced. In June the T2-Mk1 target was inspected in the hot cell. The beam spot profile was documented and target travel positions were measured and recorded. This was all in an attempt to explain the low beam spot believed to be responsible for the recent target failure. The damaged TNF beam dump cooling vessel was removed from storage, prepared, and cut in sections to reduce storage volume.

Assistance was given to beam line 2C operations with hot cell target installations during the year, and preparation for the 2C4 solid target realignment to be performed in the winter, 2004 shutdown

## Magnet Power Supplies

The vast majority of 2003 activity was related to MRO activities for the power supply system that is part of the original TRIUMF installation.

The copper water-distribution headers in the main magnet rectifier cabinet developed two water leaks, one of which was repaired by soldering and the other was repaired by peening the metal at the joint. This may indicate problems in the future that may require the replacement of the header system.

New supplies were installed and commissioned for DRAGON. These replaced the supplies for MD1, MD2, Q9, Q10, SX3, and SX4. Their original power supplies had been recovered from M8 but they proved to be unreliable.

Leaking pass-bank chill plates were replaced with a new copper version, which was procured from VR Electronics. This activity continues as new leaks develop in other heat sinks.

Silicon hoses, which developed leaks after 18 years in service, were replaced in the main magnet power supply. Silicon hoses were a vast improvement over the originally installed braided hoses that were replaced in 1985. The braided hoses seemed to have leaks every few weeks and caused excessive downtime.

A necessary retrofit of trim and harmonic power supplies was developed to address code compliance of the bays. Bay 4 will be addressed during the winter, 2004 shutdown.

Because of the installation of the new triplet in BL1A the asymmetric steering supply system was upgraded to provide additional steering for the triplet.

Quadrupole power supplies were purchased for the ISAC S-bend beam line. These are to be installed in 2004. Power supplies were purchased and commissioned for the charge state booster.

A KAON factory era high-voltage supply was cleaned up and commissioned for the target conditioning station at ISAC.

## Electrical Services

The ISAC-II project continued to be the major focus of the engineering and coordination efforts. About 35 engineering and installation work orders were carried to completion (the larger portion for ISAC). Among them worth noting in this section are the variable speed drives for the first 8 motors of the main cyclotron cooling tower, the office renovation in the chemistry annex for Nordion use, UPS power to the proton therapy facility and the fire alarm system operator graphic interface, conduit runs for the safety-critical radiation protection system, new services and improved grounding in the micro-electronics lab, deficiency corrections in the M20 counting room, UPS power for the new Nordion access system and power to various air conditioning services.

Continuing engineering support was provided to Nordion for the new TR30-2 radioisotope production facility project and to the ATG group for maintenance of the electrical services and the lighting of the operating facilities. A planned upgrade of the fluorescent lighting system was postponed because of the significant financial and manpower effort required to complete it in one year. We are currently in discussions with representatives from the BC Hydro Power Smart program to explore different ways to proceed with this important project to lessen its impact on a given fiscal year.

Typical maintenance activities included servicing lighting systems, motors and associated controls, air conditioning controls, panel boards and transformers, HV switchgear, breakers and capacitor banks, and the fire alarm system. Approximately 230 calls were answered (about 40 from ISAC-I and 50 from Nordion facilities) in addition to lighting maintenance. After stopping water infiltration in the conduit housing the 15 kV cable feeding the main office building, and after further consideration, it was concluded that cable replacement could be postponed.

In the summer, an incident with trim harmonic bay 4 revealed a deficiency in the wiring method of the bay control-wiring distribution. Temporary wiring was provided and the procedures for removal of a power supply from service were changed. Further study indicated that a better solution would be to change design and tap the control power directly from within each power supply. Each power supply will be retro-fitted with plug-ins as well. With this approach, turning a power supply breaker off will de-energize the unit and allow its safe removal.

A failure of the outside lighting in front of the main office building was traced to an electrical short in the underground wiring. A failure of one of the main breakers in the ac distribution of the rf system prompted a review of the whole system. The installed technology is obsolete and spare parts are in short supply. This situation demands an upgrade in the near future of the whole ac distribution in this room.

### Power delivery

Power delivery continued to be very reliable without major events or outages. Scheduling coordination continued regularly for large power HV with Power Tech High Voltage Laboratory short-circuit tests. These tests produce small transient disturbances to which, unlike other facilities, TRIUMF is particularly sensitive. However, thanks to our good working relationship with the management of Power Tech, scheduling of these events is carried out in close coordination with TRIUMF Operations, therefore causing minimal impact on our operations.

The monthly averaged peak power demand has increased 7.7% from 6834 to 7358 kVA. This was expected because of the addition of the ISAC-II building. However, the maximum peak demand decreased 2.7% from 8944 to 8702 kVA. This year, the peak was reached in November (Fig. 240) in keeping with ISAC-II increased activities over the months. The electricity consumption followed suit, increasing about 5.9% from 53.3 to 56.4 GWh (Fig. 241). The largest consumption also occurred in November (5.83 GWh).

The power factor (PF), averaged over the calendar year, inched up marginally to 96.3% from 96.1% (Fig. 242). However, the PF for a typical production month improved thanks to the addition of three automatic power factor correction capacitor banks that were brought into service in April. The benefits of this addition will be even more important when the new BC Hydro rates (7.3% higher) take effect next April.

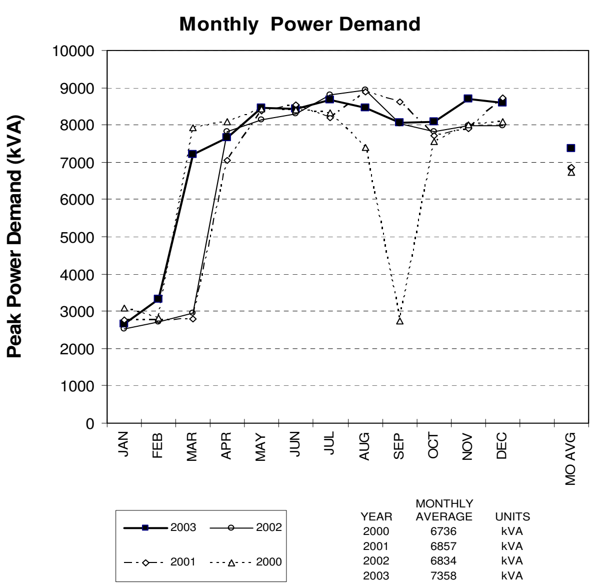


Fig. 240. Electrical power demand – four year comparison.

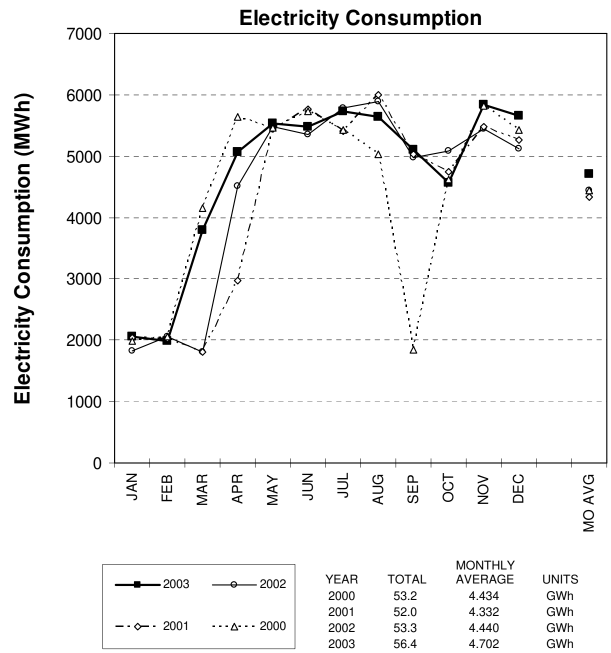


Fig. 241. Electricity consumption – four year comparison.

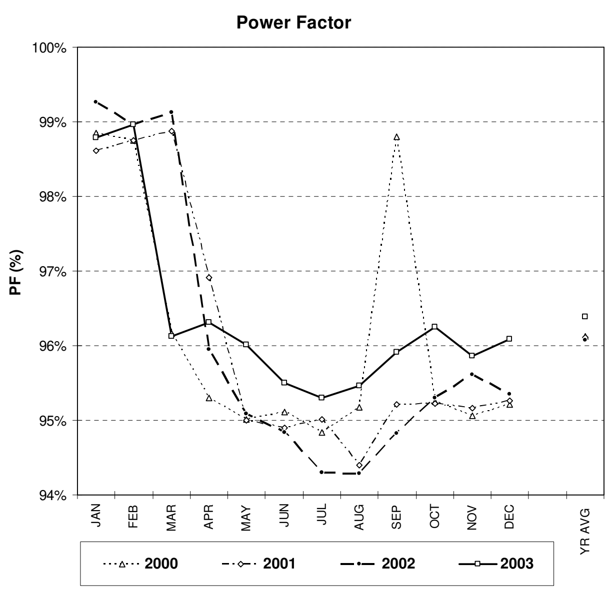


Fig. 242. Electrical system power factor – four year comparison.

**Mechanical Services**

One of the more interesting jobs was the completion of the installation of the variable-speed drives for the cooling fans in the cooling tower. These fans now regulate the temperature of the raw water much better than the old “flaps”, and the stability has led to better machine stability. The city-water lines to the cooling-tower were replaced.

There was a lot of work for rf cooling-water services, including the vault transmission line capacitors, the rf room inlet filter, the high voltage power supplies, and the transmission line. A start was made in re-commissioning the former MRS air compressor as a backup site air compressor. New pumps were installed in the building perimeter drainage sump and for the beam line 1A triplet. Other piping jobs included replacement of the original city water lines that had become corroded in the ISIS area, some hot water lines in the chemistry annexes, and the discharge lines of the M13 vacuum pump. Trailer X services were disconnected.

A new air extraction system was provided for the removal of toxic powder from the machining of G10 material in the machine shop of the probes laboratory. Air conditioning service was provided for the RMC room, trailers Gg and P, M8, the main office building air handling units 1 and 5, the ATLAS clean room, and the service annex Buffalos at elevation 264.