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SCIENTIFIC ACTIVITIES
1998

CANADA'S NATIONAL MESON FACILITY
OPERATED AS A JOINT VENTURE BY:

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UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

APRIL 1999

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

CYCLOTRON OPERATIONS DIVISION

INTRODUCTION

The strategy reported in 1997-98 of operating the cyclotron with a low budget and minimum manpower, to make more resources available to the ISAC and CERN efforts, was continued during 1998-99. In addition, the duration of the beam time schedule was reduced to less than 4,000 hours to allow time for the construction and installation of the new 100 μA 500 MeV extraction proton beam line for ISAC. This involved a number of new elements and modifications to shielding and flanges at the cyclotron periphery, where the residual activation is high. The work proceeded in a faultless manner with relatively low dose exposure, and is reported in the Beam Lines section below and in the Beam Line 2A sections of the ISAC chapter of this Annual Report. The policy of minimum budget and minimum resources for operations, and minimum scheduled production time, however, was not conducive to highly efficient, reliable beam production, and our results in terms of reliability and beam availability were below our previous good records. A series of problems, which plagued operations mainly towards year end, are reported in detail in the report from the beam production group. We should emphasize that so far none of these problems in terms of cyclotron reliability are structural and, in fact, most of the problems have been coming from ancillary systems like failing pumps and water services, main magnet power supply, or cooled collimators, or other water cooling down beam line 1A. Beam line 1A is probably the system which deserves most attention, especially along the section including the T2 target and the high intensity beam dump. Operators and maintenance personnel should be commended for their usual high dedication to the machine and for having dealt with and solved several problems in difficult circumstances.

During 1999–00 TRIUMF's priority will be to complete the ISAC-I project and deliver low energy beam to ISAC experiments, and to honour our commitments with CERN. Low resources for cyclotron operation will continue, but it is anticipated that the budget situation will improve with the new 2000–2005 five-year plan.

BEAM PRODUCTION

This report describes beam production for the full 1998 calendar year, starting with the final two weeks of Schedule 92 and ending with the completion of Schedule 94. With more shutdown time than usual required for the construction of BL2A, and because of budgetary reasons, a total of only 3834 operational hours were scheduled of which 3147 were achieved, with a rather low availability of 82.1%. These totals include 100 hours used for development and tuning and, as shown in Fig. 111, were split roughly 3:1 between high current beam production and low intensity, polarized operation with the availability considerably better for the latter. While high intensity periods served a variety of users, polarized operation was for the most part dedicated to the parity non-conservation experiment running in beam line 4A2. As Fig. 112 shows, the total beam charge delivered to meson hall experiments

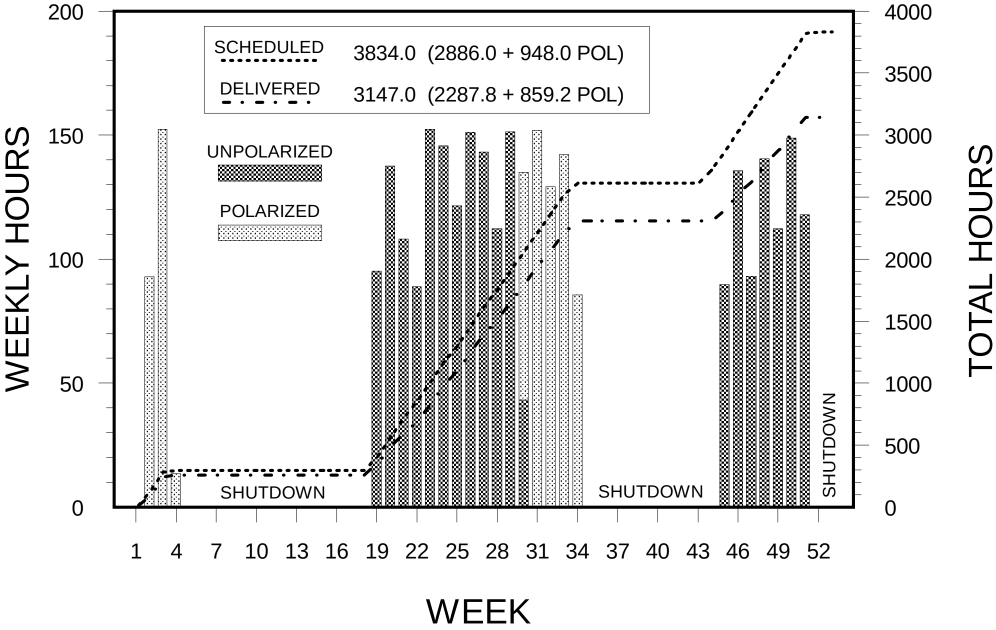


Fig. 111. Operational hours for 1998.

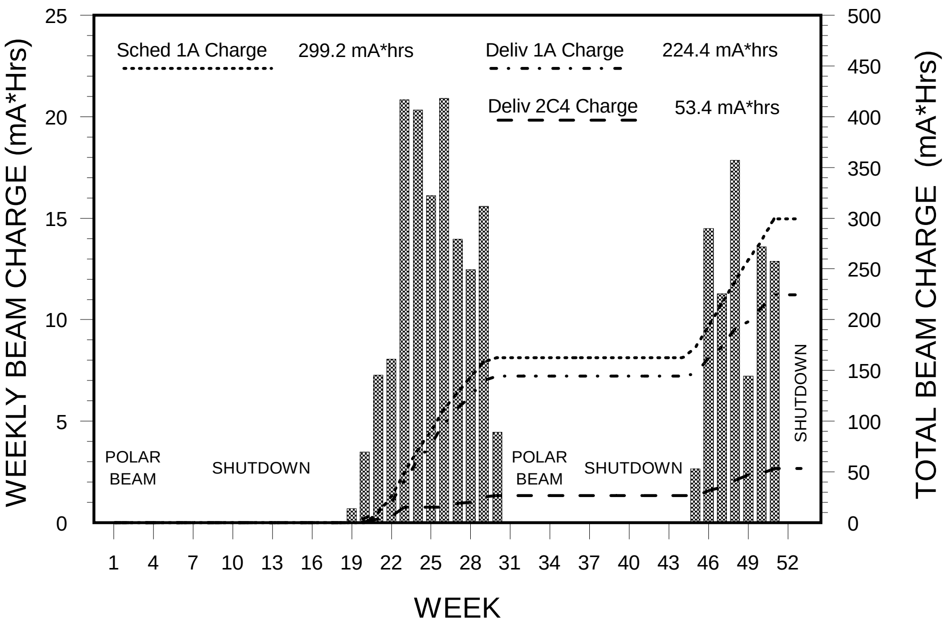


Fig. 112. Beam delivery for 1998.

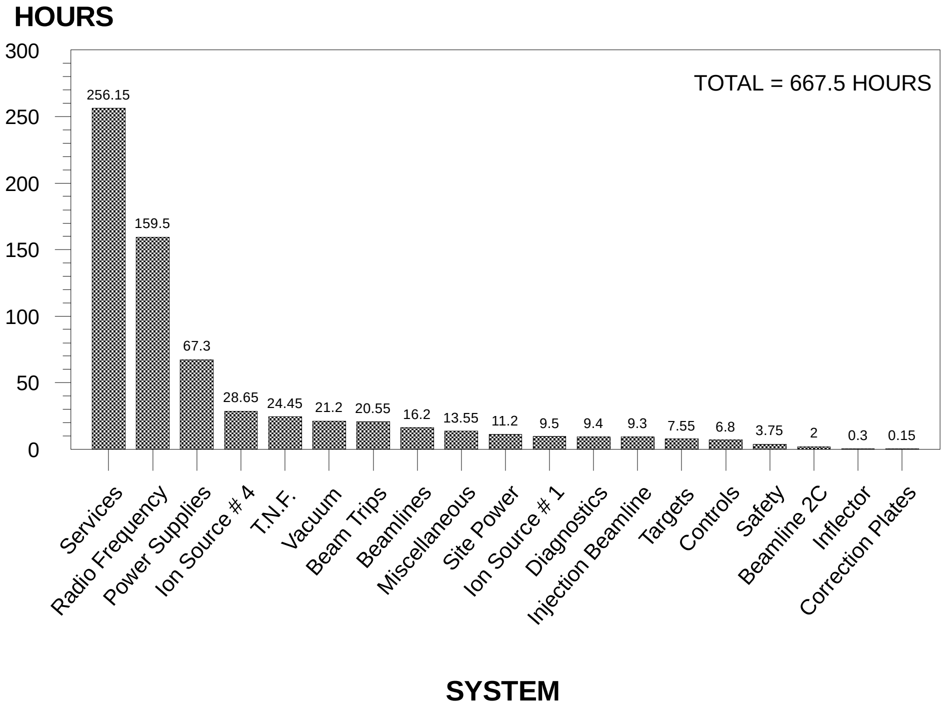


Fig. 113. Cyclotron downtime for 1998.

during high current production was 224 mAh or only 75% of that scheduled, usually at 150 μA. This percentage is lower than the availability largely because of current restrictions at TNF through much of Schedule 94. There were also 53.4 mAh delivered at 85 MeV to the solid target facility (STF) in beam line 2C4 for the production of radiopharmaceutical generators. Eleven patients were treated for ocular melanomas during six proton therapy sessions in beam line 2C1 operated at 70 MeV. The annual downtime (Fig. 113) was 667.5 hours, the fourth highest it has been in the last ten years. Unlike most years, however, it was Plant Services (with 256 hours) rather than RF (with 159 hours) responsible for the lion's share of the downtime, largely due to the failure of the aluminum active low conductivity water (Al ALCW) pump at the start of the fall schedule. The operational record and beam to experiments for the year are given in Tables XVII and XVIII.

Table XVII. Operational record for 1998.

	Scheduled hours	Actual hours
Cyclotron off:		
Maintenance	274.5	305.05
Startup	182.0	140.40
Shutdown	4490.5	4513.50
Other	24.0	16.95
Cyclotron downtime	0.0	667.50
Overhead	99.0	113.60
Totals	5070.0	5757.00
Cyclotron on:		
Development	63.0 + 0.0 P	2.15 + 0.00 P
Cyclotron tuning	144.0 + 51.0 P	36.50 + 62.45 P
Beam to experiments	2679.0 + 897.0 P	2249.10 + 796.80 P
Totals	2886.0 + 948.0 P	2287.75 + 859.25 P
Actual/Scheduled = (2287.75 + 859.25)/(2886 + 948) = 82.1 % availability		
Beam to experiments:		
1A Production	2337.0 + 0.0 P	2099.95 + 0.00 P
1A Development/tuning	9.0 + 0.0 P	13.35 + 1.70 P
1A Down/open/no user	246.0 + 897.0 P	122.05 + 795.10 P
1B Production	87.0 + 0.0 P	9.95 + 0.00 P
1B Development/tuning	0.0 + 0.0 P	0.80 + 0.00 P
1B Down/open/no user	0.0 + 0.0 P	3.00 + 0.00 P
Total 1A+1B production	2424.0 + 0.0 P	2109.90 + 0.00 P
2A2 Production/tests/tuning	397.0 + 0.0 P	73.60 + 0.00 P
2C1 Production/tests/tuning	88.0 + 23.0 P	42.50 + 8.20 P
2C4 Production/tests/tuning	1538.0 + 0.0 P	1259.35 + 0.00 P
2C5 Development/tune	18.0 + 0.0 P	16.05 + 0.00 P
4A2 Production	44.5 + 888.0 P	17.60 + 695.50 P
4A2 Development/tuning	0.0 + 0.0 P	0.85 + 74.40 P
4A2 Down/open/no user	0.0 + 9.0 P	8.80 + 26.90 P
4A3 Production	1101.0 + 0.0 P	782.20 + 0.00 P
4A3 Development/tuning	0.0 + 0.0 P	8.30 + 0.00 P
4A3 Down/open/no user	2.0 + 0.0 P	120.25 + 0.00 P
4B Production	1482.5 + 0.0 P	971.40 + 0.00 P
4B Development/tuning	0.0 + 0.0 P	31.85 + 0.00 P
4B Down/open/no user	49.0 + 0.0 P	307.85 + 0.00 P
Total BL4 production	2628.0 + 888.0 P	1771.20 + 695.50 P
1A Beam charge	299236 μAh	224426 μAh
2C4 Beam charge	70870 μAh	53403 μAh

P = Polarized source on-line (although not necessarily polarized beam)

Table XVIII. Beam to experiments for 1998.

			Scheduled			Delivered		
Experiment *	Channel	Sched.#	h	h (pol)	μAh	h	h (pol)	μAh
497	4A2	92	0.0	273.0	0	0.00	211.05	0
497	4A2	93	44.5	615.0	0	17.60	496.70	0
614	M11	93	567.0	0	61670	446.90	0	46478
614	M11	94	271.0	0	40650	179.90	0	16116
669	M20B	94	150.0	0	22500	136.60	0	18073
684	M9B	93	589.0	0	74200	604.30	0	63234
684	M9B	94	320.5	0	36650	230.20	0	21786
687	M20B	93	150.0	0	22500	149.50	0	20658
687	M15	94	150.0	0	22500	136.60	0	18073
691	M15	93	150.0	0	15000	124.25	0	12643
691	M15	94	124.5	0	17865	113.25	0	13484
697	M15	93	145.0	0	18020	124.70	0	14840
704	4B	93	730.0	0	0	475.85	0	0
704	4B	94	626.5	0	0	413.50	0	0
713	M9B	93	293.5	0	32870	270.55	0	30622
713	M9B	94	121.0	0	18150	95.25	0	5179
715	4A3	93	627.0	0	0	497.00	0	0
724	M15	93	150.0	0	22500	149.50	0	20658
737	M15	93	52.0	0	7800	57.30	0	8400
741	4A3	94	404.0	0	0	280.70	0	0
746	M20B	93	127.0	0	19050	84.40	0	10389
749	M20B	93	127.0	0	19050	125.00	0	17651
757	M9B	94	254.0	0	38100	187.00	0	24780
758	M20B	93	150.0	0	22500	140.90	0	19038
768	M15	94	161.0	0	18740	116.95	0	8302
774	M20B	94	150.0	0	22500	84.65	0	10937
775	M20B	93	148.5	0	14850	145.85	0	15782
777	M15	93	127.0	0	19050	125.00	0	17651
777	M20B	94	196.0	0	18785	116.95	0	8302
778	M13	93	1349.5	0	162536	1196.50	0	141802
782	M15	93	69.0	0	10120	66.10	0	9265
784	M15	93	127.0	0	19050	84.40	0	10389
784	M20B	93	150.0	0	15000	133.55	0	13091
791	M20B	94	104.0	0	15600	68.85	0	8257
792	M15	93	150.0	0	22500	140.90	0	19038
793	4A3	94	70.0	0	0	4.50	0	0
794	M9B	93	81.0	0	8100	71.75	0	6665
798	M15	94	104.0	0	15600	68.85	0	8257
798	M20B	94	121.0	0	18150	95.25	0	5179
799	M9B	93	271.0	0	40420	264.30	0	36703
799	M9B	94	46.0	0	6900	34.25	0	4230
804	M20B	93	121.0	0	17920	123.40	0	17665
804	M20B	94	142.0	0	21300	139.75	0	15844
807	M15	93	148.5	0	14850	145.85	0	15782
808	M13	94	121.0	0	18150	95.25	0	5179
809	M20B	93	145.0	0	18020	124.70	0	14840

Table XVIII (cont'd.)

Experiment *	Channel	Sched.#	Scheduled h	Scheduled h (pol)	Scheduled μAh	Delivered h	Delivered h (pol)	Delivered μAh
809	M13	94	150.0	0	22500	136.60	0	18073
814	M15	94	150.0	0	22500	84.65	0	10937
818	M15	94	121.0	0	18150	95.25	0	5179
819	M9B	93	69.0	0	6900	61.80	0	6426
831	M20B	93	139.0	0	4446	103.00	0	6100
832	M20B	93	92.0	0	9200	75.50	0	7036
833	M15	93	150.0	0	12550	99.30	0	8891
833	M13	94	285.5	0	36605	230.20	0	21786
834	M13	94	246.0	0	36900	208.60	0	24101
837	M11	94	124.5	0	17865	113.25	0	13484
838	M9B	94	344.0	0	51600	306.45	0	35319
1UA TEST	2A	94	4.0	0	0	1.00	0	0
737/782	M13	94	150.0	0	22500	84.65	0	10937
737/782	M20B	94	124.5	0	17865	113.25	0	13484
797/798	M15	94	142.0	0	21300	139.75	0	15844
BELLE	M15	93	81.0	0	1096	79.20	0	4245
CS TEST	2C5	94	4.0	0	50	4.55	0	53
FOIL TEST	2C4	94	2.0	0	10	0.85	0	10
ISAC RIB †	2A2	94	397.0	0	0	73.60	0	0
ISOPROD	2C4	93	816.5	0	35430	695.10	0	26905
ISOPROD	2C4	94	721.5	0	35440	566.55	0	26738
P THERAPY	2C1	92	0.0	9.0	0	0.00	4.50	0
P THERAPY	2C1	93	140.0	0	0	23.30	0	0
P THERAPY	2C1	94	130.0	0	0	10.30	0	0
PIF	1B	94	87.0	0	0	9.95	0	0
PIF	2C1	94	47.0	0	0	8.35	0	0
TBA	M11	93	736.5	0	100820	708.10	0	93224
TBA	M11	94	396.0	0	59400	345.20	0	42174
TEST	2C5	93	8.0	0	80	11.25	0	205
UBC	M11	94	196.0	0	18785	116.95	0	8302

* See Appendix D for experiment title and spokesman

† total for commissioning, TRINAT/715 and GPS/823

Beam Schedule 92

Schedule 92 was completed with about two weeks of polarized operation in January just before the year's first shutdown. With the exception of a proton therapy session for a single patient, the beam was used exclusively by the Parity group which extracted 200 nA of 80% longitudinally polarized, 223 MeV beam from a cyclotron tuned to about 13% transmission (with no bunchers). Depending on the type of extraction 4 (X4) foil in use, a variety of cyclotron probe configurations had earlier been used to horizontally shadow and/or vertically scrape the beam to clean it up before extraction to the LH2 target. Due to certain probe failures, this nominally meant vertically scraping with a short X1 foil, taking around 100 nA of 220 MeV beam down 1A, while using a light, unshadowed foil on X4. At the end of the run the HE1 probe was used to horizontally shadow a prototype bow-saw styled foil that provided encouraging results. With the exception of the failure towards the end of the run of one of the outer trim coils, which prevented beam transmission to the outside of the machine, but only marginally affected parity, the cyclotron behaved reasonably well delivering 200 hours of adequate beam and 40 hours of tuning time during this period. There were 50 hours of downtime, much of it caused by one of the non-active copper LCW pumps failing at the beginning of the run. One last item of note was the rf booster test just prior to shutdown. The deferment of this test from earlier in the schedule was well advised because the RFB feedthrough failed again, resulting in a tank vacuum burst that heralded the beginning of the shutdown.

Spring Shutdown

The cyclotron lid remained down for the first five weeks allowing the tank to cool more than usual while extensive BL2A assembly took place in the vault (and 2A tunnel). Adjustments to the elevation system control electronics were made for a trouble-free lid-raising, and a shields-in radiation survey showed general fields to be 15% lower than the previous spring. A long list of activities other than the 2A work included: electrical and plumbing repairs to vault beam line magnets, realignment of the 4AQ4/5 quadrupole doublet, two iterations of resonator levelling adjustments, inspections of the cyclotron centre region, maintenance of tank vacuum equipment, repair of burned wiring in the trim coil 45 junction box, updating of the 1AT1 water cooling package, overhaul of the rf CuLCW system north pump and a heavy slate of cycloton probe and beam line monitor maintenance. An upgrade of the site fire detection system was also completed with all zones, including ISAC, now protected by a uniform Cerberus system. Even though this was a very busy shutdown, all the work was done with doses managed within the sliding time guidelines with the final statistics showing a total dose of 82.6 mSv distributed among 90 workers.

Beam Schedule 93

There were roughly 11.5 weeks of high current and 4.5 of polarized operation in this schedule. Start-up was reasonably smooth and initial BL1A currents were held back to a maximum of 10 μA during BL2A beam commissioning tests to a temporary dump located at the end of 2A1. These nA tests went extremely well, with several energies tuned without difficulty and included various beam spill tests for TSG. A couple of weeks later beam was run successfully to the 2A2 dump module at the west ISAC target station. After the initial tests, currents were increased to 140 μA in BL1A and 60 μA in BL2C4 for several weeks of reasonably successful running until a Rb target in the latter beam line developed a small leak very near the end of its scheduled irradiation. ISOPROD runs were then suspended for three weeks while a target engineering and safety review was completed. After this, two remaining Rb target cassettes were used without incident. The last half of the high intensity beam production time was characterized by lower than usual BL1A currents as the cyclotron was tuned to reduce the beam pulse width to around 2 ns FWHM as requested by the CHAOS experiment. This was largely accomplished with radial flags which reduced the cyclotron transmission from 60% to 40% and the total available accelerated beam to 140 μA with 350 μA injected. When BL2C4 was off during the safety review, the full 140 μA was available to 1A users but when STF came back on-line taking 40 μA, then BL1A was left with 100 μA. A total charge of 144 mAh or 89% of the scheduled amount was delivered to BL1A during high current operation with the cyclotron on for 1450 or 87% of the scheduled hours. Downtime was a little high at 166 hours, the chief causes being rf sparking, services UPS trouble and a 1AT1 water leak. BL2C was also used for the treatment of 3 patients with proton therapy (5 nA at 70 MeV in 2C1) and weekly tests in 2C5, where a total of 205 μA h of 105 MeV beam was delivered to a Cs target. On the BL4 side, beam alternated between 1 μA at 500 MeV to TISOL in BL4A3 and lower currents to Expt. 704 operating in proton mode in BL4B2 at 300 MeV and in neutron mode in BL4B3 at 283 MeV.

Except for one PT session during which two patients were treated, parity was again the sole user of polarized beam. Initially there was an attempt to extract with a bow-saw foil but after two early failures a parity 'standard' foil was used and for most of the run, 200 nA of slightly lower energy beam was sent down BL1A as a short, broad X1 foil was used to vertically shadow the parity foil. The remaining beam was stopped in the machine with HE probes which were occasionally used to horizontally shadow the parity foil. Parity had their best run to date with over 250 hours of data collected from about 500 hours of delivered beam. The OPPIS ECR microwave tube failed during the run causing about 12 h of 64 h total downtime. At the end of the run there was a successful test of an improved bow-saw foil.

Fall Shutdown

There was a day of cyclotron checks before things were turned off for the fall shutdown, including a Controls Y2K test after which beam was still able to be delivered. Since no urgent faults were known to exist with the cyclotron, it was decided that the lid would not be raised for any routine maintenance; instead this would be deferred to a longer shutdown at the beginning of 1999. This saved dose and freed personnel to concentrate on preparing ISAC for its first radioactive beam. However, there was still a demand for maintenance on existing systems as performed and reported by the various support groups including: the replacement of the old, site UPS; the installation of a water cooled beam stop in BL2C5; improvements to the vault lighting and a long list of repairs to beam line devices. Other MRO was done (RF, Vacuum, Controls) but one job, at TNF, had to be left unfinished. Tests there were unsuccessful in locating the source of a small, elusive, water leak. Diagnosis was partly masked by a pre-existing air leak and somewhat thwarted by a 1AT2 target water leak that sprung during these tests and was later repaired. The eventual proposal was to run with the vacuum vessel back-filled with helium at atmospheric pressure and steps were taken to assure that this would be a satisfactory temporary solution. The total shutdown dose was 21.2 mSv distributed among 41 workers, lower than usual because the lid had not been raised for any tank work as noted above.

Beam Schedule 94

Beam delivery was beset by one problem after another to produce one of the poorest performance records for a single beam schedule in recent history. Start-up was reasonably smooth as expected because the tank remained under vacuum the entire shutdown. Soon afterwards there was a catastrophic failure of the Al ALCW pump (that circulates cooling water through the resonators and main magnet coil) whose replacement took nearly a week out of the schedule. Two weeks later the main magnet power supply was off for 2.5 days because of a faulty pre-driver circuit for which the diagnosis was hazardous and difficult. During these first few weeks of operation, TNF water levels and air activation were closely monitored and nothing too unusual was noted. In late November, however, the water loss rate there started dramatically increasing and the TNF vacuum vessel soon filled up to the beam plane. The collimator of the 500 MeV radiation facility was then identified as the culprit, its cooling circuit was bypassed and a couple of thermocouples were inserted into the empty cooling lines, close to the collimator. Currents were slowly raised to a limit of 120 μA in order to keep temperatures less than 80°C, with some cooling achieved by circulating air. Before higher current tests could be done there, a reheat coil in the rf room HVAC ducting froze and burst, causing a major flood which brought about a slightly premature end to the beam schedule. With the above failures, only 80 mA h or 59% of the scheduled charge was delivered over 838 or 68% of the scheduled hours. Downtime was high at 378 hours, nearly half of it because of the failed pump. In spite of the difficulties there were some major milestones this period. BL2A 1 μA tests went well on November 17 preparing the way for ISAC's first RIB on November 30 when 6×10^6 ^{37}K ions/sec were transported to a Faraday cup just outside the relocated TRINAT. (First radioactive beam was delivered to TRINAT on December 5. Unfortunately, ISAC suffered its first CaO target failure soon afterwards and although it was successfully replaced by the Remote Handling group using the interim warm cell facilities, further beam was not realized because of tank vacuum problems caused by extraction probe 2A.) New Rb targets were approved for 2C4 and strontium production there went well. In 2C1, five proton therapy patients were treated and further PT development work took place at 74 MeV. The machine transmission was generally good (around 60%) and tank spills were kept below 3 μA during high current production. The winter shutdown got under way December 20 before Christmas break.

BEAM AND CYCLOTRON DEVELOPMENT

Short Bunches from the Cyclotron

The CHAOS experiment required a beam with bunches less than 2 ns long at high intensity (~100 μA). This condition was set up by operators using centre region flags. The T1 Čerenkov monitor was used to show that the requirement had been achieved and the wall current monitor gave a less precise but perfectly adequate 'live' display of conditions.

Multipactoring in the RFB Coupling Loop

The loop that couples power into the 92 MHz RFB accelerating cavity has a ceramic cylinder as vacuum feedthrough. This cylinder has been cracked several times during operation and track marks of what were assumed to be secondary electrons could be seen on the aquadag coating. It was felt necessary to measure the magnetic field in the vicinity of the feedthrough to gain a more quantitative understanding. The feedthrough is located in a region difficult to access, near a magnet pole and with a radiation field of 1.5 mSv/h. The cyclotron was under vacuum so it was not possible to measure at the location of the cylinder so a hand held gaussmeter was used to measure the field at several points around the outer housing and interpolation used to estimate the fields at the damage points. These were a horizontal component between 0.7 and 2 kG and a vertical component of ~1.8 kG. A simple mathematical model was fit to the data to give the field distribution in the region in order to enable electron tracking if desired. A more accurate measurement surrounding the region occupied by the ceramic cylinder would require a special jig to be built and the cyclotron to be vented.

Cyclotron Beam Dynamics

Several calculations simulating beam behaviour in the cyclotron were carried out. These included calculations of stripped beam trajectories to determine the location of copper blocks protecting the 2A exit horn and simulations of the effect of shadowing the BL4B stripping foil with a high energy probe to improve the beam quality extracted for the parity experiment.

Stripping Foils for the Parity Violation Experiment

The polarization distribution across the extraction foil surface is a source of polarization moments, which were identified as major systematic error contibutions to the parity experiment. They are affected by the betatron amplitudes and number of turns. This distribution had been measured by scanning a short (6 mm height) "hockey stick" foil across the beam. Up to 2–3% transverse polarization difference was observed across the beam. Since the polarization moments are products of polarization and beam size, extracting only the central part of the beam by the short stripping foil, or vertical "shadowing" of the long foil, helps to keep moments within a tolerable range (less than 10 μm).

Three types of stripping foils were used for the parity experiment. Initially, a 32 mm long, 5.0 mg/cm^2 thick, pyrolytic graphite foil suspended at one end was tested (see Fig. 114a). The foil width was 2.5 mm and it extracted about 60–70% of the circulating beam. The vertical beam size is quite large at 220 MeV beam energy and use of a long foil helps to reduce beam current fluctuations caused by vertical beam oscillations. As discussed above, the short hockey stick foil (see Fig. 114b) was used for polarization distribution measurements. To avoid beam extraction by the holder's thick stainless parts, one of the cyclotron diagnostics probes was used to shadow the holder and to reduce the effective foil width to about 2–3 mm. Polarized beam scattering in the carbon foil produces an asymmetry in the beam halo distribution, which can cause systematic errors in the parity detectors. The scattering effect is proportional to the foil thickness, which can be reduced significantly.

A foil 0.2 mg/cm^2 thick is sufficient to strip 98% of a 220 MeV H$^-$ ion beam. In the tests, such a thin foil was supported along one side – the hockey stick geometry. The use of thin foil reduces significantly the extracted beam emittance due to reduction of multiple scattering and hence improves beam transport conditions. The drawback of radial shadowing is an appearance of beam profile asymmetry caused by the fuzziness of the shadowing. This asymmetry is sensitive to the cyclotron tune and produces polarization moments. The solution is the use of a 0.2 mg/cm^2 foil strip, 2.5 mm wide, attached at both ends to a C-shaped holder (see Fig. 114c). The holder shadowing doesn't affect the beam profile in this case, due to a 5 mm gap between the foil and holder. The end parts of the holder are shadowed by a second stripping foil, which is situated at smaller radius and therefore trims beam symmetrically at top and bottom. Narrow symmetrical beam profiles were obtained with the thin foil in the C-holder and this foil will be used for the next run.

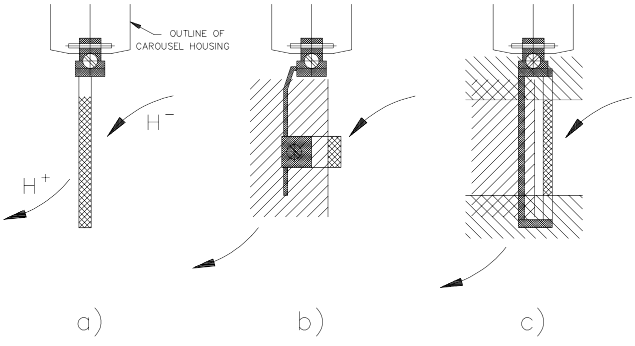


Fig. 114. Stripping foils for the parity experiment.

RADIO FREQUENCY SYSTEMS

RF Operations

The total cyclotron rf downtime for the year was 160 hours which represents 24% of the total machine down time. The combination of sparking, crowbars and out of driven caused 118 hours of this down time, despite efforts to adjust resonator tips to reduce rf leakage and temperatures in the beam gap.

A system for automatically switching through 32 rf signals from the amplifier system, measuring and logging them has been developed. This allows system problems to be diagnosed more quickly, and provides trend information on the amplifiers for maintenance purposes. The system uses a 32 × 8 rf switch matrix controlled by a PC running a Labview program and controlling the measuring instruments over a GPIB bus.

RF Support

The remaining manpower load of the RF group was dedicated to commissioning the seven-ring RFQ system with successful rf and beam tests, the assembly of the remaining 15 RFQ rings, and higher order mode dampers and filters for the CERN collaboration. The detail work on these projects is reported elsewhere.

RADIO FREQUENCY CONTROLS

A major area of activity for the RF Control group this year has been the redesign of the ISIS buncher system controls. The system currently in use employs 20 year old microprocessor technology. It has never provided adequate speed or bandwidth to ensure effective closed-loop amplitude and phase control of the prebuncher frequency components. Recently the system had several failures. The new design takes advantage of some of the modules developed as part of the ISAC effort, and adds a couple of others unique to the ISIS system requirements.

Like the ISAC and cyclotron rf subsystems, this system is housed in a VXI mainframe. The local system controller consists of an embedded Pentium PC. Frequencies at 4.6, 11.5, 23 and 46 MHz require control. Each is provided with both in-phase and quadrature control by a single dedicated digital signal processor. A 23 MHz signal from the cyclotron provides the reference frequency. This goes first to a master phase shifter module. This unit employs a digital phase shifter to provide overall control of the buncher phase. The phase-adjusted 23 MHz reference then goes to two frequency synthesizer modules. One of these provides the 4.6 MHz subharmonic, while the second produces the remaining three frequencies.

The design and construction of this system is essentially complete. It is currently being installed and commissioned, and is expected to be operational by the end of the shutdown in early 1999.

CYCLOTRON PROBES AND DIAGNOSTICS

Probes and Diagnostics Mechanical MRO

The major efforts throughout the year were focused on providing beam diagnostics for the ISAC west target station and the ISAC mass separator system. All other non-ISAC related work was limited to essential repairs of the cyclotron probes and beam line monitors. 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 cyclotron spring shutdown activities are summarized in detail in the Diagnostics group meeting notes of April 17.

Probes MRO

The high energy probe HE2 was removed in the spring shutdown for a complete overhaul. The failure that had taken it out of operation late in 1997 was found to be due to a seized bearing in the cable drum. This and several other bearings were replaced. All other bearings were cleaned and the drive cable was re-tensioned. HE1 was removed but only required minor service – bearings were cleaned and the cable was re-tensioned. The LE1 track was cleaned and re-aligned. The water cooled probe limit switch was adjusted in situ. The gear drive reduction ratio was increased for the vertical motion of variable PIP 3 to improve its operation. The 2C extraction probe was removed for inspection and routine service. The molybdenum shear plate appears to have alleviated the beam heating problem. Extraction probe Ex4 was removed for routine service.

Late in the year, the 2A extraction probe radial drive ferro-fluidic feedthrough began to leak just after start up of the radioactive beam to TRINAT GPS experiments in ISAC. The problem can be solved with a minor design modification which will be done early in the new year.

Monitor MRO

All vault and standard beam line monitors were serviced during the spring shutdown. Only the vault monitors were serviced in the shortened fall shutdown. Several monitors developed leaks during beam operation in November and required an extra application of ferro-fluid. These now require semi-annual attention and should be replaced soon with a new monitor design.

VACUUM AND ENGINEERING PHYSICS

The cyclotron and beam lines vacuum systems operated well during the year with minimal downtime until the end of November. At that time a water leak in the TNF vacuum space caused the loss of several days of high current operation. An acceptable operating mode was found and beam was run at 120 μA from December 9 until December 20, when operation ceased.

There was much accomplished on ISAC vacuum. The vacuum systems for beam line 2A, west target station, mass separator, LEBT to TRINAT and the general purpose station and the RFQ were all installed and commissioned during the year. A large part of the installation of beam lines and mass separator equipment was performed by persons from the Beam Lines and ISIS groups, with the Vacuum group providing assistance and guidance as required. The operating storage portion of the target vacuum exhaust system was installed. This allows the gases evolved during beam on target to be confined in shielded vessels until it is determined that they can be safely released. Beam had been transported through all installed sections by the end of the year.

Engineering Physics continued support for the RFQ and DTL work, as well as other tasks. A safety shield for the target high voltage conductors was designed and fabricated and the beam diagnostic station from Chalk River was completely rebuilt. There was also work on CERN rf equipment and on a tape transport system for ISAC.

ISIS AND POLISIS

ISIS

The CUSP ion source was modified with a new double half ring filament assembly. This change eliminates the run in time required after a filament change, which previously took some 36 hours of high arc current. Additional benefits are that filament changes can be done more easily and the expected lifetime of this type of filament is fifty per cent greater than the previous type. Both the ion source and injection line continued to operate well for the past year. As last year, there were no major activities undertaken during the past year as ISIS personnel were involved in the completion of the ISAC low energy beam transport systems (LEBT).

POLISIS

Polarized H^-

Parity violation experiment

The optically pumped polarized ion source (OPPIS) I4 provided very high quality beam to the parity experiment (Expt. 497) in January and for 5 weeks during the summer. The focus of the continuing development to minimize systematic errors in Expt. 497 shifted to beam extraction in the cyclotron. Details of the stripping foil and tunes used to minimize the transverse polarization moment of the extracted beam are given in the Beam and Cyclotron Development section of this Annual Report.

OPPIS injector for RHIC

Polarization facilities planned for RHIC will provide 70% polarized proton-proton collisions at centre of mass energies up to 500 GeV and a luminosity of 2×10^{32} cm^{-2} s^{-1}. The polarized injector must produce 0.5 mA H^- ion current during the 300 μs pulse, or current × duration of 150 mA μs, within a normalized emittance of 2π mm mrad. This is an ideal application for the TRIUMF-type OPPIS, where a 1.64 mA dc current was obtained, albeit at 60% polarization. Pulsed operation will greatly simplify and reduce the cost of the laser system, while providing high polarization due to ample optical pumping laser power.

Polarized beam is not presently required at KEK, and the KEK OPPIS will be moved to BNL in 1999 to supply polarized H^- for RHIC. Meanwhile, it has been at TRIUMF since September, 1997 to be upgraded to meet RHIC's requirements. Design of the matching optics between the source and the RFQ was also begun.

The existing TRIUMF OPPIS could meet the RHIC requirements even with CW laser pumping, if 300 μs pulses were accelerated (the source itself produces continuous beam). However, 100 μs accelerated pulse durations with peak currents of 1.5 mA would be preferred, since that would improve injection efficiency. The preference for the higher current, combined with the relatively low cost of pulsed lasers, dictates the use of pulsed optical pumping.

The KEK OPPIS as delivered to TRIUMF used a pulsed 18 GHz ECR proton source and CW laser pumping. At TRIUMF the KEK OPPIS is being optimized using a dc 28 GHz ECR proton source. A preliminary result of 0.52 mA dc H^- current was obtained, using a 121-aperture ECR extraction electrode with an overall diameter of 13 mm. This already satisfies the minimum RHIC beam current requirement, and a 199-aperture electrode, as used in the best TRIUMF OPPIS result, would give proportionately more beam current.

In previous tests at TRIUMF, near 100% rubidium polarization was measured in a 2 cm diameter rubidium cell having a vapour thickness of 1×10^{14} atoms cm^{-2} using a pulsed (80 μs) flashlamp-pumped Ti:sapphire laser. This year development began on producing a reliable, relatively long pulse (over 100 μs duration) flashlamp-pumped solid state laser system.

A new sodium-jet, negative-ionizer target was developed, which has some advantages over the original canal-and-condensers arrangement. A jet target can be shorter and the beam apertures larger, since sodium vapour is more effectively confined. Large apertures reduce secondary electron emission caused by the intense polarized atomic hydrogen beam striking the cell, and therefore may allow biasing the sodium cell up to 32 kV. If so, a 35 keV beam from the source will be injected into an RFQ, without requiring that the whole source be placed on a high voltage platform.

INR-type pulsed OPPIS for HERA

Studies of the hadron spin structure functions in collisions of polarized electrons with polarized-^{3}He, -hydrogen and -deuterium internal targets are in progress at DESY (HERMES experiment). The proposal to extend the kinematic range of these studies and measure the gluon contribution was recently examined. A polarized H^- ion current of 10–20 mA is required to provide sufficient luminosity for the above experiments. Such high currents were proven feasible this year at TRIUMF during development of the "INR-type" OPPIS.

In the INR-type OPPIS, the ECR proton source is replaced by two components – an atomic hydrogen "neutral injector" outside the magnetic field surrounding the rubidium vapour cell, and a pulsed helium gas ionizer cell inside the magnetic field. Hydrogen atoms pass unaffected through the magnetic fringe field and enter the helium cell, forming a small emittance proton beam that in turn enters the rubidium cell. The very high currents are due to the performance of the neutral injector. It consists of a plasmatron proton source that produces a small emittance, converging 8 A proton beam that is neutralized with high efficiency in a pulsed H_2 cell.

As part of the SPIN Collaboration, an INR-type source has been developed at TRIUMF that demonstrated by the end of 1998 a polarized H^- current of 15 mA in pulse durations of approximately 100 μs. This is by far the largest current ever attained by a polarized source. We believe that this current can be polarized to 70–80% polarization.

PRIMARY BEAM LINES

Beam line 1A T1 water package was upgraded to the same standard as that of T2 which was upgraded last year. The hydrogen recombiner system was replaced with a monitored expansion tank on the meson hall mezzanine to maintain improved water resistivity and to reduce the possibility of the release of active air. The new system was successfully tested in the summer and operated without problems for the balance of the year. MRO of existing installations continued as much as possible through the year limited by manpower resources which were employed in the onerous ISAC tasks. These tasks included the installation in beam line 2A of one combination magnet, four dipoles, sixteen quadrupoles, nine steering magnets, eighteen monitor boxes with stands and four turbo pumping stations. After the completion of the 2A line, the group focused on the alignment of the ISAC target station tank, the target module and target, exit modules I and II, the pre-separator, and the mass separator as well as the RFQ.

2C

Proton therapy on 2C1 continued to be regularly scheduled for 5 days each month during high current and polarized beam operation for a total of approximately 30 days.

The production of the radioisotope ^{82}Sr, which is produced in the solid target facility (STF) on 2C4, dropped significantly from the previous two years because of a reduction in the high current schedule, a decrease in demand and the failure of a rubidium target. In 1998 there were 85 days of ^{82}Sr production for a total charge of 553.2 mAh and a yield of 21.9 Ci at the end of bombardment. This compares with 123 days for a charge of 88.9 mAh and a yield of 31.3 Ci in 1997 and 121 days for a charge of 92.3 mAh and a yield of 34.7 Ci in 1996.

During irradiation of a rubidium target in June, the target developed a minor leak in the weld that attaches the stainless steel foil window to the target body. This was similar to two previous failures in approximately fifty target irradiations, so an engineering design review was held to review the target design and the irradiation procedure. The target foil weld has been modified so that the foil is held by a ring that is electron-beam welded to the target body. Procedures were put in place for quality control during target manufacturing. A beam trip was installed that will trip if there is a sudden drop in STF cooling water resistivity which can be caused by a rubidium leak. A ballast volume has been attached to the STF to store the kryptons released during a target leak and handling procedures if there is a leak have been modified. Two of the redesigned targets have been irradiated without incident.

Commissioning of the cesium target on 2C5 for ^{127}Xe production continued. The hole in the halo monitor and collimator was enlarged to 25 mm during the spring shutdown following a number of unsuccessful attempts to reduce the beam size. A number of commissioning tests followed, with currents up to 25 μA at 105 MeV and two gas transfers of ^{127}Xe were made. 206 μA h of beam were delivered to the cesium target in this period. In the fall shutdown, the graphite beam stop was replaced by a water beam stop with water circulating through the STF cooling water package. The heat load on the Cs target containment volume exit window has been greatly reduced because the water beam stop is designed for 10°C rise at full current of 50 μA compared with over 300°C rise for the graphite beam stop. The beam stop has been tested to 28 μA with a charge of 54 μA h.

The 2C extraction probe ran smoothly despite missing a regular maintenance and foil replacement during the fall shutdown because the lid was not raised. The extraction foils had twice the nominal use with up to 29,000 μA h on one foil.

The target shineblockers continue to operate erratically. The water pressure of the vault water system that operates the shineblockers will be increased in the 1999 spring shutdown and redesign of the system is being considered.

CONTROLS

CCS Operation

The Central Control System (CCS) ran well during 1998. Downtime was 6.8 hours, compared to 16 hours for 1997, and an average of 24 hours for each of the previous 10 years. The majority of 1998's downtime was as a result of significant hardware failures. The remaining CCS downtime is a result of software related problems. Many other hardware problems occur but are not serious enough to prevent Operations from delivering beam. There are also occasions, such as unexpected power outages, where failures occur to many systems including the CCS but the control system problems do not occur first. As a result, they are not recorded as CCS downtime. As well, the CCS problems are usually more quickly fixed than other simultaneous problems, so no CCS downtime occurs afterwards.

Power outages, both planned and unexpected, have been destructive to a wide variety of CCS hardware. Much of the CCS is protected by uninterruptable power supplies (UPS) but on two occasions the UPS failed, causing some inconvenience. One of the smaller UPS units had its batteries replaced and resumed running reliably at its specifications. Another, more important development was the replacement of the old, site UPS by a new, larger facility. The present UPS configuration is a tremendous improvement and allows Operations to assess the cyclotron (pumps, vacuum, etc.) via the CCS immediately after power outages and thus helps to shorten beam downtime. In addition, much less of the CCS requires attention after these outages, saving downtime and money in hardware repairs.

Beam Line 2A

The beam line 2A (BL2A) controls component of the ISAC project was the largest area of development for Controls during 1998. Work on BL2A controls proceeded through 1997 but accelerated in 1998 to the successful completion of the beam line and beam delivery to the ISAC west target dump on May 25. This milestone was later followed by the successful delivery of beam onto a CaO target and the first production of radioactive beam on November 30. To meet the controls requirements for these milestones, a number of tasks were completed. The BL2A serial CAMAC branch was extended, including optical isolation, to the ISAC electrical room and hardware support for a variety of equipment was installed. Dedicated Xwindow terminals were established in the 500 MeV cyclotron's control room and the ISAC temporary control room. Beam line 2A software (safety displays, device scans, display pages, parameter logging, beam line save and restore, and other software components) was configured to be consistent with software for existing beam lines thus providing the same look and feel to which Operations is accustomed. To enhance safety issues, a beam line overcurrent scan and support for target interlocks was implemented.

Year 2000 Issues

There was concern about Year 2000 (Y2K) issues involving the CCS. To address this, the software components in the CCS were reviewed to determine which might fail. Only one software program was expected to have difficulty and it was not related to beam delivery but used in an off-line procedure for extracting data related to the cyclotron (and can be easily fixed to be Y2K compliant). Under controlled conditions the date on CCS computers was pushed ahead, and while the clock rolled over to January 1, 2000, personnel watched how the control system performed. No problems were detected and subsequently beam was injected and accelerated without problems. TRIUMF does not run beam over the New Years period but this testing indicates that the CCS should run smoothly in the new year. Some similar work has been done on the proton therapy facility and no Y2K problems have been detected but more investigation and testing will be done during 1999.

Other Systems

The proton therapy computer was upgraded from a VAX 3400 to a VAX 4100. In addition, the operating system was updated to OpenVMS version 7.1 to be in line with the CCS.

Although the beam line 2C (BL2C) computer seriously needs to be replaced, only the memory was improved during 1998. BL2C control system hardware received attention to help improve reliability and in diagnosing errors. The BL2C control system software, from Vista Control Systems, was upgraded to version 2.7.

Support for the parity experiment and ion source 4 continued on items such as the rotary stage and Wien filter. More work is anticipated during the 1999 running period.

CCS Facilities

There were a number of CCS hardware developments other than those already mentioned. In the ongoing process of slowly phasing out old VAXes, one used ALPHA was purchased and two very old VAXes were removed. The remaining two production cluster VAXes should be phased out next year. To handle increasing CCS requirements, CPU memory and disk space were expanded. Together, these changes precipitated a reconfiguration of the production and development clusters' hardware. One of the benefits was the significant improvement in the ability to run diagnostic programs on the CCS. The policy of replacing old CAMAC equipment has dramatically improved reliability. In 1998 two more old CAMAC crates were replaced. To support new requirements, an additional crate was set up in the computer room. One area of concern was the aging Xwindow terminals of which approximately 50 are supported by the Controls group. An increased frequency of failures has been noted.

Software associated with the CCS infrastructure received a number of improvements. The operating system on both clusters and on the proton therapy VAX was upgraded to OpenVMS version 7.1. DECMessageQ, an interprocessor/interprocess messaging product, was upgraded to version 3.2. ORACLE was moved to a production cluster ALPHA and upgraded to version 7.3 and SQLnet support was expanded to an Ops

PC. CAMAC interrupt (LAM) handling has been developed and support provided on the production cluster ALPHAs.

The task of relocating existing processes from the VAXes to ALPHAs has proceeded smoothly. In addition, there were several enhancements to the control system software functionality. In one development, a beta version of an Xwindow based program to display logged cyclotron parameters (Xstrip) was released. A new software utility called Xsoftwatch was written to monitor computers, key processes, batches, and queues. It starts the primary CCS processes when computers boot, sends messages to the Operator log when problems occur, and tries to restart processes if they are stopped. Xsoftwatch has an Xwindow interface which provides both a convenient summary and a detailed breakdown. A similar software utility (Xhardwatch) to watch hardware components is under development and already in use. Requests from the Operations group led to control of the rf voltage from the main console and several improvements in the main magnet run-up procedure. Colleagues at Fermilab have kindly provided an electronic log software package that is being evaluated with the anticipation of Controls group use in the next year.

A development that has received both hardware and software effort was the expansion of PC functionality. The successful CCS configuration of having separate production and development facilities is being followed for PCs. A simple NT server has been set up for each of the production and development activities. A SCSI tape drive from the control system computers was relocated for backups. Unfortunately, the PC hardware was not initially very reliable although after a number of failures were fixed these servers have run smoothly.

Miscellaneous

A project to provide hardware and software support for a PCI to CAMAC executive crate interface proceeded well. The initial implementations were completed by the end of the year and they are expected to be in service during the first quarter of the new year.

The second international Workshop on Accelerator Operations (WAO'98) was hosted by TRIUMF with some Web and database support provided by the Controls group.

OPERATIONAL SERVICES

Remote Handling

ISAC

By year end virtually all of Remote Handling personnel were committed to various ISAC construction jobs with responsibilities for target hall shielding, module services, TIS/RIB beam optics component assembly and alignment, remote handleable beam line sections and pre-separator services as well as an interim shielded low level handling facility for removal of the first irradiated CaO target assembly.

Design of the new ISAC target handling hot cell is near completion. Work will begin on construction immediately following wrap-up work on the completed ISAC jobs. The target hall crane is now manually operable by wireless remote, although not fully commissioned.

Cyclotron servicing

During the single shutdown for the year a routine operation of personnel shadow shielding was installed and the 2C extraction probe removed for servicing.

Cyclotron elevating system

Routine maintenance was performed on the elevating jacks and gear reducers during the shutdown.

Beam lines servicing

During the winter shutdown assistance was given with removal of the neutrals mask probe and valve on exit horn #4. A remote handling indium vacuum blank-off was installed at this location.

A leaking monitor drive feed-thru required replacement of the 4VSM2/4VB1 indium seal.

A new water cooled window was designed, built and installed in the 2A proton beam line. This and other remote handling equipment were developed for use in the ISAC radioactive ion beam line and for handling of the ISAC pre-separator magnet.

Hot cells and targets

During the year the 1AT2 Mk-II target twice required replacement of a lower C-seal in two separate incidents. The 1AT1 Mk-I also required a lower C-seal replacement. The T2 Mk-I target required a rebuild of the target positioning gear box drive. The M9 beam blocker also experienced an air leak and required replacement of the vertical drive seal.

The T1 target cooling package was upgraded this year for improved operation, and a new design of expansion tank installed on both T1 and T2 packages.

Support was given to beam line 2C operation by replacement of the de-ionizer resin, repair of resin can, and repair to the 2C target handling shielding flask door.

In the lab a series of heat/strength testing was performed on MYKROY insulator material and a new vacuum brazing oven was set up and used for carbon target development.

Magnet Power Supplies

1998 saw the installation and commissioning of the remaining power supplies which were required for beam transport through the mass separator of ISAC. This included 2 bender power supplies which were acquired from Chalk River.

Routine maintenance and experimental support was carried out with leaking pass banks still being a major activity.

Coming out of the fall shutdown, difficulties were experienced with the main magnet power supply which was no longer regulating, and delivering only about 90% of normal current. A solution was found which was the independent powering of the master/slave amplifier boards as opposed to the previous connection which was to the raw dc supply for the driver stage. Due to the high gain of the system, eliminating the noise present on the raw dc supply for the pre-driver and amplifier resulted in much more stable operation of the supply which is now almost an order of magnitude more stable than previously with the precision feedback loop provided by trim coil 54 disabled. As well, during turn on, there is now a smooth transition from ramp up, to regulated current. This can be seen by monitoring the collector emitter voltage of the pass transistors which goes smoothly from near saturation during the ramp up to normal regulating voltage of roughly 7 V. Previously one had always seen a transition from near saturation to roughly 14 V as the current set point was reached and then after a minute or so the Vce would settle down to the normal 7 V.

Difficulties were experienced on the BL1A supplies which caused a number of beam trips. The problem was traced to the 1AQ10 supply which was repaired. Primary beam line supplies will be examined and recalibrated during the spring shutdown.

Electrical Systems

The major effort of the electrical department was the support of the ISAC project, which is described in the ISAC chapter of this Annual Report. Other responsibilities included the CERN project, cyclotron operation, maintenance of the site electrical services, power delivery and engineering support to TRIUMF users. Additional activities started and/or completed during the year are listed below.

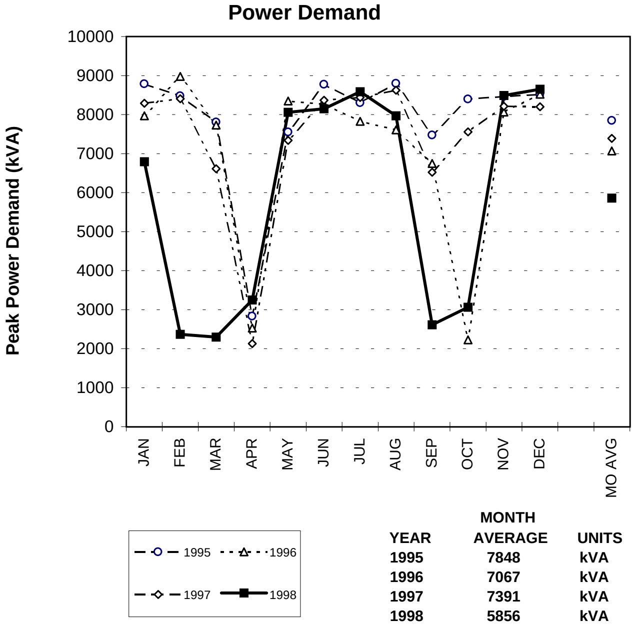
- Installation and commissioning of the final stage of the fire alarm upgrade (cyclotron vault, service annex, proton annex and extension), including a fully supervised style 7 communication with the fire department.
- Replacement of half section of cyclotron vault lighting. The other half will be installed in the 1999 winter shutdown.
- Improvement of the outdoor site lighting.
- Replacement of the obsolete main power distribution centre in the radiochemistry laboratory. Given the importance of production losses, a careful plan was drafted and the system was re-energized in a record 7 days.
- Modifications to the services in the clean room 112 required by Nordion for new radioprocessing equipment.
- The trouble-plagued Elgar 37.5 kVA UPS system installed in the service annex was finally phased out and replaced with a modern MGS 50 kVA system. This new unit will provide much needed power to the electronic loads located in the accelerator building. Another locally dedicated 10 kVA UPS unit was added to the cyclotron data acquisition computer system.

Routine maintenance included lighting, power distribution centres, motors and transformers. An investigation of the non-active low conductivity water pumping system, which tripped a few times, revealed that the change of pump impeller increased the power requirements. Temporary modifications were introduced to continue operation to the winter shutdown when higher HP motors will be installed.

Power delivery

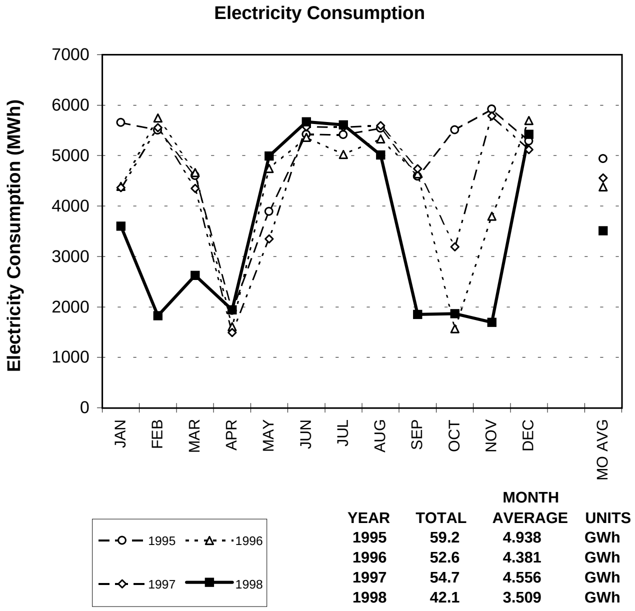
A transmission line bridge was installed by BC Hydro and UBC between lines 60L56 to UBC and 60L57 to Discovery Park. The new link is not a fully redundant feeder, but it offers greater continuity of service should a fault occur on the BC Hydro side of the transmission line. In case of loss of line 60L57 (from Camosun substation to Paprican), TRIUMF will no longer be subject to the 1.5 MW power restriction and may continue regular operation, after a brief shutdown for switching over.

Power management continued as routine work. The start-up of the ISAC facility is evident in the increased power demand and electricity consumption. To make possible the construction of the ISAC facility, the cyclotron was shutdown for a longer period of time. This is reflected in the large decrease both in the average peak power demand, –21% from 7391 kVA to 5856 kVA (Fig. 115) and the electricity consumption, –23% from 54.67 GWh to 42.11 GWh (Fig. 116). The average monthly electricity consumption was 3509 MWh. However, both kVA and kWh increased during the operating months as the ISAC systems started operation. The annual average load factor decreased 6.2% to 81.4%, primarily due to increased problems with cyclotron cooling services and the main magnet. The annual average power factor (PF) edged up 0.5% to 97.1% (Fig. 117) thanks to the larger number of shutdown months, which have a much higher PF value. The average PF for an operating month decreased about 0.8% to 95.4%. Additional capacitors will have to be installed during next year to limit the peak power demand at current values. A 1% power factor decrease corresponds to an additional power bill of about \$8000/year at 8000 kW demand, assuming 8 months of beam production.



YEAR	MONTH AVERAGE	UNITS
1995	7848	kVA
1996	7067	kVA
1997	7391	kVA
1998	5856	kVA

Fig. 115. Electrical system power demand – four year comparison.



YEAR	TOTAL	MONTH AVERAGE	UNITS
1995	59.2	4.938	GWh
1996	52.6	4.381	GWh
1997	54.7	4.556	GWh
1998	42.1	3.509	GWh

Fig. 116. Electrical system energy consumption – four year comparison.

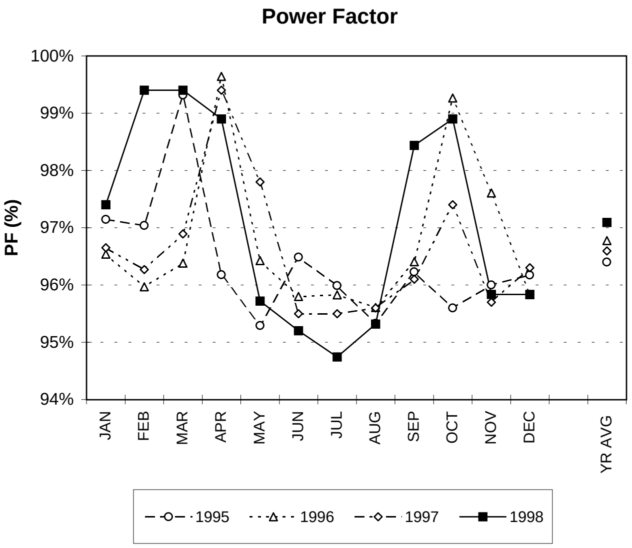


Fig. 117. Electrical system power factor – four year comparison.

Mechanical Systems

Activity was divided between ISAC work and the remainder of the site. ISAC work consumed almost 90% of the time.

The TRIUMF-related work included: machine shop exhaust system upgrades in three areas, the replacement of the Al ALCW pump with a temporary pump while awaiting delivery of a new one, new air conditioning for the telephone exchange room, new exhaust system for the carpenter's shop, repair of the GERBER room air conditioner, check calculation and certification of hoist beam in MESA basement, tie-in of the new ISAC air compressor to the TRIUMF air system, and studies for new uses of the medical annex and MESA.