ANNUAL REPORT
1986

SASKATCHEWAN ACCELERATOR LABORATORY
UNIVERSITY OF SASKATCHEWAN
SASKATOON, SASKATCHEWAN, CANADA
S7N 0W0
ANNUAL REPORT

1986

Saskatchewan Accelerator Laboratory

Saskatoon, Saskatchewan
Canada
S7N 0W0
# Saskatchewan Accelerator Laboratory

## ANNUAL REPORT

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Preface

The highlight of the past year was the commissioning of the injection line and the transport of the beam to the end of the South leg of the pulse stretcher ring. We had hoped to store the beam before the release of this report but feel confident that that milestone is imminent. We still expect to have our first extracted beam early in 1987. Thus the main thrust of our effort is now moving from the machine to the experimental equipment. In this area we are greatly encouraged by the collaboration of groups from other parts of Canada and the world.

Henry S. Caplan

1st November 1986
I. ADMINISTRATION

A. Introduction

H. S. Caplan

We have now completed the third year of the upgrading project to convert our conventional linear accelerator to a 300 MeV CW electron beam facility. The original Natural Sciences and Engineering Research Council (NSERC) grant in 1983 was for the following items:

- An energy compressor to improve the spectrum from the linac.
- A pulse stretcher ring to give ~ 100% duty cycle.
- A modern QDD spectrometer for efficient data taking.

Over the last three years the following items have been added to the project:

- A VAX11-785 computer (from NSERC) for design and simulation computation.
- A photon tagging spectrometer (with the University of Montreal and from NSERC) to give a monochromatic photon facility.
- An RF system for the ring (from contingency) to give us the capability to store the beam.
- A 44 inch spectrometer (from HEPL, Stanford) to serve as a hadron arm opposite the QDD.
- A MicroVax II computer (with Trent University from NSERC) for data acquisition on the tagger.

The status of all these items and other equipment funded for experiments is discussed in the text of this report. More details on the parameters of the various components may be found in previous annual reports (1984 and 1985).

The 1984 report also describes the administrative structure of the project and how the performance of the laboratory is evaluated. Part of that supervisory structure is NSERC's Saskatchewan Advisory Committee. That committee visited the laboratory on 10-11 April 1986 and sent a satisfactory report to the presidents of NSERC and of the University of Saskatchewan. One more visit of this committee is expected at the completion of the project.
B. Project Management

D. M. Skopik

1. Pulse Stretcher Ring

Good progress has been made since last year’s annual report. The link between the injection line and the ring has been completed with the installation of the six and two degree septa. The septa were tested and beam was injected four meters into the ring at the end of September. Two weeks later the beam was transmitted completely through the south drift line. This testing was done only on weekends in order not to interrupt the remaining installation jobs. Using the results of these tests we made minor modifications to the tune lines that are used to set up the injection system, and re-surveyed the two degree septum in order to better establish the external alignment offsets. These external offsets are crucial since this septum is entirely inside the vacuum system and must be translated by 10 mm for various injection mode tests. Further tests with the electron beam will be made in the next few weeks as time permits.

The PSR installation is essentially complete except for the fast kickers and the electrostatic septum. Both of these jobs however are well underway and do not present major obstacles at this time. The mechanical work associated with the kickers will be completed by early November, while the electrostatic septum will be in its final stage of completion by the end of November. The electrical work for the kickers has been given a high priority and should be completed by the time we need them.

The final precision alignments (100 micron level) of the RF cavity and the East bend were delayed until the very last since the cavity cannot be connected to the PSR vacuum line until the final bake-out of the Linac drift line is completed, and the East bend final alignments are presently being done. The remaining installation job is that for the first fast kicker which will be underway shortly. We plan to install and thoroughly test the first kicker before re-opening the vacuum system to install the second. The ring will be commissioned using single turn injection for which only one of the kickers is employed.

Gantt charts of the PSR installation are shown in Fig. I.1. Overall the project has slipped by about six months compared to our estimate of October 1982.
2. Extraction Line

The major installation and fabrication tasks have been defined, and we are presently putting together the level-4 tasks that are generated with the detailed work sheets. The magnetic septa have been detailed and are scheduled in the shop workload. The support structure for the extraction line elements has been designed and is in the process of being detailed.

The magnetic elements for the extraction line are now expected to be shipped in November. Most of the ancillary purchasing was anticipated and was incorporated into the PSR orders.

3. QDD Spectrometer

The building modifications have been completed and a support ring/gear for the spectrometers has been installed. The platform that the QDD rests on is finished the spectrometer itself was delivered from Scanditronix on October 23.

4. Financial Statements

H. S. Capian

As is to be expected near the end of a project, nearly all the available funds have been committed. Over the past three years we have received from NSERC installments totalling the $5,800,000 promised. The interest on the cash flow which has accrued plus that projected to the end of the project is estimate to be $925,100. Thus on Table I.1 we see a total budget of $6,725,100 of which $6,402,300 is committed leaving a balance of $322,800. Our current best estimate of items yet to be procured is $316,800 and the calculated contingency on these items and on the outstanding orders ought to be $76,200. It is clear that this budget is slightly overspent with a variance of -$70,200.

It should be pointed out that a considerable number of items in the original budget have been red-lined to achieve this close match with the funds available. Mercifully most of the red-lined items have been made up from in house surplus equipment or are not essential for the operation at this time.

The operating budget (NSERC's Infrastructure Grant) is in rather worse shape due, for the most part, to past sins. This is summarized in Table I.2. One reason for this situation is that the manpower in the laboratory rose faster than the operating grant during the initial phase of the project. Manpower is still our dominant operating cost and amounts to almost two thirds of our budget.
TABLE 1.1
Major Installation Grant Status

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<td>Expended</td>
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<td>$ 322,800</td>
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<td>Balance required</td>
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<td>316,800</td>
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<td>Contingency required</td>
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<td>Total required</td>
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<td>393,000</td>
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<td>Variance</td>
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<td>-$ 70,200</td>
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TABLE 1.2
Infrastructure Grant Status

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<tr>
<td>Amount of award (1986-87)</td>
<td>$ 1,497,280</td>
</tr>
<tr>
<td>Projected expenditures to year end</td>
<td>1,535,800</td>
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<tr>
<td>Projected deficit for year</td>
<td>38,520</td>
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<td>Deficit carried forward from previous years</td>
<td>173,692</td>
</tr>
<tr>
<td>Projected cumulative deficit</td>
<td>$ 212,212</td>
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</table>

5. Manpower

H. S. Caplan

The level of non-academic manpower in the laboratory has remained constant in the past year. There is still a great deal of work to be done to install and commission the tagger, the remaining beam lines and the spectrometers. Thus it is unlikely for our manpower level to decline in the next year. However, once the experimental programs are underway some of our temporary staff may not be required.

On the academic side, the university still has not authorized a new faculty position. This is singularly unfortunate as our need for dynamic young physicists is increasing as we move from accelerator building to the instrumentation and execution of experiments. Fortunately, we have been able to add one post-doctoral fellow and one research associate in the past year. Also, we are helped by the fact that user groups are starting to send their own people to the laboratory to do the groundwork for future experiments.
6. Summer Students and High School Teachers

H. S. Caplan

Each year the laboratory employs about half a dozen undergraduate students to help during the holiday season and to encourage them to enter graduate school in Nuclear Science. This year the jobs available matched very well with the students employed and both parties were well pleased with the results.

Last year we instituted a summer program for high school teachers to try to improve the quality of physics teaching in the Province of Saskatchewan. This year we decided to continue the program and another two teachers were given the opportunity to work at the laboratory during the summer. By giving these people the chance to see how research is carried out in a high technology environment, they are better equipped to transmit the enthusiasm and excitement of science to their pupils. Once again the program worked very well. The teachers got the expected boost and the laboratory got considerable useful work out of them.
II. NEW CONSTRUCTION

A. Conventional Construction

H. S. Caplan

1. The QDD and Tagger Halls

Last year we described plans for major changes in the halls to house the QDD and the tagging spectrometers. Briefly the plans were to lower the floor of the hall for the QDD by 2.2 m to fit the spectrometer into the space and to introduce the necessary vertical dispersion on the target without the use of a rotator. To house the tagger, the plan was to remove the massive shielding from our Neutron Cell and create a room just large enough for photonuclear experiments. This work was completed very efficiently by the contractor by March 3, 1986.

In light of our previous bad experience with construction work contiguous to the installation of equipment, we took great pains to seal the areas where concrete breaking was going on. This included disabling or removal of transfer fans and the sealing of ducts. This work paid off abundantly as we had no problems of contamination of vacuum or RF gear by dust. The only delay incurred was in alignment tasks which had to wait until the building settled following the replacement of the overburden.

Needless to say there were a few changes introduced as the work progressed. In the QDD hall the spatial constraints are very severe and the only change was in the beam dump area. Here slightly more space was generated and a niche for the dump quadrupoles was introduced. In the Tagger Hall the changes were more significant. Most important of these was the decision to lower the floor of the room by 61 cm to accommodate tall cryostats or detectors. Figure II.1 shows the current design of this area.

Other changes in the building include the upgrading of cranes to lower and install the QDD spectrometer and the Tagger. These cranes now have 10 tonne capacity which was the limit achievable without total replacement and structural changes in the building. A more minor change, but one which required considerable effort, was the installation of shielding block walls to accommodate the changed distribution of radiation sources in the accelerator vault.
Figure II.1
The tagger hall
2. The New Power Source

Right from the outset of the upgrading project, it was clear that more electrical power capacity would be required. The current transformer and switchgear can handle only 0.8 MW while the calculated load with all systems flatout is 1.6 MW. It was therefore proposed to allow for some expansion by installing a 2 MW system. The problem was, "How is this to be funded?" After exploring several avenues, the University decided to pay for this system itself and most of the equipment such as main transformer, switchgear and high voltage components are on order. The installation is expected to be complete by February 1987. This does not represent a problem as there are no plans to run the ring and the QDD spectrometer simultaneously before that time.
III. ACCELERATOR OPERATION

A. Accelerator Operation

F. T. West and T. P. Dielschneider

The modification of the tagger and QDD halls precluded any running of the accelerator from mid-November 1985 to early March 1986. Before this shutdown there was the last experimental run using the old system. When the machine became available again in March the Injection Line was commissioned. More recently the beam has been dedicated to the testing of the injection septa and the south leg of the ring. The actual hours run is presented in Table III.1. Not shown are the long periods of RF conditioning required after each shutdown period.

<table>
<thead>
<tr>
<th>TABLE III.1</th>
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<tbody>
<tr>
<td>Accelerator Operating Hours</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>Mode</td>
</tr>
<tr>
<td>Beam testing</td>
</tr>
<tr>
<td>Low energy beam line</td>
</tr>
<tr>
<td>Injection beam line commissioning</td>
</tr>
<tr>
<td>Experiments</td>
</tr>
<tr>
<td>Injection septa and south leg tests</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

B. Transmitter Improvement

Our linac has six transmitters for its six sections but these transmitters are housed in only three cabinets. A major problem of this design has been cross-talk between the pairs of transmitters sharing a single cabinet. In the summer of this year, English Electric Valve Company, which is supplying thyratrons for our injection kickers, asserted that they had a solution to the cross-talk problem involving the use of their tubes. Although the problem did prove a little more refractory than anticipated, EEV engineers did succeed in solving it. One pair of transmitters with their thyratrons is now being life tested. Although there is no doubt that the transmitters operate better, the cost of the thyratrons is considerably higher and we will wait for the results of the life tests and the award of our operating grant before deciding whether to change over the remaining four transmitters.

The presence of these engineers also helped with other transmitter problems including the de-Qing. Again a change to EEV tubes was involved. However in this case there was also a cost saving.
C. Accelerator Control

Until recently the accelerator control was separate from the control system developed for the ring and the rest of the upgrading program. The accelerator was controlled by a PDP11-55 coupled to CAMAC by an MBD micro-computer while the rest of the system used a VAX11-750 and a CAMAC serial highway. We had no plans to change this system as it worked and we had plenty of other things to do. Unfortunately the upgrade became involuntary when the MBD failed in a dramatic and irreversible way. Thus the accelerator is now integrated into the rest of the control system on the VAX11-750.

D. The RF Source

The RF prime mover in our system for the last twenty odd years has been a Hewlett-Packard oscillator and frequency stabilizer. This vintage equipment is no longer supported by the company and even with two complete sets of the electronics, we have had considerable difficulty keeping one operational.

A new source system has been built using modern equipment and has been installed and tested. The system has a greater output power and is more stable than the previous source which will allow it to also drive the CW transmitter for the ring.

E. Temperature Stabilization

We are embarrassed to report that the perennial problem of precision temperature control is still with us. Although we know how to solve it, we still have not completed the modification of all nine heat exchangers involved. This is due in part to lack of operating funds and in part to lack of manpower due to the higher priority of the ring project. The mechanical parts of this job are being saved to fill in any hiatus in plumbing tasks.

F. New RF Drive System

Our dream of replacing our TWT based RF drive system with a klystron based unit is still dormant. We have discussed the problem with Thomson-CSF and they have a suitable tube. Again it is a question of the availability of funds which we have requested for the tube and the modulator.
G. The Energy Compressor System

There is little to report in this area other than the fact that the equipment has functioned correctly without problems through the running periods. A small change in the synchrotron light diagnostic system has been made to bring the light from all three ports to one camera. However the system is so easy to use that for the most part only the light from the central magnet is used.
IV. COMMISSIONING OF THE INJECTION LINE

A. The Injection Beamline

J. C. Bergstrom

The Injection Beamline transports the electron beam from the Energy Compressor (ECS) to the injection point of the stretcher ring. It consists of a phase-space telescope consisting of four quadrupoles, followed by a 180° bend, of which the second segment is tilted upward about 8° in order to direct the beam towards the injection septum magnets directly beneath the PSR lattice. The system was described in detail in last year’s Annual Report.

During the past year, construction of the Injection Beamline has been completed and the system has been commissioned with live beam. The results of these tests are summarized below.

1. The 180° Bend

This consists of two 90° cells, each cell in turn is constructed from two 45° dipoles and five quadrupoles. As originally designed, the phase advance across each cell (in the vertical and horizontal planes) was supposed to be \( \Delta \phi = \pi \). To achieve this, the quadrupoles of each cell are grouped into two families, with slightly different field excitations between the families.

The preliminary tests revealed that the required phase advances could only be achieved if the two families of quadrupoles were powered such that the relative strengths deviated by roughly 3% from the theoretical ratio as based on the measured characteristics of the magnets (i.e., effective lengths, etc.). Optical studies showed that the only mechanism which could cause such an effect would be an error in the fringe-field parameter \( K_1 \) of the dipoles: the study suggested a value \( K_1 = 0.49 \), compared with the value \( K_1 = 0.57 \) as supplied by the manufacturer. The 180° Bend was subsequently partially dismantled and the \( K_1 \) value measured in-house (see Sect. V.B). The result obtained was \( K_1 = 0.51 \). With this value, the system is now behaving well within our design specifications.

While these tests were proceeding, optical studies revealed an alternative operating mode for the 180° Bend, which has now been adopted as the principle operating mode. In this new mode, the phase shifts across the Bend are not exactly \( 2\pi \), and the transform is no longer a diagonal unit matrix. However, the phase advances between a steering coil judiciously located near the entrance of the Bend, and a view screen near the exit, are exactly \( 2\pi \). This has made the tune-up procedure extremely operator-friendly: the two families of quadrupoles are adjusted until the oscillating field of the steering coil produces no visible motion in either plane at the view screen.

Besides simplifying the tune-up procedure, the new mode greatly improves the system optics, in two respects.

i) The mixing of the x- and y-plane phase spaces is now negligible (this is introduced by the tilt of the second 90° cell);
ii) Emittance growth caused by residual dispersive effects at the injection point is under much better control.

Implementation of the new mode has already made one piece of hardware obsolete. That is Tune-line 2 described in last year’s Annual Report.

2. The Injection Septum Magnets

The beam is deflected vertically into the PSR by a pair of septum magnets. The first deflects through an angle of $6.1^\circ$, and the second $2.1^\circ$. The latter magnet has an aperture of only 12 mm, and is 1.0 m long. The first “target” in the PSR is a view screen about 3 meters after the $2.1^\circ$ septum magnet.

After several days of effort the first real milestone was achieved on October 1 (at 2:15 a.m.!) when the beam was delivered to this view screen. However, all attempts to shift the beam spot to the correct position on the target failed. Having duly noted the influence (or lack of it) of the various steering coils, and the field settings of the septum magnets, the situation was reconstructed with our off-line optical codes, and the cause of the problem was discovered within a day. The next trial with live beam (October 26) placed the beam exactly on target, following a modified tune-up procedure suggested by the aforementioned off-line study.

During the same trial, the PSR quadrupoles were activated for the first time, and beam was successfully transported to the far end of the Ring. Once again, some anomalies appeared which, at writing, are being reconstructed in our off-line codes.

The tests to date have taught us at least one valuable lesson: the ample number and critical location of our beam monitors allow us to reconstruct the anomalies and cure them without having to resort to endless “knob-twiddling” on the actual machine.
V. PULSE STRETCHER RING STATUS

A. General

H. S. Caplan

The first magnets for the ring arrived a little under a year ago and the last elements arrived in March of this year. During the reporting period all these magnets have been tested and a representative sample have been mapped. They have been installed, aligned, powered, cooled, controlled, and interlocked. The vacuum system for the ring has been built in-house, installed, leak checked and baked-out. The diagnostic beam monitors have been developed, built, installed and even used in some cases. The novel RF system has been assembled and tested at low power. The state of the art injection kickers have been assembled on the bench and dismantled for final assembly in the ring. The control system and its software, which seemed so remote a year ago, were actually used in the beam tests described in the previous section. Even the running of the parallel simulation programs, which some had regarded as science fiction, actually occurred during these tests. These achievements are reported in more detail in this section.

B. Magnet Measurement and Calibration

Emil Hallin

The automated control of EROS ring elements has required the measurement of several of their ion optical parameters. The inhomogeneous fields were measured with an xyz manipulator and Hall effect probes while the homogeneous fields were measured with a CERN-type NMR probe. The status of the field determination for each of the major optical components of EROS is summarized below. As a result of these measurements the beam can be found in actual operation by setting the individual elements to the nominal values (predicted by TRANSPORT) using the calibration curves as described.

1. Injection Dipoles

The early installation of the injection dipoles prevented an exhaustive map of the fringe field of these elements. However, the location of the effective field boundary and the measured fringe field "K1" value were determined for a representative injection dipole. The "K1" value was found to be different from that specified by the manufacturer but consistent with the actual optical performance of these magnets.

The first two of these magnets define the beam energy prior to injection into the ring. The homogeneity of their fields was measured and found to be better than the design requirements. A field versus power supply setting calibration curve was determined for a carefully controlled and reproducible field setting procedure. A third order polynomial fit to this curve allows the machine operator to specify the momentum of the particle to be transmitted along the main optical axis through these first two magnets. This curve was not determined for the
remaining two injection dipole magnets, since the difference between the two measured magnets is small enough that an "average" is an adequate approximation for the control of the other two. This scheme has worked well in practice.

2. Ring Dipole Magnets

The fringe field "K1" values and the location of the effective field boundary have been determined for all eight of the ring dipole magnets. A field versus power supply calibration curve has been determined for four of these magnets (those in the "east bend") and will be installed in the machine control algorithm in a similar way to that for the injection dipole magnets. The west bend will be measured in the near future. For each magnet, a reference calibration at each power supply setting was established by measuring the voltage across a precision shunt.

3. Ring Quadrupoles

There are 28 quadrupoles in the ring, of which 7 have been measured with Hall effect probes. The measurements have allowed the determination of the effective length of these ring elements, a comparison of their geometrical and magnetic centers and the determination of the field gradient versus power supply setting calibration curve. Only seven elements were measured since, within the measurement error, it was not possible to distinguish any systematic differences among them. The machine operator can specify a required poletip field for the ring quadrupoles.

4. Ring Quadrupole/Sextupole Combined Elements

There are 18 quadrupole/sextupole elements in which the quadrupole and sextupole components can be independently adjusted. Five of these elements have been measured with Hall effect probes, for both the quadrupole and the sextupole components. The quadrupole measurements were comparable to those described above, as were the sextupole measurements with the exception that, in the latter case, the calibration curve of interest was the field second derivative versus power supply setting. This information will be installed in the ring control algorithm so that the operator can specify equivalent poletip fields for these elements.

C. Alignment

D. N. Craddock, J. A. Greefkes, H. Purdie and D. M. Skopik

The alignment effort for the EROS project this past year has concentrated on the following items. We needed to:

- Establish a reference to determine the ring height.
- Locate the basic ring network, i.e., the four corner points and the accelerator center line.
- Install and reference secondary fiducials.
- Locate all the new components; ECS, INJ and PSR at the appropriate locations in the network.
The alignment network is now firmly established with only some of the lateral offsets from secondary pins yet to be determined. Additional references relative to the Ring datum have been installed in the Tagger and Spectrometer rooms.

From the first round of Injection line tests we concluded that some of the magnetic elements were misaligned. An alignment audit was carried out and confirmed that some of the quadrupoles and two of the dipole magnets were outside of the installation specifications. A complete realignment of the injection line elements was done using offset techniques, since the vacuum system could not be conveniently removed. The most recent injection line setups with the electron beam were done using intermediate steps that impose very stringent alignment tolerances in order to be successful. In our earlier work with the injection line we were not able to completely accomplish these steps; now we are.

The alignments of the ring elements are nearly complete, the magnetic elements have been installed to ± 100 μm linear (x,y), and 0.05 mrad angular tolerances using in combination a laser system, precision optical devices, alignment bars and spirit levels.

Another region that provides a severe test of alignment quality is the injection point where the beam is brought up from the level of the linac and inserted off-axis into the ring. We were able to accomplish this with relatively little effort by setting the septa and magnetic elements in the injection upswing to "book" values. The beam was transmitted through the septa and observed to be very close to the expected position. The remaining alignment job of note, which is nearly complete, on the PSR is that of the east bend magnets. We have postponed this task until the very last because we have observed some vertical shifting of the building due to the removal of fill over the old photoneutron cell that was renovated for the photon tagger. The building appears to be stable now, and our secondary reference levels in that part of the building have settled back to the earlier measurements.

D. Vacuum System

P. Freimanis

Throughout the development of the EROS project, machining, fabrication and installation techniques have greatly improved. In April a facility for the chemical cleaning of vacuum components was established. The procedures and equipment for this cleaning are being optimized as experience in this area is obtained. Prior to the installation of vacuum components, magnets had to be installed and roughly aligned. The ring vacuum system was closed in early September except for gaps on either side of the Haimson RF cavity. Beam pipe was used to temporarily replace outstanding components such as the electrostatic kickers. Only two leaks marred the vacuum system installation and we feel this is a vindication of the "keyhole" plasma arc welding technique developed to a fine art here at the linac. One leak was due to a manufacturers defect in a flange knife edge while the other was due to a weld stress crack. Note that magnet boxes and beam pipe required final welding in-situ due to the physical constraints of magnets.

The south leg of the ring was baked out for the recent beam tests and the resultant pressure achieved was 1.0×10⁻⁸ torr. This was measured by a residual gas analyzer and was due
almost equally to the partial pressures of water and hydrogen. Other residual components were in the noise on this pressure scale. This gives us confidence in the cleaning techniques we have adopted and that the ultimate pressure will be low enough to store beam. It is worth noting that in order to achieve this we had to adopt the suggestion made by Dr. Paterson of the Saskatchewan Advisory Committee to vent all roughing pumps to the outside. This fume exhaust system was completed in July. Prior to this the "fingerprint" of rotary pump oil was clearly shown by the residual gas analyzer. The roughing system uses a turbomolecular and rotary vane pump as the foreline pump. This system is directly connected to the "Seiko Seiki" turbos which are near the injection and extraction points.

Recently we began to bake out the north leg of the ring as part of our plan to thread the beam round the ring in steps. At this point a totally unexpected problem arose which caused a change in planning and introduced significant delay. Our vacuum system design uses ten expensive all metal VAT valves. One of these valves failed, then another and eventually four, at which stage all were removed. Since the four shock wave shutters were still operational, we decided to reclose the ring replacing the valves by spool pieces except for the gaps at either side of the RF cavity. Since segmented bakeout cannot occur now, additional heating equipment had to be ordered. Following this bakeout the RF cavity will be coupled to the ring after its final alignment in early November. This procedure has been adopted as we have no intention of heating the cavity and also do not want it to be the coldest part of the system during bakeout.

The present plan is to install all the remaining components including one injection kicker and try to thread the beam all the way round in one step. During this process the vacuum should improve sufficiently to enable us to attempt storing of beam in late November.

Final detailing is now underway on the extraction system and the remaining beam lines. Most components such as the electrostatic and magnetic septa are already being fabricated. Other components such as monitors were completed in advance as the total number required for the whole system was built as a batch. The work on the extraction line will have to await the arrival of the magnets (due in December 1986) while the other beam lines cannot be installed until after the delivery of the Tagger in January 1987. We feel confident that all ancillary components such as periscope boxes will be completed before they are required.

E. Beam Monitors

W. E. Norum

The beam monitors used in the laboratory are summarized in Table V.1.
TABLE V.1
Beam Monitors used in the Laboratory

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
<th>Principle</th>
<th>Where used</th>
<th>Int.</th>
<th>No.</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toroid</td>
<td>Pulsed beam current</td>
<td>Magnetic induction</td>
<td>Accelerator &amp; beam lines</td>
<td>N</td>
<td>10</td>
<td>Operational</td>
</tr>
<tr>
<td>Pop-up viewers</td>
<td>Beam position &amp; shape</td>
<td>Scintillator</td>
<td>Accelerator &amp; beam lines</td>
<td>Y</td>
<td>12</td>
<td>Operational</td>
</tr>
<tr>
<td>Synch light</td>
<td>Beam position &amp; shape</td>
<td>Synch light</td>
<td>ECS, beam lines &amp; ring</td>
<td>N</td>
<td>12</td>
<td>Operational</td>
</tr>
<tr>
<td>Spill</td>
<td>Detect beam impingement</td>
<td>Ionization</td>
<td>Everywhere</td>
<td>N</td>
<td>20</td>
<td>Development</td>
</tr>
<tr>
<td>NIKHEF</td>
<td>Beam position</td>
<td>RF phase</td>
<td>Injection line</td>
<td>N</td>
<td>2</td>
<td>Operational</td>
</tr>
<tr>
<td>Strip lines</td>
<td>Beam position &amp; current</td>
<td>RF amplitude</td>
<td>Ring</td>
<td>N</td>
<td>10</td>
<td>Development</td>
</tr>
<tr>
<td>Turn viewers</td>
<td>Beam position &amp; shape</td>
<td>Scintillator</td>
<td>Ring</td>
<td>Y</td>
<td>6</td>
<td>Operational</td>
</tr>
<tr>
<td>SLAC</td>
<td>Beam position &amp; current</td>
<td>RF amplitude</td>
<td>Ring run outs</td>
<td>N</td>
<td>2</td>
<td>Operational</td>
</tr>
<tr>
<td>Thermocouple</td>
<td>Detect beam impingement</td>
<td>Temperature rise</td>
<td>Everywhere</td>
<td>N</td>
<td>&gt;100</td>
<td>Operational</td>
</tr>
<tr>
<td>Wire scanners</td>
<td>Beam position &amp; profile</td>
<td>Secondary Emission</td>
<td>Beam lines</td>
<td>~Y</td>
<td>6</td>
<td>Operational</td>
</tr>
</tbody>
</table>

Of these the Wire Scanners, Turn Viewers, Synchrotron Light and Strip Lines have received the most attention over the last year and are discussed here.

1. Monitor Computer

A Digital Equipment Corporation LSI-11/73 computer has been assigned to acquiring and displaying the data from all monitors but the thermocouples and pop-ups which are handled by the LSI-11/21 protection computer and by closed-circuit television, respectively. The monitor computer drives an auxiliary crate controller on the control system serial highway (see Fig. VI.1). A shared memory module in the crate provides communication between the monitor and control computers. All monitor data acquisition CAMAC components are located in this crate.

2. Wire Scanner Monitors

These monitors produce a beam profile by measuring the secondary emission from a 30μm L-shaped carbon wire as it is passed through the beam. The wire is driven by a stepping motor and a lead-screw with position feedback provided by a linear potentiometer attached to the scanning frame. The signal from the wire is passed through a charge-sensitive preamplifier, a peak-sensing sample and hold amplifier, and an analog to digital converter. One monitor is located in the ECS, two at the beginning of the injection line, one just before the injection point, and two in the ring just after the injection point. A seventh monitor will be located in the extraction line.

Considerable effort has been expended on the development of signal-processing electronics and software for these monitors. Initial profiles were obtained in March and the monitors are now becoming a routine part of setting up procedures.
3. Synchrotron Light Monitors

There are eight synchrotron light ports, one on each dipole magnet, on the two ends of the ring. Each has a periscope and can be equipped with an ordinary TV camera. In addition we have obtained a gated TV camera capable of taking a snapshot of one turn of the beam (300 ns). This camera can be used on one port to check successive turns to set up the injection. A pair of these cameras will be used on separate ports for phase space measurement. The signal from the cameras can be displayed on a television monitor or digitized and processed by the monitor computer.

The gated cameras and video digitizer have been bench-tested and preliminary acquisition software has been written.

4. The Turn Viewers

These are beam intercepting Al₂O₃ screens for setting up the ring as a beam line. The horizontal tune of the machine is close to the one third integer resonance and with the normal off axis injection there are places in the ring where the first three turns are well separated horizontally. The turn viewers are located at these places and each viewer can be positioned to intercept the first, second or third turn only. This implies that for commissioning the ring the beam can be threaded three times round the ring as a beam line before non-intercepting monitors need be used. The monitors have been installed and integrated into the control computer software. The drive and feedback mechanisms are similar to those used on the wire scanner monitors.

5. The Strip Lines

These monitors consist of four 3λ/4 antennae parallel to the beam. The 2856 MHz signals from opposing pairs of antennae are compared to obtain the position signal. Since the amplitude difference between these signals is small, it is converted to a phase difference which is easily measured after down converting from 2856 to 100 MHz. These monitors have been installed in the ring and the detector electronics have been bench-tested. The next step will be a series of pulsed beam tests although precision results are only to be expected with a CW beam.

These monitors double as tune monitors in storage ring mode. Here the signal from a single antenna is detected and fed to a spectrum analyser. This measures the frequency domain response corresponding to a pulsed perturbation.

Our ring has the combination of a high RF frequency and a large diameter beam pipe implying that the pipe can transmit the fundamental 2856 MHz RF as a waveguide and give spurious signals to the monitors. The problem was addressed by installing a ‘fish-trap’ RF attenuator in the beam line before each monitor.
F. Ring RF

T. P. Dielschneider

The EROS project requires an RF system capable of meeting the following specifications:

- $f_0 = 2856$ MHz
- $V_{\text{cavity}} = 45$ kV
- $I_{\text{beam}} = \text{up to 500 mA}$

A travelling wave structure was seen as the best way of coping with the problems of high beam loading and the resulting heat dissipation. A small S-band structure was designed and built by Haimson Research Corporation of Palo Alto, Calif. This device has the following properties:

- Number of cells = 11
- Effective length = 38.5 cm
- Shunt impedance = 32.5 M$\Omega$/m
- Attenuation parameter = 0.035 nepers/m
- Unloaded Q = 12750
- Beam aperture = 4.0 cm.

This structure has an interesting quality in that the phase velocity of the RF wave is less than the speed of light. This serves to reduce the effective beam loading in much the same way non-resonant operation of a standing wave cavity does. Even so, power requirements remain rather high.

Power studies have been done to determine how much RF drive will be needed for optimal performance of the ring. At 300 MeV with 500 mA of circulating current, about 10 kilowatts of power is needed. Unfortunately, difficulties exist in building a 10 kilowatt CW driver at 2856 MHz since klystrons at this power level are not commercially available. This problem will eventually be overcome through custom building of a source or summing the output of several 1 kilowatt klystrons that are available. In the interim, a 2 kilowatt amplifier has been built based on Thomson TH2047WW 1 kilowatt tubes. Studies have shown that this power level will accommodate about 250 mA of circulating current.

All components for the Ring RF are now in Saskatoon and assembly of the EROS RF system is essentially complete. The RF system can be broken down into four major areas of development:
• Travelling Wave Accelerating Section
• 2 Kilowatt Transmitter
• Klystron Power Supply
• Controls

The travelling wave accelerating structure was delivered on July 4, 1986 and installed in the ring. Cold tests done at the factory showed good higher order mode performance. These tests will be verified under actual beam conditions.

The RF transmitter consists of 2 one kilowatt CW klystrons supplied by Thomson-CSF. The klystrons arrived on March 24, 1986 and are now installed in the transmitter location next to the accelerating structure in the ring. The only delay in completing the transmitter is the perennial problem of cooling water. Upon installation of the heat exchanger needed to provide the necessary cooling and temperature stabilization, high power RF tests will begin.

The high voltage DC power supply required to drive the CW klystrons was custom-built by ORAM Electronics and delivered to the laboratory on May 23, 1986. The power supply was damaged in transit and initial testing showed unacceptable performance as the stability specifications were not met. The problem was eventually diagnosed and solved but a good deal of time was lost. The power supply is now fully tested and has been interfaced to the EROS control and protection systems.

Precise control of the CW RF drive phase and attenuation is critical to proper operation of the transmitter. Operation of extraction mode in the ring requires voltage modulation of the RF. The control system which will allow this to take place has been tested at low power and works very well. Further testing of the voltage modulation will occur upon successful high power commissioning of the RF transmitter.

G. Kickers
C. E. Figley

The detailed design and major component procurement for the electrostatic injection kickers and high voltage power supplies has been completed. The kickers each consist of two parallel plates mounted inside a grounded box. The plates will be driven symmetrically about ground to as high as 33 kV, providing a pulsed electrostatic deflection field. Pulse risetimes will be approximately 5 microseconds, flat topped to 0.1 percent for 1 microsecond, with falltimes of less than 10 ns. Fall time jitter is expected to be about 5 ns.

The mechanical fabrication of the vacuum chambers is complete, and final assembly has begun (Fig. V.1). The deflection plates were manufactured in house and have been installed to ensure proper alignment. The high voltage feedthrough insulators and crowbar thyratrons have been attached to their respective mounting hardware and the overall dimensions checked to verify correct positioning (Fig. V.2).
The electrical layout of the pulsed power supplies consists of a charging triode connected to each plate, and a pair of crowbar thyratrons shunted across each kicker. Operation consists of setting the proper high voltage levels, gating the triodes and waiting for the voltage values to stabilize on the plates. Injection of the LINAC pulse occurs, and upon completion, the shunting thyratrons are fired and the electric field in the kickers collapses. The rapid discharging of the kicker capacitance when the thyratrons are fired ensures a very short fall time, and prevents the bulk of the circulating beam from seeing any differential field between the kickers. Representative portions of the control circuitry, filament power, bias supplies, trigger generators, and of the timing electronics have been completed and are undergoing testing (Fig. V.3). Preliminary results are very encouraging, with the design specifications being easily met. Installation layouts for the ancillary equipment have been completed and cabling and cabinet installation is proceeding. Testing of the kicker and kicker power supplies under DC conditions has already been carried out and testing under full power loading will begin the third week of November.
Figure V.1
Side view of kicker showing deflection plates

Figure V.2
End view of kicker showing thyratrons
Figure V.3
Electronics for the injection kicker
H. Theory Simulations

L. O. Dallin and R. V. Servranckx

Theoretical studies in many different areas of the ring have continued over the past year. These studies included tune and chromaticity measurement, low current extraction, and transverse RF resonance effects as well as on-going simulations of extraction to improve the quality of the extracted beam. A specialized program, VIEWR, has been written to show the predicted position and shape of the beam at all monitors in the ring. This program along with the improved DIMAD have already been used in the ring commissioning.

1. Tune and Chromaticity Measurements

Various techniques of determining the machine tunes in EROS have been studied through computer and bench-top simulations\(^1\). Both the horizontal and vertical tunes can be deduced from the betatron motion in the ring as seen by a single detector. The betatron motion is present for several hundred thousand turns after injection or can be induced on a damped beam by using a pulsed kicker for less than one turn. The signals observed in the monitor can be analyzed by computer or by a spectrum analyzer to give the tunes. Another approach involves the use of a harmonic kicker acting on the beam over many turns. In this case, when the kicker is resonant with the ring tune, the beam amplitude will grow. The beam blow-up can be observed in one of the synchrotron light monitors. Either of these techniques should be able to provide tune measurements to an accuracy of \(10^{-4}\).

The design of both the pulsed kicker and the harmonic kickers to be used for tune measurements has been done using POISSON. These elements will be electrostatic and housed within the ring vacuum. A location has been chosen in the ring lattice and simulations have been done to determine the details of the engineering requirements of these elements. A single drift region in the ring has been reserved to house both horizontal and vertical harmonic kickers and the single pulsed kicker which can be operated horizontally or vertically.

The chromaticities can be measured\(^2\) by measuring the tunes at different beam momenta. To do so the ring must operate in storage mode for about half an hour. With tune measurements with accuracy of \(10^{-4}\) and relative momenta differences of \(10^{-3}\) the chromaticities should be determined to an absolute accuracy of about 0.2.

2. Low Current Extraction

The harmonic kicker used for tune measurements may also be used to kick a damped beam into a phase-space configuration suitable for extracting\(^3\). This mode of operation is useful for diagnostic purposes when it may be desirable to extract very low currents. As well, simulations have been done to investigate a method of preventing the beam from damping while being stored in the ring. This "anti-damping" also uses the harmonic kicker. Simulations\(^4\) done for the horizontal motion in EROS show that the combination of damping and the harmonic kicker can bring particles to an equilibrium betatron amplitude which is independent of the initial particle coordinates and dependent only on the amplitude of the kick used. By varying the kick amplitude over one revolution frequency of the ring it is possible to fill the phase-space with a variety of particle density distributions. Once an equilibrium has been reached it should be possible to slowly extract the beam using the achromatic extraction method (horizontal chromaticity, \(\chi_x = 0.0\)) or by using a strategically placed thin wire in the ring to scatter particles into the extraction septum. For scattering from a point on...
the closed orbit it can be shown that the scatterer must be located upstream from the septum by a phase, \( \Delta \phi \), given by

\[
\Delta \phi = \tan^{-1} \left( \frac{1}{\beta x' / x + \alpha} \right)
\]

where \( x, x' \), \( \alpha \) and \( \beta \) are the beam coordinates and the machine parameters at the septum.

3. Transverse RF Resonances

Approximate formulae have been derived for the vector behavior of lower order modes in the EROS cavity in the vicinity of the beam\(^5\). The effects of these modes were studied with computer simulations to determine what magnitude of transverse kicks can be tolerated as a function of possible mode frequencies. Table V.2 summarizes the modes studied.

**TABLE V.2**
Summary of Transverse Modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Electric field</th>
<th>Resonance</th>
<th>( A_{\text{max}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM(_{011})</td>
<td>( \vec{E} = A(x' + y') )</td>
<td>( \pm 2v_x(y) )</td>
<td>0.001</td>
</tr>
<tr>
<td>TM(_{111})</td>
<td>( \vec{E} = A \hat{x} )</td>
<td>( \pm v_x )</td>
<td>0.00001</td>
</tr>
<tr>
<td>TE(_{111})</td>
<td>( \vec{E} = A \hat{y} )</td>
<td>( \pm v_y )</td>
<td>0.000001</td>
</tr>
<tr>
<td>TM(_{211})</td>
<td>( \vec{E} = A(x - y) )</td>
<td>( \pm 2v_x(y) )</td>
<td>0.001</td>
</tr>
<tr>
<td>TE(_{211})</td>
<td>( \vec{E} = A(y\hat{x} + x\hat{y}) )</td>
<td>( \pm (v_x \pm v_y) )</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Here \( A_{\text{max}} \) is the value of \( A \) (mks units) that will result in a relative "emittance" growth no larger than 10% independent of the mode frequency. The vectors \( \hat{x} \) and \( \hat{y} \) define a horizontal and vertical position relative to the centre of the RF cavity. The most destructive mode frequencies would occur when the remainder resulting from dividing the mode frequency by the ring frequency is equal to \( 2\pi \) times the resonance condition indicated in the table. By avoiding the destructive resonances the tolerable kick amplitude, \( A_{\text{max}} \), can be about 10 times larger. If the mode frequencies cannot be adjusted in the RF cavity, some destructive frequencies could be avoided by changing the vertical tune, \( v_y \), of the ring.

4. Ring Simulations

Further simulations have been done with the normal extraction mode to improve the beam quality. Adjustments to the voltage modulation of the RF cavity have made possible duty factors up to 80%. As well, the horizontal emittance can be improved by operating at smaller chromaticities. The emittance, \( \varepsilon_x \), is now approaching 0.3 (\( \pi \)) mm-mrad for all operating energies.

In preparation for the commissioning of the ring, a program, VIEWR, has been written to show the position and size of the beam at any ring monitor for several turns after injection. The program also includes the injection line so that the effect of adjusting injection line elements can be seen at the ring monitors. Both injection and ring quadrupoles have been assigned to "single knob" control as defined in the commissioning reports\(^6\) for ease of simulating the commissioning procedure. At the same time, care has been taken to insure that all programs used to simulate activity in the ring have data files that are in agreement with the "as built" ring. In this respect, the ring elements were positioned with coordinates generated
from DIMAD.

5. Optics and Dynamics

By the end of 1985 the design of the ring EROS had reached the stage where further studies needed input from practical tests done on the machine. Efforts were concentrated on polishing the simulation tools.

The collaboration with the SLC (Stanford Linear Collider) beam dynamics task force proved very useful. The SLC project had reached about the same stage as the EROS project. From January to July, the SLC task force concentrated its work on the simulation of the behavior of the "real" arcs, that is arcs with likely errors and arcs with extreme errors. Though the results of that study may be irrelevant to EROS, the fact that the new simulation options were introduced in the program DIMAD\(^7\) has been very useful in the initial commissioning operations of EROS.

The development of DIMAD has enhanced its capability to serve as an on line control code. A simplified version of it is being used to simulate the Final Focus System of the SLC and is implemented within the computer control system. A full version, modified to include accelerating cavities, is being used at CERN for the simulation and control of the LIL linac and the EPA ring. Both are subsets of the LEP project.

In September and October a beam of 155 MeV was successfully guided through the injection ramp and the injection septa and then to the end of the first straight section of the ring. One aspect of the success of this part of the commissioning lies in the fact that the predictions of the simulation runs helped overcome some slight difficulties around the septa area. Actually it is the simulation runs that enabled us to design the proper procedure for injecting. When this procedure was implemented the beam went through the injection area relatively easily.

Work is still being done to make the simulations more user friendly at the control console.

The above results have given us confidence that the subsequent commissioning steps will proceed smoothly to the storage and pulse stretcher operation modes.

References

VI. COMPUTERS AND CONTROL SYSTEM

D. R. Murray

A. Introduction

Our goal of implementing a distributed computing system to handle all aspects of Laboratory work has been reached. Four VAX processors make up most of the system which includes a VAX-11/785, a VAX-11/750, and two MicroVax II computers. Although the number of processors is not expected to change in the foreseeable future, the peripheral hardware and software on the systems will have to expand to keep pace with the demands of the users. Considerable hardware and software changes have already occurred on the larger processors, and will soon occur on the MicroVaxes.

The people involved with computing systems at the Lab in 1986 included:

H. Buchmann
T. Dielschneider
C. Figley
D. Murray
E. Norum
A. Wilson
G. Wright

Three major applications of computers in the Lab will be discussed in the chapter; General Computing, Accelerator Control Systems, and Data Acquisition and Analysis Systems. The first two applications are handled by the VAX-11/785 and 11/750, respectively. The MicroVaxes are dedicated to data acquisition. The structure of computing in the Lab is shown in Fig. VI.1.

B. General Computing

1. Hardware

As the EROS project nears completion, an increasing number of physicists are turning their attentions from equipment development to experimental and theoretical physics. This change has made itself apparent on the central Lab computer, which is running more CPU intensive jobs than ever before. To meet these changing needs, the storage capacity of the VAX-11/785 has been doubled to almost 1 Gigabyte of disk space. The current configuration of this system includes:
A high density tape drive has been requested for 1987, to allow complete backups to be done, and permit easier communication with external users. The system has been very reliable, except for hardware problems in the spring of 1986.

Ethernet connects all VAX processors in the Lab. The relatively short physical distance between computers (<80 meters) has allowed us to simply connect the transceiver cables with a Local Network Interconnect (DELNI) unit from Digital Equipment Corporation. There is actually no ethernet coaxial cable in the Lab. Unfortunately, connection to the campus ethernet has been delayed but is still expected before the end of 1986. Until then we
continue to rely on dedicated telephone lines.

A computer assisted drafting system exists in the Lab, consisting of two personal computers running AutoCad software, and a high precision drum plotter. Although one computer had initial hardware problems, both systems are in constant use by the engineering and technical staff at the Lab.

A laser printer was purchased late in 1985, and almost 22,000 pages have been printed to date. A common format for technical reports and papers has been implemented and an elaborate cross reference and filing system has been set up in the computer by the administrative staff.

2. Software

In 1986, the operating system software on the VAX-11/785 changed from version 4.2 BSD UNIX to Digital Equipment's ULTRIX system, version 1.2. We encountered few problems with the conversion, because ULTRIX is based on the 4.2 BSD UNIX system that it replaced.

ULTRIX provides some new features, but most notably, it allows us to run a version of the VAX/VMS Fortran compiler. Although we have found a few restrictions with the compiler, it has essentially solved our problems with Fortran in the Lab. Most of our existing Fortran programs have been recompiled, and many of them execute 250 to 300 percent faster.

We have also received Decnet/ULTRIX software, which will allow convenient access to other ULTRIX and VMS systems on campus. DATAPAC, BITNET, and USENET already exist on the campus, and this software should allow us to access these networks directly.

The accounting and cable management software that was developed last year are working properly under the new operating system. A symbolic algebra system called MAPLE was installed and is being used for many applications. Graphics software will be acquired within the next year to handle the increased user need for graphics.

C. Accelerator Control

The CAMAC serial highway system which drives the control system is very close to its final configuration. There are currently 11 crates on the highway, which operates at 5 MHz. Only minimal hardware remains to be installed, along with associated cabling, for the extraction beam line, the transport lines and spectrometer areas.

A major setback was encountered early in 1986 when the MBD-11 parallel branch driver developed irreparable problems. This unit attached our PDP-11/55 computer to the existing CAMAC equipment on the Linac, and its failure left us with no control over the older system. After moving the CAMAC equipment into the new serial highway system, software was written to temporarily integrate the equipment into the new control system. The hardware and software work well in the new system, but the completion time of the final system has been delayed.
The protection mechanism of the control system has been working for some time, and authorized technicians have a convenient way to install or bypass various interlocks. Problems were caused initially by certain interlocks changing state very rapidly, flooding the system with event messages, and causing inter-computer communications to lock up. Small changes to the hardware and software have essentially solved the problem.

A small PDP-11/73 computer system is being used to interface beam monitors with the control system. Communication takes place through a CAMAC dual port memory module, identical to the one used for protection system communication. As mentioned earlier in the Report, a variety of monitors will be connected, and very fast measurements can take place with this specialized computer. Ideally, the VAX will do minimal processing of the data, because it need only issue a high level command and preprocessed data will be returned.

The database of signal information has been implemented, although small changes are being made as work proceeds. A database "editor" is being used to add new signals as hardware is installed. When a piece of equipment changes, the user need only change a particular element within the appropriate database record, meaning that the software itself will change very seldom.

The touch panel interface for the control room is close to completion. A portion of an accelerator map can be displayed and the user can indicate a desire to monitor or control something by merely touching the image on the display. Commodore Amiga computers are being used to drive the displays and accept commands from the touch panels, which are interfaced in conjunction with the mouse interface of the Amigas: Pointing and moving a finger is similar to clicking or moving the mouse. The mouse can be used if problems develop with the touch panel, but limited space on the control room tables prevent the mouse from being used permanently, and the operators seem to prefer the touch panels to the mouse for the purposes of control.

D. Data Acquisition and Analysis Systems

As mentioned, an increasing number of physicists are turning their attentions from equipment development to experimental physics. Accordingly, we have allocated more time to designing the computer systems that will acquire this experimental data.

Through the generosity of Digital Equipment of Canada and the University of Saskatchewan, the Lab was able to take advantage of a grant for computing equipment. After reviewing our project description and grant request, members of a joint committee were shown the Laboratory and in particular, plans for the data acquisition systems. Our proposal was accepted and the equipment was purchased over the course of several months, near the beginning of 1986.

We were able to purchase a MicroVax II system to instrument the QDD spectrometer, and with help from colleagues at Trent University in Peterborough, a second system based on another MicroVax II was designed, and the equipment purchased for the photon tagger. Each of the MicroVax systems will acquire data through a new serial highway interface, designed specifically for this Q-bus computer. The interface is from Kinetic Systems.
Corporation, and data throughput can be up to twice that of a regular serial highway running at 5 MHz, which is essentially the speed of a parallel branch. Technical information on this interface has been requested, and assuming favourable specifications, two of them may be ordered before the end of 1986.

It should be noted that in conjunction with the grant from DEC and our University, we purchased two other items: One was a second RA81 disk drive for our central VAX computer, to handle the large amounts of data that will be analyzed offline, and the second was all the ethernet hardware necessary for interprocessor communication.

1. QDD Data Acquisition

Plans for the serial highway system in the scatter room include at least two CAMAC crates for QDD wire chamber instrumentation. The serial highway system will only be connected to one crate, which will house the high voltage control modules for the wire chambers, and possibly scalers or ADCs which would be needed for the backup scintillators. In any case, an intelligent TDC (time to digital conversion) interface module will exist, which communicates with TDC modules in the second crate.

Such a TDC interface already exists, and we are encouraged by results to date. The system can be programmed to reject bad events due to channels which have timed out, or events with the wrong number of consecutive wire hits. For the wire chambers to be installed on a second spectrometer (hadron arm), the same TDC system could be used to interface a third crate of TDC modules, even though they would have separate start and stop pulses and calibration constants. Provision has been made for housing the CAMAC equipment and other electronics on the QDD spectrometer.

2. Photon Tagger Data Acquisition

Acquisition of data from photon tagger experiments will occur with a system very similar to the QDD system. A MicroVax II will be connected to CAMAC crates via a specialized serial highway system. The MicroVaxes should be interchangeable in every respect, giving redundancy to both systems.

Wire chambers on the electron focal plane of the photon tagger will be instrumented in the same way as the QDD chambers, although the layout of backup scintillators may increase the number of CAMAC crates. Because of the immense electron rates (\(10^7\) per second) on this set of chambers, the electronics must be triggered by the occurrence of a valid event on the hadron side of the tagger. Our plans include a front end processor which resides in a CAMAC crate to accommodate the large number of bytes expected per event. A large dual port memory will allow the preprocessor to communicate with the MicroVax, and allow it to handle \(10^3\) events per second.

Provision for a variety of hadron detectors is being considered. The system should be able to handle chambers requiring delay time measurements, wires having charge division measurements, or simply solid state detectors. We are confident that the MicroVax and its event preprocessor will perform well using the specialized serial highway system.

A Commodore Amiga computer will be used to assist the MicroVax with online analysis and display, for the photon tagger system. Mr. Brent Astley from Trent University is developing Amiga software to perform this task.
A system is being designed to provide on and off line analysis in a very high level language. After describing in minimal detail what makes up an event, and what special functions he may want to perform, a user will be provided with a program to do the work. This would ideally control the actual acquisition of data as well as the analysis, but such a system will not be available for some time.
A. General

Electrons destined for extraction from the ring pass through an electrostatic septum which forms part of the extraction beam line. This line will carry beam down from the ring and back to the line of the linac beam. This beam line will serve the Tagger directly. The switchyard will bend the beam 90° in a horizontal plane to direct it towards the hall with the spectrometers. Finally, the vertical chicane will provide the 2.2 m offset to the spectrometer target and give the necessary vertical dispersion.

The layout of these systems is shown in Fig. VII.1 and their present status is discussed below.

B. The Electrostatic Septum

H. Purdie, J. C. Bergstrom, L. O. Dallin and D. M. Skopik

The electrostatic septum is essentially the design that has been developed at TRIUMF with a few modifications. The high voltage anode plate is mounted on two 100 kV insulators manufactured specifically by English Electric Valve for this application. The foil holder (cathode) was redesigned to incorporate insulated foils along the septum that will allow us to measure the actual beam losses during extraction. This is shown in Fig. VII.2. The cathode plane can be moved online in order to provide fine tuning of the electric field for maximum extraction efficiency. For this purpose we have adapted the drive system for the viewers that we have been using to measure beam position and size. The drive unit is coupled to a linear bearing system inside the septum housing. Each end can be driven independently to change the angle of the septum foils relative to the high voltage plate. This is essential if excessive beam losses on the septum plane are to be avoided.

The septum housing is in the final stage of manufacture and the rest of the electrostatic septum is about 80% complete.
Figure VII.1
Layout of the extraction, switchyard and vertical chicane beam lines
Figure VII.2
Extraction septum foil holder
C. The Extraction Beamline

J. C. Bergstrom

The Extraction Beamline which directs the beam from the PSR down towards the Switchyard area is described in last year's Annual Report. It consists of the electrostatic septum followed by two magnetic septum magnets, a quadrupole channel and then a small dipole. Optically, the system is an achromatic parallel-to-parallel transform. Various collimators and high-power slits remove the beam halo (created by the electrostatic septum) and control the emittance of the beam.

The status of the electrostatic septum has been described above. The detailed drawings for the magnetic septa have been completed and are now in the machine shop for fabrication. The soft iron for the magnets was bought from TRIUMF and was part of the batch from which the original cyclotron magnet was built. The quadrupoles and the last dipole along with the power supplies for the whole channel are expected from Bruker by December 1986.

D. The Switchyard

The beam will be directed into two experimental areas, the Photon Tagger hall, and the Spectrometer hall. The former lies on the straight-through line, and only requires a few quadrupoles for shaping the beam. The beam is directed into the Spectrometer area via the Switchyard, which consists of two 45° dipoles and three quadrupoles. Optically, it behaves as a passive achromatic drift. A pin-hole plate will be situated near the midpoint of the Switchyard, whose apertures are to be imaged at the target area during tune-up of the Dispersion Chicane.

All magnetic elements and power supplies for the Switchyard have been ordered. The dipoles will come from Danfysik while the quadrupoles will come from Bruker. Delivery is expected around December 1986.

E. Dispersion Chicane

Since the floor of the Spectrometer hall is well below the floor level of the Switchyard, the beam is delivered to the target area by means of a vertical chicane that drops the beam about 2.2 meters.

The chicane consists of two 50° dipoles and five quadrupoles, and is symmetric about the mid point (except for the reverse bend of the second dipole). Optically, it behaves as a parallel-to-parallel transform with the required 2.2 m offset. The transforms across the chicane are -I in the horizontal plane (i.e., phase advance $\Delta \phi = \pi$) and +I ($\Delta \phi = 2\pi$) with dispersion in the vertical plane. Thus, by placing identical quadrupoles, but of opposite polarity, at the entrance and exit of the chicane we can control the vertical dispersion at the target without affecting any of the geometric optics, such as intrinsic beam size, etc. Even the sign of the dispersion can be readily changed by means of these "dispersion quadrupoles". Some
2nd order chromatic and geometric aberrations exist in the system which could compromise the highest resolutions we expect to achieve (~ $10^{-4}$ Δp/p). These will be corrected by a pair of rather weak sextupoles to be constructed in-house.

A focussing doublet situated between the Switchyard and the Dispersion Chicane controls the intrinsic (i.e., monochromatic) beam-spot size on the target. By locating the doublet before the chicane, we thus separate the geometric and chromatic functions of the two systems. That is, changing the spot size has no effect on the dispersion, and vice-versa.

The Dispersion Chicane thus serves two functions. It drops the beam to the target area, and it generates the required vertical dispersion for dispersion-matching to the QDD spectrometer. We thus avoid the necessity of a multi-quadrupole phase-space rotator, common to most dispersed-beam facilities. Since the vertical emittance from the PSR will be somewhat better than the horizontal, we therefore maintain the "good" emittance in the vertical plane on-target, which of course is exactly what is desired.

All quadrupoles and dipoles, and their power supplies, have been ordered from the same companies as the switchyard and installation is expected early in 1987.
A. Photon Tagging Spectrometer

R. E. Pywell

1. The Clamshell Magnet

The Photon Tagging Spectrometer was funded by NSERC in spring 1985 through a grant to Dr. Walter Del Bianco of the University of Montreal. The contract to manufacture the "Clamshell" magnet was awarded to Instrument AB Scanditronix and the Procurement Specification (SAL-PS-396-01) was signed in December 1985. No power supply dedicated to the Tagger was purchased, as it was determined that the power supply purchased for the QDD Spectrometer would be more than adequate to drive the Tagger. A beam will never be delivered to both the Tagger and Spectrometer halls simultaneously and therefore we can live with only one power supply for both, at least in the immediate future.

One concern with the design of the Tagger magnet was that the pole tips of the dipole were likely to move under the vacuum and magnetic forces, thus degrading the magnetic field quality. We were reluctant to include spacers between the pole faces to prevent them coming together under high magnetic fields since this is likely to create a large radiation background when untagged electrons hit these spacers. An improved return iron geometry, however, reduced the amount of unsupported pole iron and thus reduced the amount of pole gap change at the highest magnetic field setting. Simulations of this gap change with RAY-TRACE showed that the optical quality of the spectrometer was reduced only slightly, the major change being a shift in the position of the focal plane by approximately 1 cm. This can be corrected for, either by making careful measurements of the magnetic field change and then performing software corrections, or by shifting the focal plane detector slightly at the highest magnetic field setting.

Before construction of the magnet began, the basic design of the tagger spectrometer was modified slightly. The shape of the entrance pole edge was made straight instead of curved as in the original design. This simplified construction and made very little difference to the optics of the tagger since the beam size at the entrance is very small. In addition the exit pole edge was modified in order that the focal plane could be made more flat. The focal plane is now flat over a momentum range of $p_0 - 20\%$ to $p_0 + 40\%$, where $p_0$ is the central momentum.

This modified design is also capable of being used as a zero degree spectrometer. In this mode the radiator position, which now becomes the target position, must move back by about 20 cm so that other detectors may be placed around it. The radiator position is otherwise too close to the entrance of the spectrometer. This results in the focal plane position moving a corresponding distance towards the exit edge of the spectrometer with only a small decrease in the resolution.

Construction of the tagger magnet has been proceeding at Scanditronix with, at the time of writing, most major parts being completed. Emil Hallin is scheduled to visit Scanditronix on December 15, 1986 in order to complete the magnetic field mapping. This is delayed...
slightly from the original schedule and means that the tagger will not arrive in Saskatoon until late January 1987. Figure VIII.1 shows the configuration of the tagger in the tagger experimental hall.

**Figure VIII.1**
Layout of tagger and dump magnets
2. Focal Plane Detector

It is intended, initially, that only the flat part of the focal plane will be instrumented. The detector system will be a wire chamber, consisting of three planes, along with an overlapping set of plastic scintillators as backup counters. The wire chambers, designed by Curtis Figley, are being manufactured by the University of Montreal and are nearly complete. The backup counters were designed by Emil Hallin and have been manufactured at TRIUMF.

The wire chamber has an active area of 25 cm high by 80 cm long. The central plane has 160 vertical wires with 5 mm spacing and can be operated in the drift or proportional counter mode. The outer planes have 75 horizontal wires each with 3 mm spacing that can be operated as proportional counters only. This combination will be able to measure the x-position (horizontal) which will give the particle momentum, and the y-position (vertical). Due to the parallel-to-point optics in the y-plane, the y-position will give the angle $\phi$ of the electron from the radiator, which is necessary for doing polarized photon experiments. When the centre plane is used in drift mode a measurement of the angle $\theta_f$ (the horizontal angle the electron makes with the focal plane) can be made and this may be used in software corrections for high resolution work. The expected resolution in drift mode is between 150 $\mu$m and 200 $\mu$m.

3. Backup Detectors

The tagger wire chamber backup detectors consist of a long Cherenkov detector in the bend plane, two long NE-110 plastic scintillators (one above the bend plane and one below it) and 20 small NE-110 plastic scintillators in the bend plane.

The Cherenkov detector provides a means to reduce background due to pions. It has a nominal thickness of 12 mm and is about 150 mm high. The length is 810 mm and it will be viewed from each end with a photomultiplier.

The two long plastic scintillators will be movable vertically and will normally be situated on either side of the bend plane to provide additional background rejection in areas where the incident electron flux is low. The long plastics are 130 mm high by 810 mm long and have a nominal thickness of 3 mm. These long scintillators will be viewed through a combination of adiabatic light guides and a photomultiplier at each end.

The small scintillators are one of two types. The first is a group of 18 scintillators whose dimensions are 50 mm high by 85.26 mm long with a nominal thickness of 3 mm. The second is a group of 2 scintillators whose dimensions are 50 mm high by 42.63 mm long with a nominal thickness of 3 mm. In use, 9 of the first type and one of the second will be assembled so that 810 mm of the focal plane is covered. A second similar set of scintillators has the short segment at the other end so that the operation of these two assemblies will provide a coincidence signal as well as giving a coarse position resolution of about 43 mm. This corresponds to about 4% in energy. Each segment has an adiabatic light guide incorporated so that it can be viewed with photomultipliers above or below the bend plane.
B. Dump Magnets

1. The Tagger Dump Magnet

R. E. Pywell

Once the design of the tagger magnet had been frozen it was possible to complete the
design of the system for dumping the primary electron beam from the tagger. Our desire is
to dump the beam down an existing hallway at one side of the tagger experimental hall (see
Fig. VIII.1). Since the primary electron beam will exit from the tagger in various directions
depending on the field setting of the tagger and on the incident beam energy, a movable mag-
net system is required. It was hoped that an existing magnet from the old beam handling sys-
tem could be used for this purpose. However this magnet proved inadequate for the purpose
at hand due to its low maximum magnetic field, small size and poor optical quality.

Many different systems for dumping the beam were investigated using either existing or
new magnets. There were severe space restraints on this system as it was desirable to leave
as much space available for experimental equipment as possible. The most notable such res-
traint was the space required for the SALAD large solid angle hadron detector (Saskatoon,
Alberta Large Acceptance Detector). A C-type yoke was preferable since this will reduce
background from untagged electrons hitting the return iron of the magnet. The final system,
described below, was chosen for it relative simplicity and it resulted in the smallest beam
spot size at the dump point. This system requires the building of a new Tagger Dump Mag-
net.

The magnet is a least pole area switch magnet (a parallel sided magnet with circular
ends) which will deflect the primary electron beam by a variety of bend angles depending on
orientation and excitation. The magnet will sit on a support that will be movable along a cir-
cular track as well as rotatable about an axis which is concentric with curvature of the beam
entrance end of the magnet (see Fig. VIII.1). In this way the beam may be delivered to a
point just inside the dump hallway entrance where, if necessary, an (existing) small circular
pole magnet may be used to straighten the beam down the hall so that it may be dumped far
from the experimental equipment.

Some parameters of this dump magnet are summarized below.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection angle</td>
<td>-30.6° — +57.8°</td>
</tr>
<tr>
<td>Pole gap</td>
<td>50 mm</td>
</tr>
<tr>
<td>Magnetic field range</td>
<td>0 — 14.6 kGauss</td>
</tr>
<tr>
<td>Yokes</td>
<td>C type</td>
</tr>
<tr>
<td>Entrance and exit pole edges</td>
<td>Circular (radius, 150 mm)</td>
</tr>
<tr>
<td>Side pole edges</td>
<td>Straight (Square edge profile)</td>
</tr>
<tr>
<td>Pole width</td>
<td>250 mm</td>
</tr>
<tr>
<td>Ampere turn (max)</td>
<td>33000 Amp-turn/coil</td>
</tr>
<tr>
<td>Current (max)</td>
<td>330 Amp</td>
</tr>
<tr>
<td>Total weight</td>
<td>~ 2.7 tonnes</td>
</tr>
</tbody>
</table>
2. Bremsstrahlung Dump Magnet
E. L. Hallin

Several experiments have been proposed using a bremsstrahlung beam instead of a tagged photon beam. One possibility is to use the tagger as a dump magnet for these experiments. However, the distance between the radiator and the target would be large in this configuration with little space available to put shielding and collimation. Also, with the SALAD detector in place there would be very little room for extra experimental equipment. It was decided to build a separate bremsstrahlung dump magnet that would be placed before the wall at the entrance to the tagger experimental hall. The tagger support will be made such that the tagger may be moved to the side when bremsstrahlung experiments are to be performed.

The bremsstrahlung dump magnet was designed to satisfy several severe constraints. The acceptance had to be high enough to cleanly dump the primary beam (implying a large gap) but within the capabilities of an existing power supply (implying a small gap). The compromise solution involved an \( n=0.5 \) H-magnet with the poletips forming an integral part of the vacuum envelope. Some of the design parameters of this magnet are summarized below.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection angle</td>
<td>90.0°</td>
</tr>
<tr>
<td>Pole gap</td>
<td>42 mm</td>
</tr>
<tr>
<td>Magnetic field range</td>
<td>0 — 16.7 kGauss</td>
</tr>
<tr>
<td>Yokes</td>
<td>H type</td>
</tr>
<tr>
<td>Entrance and exit pole edges</td>
<td>approximate Rogowski contour</td>
</tr>
<tr>
<td>Side pole edges</td>
<td>Straight</td>
</tr>
<tr>
<td></td>
<td>(Square edge profile)</td>
</tr>
<tr>
<td>Pole width</td>
<td>126 mm</td>
</tr>
<tr>
<td>Ampere turn (max)</td>
<td>43000 Amp-turn/coil</td>
</tr>
<tr>
<td>Current (max)</td>
<td>430 Amp</td>
</tr>
<tr>
<td>Total weight</td>
<td>~ 2.0 tonnes</td>
</tr>
</tbody>
</table>

3. Dump Magnet Procurement

A Request for Proposal (SAL-RFP-396-02) was prepared which included both of the above dump magnets. Bids for the construction of these magnets have been received and are being considered. It is anticipated that, due to financial constraints, the tagger dump magnet will be purchased and the bremsstrahlung dump magnet will be manufactured in house.
IX. QDD AND HADRON SPECTROMETERS

A. The QDD Spectrometer

R. E. Pywell

During this year the construction of the QDD Spectrometer was completed at Instrument AB Scanditronix in Uppsala, Sweden. Only minor changes to the design occurred over the past twelve months.

Magnetic field measurements performed by Scanditronix have shown that there are only slight differences between the measurements and the specifications. The largest deviation is in the position of the Effective Field Boundary (EFB) on the entrance of Dipole 1 at the point where the curvature of the EFB is greatest. Shims were added to the side edges of the D1 pole pieces in order to help correct this error. Measurements were again made of the EFB at the D1 entrance. Using the measured positions of the EFB’s and measurements made of the multipole components in the Quadrupole as input to the program RAYTRACE, it was found that the performance of the spectrometer was not significantly different from that defined by the original specifications.

After these measurements were completed the spectrometer was completely assembled at Scanditronix in order to assure the proper fitting together of all components (see photograph, Fig. IX.1). The spectrometer was then disassembled and packed for shipping. This disassembly was necessary since all pieces of the spectrometer must fit through the limited size of the access door to the Spectrometer Hall. The shipment arrived at SAL on October 22, 1986 and all pieces are now in house except for the dipole power supply which is being held at Scanditronix in order that the Photon Tagging Spectrometer may be tested in December 1986. The dipole power supply will be shipped along with the tagger in January 1987.

The excavation of the spectrometer hall "pit" was completed early this year. As described in the last annual report the rotating support structure for the spectrometer mounts centrally on a bearing pedestal and slides on the outer rail on two linear motion bearing plates. These have a Rulon coating which has a very low coefficient of friction (0.04). The support will be rotated by a gear on the outer perimeter of the rail and driven by a stepping motor through a reduction gear box. The rotating support structure for the spectrometer will arrive at the laboratory in early November and will be installed shortly thereafter. The circular rail on which this support will rotate has already been installed.

The reassembly of the spectrometer will take place, under the supervision of a Scanditronix engineer, beginning on December 1, 1986, and will be completed before Christmas. Testing of the magnetic properties of the Spectrometer can begin once the dipole power supply arrives in January 1987. The spectrometer and the support structure is illustrated in Fig. IX.2.
Figure IX.1
The QDD spectrometer
A multi-wire drift chamber detector has been designed by Curtis Figley for the QDD focal plane. This will consist of three or four wire chamber planes each with 120 wires. These chambers will be about 60 cm high and 22 cm wide. The first and third planes will have horizontal wires, while the second (and possibly fourth) planes will have wires tilted such that the angles between them and the wires in the first plane are those of a 3-4-5 right-angle triangle. This is preferable to having vertical wires running the full length of the detector since the count rate on any one wire will be reduced, thus increasing the overall count rate that can be handled by the chamber. The position resolution in the x (momentum) direction will be 150 — 200 μm, while the resolution in the y direction will be ~ 500 μm allowing the scattering angle $\theta$ to be measured to an accuracy of ~ 1 mrad. The angle between the particle trajectory and the focal plane will be measurable to within 10 mrad which will aid software corrections to optimize the resolution of the spectrometer.

B. The Hadron Spectrometer
R. E. Pywell and K. I. Blomqvist

The 44" dipole that we obtained from HEPL is proposed to be used as a hadron spectrometer mounted on the same pivot as the QDD spectrometer. The main uses of this spectrometer will be as a coincidence arm in (e,e'x) measurements and as a monitor spectrometer for single arm experiments, especially when using composite or inhomogeneous targets.

As used at HEPL the spectrometer had a solid angle of 8 msr, 10% momentum bite and a resolution of about $10^{-3}$. The dipole has curved entrance and exit pole edges to eliminate the $<x|\theta^2>$ matrix element and to make the focal plane perpendicular to the central ray. The curvatures are machined as inserts that can be removed.

We have investigated five alternatives for the installation of this spectrometer at SAL. These are:

1. Install the dipole as it was at HEPL.
2. Use the dipole only, but change the curvatures of the entrance and exit pole edges.
3. Use a small quadrupole in front of the dipole to obtain parallel-to-point optics in the axial plane.
4. Use a QD layout with point-to-point optics in both the axial and radial planes.
5. Use a QDQ layout, also with point-to-point optics in both planes.

For all of these configurations, except the first, the entrance and exit pole edge curvatures must be changed. Also, for all of these configurations, except the first, it was found that a smaller minimum angle could be obtained if the exit edge of the magnet (as used at HEPL) was used as the entrance. The properties of these designs are summarized in the following table.
### TABLE IX.1
Summary of Possible Designs for the Hadron Spectrometer

<table>
<thead>
<tr>
<th></th>
<th>D as is</th>
<th>D modified</th>
<th>QD</th>
<th>QD</th>
<th>QDQ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First order optics:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radial plane</td>
<td>point-to-point</td>
<td>point-to-point</td>
<td>point-to-point</td>
<td>point-to-point</td>
<td>point-to-point</td>
</tr>
<tr>
<td>Axial plane</td>
<td>-</td>
<td>-</td>
<td>parallel-to-point</td>
<td>point-to-point</td>
<td>point-to-point</td>
</tr>
<tr>
<td><strong>Quality factor (cm/%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$&lt;x</td>
<td>\delta x</td>
<td>&lt;x</td>
<td>&gt; $</td>
<td>-1.87</td>
<td>-1.87</td>
</tr>
<tr>
<td><strong>Minimum angle</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\theta_0$ (mrad)</td>
<td>± 90</td>
<td>± 100</td>
<td>± 70</td>
<td>± 40</td>
<td>± 40</td>
</tr>
<tr>
<td>$\phi_0$ (mrad)</td>
<td>± 20</td>
<td>± 20</td>
<td>± 25</td>
<td>± 90</td>
<td>± 80</td>
</tr>
</tbody>
</table>

It has been decided that the QD configuration with parallel-to-point optics in the axial plane will be implemented. The quadrupole is small and relatively weak and requires only a small octupole component making it relatively easy to build. The parallel-to-point geometry in the axial plane allows the use of extended beam spots for fragile targets and also permits a relatively simple software correction procedure to measure the scattering angle to good precision. This is necessary to obtain good missing mass resolution in coincidence experiments. The focal plane is inclined at an angle of about 30° and is about 30 cm by 30 cm. A wire chamber detector system will be required to measure both the x and y positions on the focal plane.

The hardware required for these modifications to the HEPL dipole are currently being designed and will probably be built in-house. A second support structure, similar to that used for the QDD, will be used. Indeed some identical parts have already been built. Both spectrometers will rotate on the same rail as illustrated in Fig. IX.2.
X. SCIENTIFIC RESEARCH

A. Nuclear Science Research
1. Study of \(^{3}\text{He}(e,T)^{e},^{7}\text{Be}^{+}\)

D. M. Skopik, G. A. Retzlaff, H. S. Caplan and E. T. Dressier

The electropion production cross-section may be written as:

\[
\frac{d^3\sigma}{de_t d\Omega_e d\Omega_\pi} = \frac{\alpha^2}{\pi^2 k_f^4} \frac{k_f}{k_i} \frac{k_\pi M}{2} \left\{ \frac{1}{E_t + E_\pi (1 - k_f k_\pi/k_\pi^2)} \right\} (V_L W_L + V_T W_T + V_P W_P \cos 2\phi_\pi + V_I W_I \cos \phi_\pi)
\]

where the \(W\)'s are structure functions, and the \(V\)'s are kinematical functions (longitudinal, transverse, polarization and interference respectively). This process should be dominated by the transverse structure function, which is related to the photoproduction cross-section by virtual photon theory. As a consequence the \(W_T\) structure function can be extracted from the electrodisintegration cross-sections, and our most recent data are shown for two incident electron energies in Fig. X.1.

We are presently investigating the validity of the assumptions of this method, and are looking at:

- The role of longitudinal contributions.
- Recoil corrections to the virtual photon spectrum.
- Lack of gauge invariance in the electropion production amplitude.

References


Figure X.1
The transverse structure function $W_t$ for pion production from $^3\text{He}$
B. Radiation Chemistry Research


Owing to the modifications being carried out in the low energy area, the pulse radiolysis group has not been able to use this area until quite recently. Consequently during this last year, much of our effort has been directed at preparing for the use of the facility in the upcoming year. As a first step in the rejuvenation process, the flight tube needed for pulse radiolysis experiments has been installed, and dosimetry experiments are to be carried out in the near future in order to characterize the energy distribution profile in our reaction vessels.

Acquisition of the equipment required to use the new detection technique based upon conductivity has been completed. This will allow us to study charge transfer processes such as the protonation dynamics of transient species in conjunction with their detection by uv-visible absorption spectrometry. Currently we are focusing on the development of computer-based data collection and analysis capability.

To complement and extend the experimental program, theoretical calculations using the x-alpha and ab initio SCF MO methods have been carried out. The latter method has been used to investigate the reactions of hydroxyl radical with biologically important nitrogen heterocyclic compounds such as cytosine. Using the x-alpha approach, one can calculate electronic charge transfer spectral positions for comparison with the experimentally observed spectrum. A successful comparison provides insight into the structure of the substance. We have been applying this approach with considerable success to the study of transitory platinum(III) chloro species that are generated experimentally by pulse radiolysis (and by laser photolysis) of platinum(II) and (IV) chloro compounds.

C. Theoretical Research

1. Trinucleon Properties

E. L. Tomusiak, and Los Alamos Group

Magnetic moments of the trinucleons have been calculated using 5-channel wave functions. These results have been published. At present these 5-channel results are being used as checks for 34-channel calculations. Whereas the 5-channel calculations were done largely by manual algebraic manipulation to obtain formulae for the magnetic current densities, the 34-channel results are done completely numerically.

2. Six-Quark Bags in the Trinucleons

E. L. Tomusiak, R. K. Bhaduri and M. V. N. Murthy

The possibility that nucleons may coalesce into six quark bags whenever they come within about 1 fm of each other has implications for the magnetic moments. Since the magnetic moment of the bag scales with its radius, the magnetic moment of a "nucleon" is enhanced by about 30% when it is part of a six-quark bag. We have estimated the probability of six quark bag formation, P(6q), by using the RSC wave functions of the Los Alamos group. The results of our calculation are that a value of P(6q) in the range 10-20% gives
results which are compatible with the magnetic moment data, even after the long-range exchange effects due to pions are included.

3. Studies of the Pion Electroproduction Operator

E. T. Dressler

Earlier methods of obtaining electroproduction operators for use in nuclei were based on taking the non-relativistic approximation to a standard set of relativistic Feynman diagrams. Even though the relativistic operator is gauge invariant, the various techniques of reducing to the NR limit have problems with maintaining this invariance to the requisite order of p/M. Our method approximates a combination of pseudovector Born plus Delta resonance diagrams using a method which does not break up the nucleon propagator into positive and negative energy contributions, as was done previously. This method gives an operator that maintains its gauge invariance cancellations exactly. The results have been submitted for publication.

4. Linear Polarization of Tagged Photons

J. Asai, H. S. Caplan and D. M. Skopik

The linear polarization as a function of bremsstrahlung photon angles was studied where the post bremsstrahlung electron directions were integrated numerically over the region pertinent to the SAL tagging magnet. Typical results are shown in Fig. X.2 where $\theta_g$ is the angle of the photon with respect to the incident beam direction (z) and $\phi_g$ is its angle, projected in the vertical plane, with respect to the horizontal symmetry axis of the tagger (x). To check our results the integration over all scattered electron angles were also carried out resulting a good agreement with May\textsuperscript{1}) and with Motz and Placious\textsuperscript{2}).

References

[1] M. May, Phys. Rev. 84, 265 (1951)


5. Kinematics for Chicane-Beam Coincidence Experiments

J. Asai, J. C. Bergstrom, H. S. Caplan and D. M. Skopik

A paper on this subject was submitted for publication in Nuclear Instruments and Methods last year. The referee requested that more work be done, including estimates of the count-rate and of the accuracy of extraction of the structure functions. This has been completed and the paper will be resubmitted shortly.
Figure X.2
$\varepsilon_i = 200$ MeV, $\varepsilon_f = 100$ MeV electron angles are integrated over $-25 \leq \theta_e \leq 25$ mrad and $0 \leq \phi_e \leq 10$ mrad
D. Research Performed at Other Laboratories

1. Electron Scattering Studies of Tritium

G. A. Retzlaff, D. M. Skopik, H. S. Caplan, E. L. Hallin, N. G. Videla et. al., in collaboration with MIT, WPI, UVa, CEBAF, UPitt, NBS, and CM

A cryogenic tritium ($^3$H) target system was developed, and was operated at the MIT-Bates Linear Accelerator during early 1986. This target allowed electron scattering studies to be conducted on pure, gaseous tritium. This is a continuation of a collaboration that measured $^3$H form factors with a tritiated titanium target$^{1}$. The aim of the collaboration was to complete an exhaustive, precise study of the elastic and inclusive inelastic electron scattering from free tritium gas. Elastic scattering from free tritium has been measured before only rarely, and inelastic cross-sections from free tritium had not been well measured until now. Recent advances in three body theory have given these data much importance in the understanding of the details of the A=3 wave functions. The electromagnetic form factors of $^3$H were measured up to a momentum transfer of $q = 5$ fm$^{-1}$ (second maximum), and a precise comparison of $^3$H and $^3$He form factors at lower $q$ was also done. Complete inelastic spectra were taken, particularly in the threshold breakup, quasi-elastic and $\Delta$ excitation energy loss regions.

Electrons scattered from the tritium were detected in the ELSSY spectrometer. The spectrometer focal plane instrumentation was standard Bates instrumentation, and the high resolution capabilities of ELSSY were not needed. A complete copy of all data and assorted analysis software was transferred from Bates to SAL in July 1986. Work is presently progressing on the analysis, and final cross-sections for the threshold breakup region will soon be completed here. Analysis for the other data is progressing at the other collaborating institutions. A complete description of the target system is presently in preparation for publication.

References


2. Radiative Transitions in $^{27}$Al

C. Rangacharyulu and the group of A. Richter at Darmstadt

Inelastic electron scattering of electrons from an $^{27}$Al target has been measured for the incident electron energies and scattering angles, $E_e(\theta_e) = 25 \, (165^\circ), 35 \, (117^\circ, 165^\circ)$ and $40 \, (117^\circ, 165^\circ)$ MeV and for the excitation energy range of 6-8 MeV in $^{27}$Al. Figure X.3 shows three of the spectra taken for the experimental conditions marked on the figure.
Figure X.3
Spectra of electrons inelastically scattered from $^{27}$Al
The two lower spectra are q-matching measurements, which clearly indicate that the transitions seen in this experiment are mainly transverse. The multipolarities of the transitions for 6.8 < Ex (MeV) < 8.1 are deduced to be pure M1 and the transition strengths are listed in Table X.1.

**TABLE X.1**

<table>
<thead>
<tr>
<th>E_x (MeV)</th>
<th>B(M1) (μ²)</th>
<th>(2J_ex + 1)Γ_γ (eV)</th>
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<tr>
<td>6.84</td>
<td>0.16 ± 0.02</td>
<td>3.5 ± 0.5</td>
</tr>
<tr>
<td>7.44</td>
<td>0.21 ± 0.02</td>
<td>5.8 ± 0.6</td>
</tr>
<tr>
<td>7.60</td>
<td>0.15 ± 0.02</td>
<td>4.4 ± 0.6</td>
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<tr>
<td>7.7</td>
<td>0.33 ± 0.03</td>
<td>10.1 ± 1.0</td>
</tr>
<tr>
<td>8.06</td>
<td>0.26 ± 0.03</td>
<td>9.2 ± 1.1</td>
</tr>
</tbody>
</table>

The main interest of radiative transition strengths in this excitation region is that one can deduce the corresponding transition strengths in the mirror nucleus ^27^Si. The contribution of the radiative proton capture for the depletion of ^26^Al has been of considerable astrophysical interest in recent years. We have deduced the stellar interaction rates from the present data, supplemented with the previously available information\(^1\). Table X.2 shows that these reaction rates for T_9 < 0.2 can be a few orders of magnitude larger than the previous estimates. However, the importance of this channel in the Mg-Al cycle under stellar conditions awaits further evaluation.

**TABLE X.2**

<table>
<thead>
<tr>
<th>T_9</th>
<th>Present</th>
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<tr>
<td>0.05</td>
<td>3.6E - 12</td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>4.3E - 06</td>
<td>2.3E - 10</td>
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<tr>
<td>0.2</td>
<td>3.5E - 03</td>
<td>8.4E - 04</td>
</tr>
<tr>
<td>0.3</td>
<td>1.34E - 01</td>
<td>1.4E - 01</td>
</tr>
<tr>
<td>0.4</td>
<td>1.9E - 00</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>1.1E + 01</td>
<td>9.6E - 00</td>
</tr>
<tr>
<td>0.6</td>
<td>3.7E + 01</td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>9.0E + 01</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>2.3E + 02</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>3.0E + 02</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>4.5E + 02</td>
<td>1.9E + 02</td>
</tr>
<tr>
<td>1.5</td>
<td>1.5E + 03</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>2.4E + 03</td>
<td>6.1E + 02</td>
</tr>
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</table>

\(^a\) For the two lowest resonances, s-wave proton capture with maximum reduced width is assumed. For the higher ones, the experimental gamma widths are used.

\(^b\) In units of sec\(^{-1}\) mole\(^{-1}\) cm\(^3\).
The level structure of $^{28}$Si, a self-conjugate nucleus in the middle of $2s$-$1d$ shell, has been a subject of continuing interest. Our interest in this nucleus was to verify if the $T=2$, $J_n=0^+$ level at 15.23 MeV excitation is accessible for radiative proton capture on $^{27}$Al. Detailed measurements of the excitation functions of the capture gamma rays and $(p,p'\gamma)$ to various levels in $^{27}$Al and the $(p,\alpha\gamma)$ channel did not reveal the presence of the $T=2$ level. However, in the neighbourhood, at 15.235 MeV excitation we found a narrow level decaying exclusively to high spin states. Detaileld angular distribution measurements determined the spin and parity of the resonance to be $J^r=3^+$. In view of the recent interest in the M3 quenching in this nucleus, we have deduced the radiative decay strengths for all the known $J^r=3^+, T=1$ levels in $^{28}$Si. The results are shown in Table X.3.

The table also presents the B(M1) strengths to be expected from the positron decay of the ground state of $^{28}$P. It is apparent that the ground state analogue strength is spread over quite a few levels in $^{28}$Si, which indicates large configuration mixing in the levels of $^{28}$Si. We therefore conclude that one requires ground state M3 transition strengths for at least the known $J^r=3^+$ levels, before attempts to estimate M3 quenching are made.

**TABLE X.3**
Gamma Transition Strengths, in units of $\mu N_2$, for $J^r=3^+, T=1$ Levels in $^{28}$Si.

The values for 15.235 MeV level are from the present work and the rest are deduced from the tables of Endt and Van der Leun (Ref. 1).

<table>
<thead>
<tr>
<th>$(MeV)$</th>
<th>Ex(f)Ex(i)</th>
<th>9.32</th>
<th>12.54</th>
<th>12.92</th>
<th>15.235</th>
<th>B(M1,\sigma)\textsuperscript{a)}</th>
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</thead>
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<tr>
<td>1.78</td>
<td>0.005</td>
<td>0.24</td>
<td>0.18</td>
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<td>0.014</td>
<td>0.23</td>
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<td>4.62</td>
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<td>0.04</td>
<td>0.036</td>
<td>0.014</td>
<td>0.19</td>
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<tr>
<td>6.28</td>
<td>0.055</td>
<td>0.04</td>
<td>0.054</td>
<td>0.014</td>
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<td></td>
</tr>
<tr>
<td>6.89</td>
<td>-</td>
<td>-</td>
<td>0.02</td>
<td>0.018</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>7.8</td>
<td>-</td>
<td>0.35</td>
<td>0.03</td>
<td>0.023</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>7.93</td>
<td>-</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>8.26</td>
<td>-</td>
<td>-</td>
<td>0.03</td>
<td>-</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>8.59</td>
<td>-</td>
<td>0.02</td>
<td>0.13</td>
<td>-</td>
<td>0.54</td>
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<tr>
<td>9.38</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.34</td>
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</tr>
<tr>
<td>9.48</td>
<td>-</td>
<td>0.02</td>
<td>0.11</td>
<td>-</td>
<td>0.06</td>
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</tr>
<tr>
<td>10.67</td>
<td>-</td>
<td>-</td>
<td>0.31</td>
<td>-</td>
<td>0.26</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a)} deduced from the positron decay of $^{28}$P

References

4. Photonuclear Processes on $^2$H and $^4$He

C. Rangacharyulu with the TAGX group at the University of Tokyo

So far, there has been very limited information available on the photonuclear processes above the delta resonance in light nuclei. The main reason was the nonavailability of the optimal experimental arrangements. At Tokyo, the tagged photon facility has been upgraded to nearly 20% duty factor. The TAGX group has been developing a $\pi$ steradian detector, which makes exclusive measurements possible. This detector consists of thin plastic scintillators as the inner hodoscope, with a surrounding drift chamber and an outer hodoscope of scintillation detectors. This detector is situated in an axial magnetic field of up to 5 kG. Information on the particle tracks, TOF and dE/dX can be obtained for final state charged particles. Thus, kinematically complete measurements for multiple particle final states with not more than one neutral, can be obtained for light nuclei. During the summer, we investigated the response of the detector system under magnetic fields and found that H2611 photomultipliers are suitable for the inner hodoscope. Due to the constraints on the system, optical fibres have been chosen for light guides for the outer hodoscope.

An experiment to investigate exotic intermediate states, such as contributions of N* resonances and dibaryonic clusters to photonuclear processes involving pions and also disintegration of $^4$He has been approved to run at this facility during the summer of 1987.

E. Conferences

1. NATO Advanced Study Institute

E. L. Tomusiak, H. S. Caplan and E. T. Dressler

Last year we reported the Institute on New Vistas in Electro-Nuclear Physics which was held at Banff, August 22 to September 24, 1985. In the past year the proceedings were edited and sent to the publisher (Plenum Press) as camera ready copy. This work was completed in May 1986 and the book appeared in October.

2. Western Regional Nuclear Physics Conference

D. M. Skopik, C. Rangacharyulu and H. S. Caplan

The Western Regional Nuclear Physics Conference held at Lake Louise, February 13-15, 1986 was organized by the Saskatchewan Accelerator Laboratory. The conference was attended by over fifty physicists including some from outside our region. There were six invited talks and twenty five contributed papers in the two day meeting.

3. Canadian Accelerator Physics Conference

T. P. Dielschneider

The third meeting of the Canadian Accelerator Conference was held on September 8 and 9 at the Accelerator Laboratory in Saskatoon. This annual conference is held to promote communication between Canadian accelerator physicists. Approximately 35 physicists and
engineers from laboratories across Canada participated in the meeting. This year the scope of the conference was broadened to include accelerator physicists from industry and medicine. This was very successful and several talks dealing with the applications of accelerators other than nuclear physics were presented.

The conference in Saskatoon was used to develop the first Canadian Accelerator Physics Directory. This document is a list of all accelerator physicists in Canada. Address, phone number and areas of interest are included. The directory has been distributed to accelerator departments across the country and it is hoped that it will be updated annually by the host of the conference.

The next Accelerator Conference will be held at TRIUMF in the fall of 1987.
XI. PROPOSED RESEARCH PROGRAM

A. PAC Meeting

C. Rangacharyulu and E. L. Tomusiak

The second meeting of the Saskatchewan Accelerator Laboratory’s Program Advisory Committee (PAC) took place September 4-5, 1986. A total of nine proposals for experiments on the new facility were submitted to the Committee. A copy of the summary page of each of these proposals together with the PAC recommendation is included in this section.

These submissions requested a total of 3500 hours of beam time with 3300 of these hours being for experiments in the photon area and the remaining 200 hours for an experiment in the QDD spectrometer area. The small fraction of time requested for the QDD spectrometer facility is a result of the fact that the call for proposals was explicitly for experiments in the photon area where beam is expected by early 1987.

The Committee assumed that the first year of experiments would extend from approximately August 1987 to August 1988. During this first year of running the PAC recommends an allocation of 2000 hours or 250 8-hour shifts. The expectation is that the next PAC meeting will see even more beam time requested since proposals for coincidence type experiments using the new electron spectrometer will be called for. So far there is only one proposal for an experiment of this type, proposal #001.

The response to the first call for proposals is indicative of the great interest which the physics community has for the new facility. Indeed it is realized by that community that the capabilities of the Saskatchewan Accelerator Laboratory will be unique in the world for the next several years.
B. SAL Proposals

SAL PROPOSAL 001

Summary

1. Title of Experiment: Proposal for an (e,e'f)-Coincidence Experiment on $^{232}$Th


3. Date Received: July 23, 1986

4. Participants

<table>
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<td>U. Kneissl</td>
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<td>H. Ströher</td>
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<td>T. Weber</td>
<td>U. of Giessen</td>
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5. Abstract:

We propose to do an (e,e'f)-coincidence experiment on $^{232}$Th for at least 5 or 6 different momentum transfers (0.14, 0.26, 0.40, 0.52, 0.65, and 0.77 fm$^{-1}$) at the 300 MeV Saskatchewan Accelerator Laboratory. This will be a continuation of (e,e'f)-experiments on uranium isotopes $^{235,238}$U, which we have successfully performed at the 185 MeV stage of the Mainz Microtron (MAMI) in order to investigate the fission probabilities of giant multipole resonances. By varying the momentum transfer $q$ we are able to excite the lowest multipole resonances (E1, E2/E0, and E3) almost selectively. The strength functions of these multipolarities will be determined in a model independent decomposition. In our performed experiments we also investigated odd-even effects near the fission barriers by comparing the data of $^{238}$U and $^{235}$U. First test measurements on $^{235}$U showed, that the time resolution of the used fission fragment detector system will be very well suited in order to investigate for the first time the dependence of the fission fragment mass- and energy-distribution from the momentum transfer $q$ and the angular momentum via a double-time-of-flight measurement. However, experiments of this kind can be done best on $^{232}$Th because of its larger mass splitting. Additionally $^{232}$Th is a very interesting candidate to investigate the fission decay of giant resonances of nuclei with a lower first chance fission probability as compared to the uranium isotopes $^{235,238}$U. In conclusion we expect that the proposed experiment will provide very valuable new information on the decay properties of giant resonances as well as the dynamics of the fission process itself.

6. Beam Time Required: Starting with the experience from our experiments at Mainz and assuming the following experimental parameters we need an amount of beamtime as stated below:

   a. 8 hour shifts: 26.5 shifts
   b. Energy: 80-300 MeV
   c. Current: $\approx 10 \mu$A
   d. Duty Cycle: $\approx 100\%$
7. Grant Status: Requested

8. Ready:
   a. Fission Detector: Immediately
   b. Running: March-April or July-September 1987

PAC Recommendations
Action: Accepted
Shifts Allocated: 25

SAL PROPOSAL 002

Summary

1. Title of Experiment: Two-Body Photodisintegration of $^3\text{He}$ between 100 and 300 MeV

2. Names of Spokespersons: G. J. Lolos

3. Date Received: July 23, 1986

4. Participants

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<tr>
<td>G. A. Retzlaff</td>
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<td>Grad. Student</td>
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5. Abstract:

   We propose to investigate the $^3\text{He}(\gamma,p)d$ reaction with the CW bremsstrahlung beam in the energy range $100 \text{ MeV} \leq E_{\gamma} \leq 300 \text{ MeV}$ by a p-d coincidence method. Differential cross sections as well as total cross sections will be extracted at this energy range. The statistical and systematic uncertainties will be minimized in order to remove some of the discrepancies existing between different sets of data measured at various laboratories in the past.

6. Beam Time Required:
   a. 8 hour shifts: 23 shifts
   b. Energy: 350 MeV
   c. Current: $\sim 10 \mu\text{A}$
   d. Duty Cycle: maximum
7. Grant Status: NSERC two year operating grant

8. Ready:

PAC Recommendations

Action: Deferred
Shifts Allocated: 10 (Detector Development)

SAL PROPOSAL 003

Summary

1. Title of Experiment: The Reaction $\gamma d \rightarrow np$

2. Names of Spokespersons: W. J. McDonald and W. Ziegler

3. Date Received: August 1, 1986

4. 

<table>
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<td>H. S. Caplan</td>
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<td>W. Del Bianco</td>
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<td>Physicist</td>
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<tr>
<td>E. B. Cairns</td>
<td>U. of Alta.</td>
<td>Service Officer</td>
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</table>

5. Abstract:

It is proposed to use the SAL Tagged Photon Facility and the Saskatoon Accelerator Large Acceptance Detector (SALAD) to measure deuteron photon disintegration. The results will complement the $np \rightarrow d\gamma$ cross section and asymmetry studies currently under way at TRIUMF. The aim is to generate a self consistent data set for this two-body process by measuring $A$ in the $np \rightarrow d\gamma$ process and $\sigma(\theta)$ for the inverse $\gamma d \rightarrow np$ reaction. Lack of a reliable data set for this fundamental process has thus far frustrated attempts to provide a convincing picture of the reaction mechanism in a kinematical region (90 to 260 MeV) where the meson exchange and isobar currents are important. This experiment will be the first to use the Large Acceptance Detector. It will also serve to commission SALAD.
6. Beam Time Required:
   a. 8 hour shifts: 50 shifts
   b. Energy: 300 MeV
   c. Current: 10 na
   d. Duty Cycle: 100

7. Grant Status: NSERC 1986-87

8. Ready: Earliest date ready for beam: September 1987

PAC Recommendations

Action: Accepted
Shifts Allocated: 50

SAL PROPOSAL 004

Summary

1. Title of Experiment: The Reaction $\gamma d \rightarrow p\Delta$

2. Names of Spokespersons: J. M. Cameron

3. Date Received: August 1, 1986

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<tr>
<th>Participants</th>
<th>Institution</th>
<th>Status</th>
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<tbody>
<tr>
<td>J. M. Cameron</td>
<td>U. of Alta.</td>
<td>Physicist</td>
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<td>H. S. Caplan</td>
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<tr>
<td>W. Del Bianco</td>
<td>U. of Montreal</td>
<td>Physicist</td>
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<tr>
<td>L. G. Greeniaus</td>
<td>U. of Alta.</td>
<td>Physicist</td>
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<tr>
<td>D. A. Hutcheon</td>
<td>U. of Alta./TRIUMF</td>
<td>Physicist</td>
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<tr>
<td>J. W. Jury</td>
<td>U. of Trent</td>
<td>Physicist</td>
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<tr>
<td>F. C. Khanna</td>
<td>U. of Alta.</td>
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<tr>
<td>W. J. McDonald</td>
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<tr>
<td>W. Ziegler</td>
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</table>

4. Abstract:
   It is proposed to use the SALAD detector system and the CW photon beam at SAL to measure angular distributions and decay products for the $\gamma d \rightarrow p\Delta$ reaction at maximum photon energies available. From the measured angular correlations of the $\Delta^0$
decay products it should be possible to extract information on the polarization of the \( \Delta \) in addition to angular distributions at several energies. Such an extensive data set will allow the coupled channel approach to be expanded to study the effect of P waves for the \( \Delta N \) interaction.

6. Beam Time Required:
   a. 8 hour shifts: 50 shifts
   b. Energy: 300 MeV
   c. Current: 10 na
   d. Duty Cycle: 100

7. Grant Status: NSERC 1986-87

8. Ready: Earliest date ready for beam: September 1987

PAC Recommendations

Action: Deferred

SAL PROPOSAL 005
Summary

1. Title of Experiment: Photo-Pion Production on Nuclei

2. Names of Spokespersons: W. Ziegler and F. C. Khanna

3. Date Received: August 1, 1986

4. Experiment No. 005

<table>
<thead>
<tr>
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</table>
5. Abstract:

It is proposed to use the SAL Tagged Photon Facility and the Saskatoon Accelerator Large Acceptance Detector (SALAD) to measure the $^4\text{He}(\gamma,\pi^-)$ reaction. There is a serious lack of data in this area. This initial experiment will provide the needed data to compare to detailed consistent calculations. This will provide a useful method to learn about the formation, propagation and decay of isobars in nuclei as well as the role played by the meson exchange currents.

6. Beam Time Required:
   a. 8 hour shifts: 50 shifts
   b. Energy: 300 MeV
   c. Current: 10 na
   d. Duty Cycle: 100

7. Grant Status: NSERC 1986-87

8. Ready: Earliest date ready for beam: September 1987

PAC Recommendations

Action: Deferred

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SAL PROPOSAL 006

Summary

1. Title of Experiment: Proton Compton Effect

2. Names of Spokespersons: W. Del Bianco, C. Rangacharyulu

3. Date Received: August 5, 1986

4. | Participants     | Institution   | Status | % | Signature |
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<td>C. Rangacharyulu</td>
<td>U. of Sask.</td>
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<td>G. A. Retzlaff</td>
<td>U. of Sask.</td>
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5. Abstract:

It is proposed to determine the electric and magnetic polarizabilities of the proton by a measurement of the angular distribution of the reaction $\gamma + p \rightarrow \gamma + p$. While the...
kinematics of this reaction are completely determined by measurement of the energy and angle of the recoil proton, the low cross section may require redundant coincidence with the scattered photon to reduce background.

6. Beam Time Required:
   a. 8 hour shifts: 125 shifts
   b. Energy: 140 MeV
   c. Current: 2 μA
   d. Duty Cycle: 100%

7. Grant Status: None

8. Ready:
   a. Tests: January 1987
   b. Running: July 1, 1987

PAC Recommendations
Action: Deferred
Shifts Allocated: 10 (Detector Development)

SAL PROPOSAL 007

Summary

1. Title of Experiment: Coherent (γγ) Scattering on Nuclei in the Δ(1232) Energy Region

2. Names of Spokespersons: E. C. Booth and James Miller

3. Date Received: August 5, 1986

4. | Participants    | Institution     | Status | % | Signature |
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<tr>
<td>E. C. Booth</td>
<td>Boston U.</td>
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<td>E. K. MacIntyre</td>
<td>Boston U.</td>
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<td>J. P. Miller</td>
<td>Boston U.</td>
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<td>J. C. Bergstrom</td>
<td>U. of Sask.</td>
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<td>U. of Sask.</td>
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5. Abstract:

   We propose to measure coherent nuclear Compton Scattering in the Δ(1232) energy region for the nuclei ¹H, ⁴He, ¹²C, and ²⁰⁸Pb. In addition we expect to measure incoherent scattering summed over the first 10 MeV of excitation in ¹²C and ²⁰⁸Pb. Some information may also be obtained on the (γ,π⁰) coherent cross-sections.
6. Beam Time Required:
   a. 8 hour shifts: 100 shifts [or 50 shifts using a 4 µa (average) beam]
   b. Energy: 200-300 MeV
   c. Current: 1 µa [or 4 µa]
   d. Duty Cycle: Greater than 30%

7. Grant Status: Expect NSF funding for part of expenses

8. Ready: Earliest date will be February 1987

PAC Recommendations
Action: Accepted
Shifts Allocated: 55

SAL PROPOSAL 008
Summary

1. Title of Experiment: Detection of Coherent Transition Radiation and Its Application to Beam Diagnostics and Particle Identification

2. Names of Spokespersons: Dr. Melvin A. Piestrup

3. Date Received: August 7, 1986

4. | Participants | Institution       | Status   | %  | Signature |
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<tr>
<td>M. A. Piestrup</td>
<td>Adelphi Technology</td>
<td>President</td>
<td>100</td>
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</table>

5. Abstract:

The objective of the proposed program is to investigate the use of resonance or coherent transition radiation for the identification of high-energy particles. The techniques proposed can be used for particle-mass identification or for beam diagnostics and monitoring. Two devices will be constructed. One will utilize the fact that the energy thresholds of various resonant modes occur at different energies. A foil stack will be designed which will be rotated along an axis perpendicular to the particle direction, allowing selection of various resonant modes and thereby determining particle energy. A second detector will be designed and constructed which enhances the angular radiation pattern of the x-ray emission. This will allow a more accurate determination of the emitting particle’s energy. By enhancing resonant modes which emit at angles greater than 1/γ, the energy of the emitting particles can be determined at larger values than previous detector schemes.

6. Beam Time Required:
   a. 8 hour shifts: 4 or 5
   b. Energy: 250 MeV, 100 electrons/pulse at 60 to 360 Hz
Saskatchewan Accelerator Laboratory

c. Current:
d. Duty Cycle:

7. Grant Status:
8. Ready:
a. Running: window of 6 months

PAC Recommendations
Action: Director’s time
Shifts Allocated: Discretion of the Director

SAL PROPOSAL 009
Summary

1. Title of Experiment: Measurement of the $^3\text{He}(\gamma,pp)n$ Cross Section with CW Bremsstrahlung
2. Names of Spokespersons: J. W. Lightbody
3. Date Received: August 18, 1986

<table>
<thead>
<tr>
<th>Participants</th>
<th>Institution</th>
<th>Status</th>
<th>%</th>
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<tr>
<td>J. W. Lightbody</td>
<td>NBS</td>
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<tr>
<td>J. S. O'Connell</td>
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<td>C. Rangacharyulu</td>
<td>U. of Sask.</td>
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<tr>
<td>E. L. Mathie</td>
<td>U. of Regina</td>
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<tr>
<td>G. Lolos</td>
<td>U. of Regina</td>
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5. Abstract:

We propose to measure the $^3\text{He}(\gamma,2p)n$ cross section for $E_\gamma$ between 50 and 150 MeV using the SAL 200 MeV cw bremsstrahlung beam. Equal energy protons emerging from opposite sides of the target will be detected symmetrically at 80 degrees with respect to the beam direction. This kinematics corresponds to 90 degree breakup in the pp cm system, where evidence of enhanced cross sections can be attributed to the effect of three-body forces. Plastic scintillator DE-E telescopes will be used for detectors.

6. Beam Time Required: 100 hours of 200 MeV, 10 μa beam.

PAC Recommendations
Action: Accepted
Shifts Allocated: 12
XII. SAFETY AND HEALTH PHYSICS

S. D. Choubal

The annual compliance report required by the AECB as part of their licensing procedure was filed in September. That report contains records of all routine radiation surveys of the restricted and unrestricted areas, removable contamination, special measurements and radioactive waste generated. This information is available in the Radiation Safety Office and at the Accelerator Laboratory so only the highlights will be reported here.

A. General

The machine only ran about 400 hours in the past year and delivered about 140 kW-hr of integrated energy. This reduced the amount of activation and radiation surveys were required less frequently.

B. Personnel Exposure

A total of 68 people were monitored for whole body external radiation absorbed. In addition 22 of these were monitored for extremity exposure. All those monitored are classified as Atomic Radiation Workers and are subject to a limit of 5 mSv in any 52 week period. The maximum individual dose was 3.2 mSv and the collective dose for the licensing year was 0.028 man-Sv corresponding to an average dose per year of 0.42 mSv.

C. Special Measurements

The raw beam from the linac is first defined geometrically and in energy in the Energy Compressor System. After this definition the beam passes through the rest of the magnetic optical system with little impingement and resultant activation. Thus the slits in the ECS have now become the dominant source of prompt and residual radiation.

The contact dose on these slits was measured as a function of time after shutdown. Two main components of the activity were found, one with half-life 18 hours and the other with 200 hours. The initial contribution of the slower component is only 10% of the radiation field. This information will be useful in optimizing the cooling time before maintenance is scheduled.
D. Radioactive Waste

While marginally radioactive waste is discarded in a controlled landfill operated by the university, the old beam lines removed to accommodate the new system were too active for disposal in this manner. Each of these radioactive components was photographed. On the photograph the contact radiation doses, the identification, the date of measurement and the weight were marked. This gives us an excellent inventory of the several tonnes of material removed. The composition is approximately 99% steel, 0.5% copper and 0.1% aluminium.

These radioactive components are stored in a building owned by the laboratory, on university property about 1 km from the laboratory. The building is locked and fenced and its occupancy is extremely low. We plan to store this material until the concentration of activity is reduced and then make decisions on its disposal.

E. Future Plans

The Radiation Protection Department views the coming year with some trepidation. During the period of upgrading at the linac, the need for service and supervision has grown greatly elsewhere on the campus. This has put considerable strain on the radiation protection staff and indeed it was only possible to provide adequate service because of the relative dormancy of the accelerator laboratory. When EROS becomes fully operational, it will require even more effort than before and the situation will become impossible. The university has been made aware of this problem and it is hoped more help will be forthcoming.
A. Professional Journals

Radiative decay of unbound levels in $^{14}$N

Trinucleon magnetic moments

Ground state M1 transition strength of the 1.115 MeV level in $^{65}$Cu

Power deposition and temperature rise at the shower maxima
Nuovo Cimento, 89A (1985) 76-84

Photoneutron cross sections for $^{14}$C

A pulse radiolysis study of Tetramineplatinum (II) complex ion in aqueous chloride media
Radiation Phys. Chem. 27 (1986) 41-45

Baryon shapes with constrained oscillators

Six-quark bag, exchange currents and trinucleon magnetic moments

Ab initio SCF MO calculations on the reaction of hydroxyl radical with Cytosine
Can. J. Chem. 64 (1986) 914-919

[10] P. S. Takhar
Energy deposition of 100-300 MeV electrons
Nuovo Cimento 92 (1986) 57

Optics modules for circular accelerator design
Nucl. Instr. Meth. (accepted June 1986)
Circular machine design techniques and tools
Nucl. Instr. Meth. (accepted June 1986)

Energy deposition by high energy electrons in water
Nucl. Phys. A (accepted August 1986)

Pulsed-laser photochemical study of Tris(1,10-phenanthroline)chromium(III) Ion in acidic and alkaline aqueous media
Inorg. Chem. (accepted September 2, 1986)

Resonances in $^{27}$Al+p for $E_p = 3.1-3.6$ MeV
Phys. Rev. C (accepted October 1, 1986)

Experimental and theoretical study of the nascent photoredox behavior of aqueous hexachloroplatinate(IV) Ion
Inorg. Chem. (accepted October 6, 1986)

Meson spectra in the interacting boson model: gluonic degrees of freedom

The shapes of baryons in the Friedberg-Lee model

The photonuclear cross sections of $^{48}$Ca
Nucl. Phys. (submitted May 1986)

Pion electroproduction from nuclei

[21] P. S. Takhar
Backscattering of electron and positron in current monitoring devices
Physica Scripta (submitted August 1986)

[22] C. Rangacharyulu, G. Küchler, A. Richter and E. Spamer
Radiative transitions in $^{27}$Al and their relevance to the $^{26}$Al(p,$\gamma$)$^{27}$Si reaction under stellar conditions
Astrophysics Journal (submitted September 1986)
B. Books


C. Papers Published in Conference Proceedings

Radiative decay of 15.234 MeV level in $^{28}$Si

Summary and recommendations of working group 2 - "The Classical Region"

Beam optical design and studies of the SLC arcs
Contributed paper, 13th International Conference on High Energy Accelerators, Novosibirsk, USSR, August 7-11, 1986
Stanford Linear Accelerator Center, Publication SLAC-PUB-4013

Circular machine design techniques and tools
Invited paper, Second International Conference on Charged Particle Optics, Albuquerque, June 19-23, 1986

D. Papers Presented to Learned Societies and Seminars

[1] C. Rangacharyulu with the TAGX Collaboration
Status of TAGX detector
Invited talk, Japan Physical Society Meeting, Kobe, Japan, October 1986

Summary and recommendations of working group 2 - "The Classical Region: Theoretical"
[3] W. L. Waltz
Experimental and theoretical studies of Platinum(III) complex ions
Symposium on Pulse Radiolysis, Columbus, Ohio, June 29-July 1, 1986

Photochemical and radiolytic studies of some monomeric Platinum(III) complexes
Invited paper, 69th Canadian Chemical Conference, Saskatoon, June 1-4, 1986

Ab initio SCF MO calculations on the reaction of hydroxyl radical with Cytosine
69th Canadian Chemical Conference, Saskatoon, June 1-4, 1986

MS-X-Alpha study of Platinum(III) model compounds
69th Canadian Chemical Conference, Saskatoon, June 1-4, 1986

[7] H. S. Caplan
EROS (Electron Ring of Saskatchewan) physics and technology
Colloquium, Department of Physics, University of Manitoba, February 12, 1986

MIT-Bates cryogenic tritium target system
Invited talk, Ninth Conference on the Application of Accelerators in Research &
Industry, North Texas State University, Denton, Texas, November 10-12, 1986

E. Theses

[1] M. O. El-Ghossain (H. S. Caplan and D. M. Skopik, co-supervisors)
Electroproduction of pions from $^3$He

F. Technical Memoranda

[1] T. P. Dielschneider
Stripline Monitor Performance #1
EROS/TM/CONT/BLM/01, March 11, 1986

P.S.R. Injection Beamline Start-up - Part II: Second 90 Degree Cell
EROS/TM/INJ/02, December 17, 1985

P.S.R. Injection Beamline Start-up - Part III: Threading the Ramp Area
EROS/TM/INJ/03, December 17, 1985

Transmission-Line Pulse Transformers
Saskatchewan Accelerator Laboratory

EROS/TM/INJ/KICK/01/86, August 29, 1986

Injection 2.1° Prototype Test Results
EROS/TM/INJ/MAG/02, June 10, 1986

P.S.R. Start-up: On-Axis Injection - Part I: Getting from the Injection Point to the First Bend
EROS/TM/PSR/05, December 30, 1985

Tune Measurements in EROS
EROS/TM/PSR/06, March 18, 1986

[8] L. O. Dallin
Delayed and Low Current Extraction from EROS
EROS/TM/PSR/07, March 21, 1986

P.S.R. Start-up: On-Axis Injection - Part II: Around the First Bend ("West Bend")
EROS/TM/PSR/08, April 4, 1986

[10] L. O. Dallin
Anti-Damping and Slow Extraction in EROS
EROS/TM/PSR/09, June 6, 1986

Chromaticity Measurements in EROS
EROS/TM/PSR/10, September 1986

[12] E. L. Hallin
The Measured Magnetic Field of the EROS Quadrupole/Sextupoles
EROS/TM/PSR/MAG/02, May 13, 1986

Photon Tagger Focal Plane
EROS/TM/PTS/01, May 9, 1986

Photon Tagger Wire Chambers
EROS/TM/PTS/02, May 27, 1986

Spectrometer Drive - Rulon Bearing Pads
EROS/TM/SPEC/MECH/01, May 9, 1986

[16] D. R. Murray
Error Message Handling in SARA
EROS/TR/CONT/01, February 13, 1986

[17] J. C. Bergstrom
The Injection 180° Bend
[18] J. C. Bergstrom  
Injection Beam - Parameters in the Horizontal Plane  
EROS/TR/INJ/03, June 17, 1986

The Dynamic Aperture of LEP in the Presence of Errors  
CERN Report LEP-TH/86-12, March 1986

Circular Machin' Design Techniques and Tools  
Stanford Linear Accelerator Center, Publication SLAC-PUB-3942, April 1986

Optics Modules for Circular Accelerator Design  
Stanford Linear Accelerator Center, Publication SLAC-PUB-3957, May 1986

[22] K. L. Brown and R. V. Servranckx  
A Study of the Linearity of the SLC Arcs when Misalignments are Present  
Stanford Linear Accelerator Center, Collider Note, SLAC-CN-348, June 1986

Conceptual Design and Optical Studies of the SLC Arcs  
Stanford Linear Accelerator Center, Publication SLAC-PUB-, 1986

G. Seminar Series

Interactions of Atmospheric Neutrinos in Nuclei at Low Energy  
February 12, 1986

[2] E. C. Booth, Boston University, Boston  
Coherent $\pi^0$ Production and Photon Scattering in the $\Delta$-region  
March 5, 1986

[3] F. C. Khanna, University of Alberta, Edmonton  
Isobars in the Deuteron  
March 11, 1986

[4] Bent Schröder, University of Lund, Sweden  
Max, Planned Activities in Nuclear Physics  
April 17, 1986

Charm and Beauty of Annihilation  
June 20, 1986
[6] M. N. Thompson, University of Melbourne, Melbourne, Australia
Physics at Melbourne
August 11, 1986

[7] H. Ströher, Justus-Liebig-Universitat, Giessen, West Germany
$\pi^0$ Experiment and Plans at Mainz
September 5, 1986

[8] Steven A. Dytman, University of Pittsburgh, Pittsburgh
The Tritium Experiment at Bates
October 7, 1986

Tagged Photons: Details in the Structure of the Bremsstrahlung Spectrum
October 16, 1986

H. Journal Club Talks

[1] N. G. Videla
The Photon Monochromator
November 26, 1985

Electropion Production from $^3$He
December 10, 1985

Some Recent Photon Tagging at Tohoku
January 7, 1986

Simpson’s Neutrino
January 21, 1986

Parasitic Losses in EROS
February 4, 1986

Hypercharge - Fourth Force
March 4, 1986

Cross Section and Polarization of SAL Tagged Photons - Estimate
April 29, 1986

[8] E. L. Tomusiak
New Methods for Treating the 3N Continuum
May 27, 1986
[9] D. R. Murray  
Programming in ‘C’:  
- Logging in  
- Introductory programming  
- Subroutines and functions  
- Arrays, pointers and structure  
- File access  
June 23-27, 1986

[10] C. Rangacharyulu  
TAGX  
October 1, 1986

The MIT-Bates Cryogenic Tritium Target System  
October 22, 1986

[12] P. C. K. Kuo  
Ground State Photoneutron Reaction in $^{18}$O  
October 29, 1986
Saskatchewan Accelerator Laboratory

XIV. STAFF

A. Scientific Staff

Physics

J. C. Bergstrom
H. S. Caplan (Director)
M. A. Preston
C. Rangacharyulu
D. M. Skopik
E. L. Tomusiak

Chemistry

W. L. Waltz
R. J. Woods
M. A. Preston

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C. Rangacharyulu
D. M. Skopik
E. L. Tomusiak

1. Research Associates and Postdoctoral Fellows

Physics

J. Asai
J. Dey
M. Doss
E. T. Dressler
E. L. Hallin
P. C. K. Kuo
R. V. Servranckx
N. G. Videla

Chemistry

S. H. Lee
E. L. Hallin
P. C. K. Kuo
R. V. Servranckx
N. G. Videla

2. Accelerator Physicists

L. O. Dallin
T. P. Dielschneider

3. Engineering Physicist

C. B. Figley

4. Spectrometer Physicist

R. E. Pywell

1) Retired May, 1986
2) Terminated June 30, 1986
3) Appointed Research Associate, August 4, 1986
4) Terminated June 30, 1986
5) Appointed Postdoctoral Fellow, September 1, 1986
5. Graduate Students

Physics
M. O. El-Ghossain\(^1\)
G. A. Retzlaff\(^2\)
A. Rouvas\(^3\)

Chemistry
B. G. Eatock\(^4\)
N. J. Nijapba
D. Woo\(^5\)

6. Summer Students\(^6\)

Physics
T. J. Langen
L. P. Nelson
P. J. O'Shea
A. J. Sarty
D. J. Seale
P. J. Wilde
K. C. Wong

Chemistry
D. A. Friesen

7. Linac Research Experience Awards

J. Armstrong\(^7\)
A. Jmaeff\(^8\)

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1) Graduated May 30, 1986
2) Started September 1, 1986
3) Started September 1, 1986
4) On leave of absence
5) Started September 1, 1986
6) For the period May 1 to August 31, 1986
7) For the period July 28 to August 10 and August 16-31, 1986
8) For the period August 4-31, 1986
B. Technical Staff

K. T. Berg
J. L. Bergstrom
S. E. Broughton
H. Buchmann
B. M. Chomyshen
S. D. Choubal
P. Freimanis
J. I. Gale
J. A. Greefkes
D. G. Gulak
W. McWillie
D. R. Murray
E. D. Neudorf
B. R. Norum
W. E. Norum
H. Purdie
S. R. Pywell
N. E. Strunk
R. J. C. Thompson
A. M. Vedress
M. Verhulst
A. B. Walston
F. T. West
A. D. Wilson
G. H. Wright

Instrument Maker (Tech. I)
Storekeeper (Tech. Asst.)
Consultant from Ellis Technology
Electronics Technician (Tech. IV)
Instrument Maker (Tech. I)
Radiation Safety Officer
Mechanical Engineer
Administrative Assistant
Instrument Maker (Tech. IV)
Mechanical Draughtsman (Tech. IV)
Electrician (Tech. III)
Computer System Manager
Inventory Controller (Cont. IV)
Millwright (Tech. III)
Electrical Engineer
Maintenance Supervisor
Systems Analyst
Instrument Maker (Tech. IV)
Electronics Technician (Tech. IV)
Secretary
Electronics Technician (Tech. IV)
Instrument Maker (Tech. IV)
Operations Supervisor
Systems Analyst
Systems Analyst

1. Machine Operators and Casual

D. V. Amendt
M. R. Besse
S. Broda
D. N. Craddock
E. G. N. Dobroskay
K. L. Klassen
T. J. Langen
R. L. MacKenzie
B. G. Marlatte
L. P. Nelson
C. R. Onclin
P. J. O'Shea
T. Pidkalenko
A. J. Sarty
J. P. Van Deursen
R. C. Verhulst

1) Terminated February 28, 1986
2) Term appointment April 1, 1986 to March 31, 1987
3) Term appointment to December 31, 1986
4) Terminated December 31, 1985
5) On sick leave January 1 to December 31, 1986
6) Appointed December 1, 1985
C. Visitors and Consultants

November 7-8, 1985
Dr. W. J. McDonald and Dr. H. Fielding, University of Alberta, Edmonton

November 20-21, 1985
Peter Mascher, University of Manitoba, Winnipeg

January 9, 1986
Dr. J.-M. Poutissou, TRIUMF, Chairman, Subatomic Physics GSC of NSERC

January 24, 1986
Alain Delaye, Thomson CSF Canada, Montreal

February 10-13, 1986
Dr. J. S. O’Connell, National Bureau of Standards, Washington

February 16-21, 1986
Brent Astley, Trent University, Peterborough

February 18, 1986
- Hugh Menown, EEV, Chelmsford, Essex, England
- Barry Newton, EEV, Chelmsford, Essex, England
- Ralph Kachur, EEV Canada Ltd., Rexdale, Ontario

February 28, 1986
Dr. Paul Redhead, National Research Council, Ottawa

March 4-6, 1986
Prof. E. C. Booth, Boston University, Boston

March 5, 1986
J. Bedau, Bruker Analytische Messtechnik GMBH, Karlsruhe, West Germany

March 10-12, 1986
Dr. F. C. Khanna, University of Alberta, Edmonton

March 21, 1986
Dr. Blaine Holmlund, Vice President, University of Saskatchewan

March 26 - April 1, 1986
Dr. K. I. Blomqvist, Massachusetts Institute of Technology, Cambridge, Mass.
April 1-5, 1986
Dr. W. Del Bianco, University of Montreal, Montreal

April 10-11, 1986
Meeting #7 of Saskatchewan Advisory Committee

April 15, 1986
John Sanders, EG&G

April 16-18, 1986
Bent Schröder, Department of Physics, University of Lund, Sweden

May 15-16, 1986
- J. M. Cameron and W. J. McDonald, University of Alberta, Edmonton
- H. Fielding and W. Ziegler, University of Alberta, Edmonton
- W. Del Bianco, University of Montreal
- Z. Papanareou, University of Regina

May 13, 1986
Dr. Art Knight, Dean of Arts and Science, University of Saskatchewan
Dr. Ron Sutherland, Associate Dean of Science, University of Saskatchewan

May 13-23, 1986
Dr. J. W. Jury and B. Astley, Trent University, Peterborough

May 19-21, 1986
1986 IEEE International Conference on Plasma Science, Laboratory Tour

May 24, 1986
Dr. Blaine E. Norum, University of Virginia, Charlottesville

June 1-3, 1986
Louk Lapikas, NIKHEF, Amsterdam

June 5, 1986
R. N. Kavanagh, Associate Vice President, University of Saskatchewan
and The Digital Project Management Committee

June 13-20, 1986
- Brent Astley, Trent University, Peterborough
- Peter Kuo, University of Toronto, Toronto

June 16, 1986
George Lolos and Z. Papandreou, University of Regina, Regina
June 16-20, 1986
Barry Newton and Les Kettle, EEV, Chelmsford, Essex, England

June 20, 1986
Dr. Janet E. Halliwell, NSERC, Ottawa

June 20-21, 1986
Prof. J. D. Prentice, University of Toronto, Toronto

July 28, 1986
Mikael Vieweg, Scanditronix, Uppsala, Sweden

August 4 - December 1986
Grant O'Rielly, University of Melbourne, Melbourne, Australia

August 9-12, 1986
Dr. M. N. Thompson, University of Melbourne, Melbourne, Australia

August 9-13, 1986
Dr. J. W. Jury, Trent University, Peterborough

September 3-6, 1986
Dr. H. Ströher, Justus-Liebig-Universität, Giessen, West Germany

September 4-5, 1986
Meeting #2 of the Program Advisory Committee
- Dr. R. E. Azuma, University of Toronto, Toronto
- Dr. K. I. Blomqvist, University of Lund, Lund, Sweden
- Dr. J. W. Lightbody, National Bureau of Standards, Washington
- Dr. T. W. Donnelly, Massachusetts Institute of Technology, Cambridge, Mass.

September 8-9, 1986
Canadian Accelerator Physics Conference

October 6-8, 1986
Dr. Steven A. Dytman, University of Pittsburgh, Pittsburgh

October 15-19, 1986
Dr. L. C. Maximon, National Bureau of Standards, Washington

October 16-17, 1986
Dr. H. Fielding, University of Alberta, Edmonton
October 16-17, 1986
Dr. G. J. Lolos, University of Regina, Regina

October 16-18, 1986
Dr. W. Del Bianco, University of Montreal, Montreal

October 17-19, 1986
Dr. J. W. Jury, Trent University, Peterborough

October 17 - November 28, 1986
Brent Astley, Trent University, Peterborough