PRESENT AND FUTURE FACILITIES AT THE CERN SC2

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7. SUMMARY OF SC BEAMS, FACILITIES AND FUTURE POSSIBILITIES
1. **INTRODUCTION**

This document assembles data on existing SC beams and those planned for the coming year; it suggests various possible short-term developments involving modest extra expenditure; and it outlines some of the possible projects which could be envisaged in the long term at the SC. The aim is to provide the participants at the "Workshop on the Role of CERN in Intermediate-Energy Physics" with as much information as possible on what beams are to be found at the SC and on what might be undertaken in the future, so that the suitability of the SC for any particular experiment may be assessed. For the long term future we have tried to be realistic within the known constraints in presenting our current thinking, but no detailed studies have been attempted and the possibilities listed here are certainly not exclusive of other ideas.

For present beams, the data provided by users have been cast into a standardized form to facilitate comparisons between the SC and PS, the PS complex being the subject of another such report as this. These data, which are presented in tables 1, 2 and 3, represent beams which have been run recently; the beam lines themselves can usually be run at other energies, however. Earlier beam reports\(^1,2\) contain further information.

2. **OPERATIONAL REMARKS**

2.1 **Accelerated beam intensity**

The accelerator has been operating now for 2\(\frac{1}{2}\) years since the end of the SC Improvement Programme (SCIP) which was essentially a complete rebuild of the machine. The general layout of elements inside and around the vacuum tank is shown in Fig. 1. As one would expect with a new machine, the performance has gradually improved during this time, and although the beam intensity has not yet reached the level originally planned, the SC2 now works fairly reliably with a typical availability of 95\%. 
The main limitation to the performance of the accelerator has been the rotating condenser (rotco) of the radio-frequency system. As well as frustrating and time-consuming problems due to defects of manufacture, the level of power dissipation in certain elements fitted temporarily in the rotcos has limited their use to one radio-frequency modulation cycle out of every N possible cycles, with furthermore a maximum RF accelerating voltage of about 24 kV having been achieved. These limitations have determined the magnitude of the internal beam current.

For most of the time since SCIP, one of the two available rotcos was in use on the accelerator while the other was either under repair or being modified to permit operation at higher power. Naturally, without a spare rotco it was necessary to work only in the relatively safe region of maximum RF voltage 20 kV, and with a repetition rate $N = 4$, in order to assure a reasonable reliability for the users. The internal proton beam current accelerated under these conditions is approximately 2 $\mu$A, or $1.25 \times 10^{13}$ protons/sec with the rotco turning at such a speed that it produces 360 possible RF modulation cycles per second.

Recently, however, the necessary improvements have been completed on rotco II and we have been able to work with an RF accelerating voltage of 20 kV and $N = 3$, which gives an internal beam of about 3 $\mu$A or $1.9 \times 10^{13}$ protons/sec. It is anticipated that this situation will further improve during the remainder of 1977 and we expect to achieve operation at 20 kV, $N = 2$ giving a beam current of about 4 $\mu$A or $2.5 \times 10^{13}$ protons/sec.

2.2 Sharing between users

The utilization of the internal beam is determined by the requirements of the schedule. The normal mode of operation is for a sharing of the beam between a user in the Neutron Hall (see section 3.3) and a user of the extracted proton beam (see sections 3.1, 3.2). Such an operation requires an internal target to be raised until a suitable division of the beam is achieved, but it is complicated by the desire of both users for a good duty cycle. In
some cases, however, there is no sharing and one user has the full beam at his disposal (for example when ISOLDE have required the largest possible beam at their target, or when a user in the Neutron Hall requests the SC "field up" configuration with protons moving in a clockwise direction in the SC).

There are also often one or more parasiting groups who are able to make pre-run checks, counter tests, etc. ... using very low beam intensities and it is usually possible to find a location for these groups where the beam is "free of charge".

2.3 Time distribution of the accelerated beam (beam stretching)

Adjustment of the sharing takes place at the beginning of a run and is complicated by the desire of most users for a good duty cycle. Two systems are available to stretch the accelerated beam burst beyond its inherent length in time of about 50 μsec (the so-called "fast burst").

The first of these, the cee accelerating electrode (see Fig. 1), takes over the acceleration of the protons at the end of normal dee acceleration, which for this purpose is cut off when the protons reach a radius of about 2.21 m, i.e. when the frequency reaches 17.03 MHz. Practically no beam is lost in the hand-over between dee and cee accelerating systems. The cee has a very much lower rate of change of frequency than the dee and thus the beam is stretched in time as it is accelerated out to full radius (2.25 m) where it may either strike an internal target or enter the extraction channel. A much improved macro duty cycle is achieved with the cee system (5 50%), but because it is an accelerating system the beam retains its radio-frequency micro-structure of 60 nsec, corresponding to 16.83 MHz (the frequency at extraction radius).

The second method for stretching the beam in time is the use of a pulsed field coil or Kim coil as it is known locally. This coil is located inside the accelerator close to the regenerator (see Fig. 1) and is pulsed during each possible RF modulation
cycle with a current whose wave-form may be varied, and at a phase relative to the main RF which may also be varied. The beam is accelerated with the dee to a radius of about 2.17 m, which is just lower than that of the regenerator, so that the protons do not feel the effect of this element. The RF voltage is then cut, and the beam coasts at this radius, losing its microstructure of 60 nsec. The Kim coil then receives its suitably tailored current pulse and the field bump thus produced displaces the orbits of the protons so that they begin to feel the regenerator field. They are then extracted from the machine with a time distribution which has very little microstructure.

The Kim coil was designed to be pulsed on every possible machine cycle, but as mentioned above (section 2.1) there is actually beam only once every N such cycles. The Kim coil's current pulse stretches the beam over only one cycle and thus the Kim coil alone cannot give a macro duty cycle exceeding 1/N. However, a mixed mode of operation has been developed which gives a better duty cycle than either the Kim coil or the cee electrode separately. Both cee and Kim coil are used simultaneously and very encouraging results have been achieved, with duty cycles of greater than 50% being quoted by users on the Proton side.

Recently a new mode of operation has been tried in which the frequency of the cee voltage is modulated at 10 KHz (much faster than normal), over the normal frequency range. This "fast modulation" mode has resulted in a much improved total duty cycle for Neutron Hall users, and the figure of 60% has been reported by one group. The reason for the high duty cycle is the almost complete loss of the 60 nsec micro-structure in the beam, coupled with good macro duty cycle; however the precise mechanism which causes this happy result is still the subject of active discussion! Proton Hall users also seem to be satisfied with this new mode of operation. One additional advantage of the new mode is that the sharing of the beam between users becomes a much simpler operation than hitherto.
2.4 **Extraction efficiency**

The proton beam from the ion source, which is captured by the RF accelerating field and arrives at a radius of 58 cm, is measured on a Faraday cup mounted on the "diagnostic target" arm. Measurements are also made using a Faraday cup on the "probe target" which permits readings as a function of radius to be obtained, the lowest radius being 40 cm. Beyond a radius of about 70 cm, however, the Faraday cup readings are unreliable because the protons' range is greater than the thickness of the Faraday cup's copper block. The extracted proton beam is measured by means of a secondary emission monitor calibrated by foil activation, and the extraction efficiency of the machine is the ratio of extracted to internal beam currents. However, as we have at present no absolute measure of the proton beam intensity arriving at large radius just prior to extraction, the transmission losses from low to high radius in the accelerator are not known, although measurements made with a thermocouple probe indicate that these are small. The term extraction efficiency as used here includes therefore both these transmission losses, as well as losses coming from the extraction channel itself.

In a fast burst mode, with no beam stretching, an extraction efficiency of greater than 70% has been achieved. This is reduced to about 65% when the Kim coil is operating. With cee operation the figure becomes 50%.

2.5 **Beam losses inside the SC**

Some beam is lost in the cyclotron during the acceleration process, but this is believed to be a small amount. The activation of the machine is caused mainly by that fraction of the beam which is used on internal targets, and 30-50% of that fraction which is used for extraction. At present the amount of beam deposited in the machine is between 1 μA and 2 μA depending on the sharing mode requested. The resulting activation of the machine and its surroundings, however, still permits access when required after a suitable cooling period.
3. **EXISTING BEAMS AND FACILITIES**

3.1 **Underground Hall**

The 600 MeV extracted proton beam from the SC may be transported 60 m to an underground hall where the ISOLDE separator is situated. Fig. 2 shows the ISOLDE beam line in plan and elevation. There are at the moment losses of about 20% in intensity associated with this beam transportation, but work is under way to eliminate them. The intensity at the ISOLDE target depends on the SC internal beam intensity and on the sharing mode scheduled, but a typical value for most runs at present is 1 μA, or $6.25 \times 10^{12}$ protons/sec; the highest value recorded has been 1.5 μA in one run. The spot size is normally chosen as 15 mm x 5 mm and its precise position and shape are adjusted at the start of the run by the ISOLDE team.

There is also a "particle physics" zone immediately upstream of the ISOLDE target zone, and this is used on occasions for other experiments requiring 600 MeV protons. It has recently been used by a group studying the fission process using a very low intensity beam of about $10^{11}$ protons/sec with a good duty cycle. To obtain such a weak beam, a careful adjustment of the height of an internal target had to be carried out in order to avoid too much proton beam emerging from the accelerator. Such an operation gives practically the full proton beam on the internal target feeding secondary beams to the Neutron Hall user, but creates scheduling difficulties because it blocks the heavily loaded ISOLDE programme. A summary of the beams to this Hall is given in Table 1.

3.2 **Proton Hall**

Protons emerge from the SC and are focussed onto a target by lenses LA1, LA2 and LA3. The emittance of the extracted proton beam is approximately $6 \pi \text{ mm.mrad}$ in each plane. Figs 3 and 4 show how the secondary beams thus produced may be transported to the Proton Hall. There are three pipes through the
shielding wall between the SC Hall and the Proton Hall, labelled B, C and D and somewhat different arrangements of lenses and bending magnets are required inside the SC Hall in each case. A summary of the beams which have been used recently is given in Table 2.

The C pipe shown in Fig. 3 is the most frequently used of the pipes through the wall. Pions produced in the 10 cm beryllium target placed after LA3 are collected at 0° and are transported to the Proton Hall through the C pipe after a deflection of 30° in the bending magnet MP4. The waste proton beam is deflected through a much smaller angle and is dumped on the shielding wall. Once in the Proton Hall the beam is then transported to the site of the experiments, which are currently either the Omicron spectrometer (using the pion beam) or the μSR magnet (using the muon beam from pion decay in flight).

A good deal of work has been done by various groups on calculating the optics of the C beam line. The so-called "high flux beam" of earlier beam reports used the C pipe to transport the pion beam to the Proton Hall, but these calculations did not consider the distribution of the beam to the actual site of the experiments in the hall. The more recent calculations, which have been verified by experiment, yield rather lower fluxes than the "high flux beam" but with much improved optical properties.

The D pipe beam was designed as a high resolution beam having a 40° bend in the magnet MP4. This beam has not been requested since SCIP and therefore nothing can be added to the remarks of the earlier reports. It is included for comparison in Table 1, with the numbers updated to the present SC conditions.

The last pipe through the wall to the Proton Hall, the B pipe, has been used for neutron beams produced either by the reaction D(p,n)2p at 0°, or by the interaction of the proton beam with a beryllium target. In both cases the neutrons produced have all energies up to nearly 600 MeV, but in the former case with a cryogenic deuterium target, the spectrum is much cleaner and
approximately 30% of the total neutron flux is to be found in a peak above 500 MeV. The beam arrangement is shown in Fig. 4, where it is seen that the deflection in MP4 is 20° in this case, and that the production target is placed after this magnet. The protons are swept away from the forward direction by a second bending magnet MP5. Currently the radiobiology group use this beam with a beryllium production target.

The B pipe has also been used in other ways. A scattered out proton beam (ASOP) is produced when a safety target is inserted in the internal beam of the machine simultaneously with one of the normal internal production targets. The function of the safety target is to prevent the main proton beam emerging through the extraction channel, but because of scattering in the internal target, some beam escapes from the accelerator and may be transported to the Proton Hall via the B pipe. A weak beam of \( \leq 600 \text{ MeV} \) protons of about \( 10^4 \) to \( 10^5/\text{sec} \) is obtained, spread over the area of the pipe (25 cm diameter).

Another use of the B pipe has been to provide a parasitic pion beam during the normal functioning of the C pipe beam. In this case the group using the C pipe chooses the pion energy they require by means of the current in the bending magnet MP4. Pions of the same sign but with 50% higher momentum will enter the B pipe and may be used parasitically for counter tests, setting up, etc. ...

3.3 Neutron Hall

Beams to the Neutron Hall are produced by the internal proton beam striking a target inside the accelerator. The arrangement of beam lines is shown in Fig. 5. The internal targets are fixed on a support which, within certain prescribed limits, may be positioned at any desired radius or azimuth in the machine, but only the vertical position may be changed remotely. The correct position for the target to feed each of the beam lines has been determined experimentally using the "Fermi trolley", which permits
the remote positioning of a target radially and azimuthally. As this device is not radiation resistant, however, it can only be used for short periods when a new beam is to be studied.

The targets, which are not water cooled, were designed to withstand a maximum proton beam of 5 μA; they may be raised remotely to block the beam, or they may be positioned to intercept only a fraction of it (sharing mode, section 2.2). The beams produced from the internal targets are then transported to the Neutron Hall through one of the three available channels. Table 3 gives details of the beams which have been used recently.

The μ channel (labelled Y in Fig. 5) is capable of delivering negative muons in the energy range 50 to 190 MeV, and also pions from 100 to 200 MeV. It is a channel which is much in demand, and by switching the analysing magnet in the Neutron Hall, the beam may be fed to two different zones. The internal target producing beam for the μ channel may be exchanged for a model which can be pulsed rapidly into a stored proton beam in order to produce a short, intense burst of secondary particles; this mode was used for the recently completed Lamb shift experiment in muonic helium. Most experiments on the μ channel at present require low energy muons; the flux is considerably greater if higher energy muons are used, however.

The 125 MeV channel (labelled K in Fig. 5) can produce pion beams in the energy range 80 to 260 MeV, but most groups have chosen to use it recently for an energy of about 120 MeV where the flux is favourable. The channel has been used mainly for π⁻ beams. A switching magnet allows the beam to pass into the parasitic area, an extension of the Neutron Hall.

The low energy pion channel LEPC (labelled L in Fig. 5) delivers π± beams of low energy, from about 60 to 105 MeV. Beam is produced from an internal target as for the other channels, but in this case there is also a "free" parasitic π⁺ beam which originates from protons striking the septum at the entrance to
the extraction channel; this "free" beam is present, of course, whenever there is an extracted proton beam, and is a much-used facility. When the LEPC is used for a low momentum $\pi^-$ beam the SC magnetic field must be reversed and so sharing with an extracted beam is not possible.

3.4 Irradiation facilities

There are often requests for irradiations of various materials, mainly from nuclear chemists. Several possibilities exist at the SC for such irradiations.

The target to be irradiated with the full intensity proton beam may be fitted to the so-called "probe target" arm which can be positioned inside the accelerator at any desired radius from 50 cm to full radius, 225 cm. The proton energy may thus be chosen between about 40 and 600 MeV. For radii less than 130 cm (250 MeV) this operation requires the mounting of an extension arm and consequently the breaking of the machine vacuum, and this is thus not a trivial matter. However for irradiations at radii above 130 cm the sample may be inserted through an air lock, and this operation is very simple.

Irradiations are also made in the extracted proton beam. Thin samples (~ 1 mm) are often placed at the upstream end of the pion production target after the lens LA3 (see Fig. 3) where the interference with normal pion production is negligible. Alternatively samples are placed in the waste proton beam as this hits the wall where it is to be dumped (RO in Fig. 3). Because the current in magnet MP4 is chosen by the group running on the C beam, the waste protons hit the wall at a position which may vary from run to run, and thus the sample to be irradiated is normally mounted on a scanning device which enables the optimum position to be found.
4. MODIFICATIONS FORESEEN FOR 1978

4.1 Beam switching

In order to make a change of programme from ISOLDE to the use of the B or C pipes it is necessary for beam transport elements to be physically removed and repositioned in the SC Hall, and for the associated vacuum system and target arrangement to be modified. Such operations are scheduled on average about once every 7 or 8 days and require the intervention of mechanics, vacuum technicians, operators etc. ... for two to four hours on each occasion, which time cannot be much further reduced. One cooling shift of 8 hours always precedes such beam changes, but even so the radiation dose absorbed by the personnel involved is of order 100 mrem. As time goes on, of course, the ambient radiation levels will increase further, so that it is essential to reduce the number and length of interventions in the SC Hall.

During the shutdown foreseen for Spring 1978 it is intended to install the equipment, currently under design, which will allow the change of programme between ISOLDE and the B or C beam to be accomplished in a short time (of order two hours), and with little or no intervention in the SC Hall. An additional gain will be that a full cooling shift is not required, thus increasing the available machine time for physics.

The principle of the new beam arrangement is shown in Fig. 6. The main feature is that the ISOLDE magnet MP1 on the one hand, and the target station with the first pion lenses LG1, LG2 on the other hand, are mounted side by side on rails such that either may be positioned in the proton beam by means of a lateral displacement. The beam change from ISOLDE then involves first the breaking of vacuum joints on both the upstream and downstream ends of MP1; then the lateral movement of MP1 and the LG lenses to bring LG1, LG2 into their correct position; and finally the remaking of the vacuum system for the pion beam. The intention is that ultimately this series of operations be carried out remotely. However, it could be that too much complication
would be introduced if the change were to be made completely remotely, and thus it will probably be preferable initially to perform one or two operations manually, requiring only the intervention of, say, one man for a maximum of 5 minutes in the SC Hall.

Details of the scheme are still under discussion, but design work on the principal elements is under way. The following list shows the main features of the new arrangement:

(a) The rapid, eventually remote switch-over between ISOLDE and the B or C pipe beam, and vice versa.
(b) Use of the existing ISOLDE beam line, with improvements (see below).
(c) Use of the existing C pipe pion beam.
(d) Use of the existing B pipe for a pion beam.
(e) The opening of the A pipe to provide a neutron beam to the Proton Hall. A neutron beam in the B pipe (as at present) could be obtained after a repositioning of elements in the SC Hall.
(f) Installation of an irradiation facility where the waste protons are dumped on the wall.
(g) Parasiting via the B pipe when the C pipe is functioning, and vice versa.
(h) At some future date, weak beams of light ions could be transported to the Proton Hall via the pipe A, or possibly the pipe B.

4.2 **ISOLDE beam**

As noted above, the new beam arrangement will permit a simple switching to the ISOLDE line from the B or C beams with no access necessary in the SC Hall (or at worst a minimal intervention) and no cooling shift required. This is particularly important for ISOLDE because it fulfils a long-standing request for the possibility of making short (minimum 4 hours) runs to test new targets and techniques.
A further modification foreseen for the shutdown in 1978 is the installation of machine vacuum in the 60 m transfer line from the accelerator to the ISOLDE target. At present there is poor vacuum in this line, which is separated from the SC main vacuum by two windows and an air gap. These windows will be removed and the line vacuum improved by the addition of more pumps, and the result should be an improved quality ISOLDE beam, with fewer losses in transmission along the transfer line.

These transmission losses are at present rather high and are due at least in part to mis-alignments, and the intention is to install beam loss monitors similar to those at the PS in order to track down the beam losses and eliminate them as far as possible. The effect of this will be felt particularly at the end of the ISOLDE beam line where the last two lenses are at present receiving large radiation doses due to the bad optics upstream.

4.3 $^3$He$^{2+}$ acceleration

The project to accelerate $^3$He$^{2+}$ ions involves the insertion of a section of transmission line between the rotco and the dee electrode. The extra section has a length of 120 cm and its function is to shift downwards the frequency range covered by the RF system. For proton acceleration in the actual magnetic field of the cyclotron the frequency is modulated between 30.13 MHz and 16.78 MHz, whereas for $^3$He$^{2+}$ the range needed is from 19.96 MHz to 13.90 MHz. Details of the project will be found in Ref. 3.

The engineering work to be undertaken to permit the installation of this extended transmission line will be carried out during the Spring 1978 shutdown, when the hardware should be ready. The first extraction of $^3$He$^{2+}$ ions could then be scheduled. Tests of acceleration to an intermediate radius which have already been carried out indicate a probable beam intensity of at least 1 µA, or $3 \times 10^{12}$ ions/sec, and this will be obtained with a rotco voltage of 20 kV and an RF duty cycle $N = 3$ (i.e. the same conditions that give a proton beam current of 3 µA or $1.9 \times 10^{13}$ protons/sec). The beam energy will be 910 MeV or 303 MeV/nucleon. No changes are
necessary to the ion source other than the exchange of the gas bottle; however the source arc current required is much higher than for proton acceleration and this will result in shorter filament lifetimes. Compared to filament lifetimes of about 150 hours for proton acceleration, it is estimated that this will fall to about 24 hours for $^3\text{He}^{2+}$ acceleration if the maximum beam intensity is required, but this is not too inconvenient because filaments could then be changed in a regular way each day.

The principal characteristics of the beam are listed below:

<table>
<thead>
<tr>
<th>Ion</th>
<th>$^3\text{He}^{2+}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>910 MeV</td>
</tr>
<tr>
<td>Energy/nucleon</td>
<td>303 MeV/nucleon</td>
</tr>
<tr>
<td>Frequency at start of acceleration</td>
<td>19.96 MHz</td>
</tr>
<tr>
<td>Frequency at extraction radius</td>
<td>13.90 MHz</td>
</tr>
<tr>
<td>Dee voltage</td>
<td>20 kV</td>
</tr>
<tr>
<td>RF duty cycle</td>
<td>$N = 3$</td>
</tr>
<tr>
<td>Rotco repetition frequency</td>
<td>360 Hz</td>
</tr>
<tr>
<td>Accelerated beam</td>
<td>1.0 $\mu$A</td>
</tr>
<tr>
<td></td>
<td>$3 \times 10^{12}$ ions/sec</td>
</tr>
</tbody>
</table>

The beam will be used mainly by ISOLDE, but it could also be extracted using the Kim coil with good duty cycle if other experiments were to request it (see section 2.3).

5. **SHORT TERM DEVELOPMENTS**

The possibilities presented in this section are not in any particular order of difficulty or cost. They are all rather modest extensions of the performance of the machine and require relatively minor investment of resources, although detailed studies have not yet been carried out. One could imagine, however, further developments of these possibilities which would require more significant investment, as will be outlined in section 6.
5.1 Higher intensity proton beam

The proton beam intensity foreseen for the next year is about 4 \( \mu \)A or \( 2.5 \times 10^{13} \) protons/sec, and this is produced with the radio-frequency system operating at 20 kV, \( N = 2 \) (which means that only one RF modulation cycle out of 2 is actually utilized). To increase the beam intensity beyond this level requires either \( N = 1 \) operation or a higher RF accelerating voltage, but in both cases the power dissipated inside the rotco will be increased. However in the latter case the RF electric fields and stored energy are also increased.

A reasonable goal might therefore be \( N = 1 \) operation at 20 kV accelerating voltage, which would give a beam intensity of about 8 \( \mu \)A, or \( 5 \times 10^{13} \) protons/sec. The increased power dissipation in the rotco would show up any weak points in the design, one of which is known to be the set of eight compensation coils through which various supplies pass from outside the rotco to the high voltage electrodes at its centre. These coils would certainly have to be replaced and the supply lines re-routed, and this would involve a redesign of this part of the rotco. Once manufactured, the new parts could probably be installed in the rotco during an annual shutdown, but this does mean stripping it down and would probably imply running the machine without a spare rotco for some time.

Any increase in beam intensity of course also increases the radiation levels to be found inside and around the accelerator. With the imminent 4 \( \mu \)A internal proton beam and a sharing mode of operation, the amount of beam which is deposited in the SC will be between 2 and 3 \( \mu \)A. Such losses mean that any intervention in the tank requires several shifts of cooling time, and of course there is in addition gradual build-up of long half-life activities in the whole of the SC Hall. This situation is probably tolerable for a machine such as the SC which is fairly reliable, and which was built to enable quick and simple changes of those elements which might break down or degrade; it should be noted
that spares exist, or will exist, for all the items essential to
the machine, except for the dee and the cee, the main magnet coil
and the vacuum chamber.

However the induced activity level in the interior of
the SC tank cannot be allowed to rise to such a level that access
is no longer possible. This is likely to occur if one were to
increase the beam from 4 µA to 8 µA. Thus any project to increase
the intensity beyond 4 µA should be linked to ways of reducing the
losses in and around the accelerator. One way would be to limit
severely the use of internal targets; another would be the improve-
ment of the extraction efficiency.

5.2 Improvement of extraction efficiency

The best extraction efficiency so far achieved has been
somewhat above 70% in fast burst operation. This figure includes
any transmission losses (believed to be small) during acceleration
up to extraction radius in the machine.

The existing extraction system 4) consists of a current-
bearing septum (EMC) of width 3 mm, which directs the beam into a
passive iron channel; the beam reaches the septum after its orbit
is disturbed by the effect of a passive regenerator at the extrac-
tion radius. Fig. 1 shows the disposition of these elements in
the vacuum tank. Such an extraction system relies for its high
efficiency on the good beam quality available since the installa-
tion during SCIP of a hooded arc ion source. The beam losses are
about 15% on the entrance septum of the extraction channel, and
about 15% along the length of the channel, leaving the presently
observed maximum of 70% to be extracted.

It is likely that an improvement in the extraction effi-
ciency could be achieved by the installation of an additional
electrostatic septum upstream of the EMC. This septum could be
very thin (~ 0.3 mm) and could eliminate a large fraction of the
losses currently observed due to beam falling on the entrance sep-
tum of the EMC, but it would not reduce the losses elsewhere in
the extraction channel. Thus the presently observed 70% extraction efficiency in fast burst mode might be increased to over 80%, but with the considerable complication of an electrostatic septum requiring an electric field gradient of 80 kV/cm across the entrance aperture of 2 to 3 cm (i.e. requiring a voltage of order 200 kV with respect to ground).

The position of this new septum inside the tank upstream of the EMC places it into the region presently occupied by the internal targets, so that these would have to be removed to allow such an installation, with the consequent loss of beam facilities in the Neutron Hall.

Other ways to improve the extraction efficiency have also been discussed, such as to change the shape of the septum of the EMC and to replace the regenerator with an improved model. This would avoid the complication of the additional electrostatic septum. Recent tests have also shown that useful improvements in extraction efficiency might be obtained by restricting the vertical size of the beam at the centre of the machine, but no quantitative estimates are available.

5.3 **Higher intensity $^3$He$^{2+}$ beam**

The $^3$He$^{2+}$ beam expected in 1978 is about 1 µA or $3 \times 10^{12}$ ions/sec. If the modifications to the rotco mentioned in section 5.1 were undertaken, however, this beam intensity could be increased in principle to about 2 µA or $6 \times 10^{12}$ ions/sec.

5.4 **Acceleration of deuterons and alpha particles**

The addition of a 120 cm section of transmission line between the rotco and the dee was noted above to be necessary for the adjustment of the radio-frequency system so as to allow the acceleration of $^3$He$^{2+}$ ions, and this work will be carried out in 1978. According to calculations, this same extension piece would also permit the acceleration of deuterons and alpha particles (for which the frequency needed is even lower than that for $^3$He$^{2+}$ ions), if the line is loaded by the addition of capacitors to reduce the resonant frequency.
There are in addition certain modifications required inside the rotco before such acceleration of d, α could be permitted. The set of eight compensating coils has already been noted as a weak point of the rotco design, and these coils would have to be replaced before accelerating deuterons or alphas because of the higher power dissipation at the lower frequencies required. However this work is also necessary for other improvements mentioned in this section.

The existing ion source of the machine will provide adequate beams of d and α if the arc current and voltage are increased above the values used for proton production. As noted before these changes would be at the expense of filament lifetime, which it is expected may fall to the order of 10 hours. Thus obviously the development of a reliable multi-filament system would be a very useful addition to any proposal for d, α acceleration, and this work has in fact already commenced.

The principal characteristics of the beams are listed below:

<table>
<thead>
<tr>
<th></th>
<th>Deuteron</th>
<th>Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>363 MeV</td>
<td>730 MeV</td>
</tr>
<tr>
<td>Energy/nucleon</td>
<td>181.5 MeV/nucleon</td>
<td>182.5 MeV/nucleon</td>
</tr>
<tr>
<td>Frequency at start of acceleration</td>
<td>15.03 MHz</td>
<td>15.12 MHz</td>
</tr>
<tr>
<td>Frequency at extraction radius</td>
<td>11.58 MHz</td>
<td>11.63 MHz</td>
</tr>
<tr>
<td>Dee voltage</td>
<td></td>
<td>20 kV</td>
</tr>
<tr>
<td>RF duty cycle</td>
<td></td>
<td>N = 4</td>
</tr>
<tr>
<td>Rotco repetition frequency</td>
<td></td>
<td>360 Hz</td>
</tr>
<tr>
<td>Accelerated beam (μA)</td>
<td>~ 1 μA</td>
<td>~ 1 μA</td>
</tr>
<tr>
<td>(ions/sec)</td>
<td>~ 3 (10^{12})</td>
<td>~ 3 (10^{12})</td>
</tr>
</tbody>
</table>

5.5 **Pulsed beam**

Some interest has been expressed in secondary beams produced from the interaction of a proton beam of short duration in a target; the requirement is for a beam of ~ 2 μsec duration with a repetition rate of several hundred Hz. A pulsed beam of slow
neutrons could be of interest in solid state physics studies using time of flight techniques\textsuperscript{5)}, and an intense pulsed beam of muons with such a repetition rate would facilitate the study of muonic systems where counting over many muon half-lives is required between beam bursts.

A fast Kim coil which would produce a beam to meet the above specification was proposed during SCIP\textsuperscript{6,14)}, and some parts of it were in fact manufactured. The new Kim coil would have to be installed in place of the existing Kim coil, and it would act only on the extracted proton beam from the accelerator.

5.6 New probe target

The use of the probe target arm for mounting targets to be irradiated in the machine was discussed in section 3.4. This probe target is also used for mounting the diagnostic detectors of various kinds which are required during machine development sessions. The main limitation is that a tank opening is required if ever it is desired to mount anything at a radius of less than 130 cm in the tank.

Experience of operation has shown that it would be extremely helpful to have a probe target which would go into the existing air lock but which could cover the range of radius below 130 cm (250 MeV proton energy): such a probe would also have to be water cooled, which would add to the design complication. The principal gain from the operational point of view would be the reduction of the number of tank openings and the improvement in the SC vacuum which would result.

5.7 Acceleration of partially stripped light ions

In view of the interest expressed in beams of ions heavier than alpha particles, possible ways of accelerating such ions in the SC have been studied\textsuperscript{10,11}). These feasibility studies take as starting point an ion source which can be located at the centre of the machine and can produce partially stripped ions. The resonant frequency of the ions at the centre of the cyclotron is
proportional to Q/A, where Q is the charge of the ion and A is its mass. The Q/A ratios which can be obtained are typically between 1/3 and 1/5. Consequently, the frequency at the start of acceleration for these ions is 1/3 to 1/5 of that for protons, and the modulation range is reduced. As the frequency range for proton acceleration is between 30.13 MHz and 16.78 MHz, the required frequencies for ion acceleration are therefore below 10 MHz and it is not possible to modify the rotcos to work at such low frequencies, or to construct a suitable extended transmission line.

However, an acceleration of the ions on the third harmonic of their resonant frequency is possible using a part of the present proton frequency programme. This technique has been tried in the SC and ions such as $^{20}\text{Ne}^{4+}$ have been accelerated to low radius (50-60 cm). The main obstacle to reaching the full radius is the low voltage available for acceleration caused by the dee cut-back (see Fig. 1), although there are also important losses in beam due to charge exchange interactions between the ions and residual gas molecules in the tank (where the pressure is $\sim 10^{-6}$ Torr).

To accelerate to large radius in the third harmonic mode, it is necessary to compensate for the decrease in the accelerating voltage felt by the particles. This reduction is due to the form of the dee which does not cover 180° at all radii but has a progressive cut-back to 128° at large radius (a cut-back to 120° would reduce the accelerating voltage to zero in third harmonic mode). Partial compensation can be achieved by rotating the rotco more slowly (so reducing the voltage gain per turn needed by the ions), but full compensation requires the insertion of an additional RF accelerating electrode in the shape of a V. This electrode would be introduced into the tank through the probe target window and would occupy the place currently occupied by the internal targets on their platform which, as was discussed in section 5.2, is also the region of the tank which could be required for an improvement in the extraction efficiency; it would be removed from the accelerator during periods of proton acceleration. The RF generator for the additional electrode would be linked to the dee RF in frequency and phase.
In recent tests the rotco has been run at reduced speed and a beam of 0.1 nA (~$10^8$ ions/sec) of $^{20}\text{Ne}^{4+}$ has been accelerated to a radius > 1.5 m in the machine, corresponding to 302 MeV. A speed reduction of a factor 2.8 was used in these tests (128 Hz repetition frequency instead of the usual 360 Hz), but such a reduction is not sufficient by itself to compensate for the dee cut-back and to allow acceleration of the ions to full radius. In addition it was only possible to run the rotco at this slow speed for very short periods since the recovery of lubricating oil from the rotor vacuum seal depends on centrifugal force. In order to allow long running periods at slow speed a redesign of the rotor seal and bearing system is required, followed by installation of the new system in the spare rotco, during which time this rotco is out of service as a spare for the one in use on the machine. However, it might be possible to avoid these modifications by running the rotco at the allowed repetition frequency of 250 Hz and to install a rather larger additional V electrode; this possibility is being investigated.

The above modifications, which must be considered as being in the upper range of what is called a "short-term development", would probably produce ion beam intensities of at least $10^8$ ions/sec at extraction radius for $^{20}\text{Ne}^{4+}$. This figure is based on the recent results achieved at a radius of 1.5 m in the existing machine vacuum and with the existing source; it assumes in addition that the rotco is run at a reduced repetition frequency and that a new V electrode is installed. The ions which might be accelerated are shown in the table below and their intensity depends on what can be achieved with the source. These beams could either be used in the ISOLDE area or could be transported into the Proton Hall; they could be extracted from the machine using the Kim coil to produce a good duty cycle.
5.8 Very low momentum muon beam

The muon beam in the Proton Hall (see section 3.2 and Table 2) is used at present by groups studying various atomic and molecular properties of materials using the μSR technique. The muons are produced by the decay in flight of π⁺, and the beam is transported to the Proton Hall where a longitudinal polarization of up to 80% is observed. Unfortunately the beam has a contamination of ~ 25% electrons which are a problem in μSR experiments because it is the decay of muons into electrons which is detected. The optimum transport momentum has been found to be 250 MeV/c; the beam is degraded to 100 MeV/c immediately before the target, but only about 50% of the degraded muons actually stop in the targets used. Thus, a reduction of the electron contamination and a lowering of the muon momentum would significantly improve the facilities available for μSR experiments at the SC.

A proposition for an alternative muon beam line has been studied recently, based on the "Arizona" muon beam at Berkeley\textsuperscript{15}). A normal pion production target is bombarded with the extracted
proton beam, and some pions which are produced at angles of order 90° will slow down in the target material and come to rest at its outer edge. Very low momentum muons are produced by the decay of these pions at rest, and these may be captured by a beam line whose entrance is at 90° to the proton direction. The momentum of the muons is 29 MeV/c (4 MeV) so that the beam line must be under vacuum, with the entrance window close to the production target; the quadrupoles and magnets along the beam line would be specially constructed, but they should be relatively inexpensive since the momentum is so low.

Such a beam line could be compatible with the changes foreseen in the SC Hall in 1978 (see Fig. 6). A fixed beam line could probably be constructed to accept the slow muons from the normal pion production target and to transport them via the D pipe into the Proton Hall; two bending magnets with deflections of 90° and 40°, and about twelve quadrupole lenses would probably be required along the beam line, whose total length would be about 18 m. The beam line would remain in place during the mechanical change-over to ISOLDE and would thus not complicate this manoeuvre. It would also have the enormous advantage of being a parasitic beam line since both it and the normal pion beam in, say, the C pipe, could be used independently and simultaneously.

The detailed design of the beam line has not yet been done, but preliminary estimates\(^{16}\) show that a flux of 29 MeV/c muons of \(7 \times 10^4\) muons/sec with \(\Delta p/p\) of order 6% might be obtained on a target of area 6 cm \(\times\) 6 cm, from a proton beam at the production target of 1 \(\mu\)A. This beam would be almost 100% polarized longitudinally and would open up new experimental possibilities due to the high stopping rate available, for example the use of very thin targets. Finally, if an electrostatic element could be incorporated in the beam line to separate the electrons and muons by their masses, it might be possible to produce a very clean muon beam, which is also an important criterion for some experiments.
6. **LONG TERM DEVELOPMENTS**

In this section some of the possibilities mentioned earlier are developed further, with the intention of indicating what might be realizable at the SC into the 1980's. It is clear that these ideas are preliminary but it is obvious that they will involve considerable resources spread over a number of years. Detailed studies can be undertaken once the conclusions of the "Workshop" have been digested.

6.1 **High intensity proton beam**

The problems associated with an increase of the proton beam intensity beyond 4 μA have already been noted. Theoretically, taking into account the actually measured field shape in the cyclotron and including the optimum shape of the frequency modulation programme, it should be possible\(^7,^8\) to accelerate a proton beam of more than 10 μA using the full 30 kV dee voltage, with N = 1, as specified in the design of the radio-frequency system.

To achieve this performance, considerably more development work will be required, particularly on the rotcos. In order to avoid compromising the performance of the machine during the development period (since there would be no spare rotco available at this time) it would probably be desirable to design and construct a third rotco, profiting from the considerable experience gained in making the first two work.

A further consequence of such high beams, as noted before, would be that improvements in the extraction efficiency and the suppression of internal targets would be essential in order to avoid too much activation of the machine.

6.2 **New experimental area**

Any move towards the suppression of internal targets implies that one large group of SC users, those in the Neutron Hall, become dispossessed of beam. It might be possible to accommodate some of them in the Proton Hall or even in ISOLDE, but
these zones are in any case rather small. Additionally, of course, the very valuable facility of sharing between internal and external targets would be lost.

The idea of a new experimental area was first presented by Michaelis\(^9\). It consists of a new zone which is situated underground not far from the present ISOLDE area. The extracted proton beam (or ion beam) would be deflected down into the ISOLDE tunnel where a switching magnet would allow the use of either the existing ISOLDE facility, or the new zone. The new zone could contain pion production target(s), a second ISOLDE, an isotope production unit, a \(\mu\) channel, etc. ..., but no detailed work has yet gone into the design of this new facility. Fig. 7 shows a sketch of how the facility might look.

6.3 Acceleration of fully stripped light ions

There are now several ion sources under development capable of producing fully stripped light ions, but these sources are not compact enough to fit into the small space available at the centre of the SC. However since there is an axial hole at the centre of 210 mm diameter for the insertion of the central region of the machine, an external source could be installed close to the SC and fully stripped ions injected axially to the centre of the machine\(^13\), after extraction from the source at 60-80 kV and passage through a radio-frequency beam buncher. The source could, for example, be located outside the SC Hall and the ions could be transported along a well pumped transfer line complete with focusing lenses to the top of the machine where a 90° bend would send them via the axial hole to the centre of the machine. Alternatively one might place the source in a room on the roof, vertically above the axial hole in the yoke. A big advantage would be gained in that repairs, modifications or developments could be carried out without the need of access to the SC Hall.

At the centre an electrostatic inflector with some capability for remote positioning would bend the ions into the correct first orbit for acceleration in the normal way. This inflector
could be inserted from beneath the accelerator using the existing series of eccentric tubes which are used to position the ion source. Voltages of the order of several kilovolts only would be required to deflect the ions in a spiral path towards their correct orbit.

Fully stripped light ions have $Q/A = 0.5$, or close to this, and thus the requirements on the RF system are the same as those for the acceleration of deuterons or alpha particles. This has already been discussed in section 5.4. Furthermore the complication is avoided of the additional $V$ electrode which is essential for third harmonic acceleration of partially stripped ions, since it is the fundamental frequency which is used in this case.

The vacuum, which was also noted as a major problem for the case of partially stripped ions, is no longer a serious problem for fully stripped ions. The reason is that the capture cross-section of electrons onto a rapidly moving fully stripped ion by gas molecule interactions is very small. Thus the existing pumping system for the cyclotron tank should be entirely adequate, but a pressure of better than $10^{-7}$ Torr is needed in the necessarily fairly long injection line.

Axial ion injection has been installed in many fixed frequency cyclotrons where dee voltages of order 100 kV are often employed, and the problems of the inflector at the centre of the machine have been well studied. Calculations are under way at present to determine the parameters of an inflector system for the SC and preliminary results indicate that an injection energy of the ions of about 60-80 kV should be chosen; the fairly large diameter central region of 150 mm diameter makes this inflection process easier in the SC.

The ion source itself would be either of the electron beam type (EBIS) which is under development in several laboratories or of the electron cyclotron resonance type (ECR). Very encouraging results have been obtained so far with this latter type of source, but it is clear that much more work remains to be done in
order to produce ions which are completely stripped; however this source has the potential of great reliability. The intensity predictions given below are based on the expected performance of the CRYEBIS source presently under construction at ORSAY, together with a conservative figure for the fraction of the beam from the source which is capable of being accelerated and extracted from the machine (5%). With further developments of the source and an improvement on the 5% transmission figure, higher ion beam intensities can be expected.

The table below shows what might be the range and intensity of ions which could be accelerated and extracted from the machine. In particular it should be noted that the energy per nucleon is fixed and has a value which is not available at any other cyclotron in the world (the K-value of the SC being ~ 800).

<table>
<thead>
<tr>
<th>Ion</th>
<th>( ^{12}\text{C}^6^+ )</th>
<th>( ^{14}\text{N}^7^+ )</th>
<th>( ^{20}\text{Ne}^{10+} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (MeV)</td>
<td>2160</td>
<td>2560</td>
<td>3600</td>
</tr>
<tr>
<td>Energy/nucleon (MeV/nucleon)</td>
<td>180</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>Beam intensity (ions/sec)</td>
<td>about ( 10^{11} )</td>
<td>about ( 10^{11} )</td>
<td>about ( 10^{10} )</td>
</tr>
</tbody>
</table>

Finally it should be noted that a project to accelerate fully stripped ions in this way would not cause great disruption to the proton or \(^3\text{He}\) programme at the SC, since the source and injection line could be developed off-line and the space occupied in the tank by the internal targets would not be taken, nor would the main vacuum system require modification.

6.4 Acceleration of partially stripped light ions

To produce partially stripped ion beams in excess of the \( 10^8 \) ions/sec noted in section 5.7, a number of other modifications will need to be made.
Possible major modifications are summarized below:

- a new source installed at the centre of the machine in place of the existing source, but mounted on the existing axial support; this would enable higher intensities to be produced and would allow an improvement of the filament lifetimes;

- a new accelerating region at the centre of the machine which could be introduced through a window in the tank, with no modification to the dee being required; the function of this central region\textsuperscript{11,12} would be to accelerate the ions very rapidly through the centre of the machine in order to reduce the chance of interactions with the residual gas molecules (stripping effect);

- an improved vacuum, which is at present of order $10^{-6}$ Torr and which causes severe stripping losses; it can be anticipated that a considerable gain would be achieved if the vacuum could be improved by a factor of 2 or 3, because the transmission of partially stripped ions from low to high radius is an exponential function of the pressure in the tank.

Upon implementation of the above modifications which would involve a lengthy shutdown, beam intensities of the order of $10^{11}$-$10^{12}$ ions/sec can be expected, the range of ions and their energies being as in section 5.7. Such intensities may cause problems related to very localized heating wherever there is significant beam loss (e.g. at the septum of the extraction channel).

It should be noted that the interest in the acceleration of partially stripped ions compared to fully stripped ions lies in the intensity obtainable from the much less complicated source. However, the installation of the modifications to the RF system implies major disruptions to the "proton" programme of the machine.
7. SUMMARY OF SC BEAMS, FACILITIES AND FUTURE POSSIBILITIES

| Existing (or 1978) beams and facilities | (a) **Primary beam:**  
600 MeV protons: intensity 4 μA or $2.5 \times 10^{13}$ protons/sec, internal (with up to 70% extraction efficiency).  
(b) **Secondary beams:**  
- 60 to 260 MeV pions, intensity $10^4$ to $10^6$/sec (per μA protons).  
- 40 to 200 MeV muons, intensity $10^4$ to $10^5$/sec (per μA protons).  
- Up to 595 MeV neutrons, intensity up to ~ $10^8$/sec (per μA protons).  
(c) **Primary beam (1978):**  
910 MeV $^3$He$^{2+}$ ions, intensity 1 μA or $3 \times 10^{12}$ ions/sec, 303 MeV/nucleon.  
(d) **Irradiations:**  
In primary beam at variable energy up to 600 MeV.  

| Possibilities of modest scale and short term | (a) **Primary proton beam** intensity increase to 8 μA or $5 \times 10^{13}$ protons/sec.  
(b) **Extraction efficiency** increase from 70% to greater than 80%.  
(c) **Primary $^3$He$^{2+}$ beam** intensity increase to 2 μA or $6 \times 10^{12}$ ions/sec.  
(d) **Primary beam:**  
- 730 MeV alphas, intensity ~ 1 μA or $3 \times 10^{12}$ ions/sec.  
- 363 MeV deuterons, intensity ~ 1 μA or $3 \times 10^{12}$ ions/sec.  
Both beams ~ 180 MeV/nucleon.  
(e) **Pulsed primary beam:** 2 μsec burst.  
(f) **New probe target.**  
(g) **Primary beam of partially stripped light ions:** Various possible light ion beams with 30 to 85 MeV/nucleon at intensities > $10^8$ ions/sec, e.g. 1022 MeV $^{12}$C$^{4+}$ ions and 631 MeV $^{20}$Ne$^{4+}$ ions.  
(h) **Very low momentum muon beam:** 4 MeV (29 MeV/c), intensity ~ $10^4$-$10^5$/sec (per μA protons), with ~ 100% polarization.  

..
| Long term or major projects requiring feasibility studies | (a) **Primary proton beam** intensity increase up to > 10 $\mu$A.  
(b) **New experimental area.**  
(c) **Acceleration of fully stripped light ion beams,**  
\~ 180 MeV/nucleon,  
intensity about $10^{11}$ ions/sec for $^{12}_6C^{6+}$, $^{14}_7N^{7+}$  
about $10^{10}$ ions/sec for $^{20}_{10}$Ne$^{10+}$.  
(d) **Increased intensity partially stripped light ion beams**  
up to an intensity $\sim 10^{11}$-$10^{12}$ ions/sec. |

It should be noted that both the short term and long term possibilities noted above require detailed studies before they can become accepted as projects.

**ACKNOWLEDGEMENT**

The numerous discussions with A. Fiebig, R. Galiana, R. Giannini, P. Mandrillon, E. G. Michaelis and N. Vogt-Nilsen are gratefully acknowledged.
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16. O. Hartmann, private communication.
<table>
<thead>
<tr>
<th>Channel</th>
<th>ISOLDE beam line</th>
<th>ISOLDE beam line</th>
<th>ISOLDE beam line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>ISOLDE</td>
<td>Lund-Oslo</td>
<td>ISOLDE</td>
</tr>
<tr>
<td>Beam line</td>
<td>US1</td>
<td>US2</td>
<td>US1</td>
</tr>
<tr>
<td>Status</td>
<td>Main user</td>
<td>Main user</td>
<td>Main user</td>
</tr>
<tr>
<td>Sharing</td>
<td>Sometimes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>SC field</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Cee or Kim coil</td>
<td>Fast burst</td>
<td>Both</td>
<td>Fast burst</td>
</tr>
<tr>
<td>or Cee</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particle</td>
<td>p</td>
<td>p</td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>600 MeV</td>
<td>600 MeV</td>
<td>910 MeV</td>
</tr>
<tr>
<td>Momentum</td>
<td>1219 MeV/c</td>
<td>1219 MeV/c</td>
<td>2438 MeV/c</td>
</tr>
<tr>
<td>Observed</td>
<td>−</td>
<td>10 %</td>
<td>−</td>
</tr>
<tr>
<td>duty cycle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spot size at target</td>
<td>15 mm x 5 mm</td>
<td>~15 mm x 15 mm</td>
<td>15 mm x 5 mm</td>
</tr>
<tr>
<td>Flux observed</td>
<td>1.5 μA&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>0.006 to 0.06 μA&lt;sup&gt;(b)&lt;/sup&gt;</td>
<td>0.7 μA&lt;sup&gt;(c)&lt;/sup&gt;</td>
</tr>
<tr>
<td>Flux in particles/</td>
<td>9.4 x 10&lt;sup&gt;12&lt;/sup&gt;&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>4.0 x 10&lt;sup&gt;10&lt;/sup&gt; to 4.0 x 10&lt;sup&gt;11&lt;/sup&gt;&lt;sup&gt;(b)&lt;/sup&gt;</td>
<td>2.2 x 10&lt;sup&gt;12&lt;/sup&gt;&lt;sup&gt;(c)&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

**Notes:**

(a) Maximum beam observed up till now, limited by heat dissipation in the ISOLDE target. For a fast burst operation and no sharing, the ISOLDE beam on target could be up to 70% of the internal proton beam in the SC if the transmission losses along the ISOLDE line are eliminated.

(b) Beam deliberately of low intensity.

(c) Expected values for 1978, taking an extraction efficiency of 70% and zero losses along the ISOLDE beam line.
<table>
<thead>
<tr>
<th>Channel</th>
<th>B</th>
<th>C</th>
<th>d(c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>Westfield</td>
<td>Omicron</td>
<td>Uppsala-CERN</td>
</tr>
<tr>
<td>Beam line</td>
<td>BO</td>
<td>BS2</td>
<td>CJ1</td>
</tr>
<tr>
<td>Status</td>
<td>Main user</td>
<td>Main user</td>
<td>Main user</td>
</tr>
<tr>
<td>Sharing</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>SC field</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Cee or kim coil</td>
<td>Cee</td>
<td>Fast burst</td>
<td>Both</td>
</tr>
<tr>
<td>External production</td>
<td>10 cm liquid D</td>
<td>10 cm Be</td>
<td>10 cm Be</td>
</tr>
<tr>
<td>Target position</td>
<td>After MP4</td>
<td>After LA3</td>
<td>After LA3</td>
</tr>
<tr>
<td>Particle</td>
<td>n</td>
<td>n</td>
<td>n</td>
</tr>
<tr>
<td>Energy</td>
<td>&gt; 500 MeV</td>
<td>20 MeV to 600 MeV</td>
<td>191 MeV 153 MeV</td>
</tr>
<tr>
<td>Momentum</td>
<td>-</td>
<td>370 MeV/c</td>
<td>≤ 5%</td>
</tr>
<tr>
<td>Δp/p (FWMH)</td>
<td>Continuous spectrum</td>
<td>Continuous spectrum</td>
<td>-</td>
</tr>
<tr>
<td>Spot size at final</td>
<td>4 cm x 7.5 cm</td>
<td>14 cm Ø</td>
<td>2 cm Ø 5 cm Ø</td>
</tr>
<tr>
<td>target (or counter</td>
<td>10 cm x 10 cm</td>
<td>3 cm x 3 cm</td>
<td>1 cm x 0.5 cm</td>
</tr>
<tr>
<td>size used</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam contamination</td>
<td>1 % charged</td>
<td>2 % charged</td>
<td>p ~ 20 %</td>
</tr>
<tr>
<td>Observed duty cycle</td>
<td>14 %</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Flux observed by group (particles/sec)</td>
<td>5.10^5</td>
<td>2.310^8</td>
<td>2.610^5(d)</td>
</tr>
<tr>
<td>Normalised flux (pps per 10^12 protons/sec)</td>
<td>1.610^5</td>
<td>2.410^7</td>
<td>810^2</td>
</tr>
<tr>
<td>Normalised flux (pps per μA proton)</td>
<td>10^6</td>
<td>1.510^8</td>
<td>510^3</td>
</tr>
<tr>
<td>Predicted flux (pps per μA proton)</td>
<td>1.510^6(a)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Notes:
(a) Predictions taken from earlier beam reports and normalised to the present situation.
(b) 4.10^6 represents the π, μ, e flux. After degrading the beam to < 100 MeV/c, the μ^+ flux which stops in the target is 9.10^3/sec with 80% polarisation.
(c) See "high resolution beam" in Ref. 2.
(d) 2 cm CH_2 absorber placed in the beam to remove low energy protons.
(e) Calculation by E. Kernel.
(f) Calculation by O. Hartmann.
(g) Normalised flux is quoted per 10^{12} protons/sec in order to aid comparison with PS values. Note that 1 μA = 6.25 x 10^{12} protons/sec.
(h) Pion flux (after 1.5 cm CH_2 filter to remove low energy protons) at the centre of Omicron magnet (90° bend).
### Table 3
Secondary Beams into the Neutron Hall
(Information supplied by users)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Group</th>
<th>µ channel</th>
<th>( \mu ) channel</th>
<th>125 MeV</th>
<th>LEPC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dubna-CERN-Oslo</td>
<td>CERN-Pisa(c)</td>
<td>Bologna</td>
<td>MIT</td>
<td>CERN-DMT</td>
</tr>
<tr>
<td>Beam line</td>
<td>YJ1</td>
<td>YJ1</td>
<td>YJ1</td>
<td>KJ1</td>
<td>KJ1</td>
</tr>
<tr>
<td>Status</td>
<td>Main user</td>
<td>Main user</td>
<td>Main user</td>
<td>Main user</td>
<td>Main user</td>
</tr>
<tr>
<td>Sharing</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>SC field</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Cee</td>
<td>Yes</td>
<td>Pulsed off</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Internal production target radius</td>
<td>223 cm</td>
<td>224 cm</td>
<td>225.5 cm</td>
<td>225 cm</td>
<td>226.5 cm</td>
</tr>
<tr>
<td>Internal target azimuth</td>
<td>35°</td>
<td>35°</td>
<td>35°</td>
<td>35°</td>
<td>23°</td>
</tr>
<tr>
<td>Particle</td>
<td>( \mu )</td>
<td>( \mu )</td>
<td>( \mu )</td>
<td>( \mu )</td>
<td>( \mu )</td>
</tr>
<tr>
<td>Energy</td>
<td>40 MeV</td>
<td>104 MeV</td>
<td>60 MeV</td>
<td>60 MeV</td>
<td>340 MeV/c</td>
</tr>
<tr>
<td>Momentum</td>
<td>100 MeV/c</td>
<td>200 MeV/c</td>
<td>128 MeV/c</td>
<td>135 MeV/c</td>
<td>204 MeV/c</td>
</tr>
<tr>
<td>( \sigma / \rho ) (FWHM)</td>
<td>( \leq 10 % )</td>
<td>( \leq 10 % )</td>
<td>( \leq 10 % )</td>
<td>( \leq 10 % )</td>
<td>( \leq 6 % )</td>
</tr>
<tr>
<td>Spot size at final target (or counter size used)</td>
<td>8 cm ( \varnothing )</td>
<td>8 cm ( \varnothing )</td>
<td>6 cm ( \varnothing )</td>
<td>6 cm ( \varnothing )</td>
<td>10 cm ( \times ) 10 cm</td>
</tr>
<tr>
<td>Beam contamination</td>
<td>( e \sim 15 % )</td>
<td>( e \sim 1 % )</td>
<td>( e \sim 5 % )</td>
<td>( e \sim 1 % )</td>
<td>( e \sim 10 % )</td>
</tr>
<tr>
<td>Observed duty cycle</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Flux observed by group (particles/sec)</td>
<td>( 2.5 \times 10^4 )</td>
<td>( 9.3 \times 10^5 )</td>
<td>( 3.3 \times 10^4 )</td>
<td>( 3.3 \times 10^3 )</td>
<td>( 4.5 \times 10^3 )</td>
</tr>
<tr>
<td>Normalised flux(^{(f)}) (pps per 10^12 protons/sec)</td>
<td>( 3.2 \times 10^3 )</td>
<td>( 1.8 \times 10^5 )</td>
<td>( 8 \times 10^3 )</td>
<td>( 8 \times 10^3 )</td>
<td>( 3.8 \times 10^3 )</td>
</tr>
<tr>
<td>Normalised flux (pps per ( \mu ) proton)</td>
<td>( 2 \times 10^4 )</td>
<td>( 1.1 \times 10^6 )</td>
<td>( 5 \times 10^4 )</td>
<td>( 5 \times 10^4 )</td>
<td>( 2.4 \times 10^4 )</td>
</tr>
<tr>
<td>Predicted flux (pps per ( \mu ) proton)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Notes:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
- Predictions taken from earlier beam reports\(^1,2\) and scaled accordingly to fit the experimental situation here.
- After moderation to reduce the \( \pi \) energy, \( 2.5 \times 10^3 \) sec pion stops recorded in 60 cm He gas at 4 Atm pressure.
- Pulsed target used ("flipping" target). In this mode the beam is stored for 1/4 sec every 4 seconds and the target is pulsed into the stored beam.
- Of these, 8 \( \times 10^4 \) sec per stop in 0.2 cm He/CH\(_2\).
- Of these, 10^4/sec per stop in the target.
- Normalised flux is quoted per 10^12 protons/sec in order to aid comparison with PS values. Note that 1 \( \mu \)A \( \equiv 6.25 \times 10^{12} \) protons/sec.
Fig. 1

General layout of elements inside and around the SC vacuum tank
FIG. 2

The underground experimental area used by ISOLDE and the beam line feeding it.
The layout in the SC Hall required for delivery of a secondary beam via the C pipe to the Proton Hall, and the layout of zones in that Hall.
FIG. 4
The layout in the SC Hall required for delivery of a neutron beam via the B pipe to the Proton Hall.
FIG. 5
The various channels which feed secondary beams from production targets inside the SC to the Neutron Hall, and the layout of zones in that Hall.
FIG. 6
The new beam layout in the SC Hall foreseen for installation during the 1978 shutdown.
FIG. 7 - NEW EXPERIMENTAL AREA