TRN ZA 9000107

SECTION 5 BEAM TRANSPORT

5.1 Operation and Development

Summary: Considerable experience has now been gained with the various beam transport lines, and a number of minor changes have been made to improve the ease of operation. These include:

(a) replacement of certain little-used slits by profile monitors (harps or scanners),

(b) relocation of steering magnets, closer to diagnostic harps or profile scanners,

(c) installation of a scanner inside the isocentric neutron therapy system, and

(d) conversion of a 2-doublet quadrupole telescope (on the neutron therapy beamline) to a 2-triplet telescope.

The beam-swinger project has been delayed by very late delivery of the magnet iron to the manufacturer, but is now progressing smoothly.

The K=600 spectrometer magnets have now been delivered and are being assembled for field mapping. The x,y-table with its associated mapping equipment is complete, together with the driver software.

One of the experimental areas has been dedicated to the production of collimated neutron beams and has been equipped with a bending magnet and beam dump, together with steel collimators fixed at 4° intervals from 0° to 16°.

Changes to the target cooling and shielding system for isotope production have led to a request for much smaller beam spot sizes on target, and preparations have been made for rearrangement of the isotope beamline to permit installation of quadrupole triplets on the three beamlines after the switching magnet.

A practical system of quadrupoles for matching beam properties to the spectrometer has been designed.

5.1.1 General

With the considerable experience which has been gained in tuning the various beamlines, a number of changes have been made to improve the ease of operation of the facility. Firstly, certain slits were replaced by profile monitors (harps or scanners) so that data on the size and shape of the beam could be more readily obtained. This data could then be fed into computer programs to determine the emittance of the beam.

Secondly, some of the pairs of steering magnets were moved further apart, and closer to profile scanners or harps, so that the information obtained from the diagnostic devices could be used to compute the settings of the steerers required to align the beam with the axis of the beamline.

5.1.2 Matching to the SSC

The emittance measurements on the beamline between SPC1 and the SSC have worked well. Three scanners about a metre apart, with the central one at a waist, are used for this purpose. (A harp was first tried, but wires were burnt through by the high-intensity beams needed for therapy and for isotope production.)

The magnet settings predicted by TRANSPORT for these measured emittances have proved fairly good, with only small adjustments being necessary. The horizontal position and divergence can be relatively well matched to the SSC using the new beam-centering harp in the SSC itself. The vertical matching is less satisfactory, but a second (proposed) harp in the SSC will allow the vertical beam profile to be monitored and should greatly facilitate this matching.

5.1.3 Matching the radiotherapy unit

Difficulties have been experienced with matching the extracted beam from the SSC to the isocentric neutron therapy unit, primarily as a result of the lack of diagnostic equipment supplied with this device. Early attempts at delivering high beam currents onto the target resulted in a vacuum failure caused by overheated 'O' rings inside the isocentric unit. We then installed a rotating wire scanner in what little space was available between the first two of the three quadrupoles, as well as a current monitoring diaphragm at the entrance to the 160° dipole.

The beam can now be transported onto the target with relative ease: all that remains elusive is the correct settings to achieve equal count rates in each half of the collimated neutron beam, in each direction, i.e. north-south or east-west, which appear to be related to the angle at which the beam strikes the target. In order to simplify the setting of this beamline, the original two-doublet quadrupole system has been upgraded into a two-triplet quadrupole system, operating as a telescope with unit magnification.

5.1.4 Beam swinger

The manufacture of the magnets for the beam swinger was seriously delayed because the first magnet steel cast was unsuccessful in reaching the low impurity levels required. The steel which was eventually delivered is so much larger than the specified final machined size that more delays have been incurred in cutting away the excess material.

The three dipole magnets which form this system, together with their vacuum chambers and stands, are expected to be delivered only at the end of this year. Meanwhile a system of movable steel collimators on rails has been devised and is now being manufactured. The walls of the vault have been constructed from our standard 1.5 m square by 3 m high concrete blocks, with 1 m high blocks being used where the collimator penetrations are required. Extra shielding blocks have now been positioned outside the building at the north end, and a screed has been laid up to rail height upon which the 0.5 m square collimator tunnels will be constructed, at 0°, 30°, 60° and 90° to the incident beam direction. (Figure 1.)

5.1.5 The K=600 spectrometer

The two large dipole magnets for this magnetic spectrometer have been delivered, and one is partly assembled on the spectrometer carriage, as shown in figure 2. The pole-pieces have been carefully machined, and then hand-scraped to an overall flatness and parallelity of some 40 microns, but errors in setting the computerised numerically-controlled milling machine seem to have introduced relative positional errors of up to 1 mm in the top and bottom chamfered pole edges. These pole pieces have been returned to the manufacturer for computer-controlled measurement of all these chamfered edges prior to re-machining. The machining will then be done with the pole-package assembled, so that top and bottom poles can be machined without resetting the machine.

Meanwhile all the pole-edge shims have been prepared and are ready for mounting, and the pole-face coils and beam-spill fingers are also available. While the pole-pieces were in house, the vacuum chambers were test-fitted into position, without difficulty.

A quadrupole magnet for this spectrometer was imported from Europe, but was unfortunately insecurely packed, and the coils were severely damaged in the dockyard when the crate containing the magnet was accidentally tipped over. A local manufacturing company is repairing the damaged coils.

For mapping the magnetic fields of the two large dipoles, a 3.7 m long lightweight arm (made of expanded aluminium honeycomb and carbon-fibre tape) has been constructed to hold 16 special Hall-probes. This arm is mounted on an x,y-table on a heavy, reinforced concrete base: the whole assembly is mobile, with screw jacks to lift it off its wheels when in use for measurement (figure 3). The arm has a long travel of 3.2 m and a cross travel of 1.6 m. The measuring head is a 400 mm wide T-shaped aluminium construction, into which the 16 Hall-probes are fitted.

A precision constant-current source (140 mA with ± 2 ppm/°C) to drive the Hall probes in series, and a battery back-up system for the probes have been designed, constructed and tested.

A proportional integral differential thermostat is used to control the temperature of the Hall-plates at about 37.4° within ± 0.1°C. 15 heater resistors in series, as well as two NTC* thermistors to control and monitor the temperature, are placed midway between or near the Hall-probes through holes in the precision-machined piece of aluminium, measuring 5 × 4 × 385 mm. This holder fits into a perspex holder and this in turn is covered by an electrical and thermal shield made of aluminium. The thermostat is very precise except for temperature gradients on the long piece of aluminium. This gradient can be measured via the NTC thermistor on the multimeter.

For convenience and simplicity all wires from the Hall-probes, temperature sensors and heater resistor chain to the control units are of the twisted-pair flat-cable type. This is possible since the Hall resistance is very low and measurements are slow. Only the control side thermistor had to be buffered at the T-piece.

The Hall voltages are fed via a 20-channel relay multiplexer to a 6½-digit multimeter and then via an IEEE interface to a microcomputer.

---

*Negative temperature coefficient

Limit switches have been provided for the x and y axes and probe/magnet contact is detected via grounding of the probe head. Stepping motors with shaft encoders drive the T-piece to the predetermined positions on the magnets.

The software for this field-measurement device has been written in Turbo Pascal 4, and resides in a dedicated AT microcomputer. This is one of the many such machines constructed by our Control Division.

This program controls the position of the measuring arm holding the 16 Hall-probes, prevents the arm and head-piece from being manoeuvred into contact with the spectrometer magnet yoke or spacers, and gives a graphic display of the actual probe position. The program also initiates the measurement cycle through all 16 probes, via the multiplexer, at each position. The measured Hall voltage is then converted to absolute magnetic field values. This data conversion uses a cubic-spline fit to interpolate between measured points on the calibration curve of Hall voltage versus magnetic flux density for each of the 16 probes. The calibration is done against the flux density measured at various excitations, using an NMR probe for absolute measurements.

5.1.6 Neutron beam facility

A collimated neutron beam facility has now been established in one of the experimental target rooms {1}. This entailed reconfiguring the shielding walls to accommodate a target chamber and a dump magnet and beam dump for the primary beam, as well as a set of collimators, built into a second shielding wall at every 4° from 0° to 16° to the primary beam.

The neutron source is (typically) a lithium target, which can handle up to 1 μA of 66 MeV protons, without cooling. However, a water-cooled target holder would permit higher beam power to be deposited in the targets

The dipole magnet is designed for bending the primary proton beam of up to 200 MeV through an angle of 15° into a well-shielded Faraday cup inside the beam dump. The coil is insulated by glass-fibre tape alone, i.e. without epoxy, because of the very high doses of neutrons to which it will be exposed.

The collimation of the secondary neutrons is provided by nominally 50 × 50 mm square openings machined as slots in a steel plate, and sandwiched between a number of 100 mm thick steel plates, forming a wall 1.4 metres thick, which is also part of the beam dump itself.

This facility appears to work well. A photograph of this facility is presented in figure 4 and some experimental measurements are also given in section 7.

5.1.7 Isotope beamlines

A new target cooling system, together with an automatic target-changer, described elsewhere in this report, has permitted much higher beam power densities to be achieved, allowing a greater specific activity to be created in the target material. To this end, we have been requested to provide much smaller beam spot sizes on target: <10 mm diameter, where previously >20 mm diameter had been required. This has necessitated a complete redesign of the isotope beamlines, because we now require quadrupole magnets on each of the lines after the switching magnet, in order to achieve the required spot sizes. As there was no room for this, we plan to move the switcher some 3 metres back, and also to move half of the thickness of the shielding wall a similar distance. Three new quadrupole triplets have been designed, and are being manufactured as a matter of some urgency, to be installed in the middle of the wall in the vault thus created. This is shown diagramatically in figure 5.

The specifications of these new 150 mm aperture quadrupoles is given below:

Table 1: Properties of Q150M quadrupoles

Aperture	156 mm
Max. flux-density	0.4 tesla
Tuns per pole	142 turns
Total power	2.3 kW
Max. current	88 amps
Pole length (physical)	300 mm

5.1.8 Matching to spectrometer

The beamline leading from the double-monochromator system to the new spectrometer has been studied in some detail, with the result that it is possible to use a system of only 6 quadrupoles to satisfy the various matching conditions required.

We need to transport the beam from the double-monochromator exit slit to the target - a distance of just over 18 m, and must be able to provide

(a) kinematic correction,
(b) dispersion matching, and
(c) emittance matching

for both positive and negative spectrometer angles. This has been attempted, using TRANSPORT, with certain assumptions:

(i) the quantity D_{16}/D_{11} (momentum dispersion/horizontal magnification) is 14.7,
(ii) the momentum dispersion D_{16} of the double-monochromator is 16.28,
(iii) the momentum-spread of the beam can be cut to 0.1% by the double monochromator,
(iv) the emittance is 1 π mm mr,
(v) the maximum allowable beam spot on target is 10 mm diameter,
(vi) the usual spectrometer parameters C, T_{11} and K lie in the ranges:

$1 < C < 2; \quad -1 < T_{11} < 2; \quad -0.2 < K < +0.2$

(where T_{11} cannot be zero, but approaches it)

[C = the change in relative momentum-spread at the target,
T_{11} = the horizontal magnification term of the target transformation matrix,
K = the kinematic change in momentum-spread with angle at the target.]

We write the total transfer matrix $[G]$ of the system from the entrance of the double-monochromator to the target as

$$[G] = [D][T][R]$$

where $[D]$ is the detector matrix, $[T]$ the target transformation and $[R]$ the matching system matrix. We can also write

$$[R] = [E][M]$$

where $[M]$ is the dipole monochromator system, and $[E]$ represents only the final 6-quadrupole matching section.

The matching requirements can then be shown to reduce to:

$$E_{12} = \frac{-K}{C} M_{16}$$

and $$E_{22} = \frac{-T_{11}}{C} \frac{D_{11}}{D_{16}} M_{16}$$

i.e. these values of the elements E_{12} and E_{22} must be provided by the 6 quadrupoles.

To satisfy these requirements, we have chosen a system of two symmetric quadrupole triplets, which we can operate either as a positive or negative telescope (i.e. either +1 or -1 on the diagonals of the transfer matrix). These telescopic modes act as starting points for the TRANSPORT fit, and in most cases the final fitted quadrupole values are not far from their telescopic values.

The symmetric two-triplet telescope has the added advantage that all quadrupoles are conveniently placed, i.e. well clear of shielding walls and not too near to the target chamber. Figure 6 shows beam envelope plots for the complete system, with 0.1% and 0.5% momentum spread respectively, to illustrate the telescopic starting point for the calculations. A whole series of solutions for the last 6 quadrupoles has been tabled for a range of values of K, T_{11} and C.

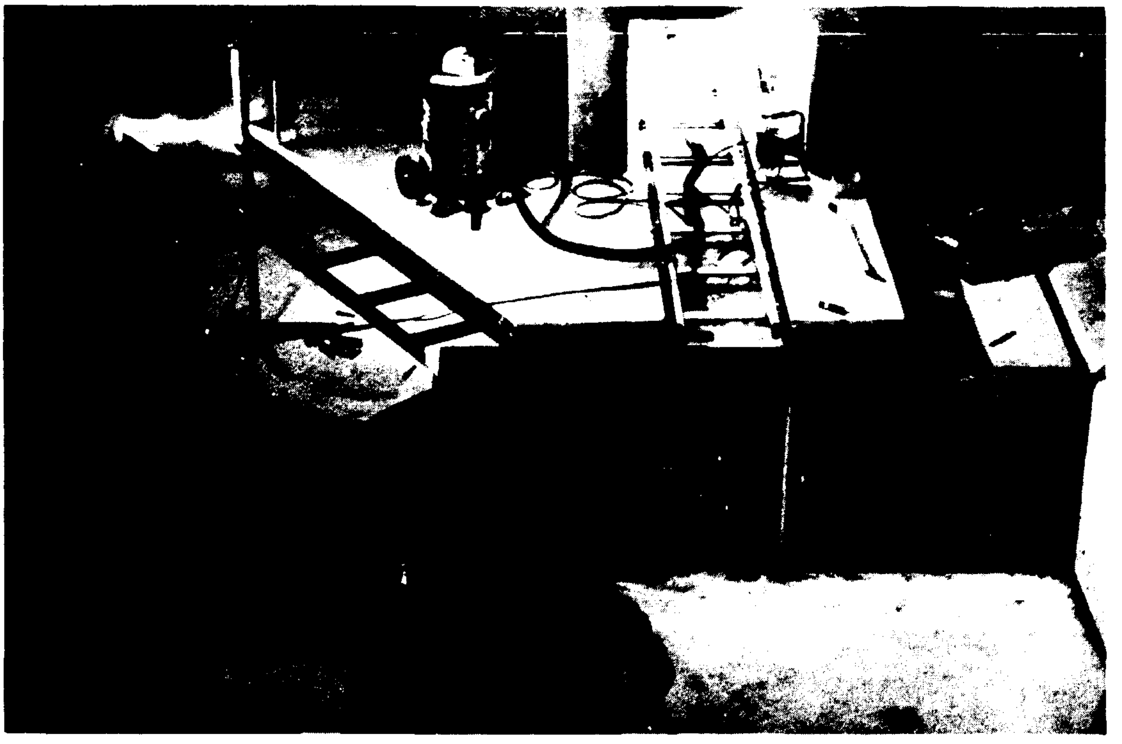

Fig. 1 View of the collimator tunnels at the north end of the experimental hall, showing the rails on which the steel collimators will travel.

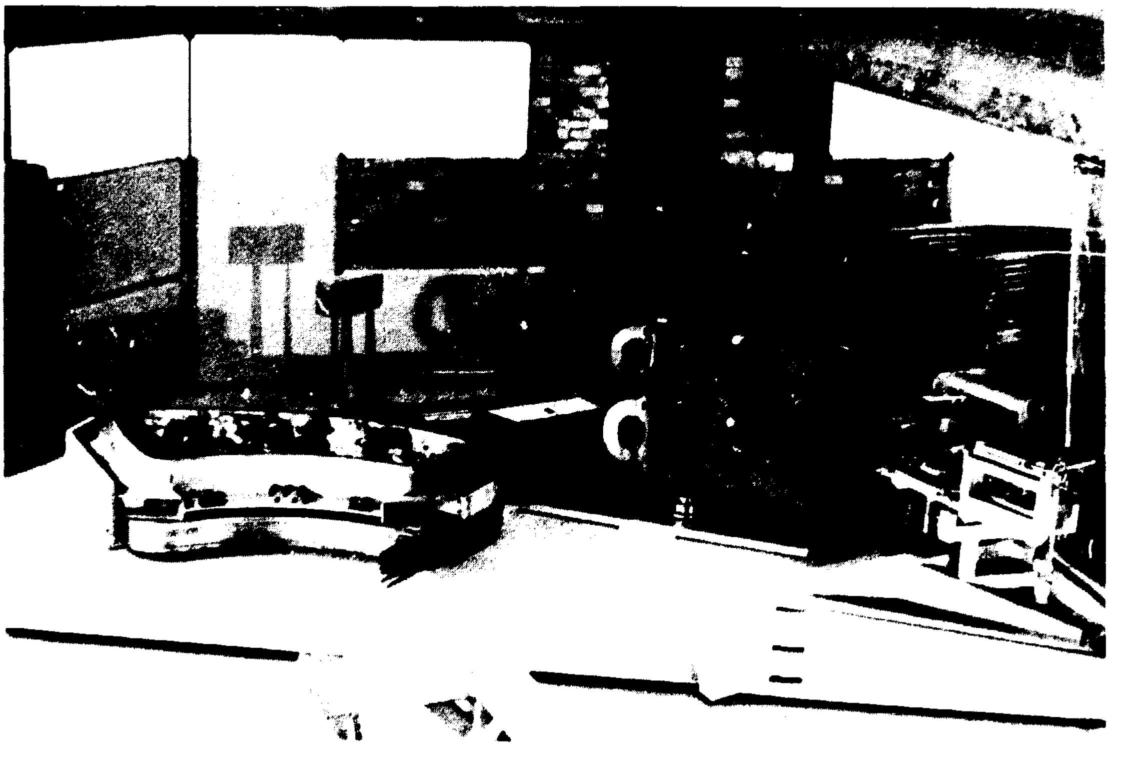

Fig. 2 The spectrometer carriage, with one of the two large dipoles being assembled.

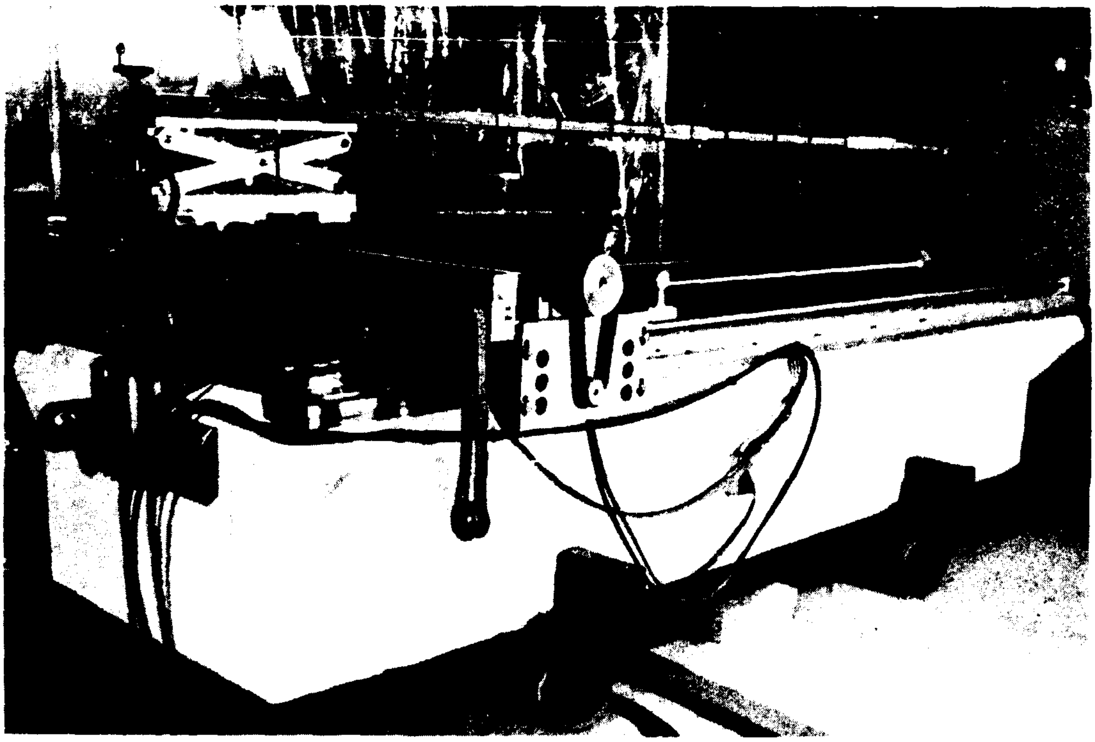

Fig. 3 The magnetic field measuring table for mapping the spectrometer. 16 Hall probes are carried on the T-shaped end of the measuring arm.

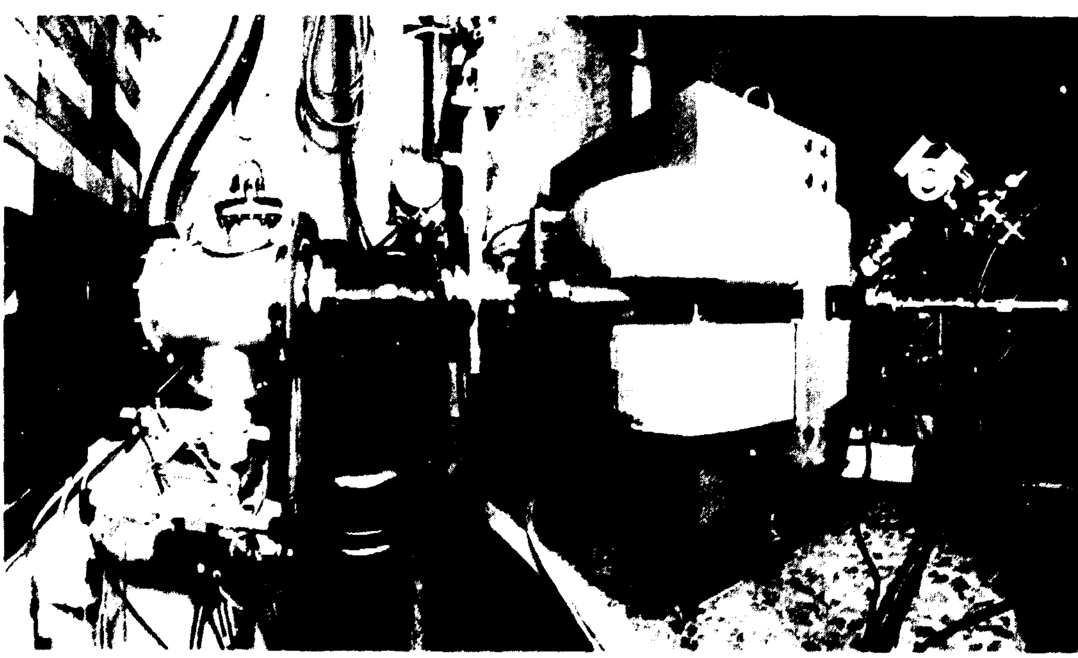

Fig.4 Composite photograph of the neutron beam facility, showing the dump magnet (right) and the beam dump (left) with one of the square neutron collimators visible (far left).

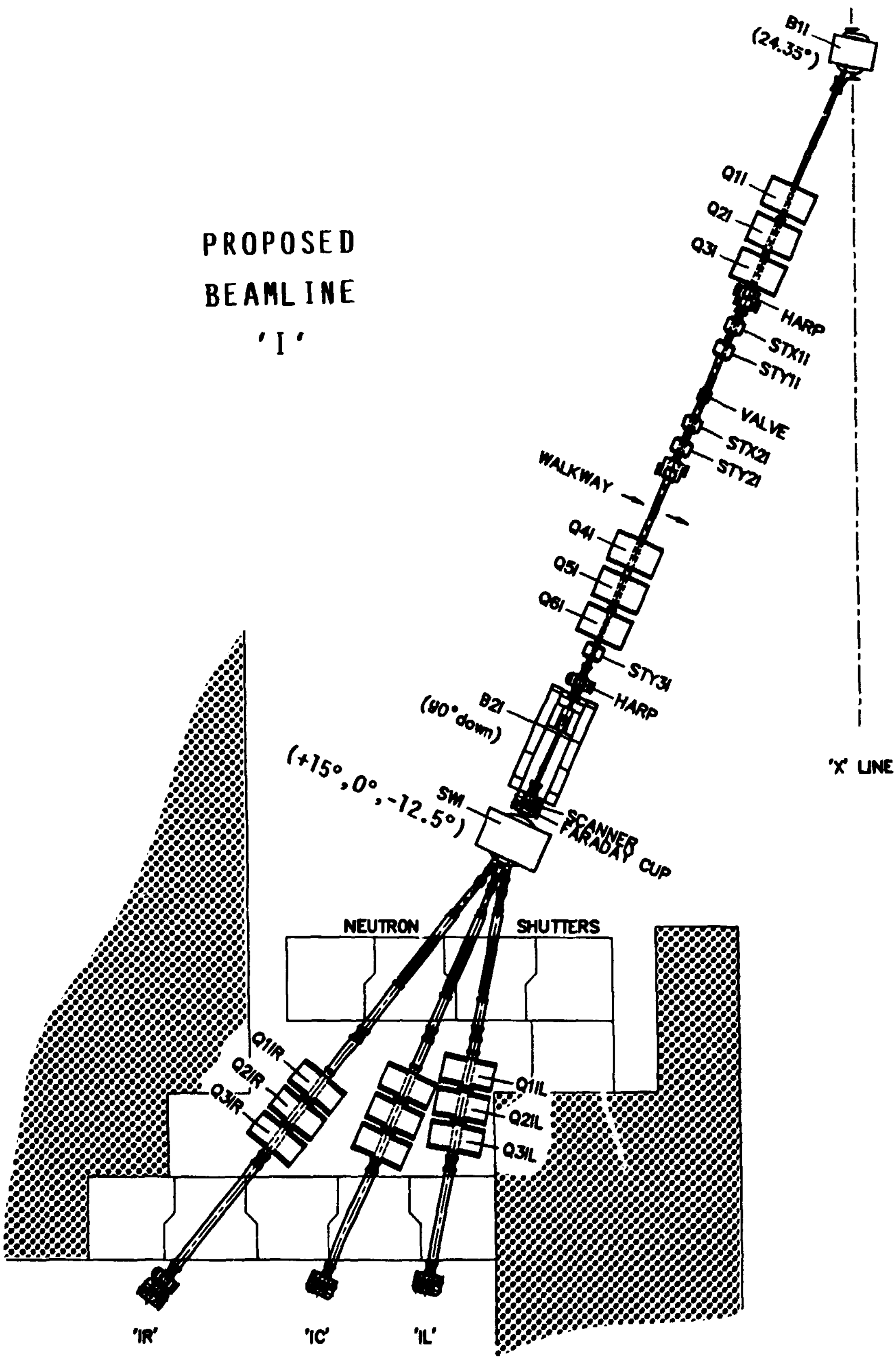

Fig. 5 Diagram of the revised isotope production beamlines, incorporating quadrupole triplets on each line after the switching magnet.

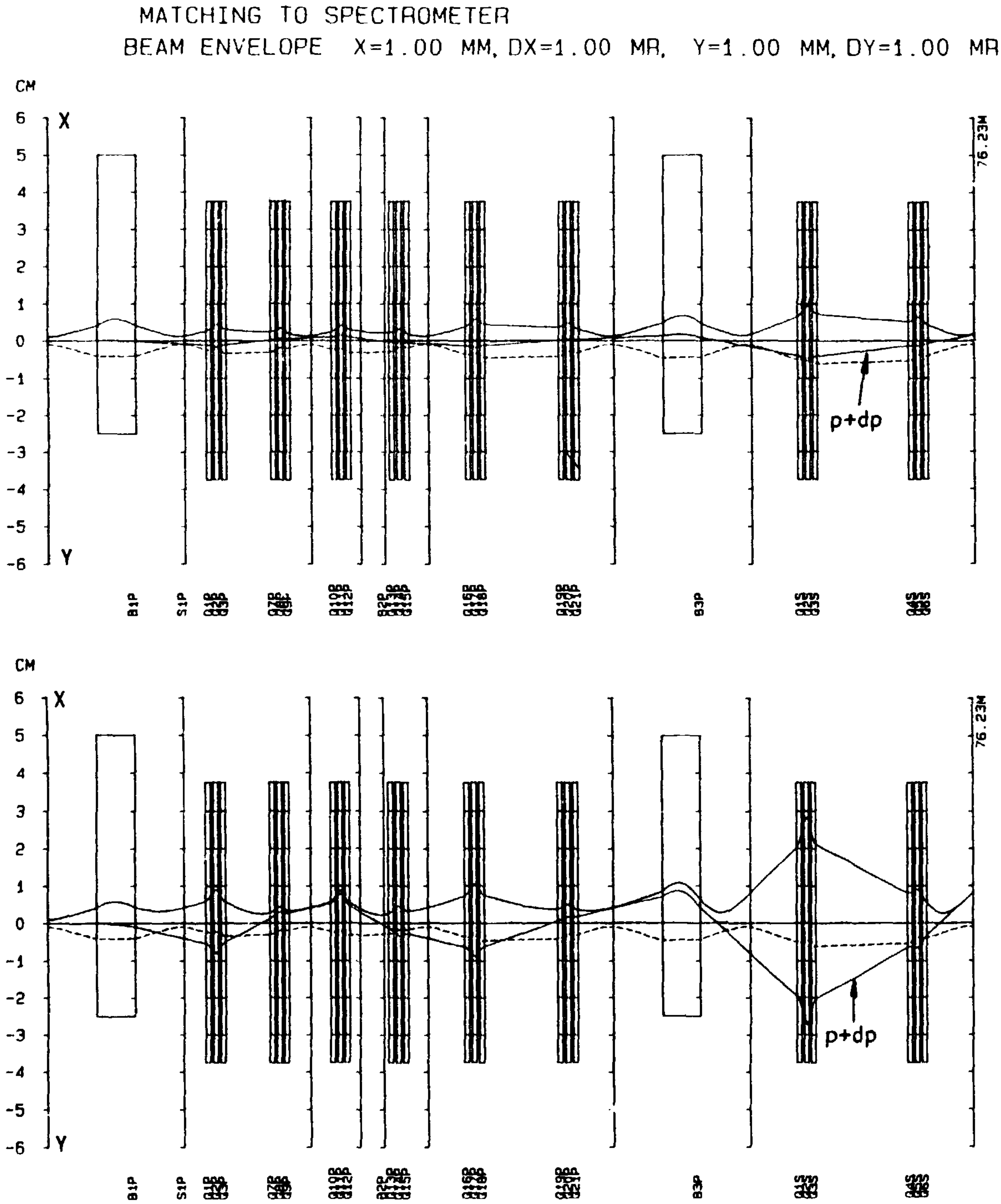

Fig. 6 Beam envelope plots for the double-monochromator and 2-triplet quadrupole matching system leading to the spectrometer target, for 0.1% (top) and 0.5% momentum spread (below).