TN-63-74
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BEAM MONITORING IN THE SWITCHYARD
(Preliminary Report)

We have dealt briefly with this subject in an earlier report (part III of TN-63-47).[1] Since that time some of the aspects have been worked out in more detail.[2-4].

The present report gives a preliminary overall description of the beam monitoring requirements in the switchyard and makes a survey of possible techniques.

The purpose of this note is to establish a basis for future R and D work in this field.

We divide this note into the following sections:

I. FUNCTION AND LOCATION OF THE MONITORS
II. PRELIMINARY SPECIFICATIONS
III. SURVEY OF TECHNIQUES
IV. FUTURE WORK

I. FUNCTION AND LOCATION OF THE MONITORS

The answer to beam monitoring in the beam switchyard is not straightforward. A proper combination of different monitoring techniques is probably required if a satisfactory solution is to be obtained.

In this note we consider only the beam monitors required in the principal magnetic deflection systems, and we limit our discussion to beam current, beam position and beam cross section (profile) monitors. Beam energy and -energy spectrum are being considered in other notes.

Figure I shows the type and location of the monitors under consideration; and, for orientation, gives some approximate vacuum chamber dimensions and the beam size along beam A. The monitors in beam B have been disregarded in this note since their requirements are the same as for beam A. The notations used correspond to the layout sketch in TN-63-47. The function(s) for each of the monitors is (are) summarized in table I and will not be described further in the text.

II. PRELIMINARY GENERAL SPECIFICATIONS

1. Beam

As a guide line we take the following conditions:

Peak current range: 10 μA to 50 mA

Pulse length: 0,1 to 2 μsec.

Pulse rate: between 1 and 360 pulses per second.

(Lower currents or shorter pulses will require special monitors.)

Pulse shape versus time: We must assume that the current pulse can deviate considerably from a square shape. This is particularly true after the slit where the shape may be deteriorated very strongly because of variations in energy spectrum versus time.

2. Range, Response

The current range (5000 : 1) is supposed to be just large enough to cover positron beams.

<u>TABLE I</u>

I = Beam Current Intensity Monitor

P = Beam Position Monitor

P_R = Beam Profile Monitor

Monitor	Function	Remark
I_1	Current from accelerator.	gated. (I_{1A}, I_{1N}, I_{1B}), (see II.8)
I_2	Current after collimator.	gated. $(I_2 - I_1)^+$ absorption in collimator.
P_1	Position in front of collimator.	P_1 gated. P_1, P_2 are precise monitors to adjust position and angle for each of the 3 beams in the collimator with pulsed steering.[x]
P_2	Position after collimator, but before $1/3^o$ magnet.	
I_3	Current neutrino beam in front $1/3^o$ magnet.	Requires more discussion.
I_4, P_3	Current and position after $1/3^o$ magnet.	Requires more discussion.
I_{10}	Current of beam A after pulsed magnet.	Check on $(I_{10} - I_2A)^+$
I_{11}	Current of beam A after first 12^o bend.	and $(I_{11} - I_{10})^+$
P_{10}	Position in front of quads.[+]	Steer beam A with pulsed magnet in center of quads.
P_{11}	Position after first 12^o bend.[+]	
I_{12}	Current beam A after slit.	Check on $(I_{12} - I_{11})$ = absorption in slit.
I_{13}	Current available for end station A	Check on $(I_{13} - I_{12})^+$
P_{12}	Position of beam A to end station A[+]	
P_{R_1}	Observe symmetry of beam cross-section in front of collimator.	
$P_{R_{10}}$	Shape of beam A in front of quad.	
$P_{R_{11}}$	Shape of energy analyzed beam before slit.	Adjust quads Q_{10-11}
$P_{R_{12}}$	Shape before entering second 12^o bend.	Adjust field lens Q_{12}
$P_{R_{13}}$	Shape of beam after 2nd 12^o bend.	Adjust $Q_{13,14}$

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x requires a measurement that the pulsed magnet is degaussed.

\+ this quantity may be used for the beam interlock system.

If possible we should cover this range with one type of monitor.

Monitors that will tie in with the beam interlock system require a fast response ($< 100\ \mu s$).

3. Interaction with beam

For some of the most critical experiments scattering allows only 10^{-4} radiation length of material. This means that monitors, which are essential during operation, should be of the non-intercepting type. Intercepting type monitors will be helpful to set up beams, and in locations where scattering is not important (e.g. in front of a target). These monitors, however, should be made removable by remote control.

4. Current intensity (precision)

The intensity monitors have 3 function:

a. To monitor the current before and after each deflection magnet, or monitor the difference between these values. The absolute precision should be $\leq 5\%$, the relative precision (stability) 0.1% - 0.5%.

b. To show the dynamic behaviour of the beam pulse; the absolute precision 5%, the relative precision 1 or 2%, the rise time 15 n sec.

c. To measure the integrated current at the end of each beam; the absolute precision should be 0.1%. (This requires a precision integrator[34,35] with an extremely high input impedance if a high impedance monitor - like an SEM - should be used.)

5. Position (precision)

It should be possible to monitor the charge center with a precision of ±0.5 mm.

In view of the positron beams we should try to keep the tolerances at low currents as good as possible. (For low electron currents one could afford to lose part of the beam.)

6. Profile

This indicator should work over the largest possible current range. The ideal profile indicator will not only show the beam cross section but also intensity contrasts within the cross section. A still acceptable profile indicator will show only the horizontal and vertical beam dimensions. (More precise specifications for the profile monitors will be established later.)

7. Calibration and checking

We should think about simple ways of checking the proper functioning and calibration of the monitors, since access to the monitors will be very much restricted.

Calibration and recalibration is particularly important for the current monitors. It is standard practice to calibrate against a Faraday cup. We cannot rely on the availability of a Faraday cup and should look for other means.

A current transformer may be preferred in this respect, since we may send down a calibration current pulse through an extra winding for this purpose.

8. Gating

As indicated before, the data taken by I_1, I_2 and P_1 (Fig. 1A) should be gated, displaying the results separately for each of the three beams. They must have a fast response (II.2).

9. Radiation damage

By scaling from DeStaebler's note (5) we assume for orientation purposes the following radiation levels for the monitors.

Average in or just outside the vacuum chamber:
10^{13} ergs/gr, 10 years
Within one meter from a dump (collimator, slit):
10^{15} ergs/gr, 10 years
Average in the upper tunnel:
10^{10} ergs/gr, 10 years

Areas in the upper tunnel above hot spots should not be used for either instrumentation or cable passage. Obviously, we should try to place monitors as far away from dump areas as possible.

Polysterene can absorb a threshold dose of about 5.10^{11} ergs/gr. and ceramic 5.10^{14} ergs/gr. Where possible we should, therefore, use ceramic type materials, metals or maybe quartz.

For cables we intend to use MgO isolation.* Coaxial cables using this isolation are RG81/u RG82/u. We have still to find a radiation resistant sealing technique for these hygroscopic cables. Stycost 2850 FT as used for

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*K. Johnson brought to our attention the "Micatemp" type cable, using reinforced mica for isolation. (Mfg. Rockbestos). This cable can absorb a threshold dose of 10^{14} ergs/gr. and is supposedly not hygroscopic.

the magnet coils may be suitable. It will require the addition of a catalyst for room temperature setting.

10. Thermal effects

Where beam interaction is involved, thermal effects as a result of power absorption should be considered.

11. Alignment

The position monitors should be properly aligned (±0.5 mm) with respect to the magnetic components in the beam switchyard. Where possible the position monitors should be rigidly connected to these components to minimize alignment equipment and alignment effort. The alignment of profile and current monitors is not so critical. As far as alignment is concerned it is desirable to build the different types of monitors as one unit.

12. Vacuum

All monitors considered here are downstream of the differential pumping system; the pressure is 10^{-4} torr.

The vacuum chamber dimensions change along the switchyard. The proper dimensions are not yet known; figures for guidance are shown in Fig. IA. No quick-disconnect flanges are being considered (as planned in the vacuum chamber for the magnets), so that a defective monitor is difficult to replace. A simple and reliable design is therefore fundamental for all monitors.

The monitors should preferably clear the full vacuum chamber opening. Where this conflicts with sensitivity, etc., one should at least clear the ±2% $\Delta E/E$ beam envelope shown in Figs. IB, IC, plus a tolerance to accommodate for beam instabilities. All monitors will require special vacuum chamber sections.

13. Display and storage

All information will have to be displayed in a logical way in the beam switchyard building. All auxiliary monitoring equipment like amplifiers, etc., should also be located in this building. A part of the information will be transmitted to the central control room.

Recording facilities for all types of information involved should be available for permanent data storage, if so desired. In choosing display and storage systems, techniques most easily adaptable to digital computers should be preferred.

III. REVIEW OF BEAM MONITORING TECHNIQUES

We will review briefly beam monitoring techniques that may be useful in the switchyard. Most of the techniques are conventional, a few ideas are new. A summary with references is given in Table II.

We limit the review of these techniques to some comments with respect to our switchyard requirements. Good general review articles may be found in Refs. 6 and 7 and detailed descriptions in the references shown in Table II.

Non-intercepting current monitors

1. Electrostatic:

The disadvantage of this principle is the high impedance and the large plates required, which make the system very sensitive to stray pick up. Since we expect a high level of scattered charge in the switchyard this technique seems not recommendable.

2. Electromagnetic:

Current transformers are widely used, employing toroidal cores made of either ferrite, iron powder or permalloy tape.

Commercially the following is available:

> Pearson Electronics can supply 6-in. toroid (permalloy?) transformers with the following characteristics: 4A/V; τ = 50 nsec; 1%/μs droop; $1635.
>
> ARCO supplies complete assemblies with the ferrite external to the vacuum envelope. With an I.D. ≈ 1,5 in., $756, and combined with 4 ferrite position pickup coils $1338.
>
> Toroids with an I.D. of 3 to 6 inches, made of high frequency Nickel Zinc ferrite can be obtained by special order (≈ $600).

TABLE II

BEAM MONITORING TECHNIQUES

	Principle	Reference
Current, non-intercepting	1. Electrostatic	
	2. Electromagnetic	8) 9) 10) 11) 12)
	3. Cavity	13) 14)
	4. Synchrotron light	4)
intercepting	5. Secondary emission	2) 15) 16) 17) 18) 19) 31)
	6. Ionization chamber	20) 32)
	7. Foil activation	21) 22)
	8. (Faraday cup)	23) 24)
Position, non-intercepting	9. Electrostatic	25)
	10. Electromagnetic	26) 27) 28)
	11. Cavities	29)
	12. Synchrotron light	4)
semi-intercepting	13. Residual gas	1) 3) 30)
	14. Beam boundary sensor	
	15. Sweeping wire	
intercepting	16. Screens	
	17. Four quadrant quartz plate	
Profile, non-intercepting	18. Synchrotron light	4)
semi-intercepting	19. Residual gas	1) 3)
intercepting	20. Screens	

For our application we have to look into the radiation damage of the core materials.

We have to consider the noise produced in the transformer as a result of electrons hitting the toroid core directly. Noise should be reduced by limiting the bandwidth of the transformer.

A compromise has to be made between frequency response and sensitivity. At some locations we will probably need two types; one to observe dynamic pulses and one with low noise and a good sensitivity and stability.

We should work on stable coils, good shielding and direct calibration by sending 0.1% reference pulses through an extra winding on the core.

3. Cavity

The cavity is not a very precise current monitor since its response depends very much on the shape of the current pulse.

The noise level seems to be quite acceptable. Zyngier (Orsay) has considered its use for positrons and Callède has made noise measurements[12] showing in his particular setup noise levels as low as .5 μA peak.

4. Synchrotron light

May be useful as a relative intensity monitor at the higher currents. At very low currents (positron beams) the light could be observed with a photomultiplier and the multiplier output could be calibrated against the current.

Intercepting current monitors

5. Secondary emission

Aluminum foil SE monitors, although not very stable, are widely used. The stability may be improved using gold covered Aluminum foils. At high beam currents local temperature rise may affect the emission constant. Isabelle has studied a water cooled SEM (Ref. 2) for use in our beams.

A SEM will often require recalibration, which would be difficult in the switchyard.

We should consider non-intercepting, ring type collector electrodes instead of the usual multiplate assemblies. For very low currents, if necessary, we could consider 500-1000 Angstrom thick KCL foils[30] which have a very high secondary emission coefficient. These foils seem stable in strong radiation. Complete discoloration does not affect the emission properties (Sternglass). A difficulty with this type of foils is surface charge build up.

6. Ionization chamber

They can be made to work perfectly over a range of about 10^5 - 10^{10} electrons/pulse. Four or 5 foils are needed to assemble a chamber. Browman has made chambers with the electrodes in the direction of the beam. This idea still requires 2 end-foils and assumes a large enough plate distance.

The current range depends on plate distance, type of gas, and gas pressure. The stability can be much better than for the SEM and depends on the purity of the gas, the gas pressure and the plate distance. Flowing gas through the chamber at a controlled pressure in order to obtain stability is probably too complicated for our application.

The ionization chamber may be the only acceptable precise monitor for the positron beams.

7. Foil activation

A monitor using this principle is described in Ref. 21 for the cosmotron. It provides average current values over a relatively long time (≈ 1 sec.). The range is small and it will probably not work at our max. current intensity. It is an impractical piece of apparatus and requires maintenance. It may be useful for experimental set-ups in external beams. Not useful in the switchyard.

Non-intercepting position monitors

9. Electrostatic (see III. 1)

10. Electromagnetic

Several variations are possible (see references) but none of them seem capable of giving 0.5 mm precision if we assume gaps as large as 4-in. or 6-in. The output signal is current dependent and requires normalization for the proper current value.

11. Cavities

This monitor has the drawback of being current dependent, and current pulse shape dependent. However, the capability of the 4 cavity type monitor to show variations of the beam position during the pulse length (see Ref. 29) deserves serious consideration.

We have to see whether a cavity type position monitor (either with 4 cavities or a TM_{11} structure) or the electromagnetic position monitor is the most suitable solution for P_1 (gated position monitor in front of collimator).

12. Synchrotron light

As described in Ref. 4, this light can be used to observe the beam position in a number of magnets. The precision is expected to be limited, making it not accurate enough to meet our specifications. It may be useful, however, as an auxiliary direct observation method.

Using this method we have to think about light reflections against the inside of the vacuum chamber walls. Instead of observing the light with a TV camera in the upper part of the tunnel (as proposed in Ref. 4) it should be considered to transmit the light through a 4-in. penetration and place the camera on top of the earth shielding. The same is true, of course, for the observation of the screens.

Semi-intercepting position monitors

13. Residual gas

It has been shown (3) that sufficient de-excitation light will be produced. The light spot will not be as sharp as for the synchrotron light. The residual gas detector may have an application at a location where synchrotron light is not available.

14. Beam boundary sensor

The principle is shown in Fig. 2. Three hollow quartz fibers, a few mils in diameter, are independently movable in the radial direction.

The tubing is filled with a scintillating material (gas or liquid). The fibers may be positioned until 3 light spots are observed (position 1) showing the boundaries of the beam. The light should be observed via reflectors by a TV camera or 3 photo resistors (or other photo-sensitive components).

Placing the fibers in position 2 and using signals from the photo-resistors the system could be used as a fast beam position interlock.*

*Similar schemes could be considered using the (secondary) emission effect of metal wires.

The quartz tubing should be pure to avoid blackening. A filling must be found that maintains its luminescent properties for a long enough time in radiation. We are proceeding with some **experiments**.

Intercepting beam position monitor

15. Screens (see 19)

16. Four quadrant position monitor

In order to steer the beam precisely through the collimator and to deflect the beam properly on the center of the first quadrupoles we need a position monitor with good resolution in the magnetic center of our deflection system.

The position monitors discussed so far may not be satisfactory for this purpose. A device that could be useful for beam centering is shown in Fig. 3. The quadrants are formed by a gold deposit on a 1 mil quartz plate. The plate is clamped between 2 ceramic rings, which support also the cylindrical collector electrodes. Differential signals from the 2 horizontal and the 2 vertical quadrants may allow a precise centering of the beam (zero method). The detection sensitivity may be adjusted by changing the charging period of the capacitors (see Fig. 3C). The monitors require, of course, precise alignment. Since they are intercepting, they have to be made removable remotely.

Non-intercepting profile indicator

17. Synchrotron light

The light from the first quadrupoles may be used for this purpose (Ref. 4). (See also XI. 12).

Semi-intercepting profile indicator

18. Residual gas

Because of light diffusion in the gas it will be difficult to use this technique as a profile monitor. The only possible way seems to look perpendicular into the beam from a horizontal and a vertical direction.

19. Sweeping fiber

In principle it may be possible to sweep a luminescent quartz fiber (1 - 5 mil thick) through the beam and observe the light.

Intercepting profile indicators

20. Screens

Since the ideas in 17, 18, and 19 are insufficient we will have to look into conventional screens placed across the beam at a 45° angle. Zinc Sulfide is not suitable since it **loses luminescence very quickly** when placed in the beam.

We plan experiments with luminescent quartz fiber grids (the same as in II. 14). Quartz is an attractive material since it has a high thermal durability and can be supplied in very thin dimensions. There are some promising new glass qualities available as a result of laser development. They show high light output under radiation.

We must try to find screen materials that need not frequently be replaced. It is important to make a simple construction allowing the quick replacement of a screen without spoiling the vacuum.

IV. FUTURE WORK

It is still too early to make a firm proposal on beam monitoring techniques to be used in the switchyard.

In Fig. 1A we have made preliminary indications as to the techniques that may be useful for the monitors indicated. The numbers in Fig. 1A correspond to those used in Table II of this note.

In the next year we will analyze and try out the techniques discussed in this note. During the same period we also will study beam operation procedures and beam interlock schemes. When these results are available we will be able to make firm proposals on the beam monitoring system.

The final proposals will include beam monitors for the complete beam channels in the switchyard (including beam A', the 6° γ-beam, the neutrino beam, and the second pulsed magnet area in beam B).

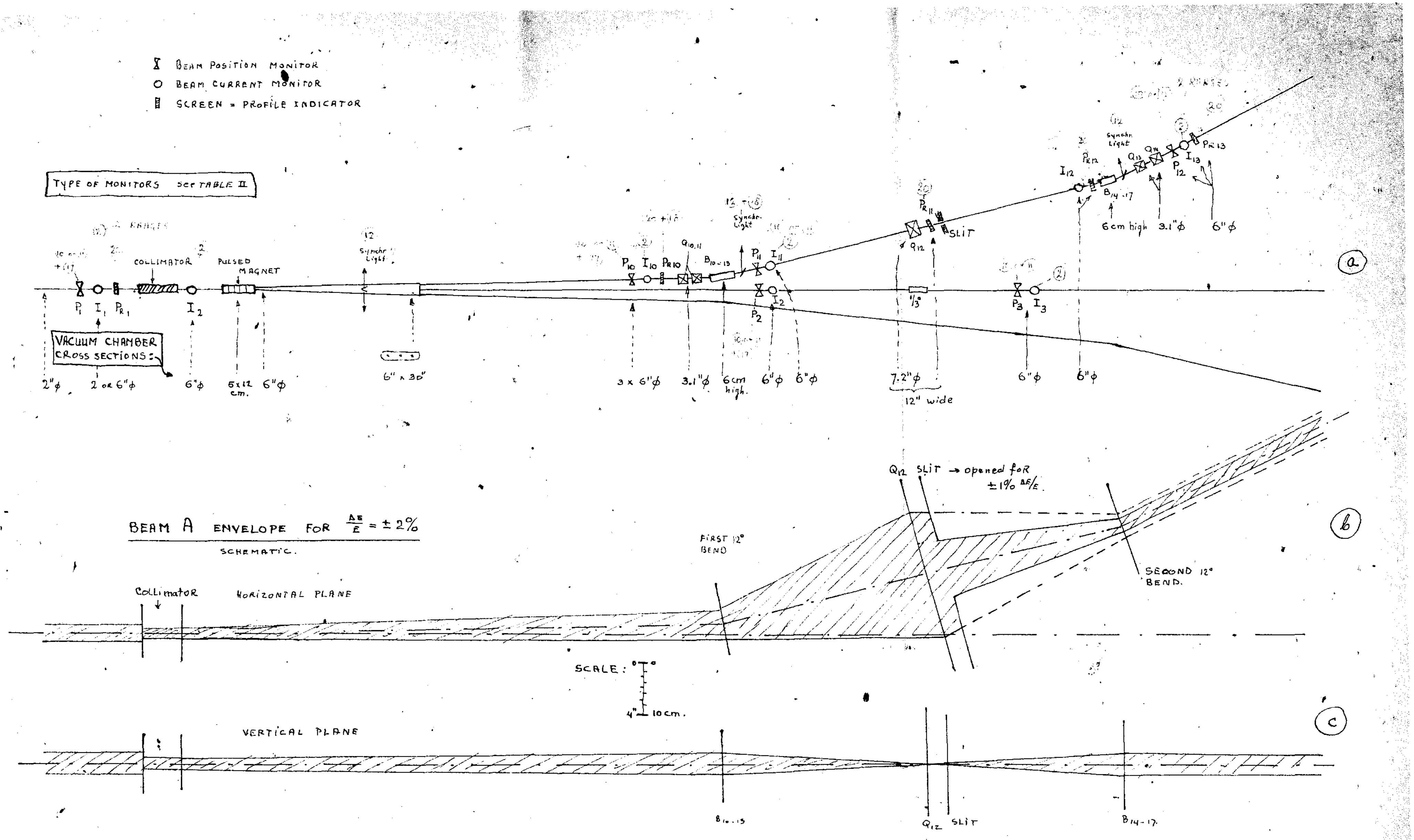

Fig. 1.

Beam Monitoring in the Switchyard

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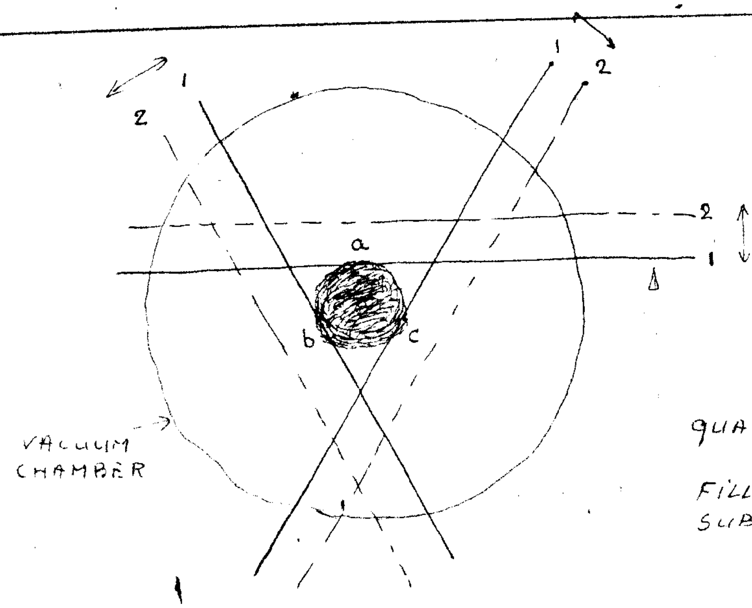
fig 2



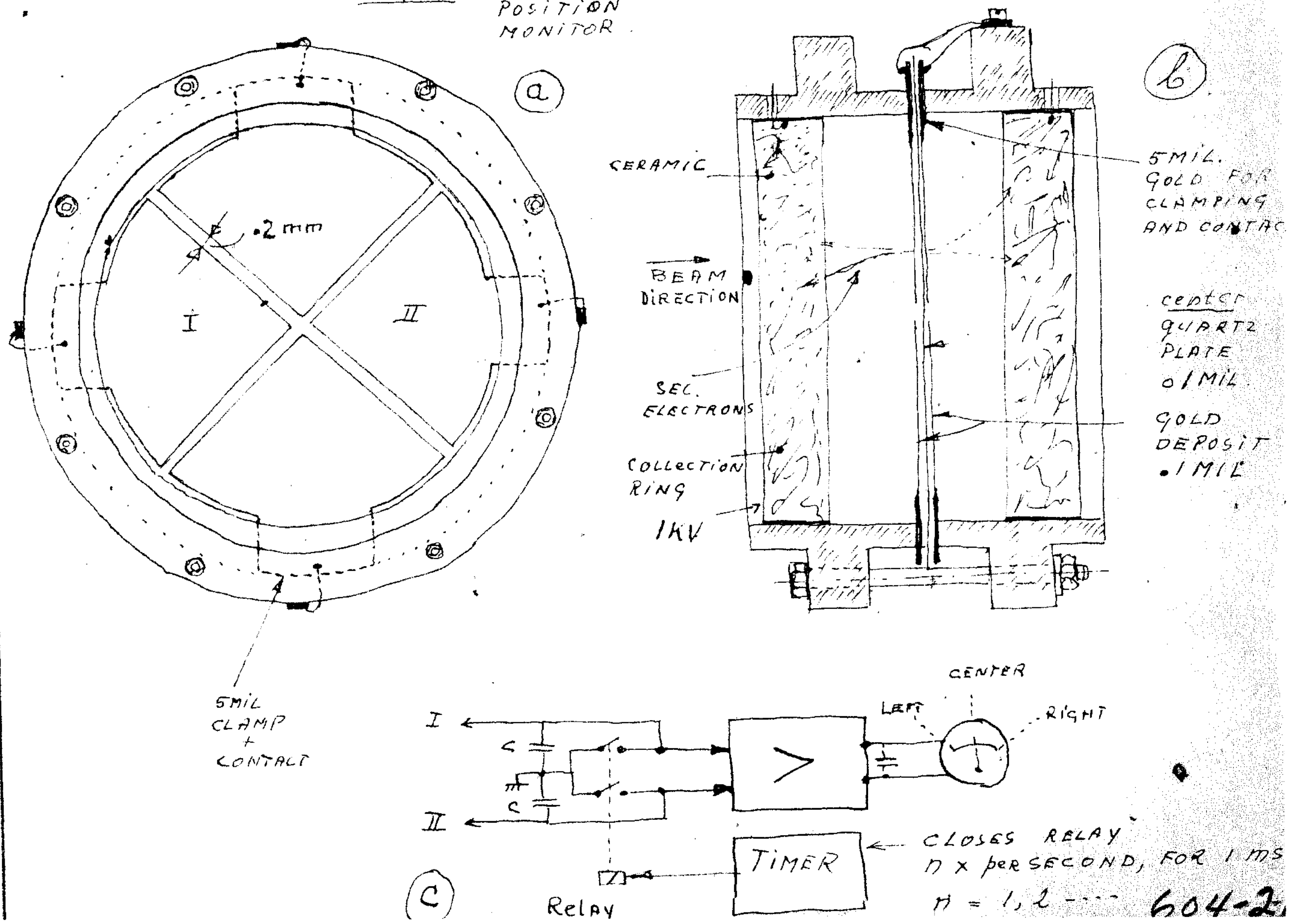
POSITION 1,
LIGHT SPOTS IN a, b, c

POSITION 2,
BEAM POSITION
INTERLOCK

QUARTZ TUBING O.D 5 MIL
I D 3 MIL

FILLED WITH LUMINESCENT
SUBSTANCE!

Fig. 3 FOUR QUADRANT POSITION MONITOR



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