A MONITORING SYSTEM FOR MEASURING THE DOSE-RATE FROM INDUCED ACTIVITY IN HIGH-ENERGY ACCELERATORS

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1. INTRODUCTION

After any shut-down of a high-energy accelerator, the hazards from induced radioactivity of the machine elements and their surroundings need to be established before allowing access to the installation. Measurements to evaluate this from the induced radioactivity are normally made at CERN by the Health Physics radiation control technicians visiting the areas. In the CERN Proton Intersecting Storage Rings (ISR) installation, which has a diameter of 300 m, this method was no longer considered to be feasible and an installed monitor system consisting of a large number of inexpensive detectors was therefore proposed. With such a system the possibility to control the large area by relatively few people could be envisaged.

With the help of a computer for data handling and registration, the radiation control technician will at a central point receive information about the levels of induced gamma radioactivity in the ring at any time after machine shut-down. This information will enable him to select regions of particular hazard which he would have to visit in order to make more precise measurements and set up appropriate restrictions and rules for access time and working conditions.

2. DESIGN CONSIDERATIONS

The main requirements of the proposed system were considered to be:

(a) simplicity
(b) reliability and stability
(c) flexibility
(d) low cost
(e) easy maintenance.

The choice of the system was greatly influenced by the availability of a multiplex cable around the ISR which offered an easy possibility of pulsed data transmission and a ready-made entry into the ISR computer. Also flexibility is guaranteed since detectors can be installed at any outlet on the line, and the system can be expanded later, if required, without any further problems. For the detector itself a simple Geiger-Müller counting device was chosen as the most practical and economic detector. Fig. 1 shows a block diagram of the system.

An important advantage of the system is that the detector can be powered from the multiplex cable. The count rate from the tube is scaled down before being transmitted. The transmitted signal is picked up by a matched receiver the output of which goes to the computer directly. Any 20 channels can also be selected for continuous registration by a recorder independent of the computer.

3. THE SYSTEM

3.1 The detector and its calibration

The detailed layout of the monitor circuit is shown in Fig. 2. It consists of a high-voltage supply in which the 30 V DC of the multiplex cable is regulated, chopped, transformed and rectified to 500 V DC to polarize the GM tube. Since the reliable maximum frequency with which the multiplex transmitter can be operated is about 10 cps, the pulse frequency from the GM tube was divided to obtain an acceptable dynamic range. In the actual design the division factor is 16. The output of the fourth binary flip-flop drives the multiplex transmitter directly. The same output also makes a lamp on the instrument flash, giving a local indication of the counting rate.

Two alternative GM tubes were used with high and low sensitivity respectively (Philips 18503 and 18509). Both tubes have about the same plateau and are made of the same material. The sensitivity of the small tube is about ten times lower than that of the larger one. This was established using known Cs-137 sources of 1, 10 and 100 mCi. Tests of the whole system showed that after an initial linear increase with dose-rate, the multiplex system goes into saturation at around 10 cps as expected. This condition is recognized by the computer and indicated by the receiver lamp being permanently on.

The calibration factors and some characteristics of the GM tubes used are summarized in Table 1. Differences between individual tubes fall within the system's overall accuracy and consequently no individual calibration factor should be necessary.

Table 1

Some characteristics of the low- and the high-sensitivity tube, and calibration factors of detectors

	High-sensitivity tube	Low-sensitivity tube
Sensitivity	0.7 mrad/h/cps	9.5 mrad/h/cps
Dynamic range*) with multiplex	0.030 - 7.5 mrad/h	0.030 - 90.0 mrad/h
Background	30 μrad/h	30 μrad/h
Cathode material	28% Cr, 72% Fe	28% Cr, 72% Fe
Cathode thickness	250 mg/cm^2	80-100 mg/cm^2
Gas filling	Ne, Ar, halogen	He, Ne, halogen
Operating voltage	400-600 V	500-650 V
Life expectancy at typical counting rate	>2 years	>2 years

*) Division factor = 16.

3.2 Readout system

The detectors are foreseen to be read continuously by a computer and this will give a listing of the dose-rate at the different monitor positions on command. The computer also recognizes whether the system is saturated and gives the appropriate indications.

The multiplex signals can also be read in analogue form. Up to 20 channels are available simultaneously and can be used if the computer is out of operation or if the activity decay is to be measured.

A quick indication of dose-rate is given by a flashing light on the receiver. When the light is permanently on, this indicates that the channel is saturated.

The response of the detector as seen by the readout system is shown in Fig. 3.

4. PROTOTYPE PERFORMANCE

Prototypes of the detector have been tested during the running-in of the ISR since September last year. Measurements for this purpose were carried out in low beam-loss areas and in regions with higher beam losses, hence at locations with higher levels of induced radioactivity. The distance from the vacuum chamber to the detector varied from 50 to 400 cm.

At all the positions, it was confirmed that the chosen dynamic range of the detector was adequate. Only in regions with higher beam losses, such as injection areas or around the internal beam dumps, the low-sensitivity GM tube will have to be used.

During machine operation the detector is exposed to high-energy radiation inducing radioactivity in the GM tube itself, and this contributes to the reading when measuring the dose-rates. Tests have shown that the reading on the monitor is about 50% from the activity of the GM tube and 50% from the ambient gamma activity. Surrounding the GM tube with 2 mm cadmium improved this ratio considerably, indicating that low-energy neutrons contribute to the activation of the tube as shown in Table 2. The cadmium screen is also expected to improve the low-energy gamma response of the detector.

Table 2

Results obtained with GM tubes with and without cadmium shielding

	Tube without cadmium shield	Tube with 2 mm cadmium shield
Gamma dose-rate	1.3 mrad/h	1.3 mrad/h
Indicated dose-rate (ambient + tube)	3.0 mrad/h	1.9 mrad/h
Reading due to tube activity	1.7 mrad/h	0.6 mrad/h
Ratio of actual to total indicated dose-rate	0.44	0.7

The ratio of the actual to total indicated dose-rate was never found to be below 0.5 for the cadmium-covered tubes, independent of position and time after end of irradiation. Hence the detector overreads by a factor of two at most.

For the final installation most of the detectors will be fixed on the cable tray on the wall in the ISR tunnel at beam height and between 1.5 and 7 m from the vacuum chamber. The system makes it possible to locate the areas of higher induced radioactivity; appropriate conversion factors have to be found experimentally for each detector and these fed into the computer for positions where more precise dose-rate values are required. More details about the operational use of the system will be described in another paper[1].

For technical reasons it will not be possible to switch off the system during operation. This will influence the life time of the GM tubes. Since, however, the distances from the vacuum chamber are large and the beam losses in the ISR relatively low, this should not cause serious problems. Life times of the order of more than two years are expected and the design is such that the tubes can easily be changed.

5. CONCLUSIONS

It appears from the experience gained so far that the system will have the ability to show the distribution of induced radioactivity in the ISR tunnel and to indicate the places where more detailed survey measurements have to be made. Changes in the radiation patterns which depend on the use of the machine can be established by comparing the corresponding computer outputs. This information can be provided within a few minutes.

An accuracy of more than a factor of two cannot be claimed from the system unless detailed information is used. However, the computer makes it possible to consider additional factors such as activity from the tube, the distance from the detector place to the vacuum chamber, etc., and consequently make a more accurate dose estimate.

A limitation of the system lies in the multiplex transmission line which needs a computer or an experienced operator for reliable data interpretation.

ACKNOWLEDGEMENTS

The technical assistance of Mr. B.A. Moy, who actively participated in the development and construction of the prototype instruments and readout system, was greatly appreciated. Also, discussions with Dr. M. Höfert concerning the specifications and with Mr. S. Larson and Mr. L. Andersson concerning technical problems contributed to the success of the project.

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REFERENCE

1. M. Höfert, This Congress paper No. 74 (1971).

FIGURE CAPTIONS

Fig. 1. Block diagram of the monitor system.

Fig. 2. Circuit diagram of the monitor.

Fig. 3. Response of the detectors as seen by the readout system.

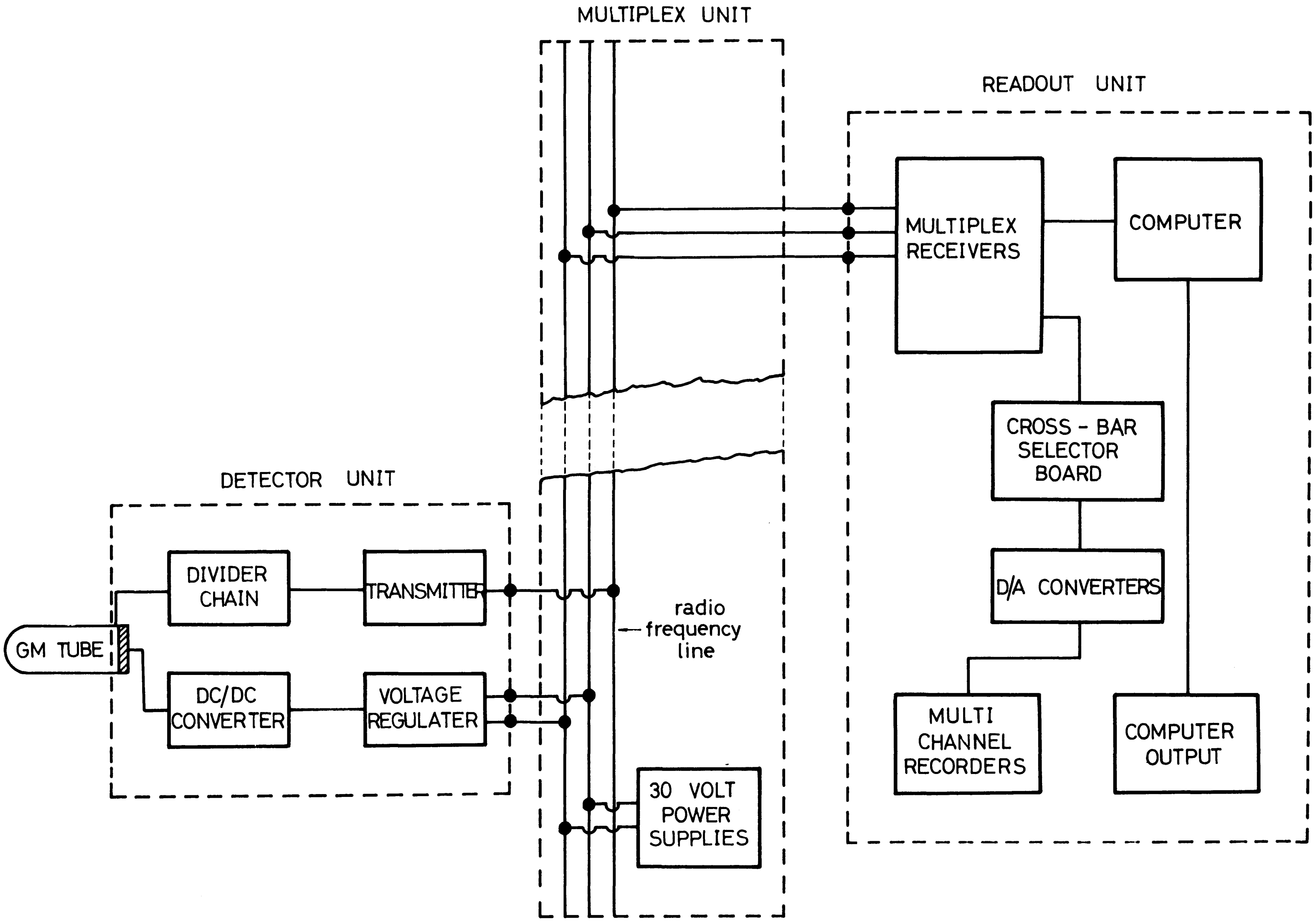

MULTIPLEX UNIT
READOUT UNIT
MULTIPLEX RECEIVERS
COMPUTER
CROSS - BAR SELECTOR BOARD
D/A CONVERTERS
MULTI CHANNEL RECORDERS
COMPUTER OUTPUT
DETECTOR UNIT
DIVIDER CHAIN
TRANSMITTER
GM TUBE
DC/DC CONVERTER
VOLTAGE REGULATER
radio frequency line
30 VOLT POWER SUPPLIES

Fig. 1

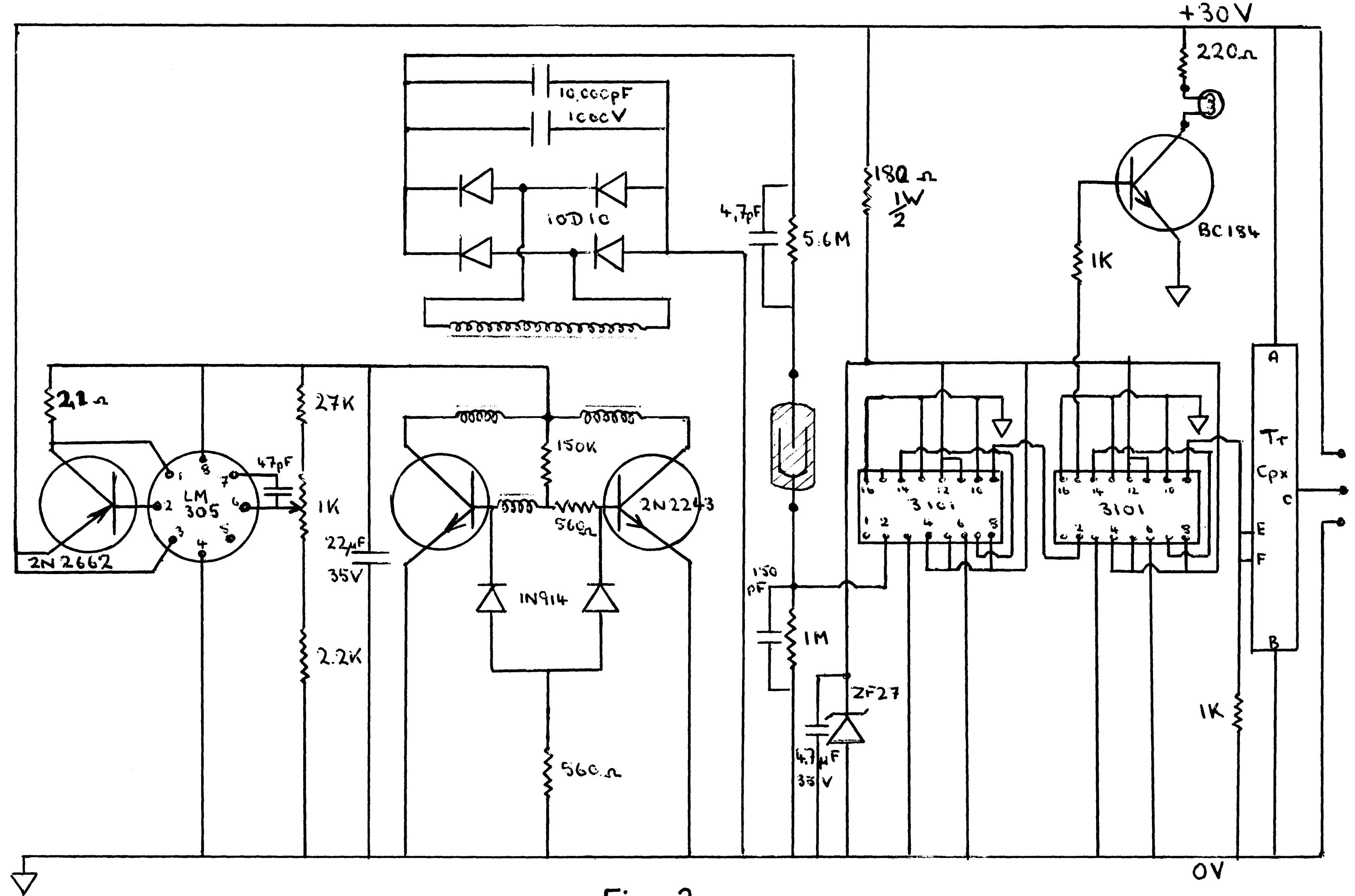
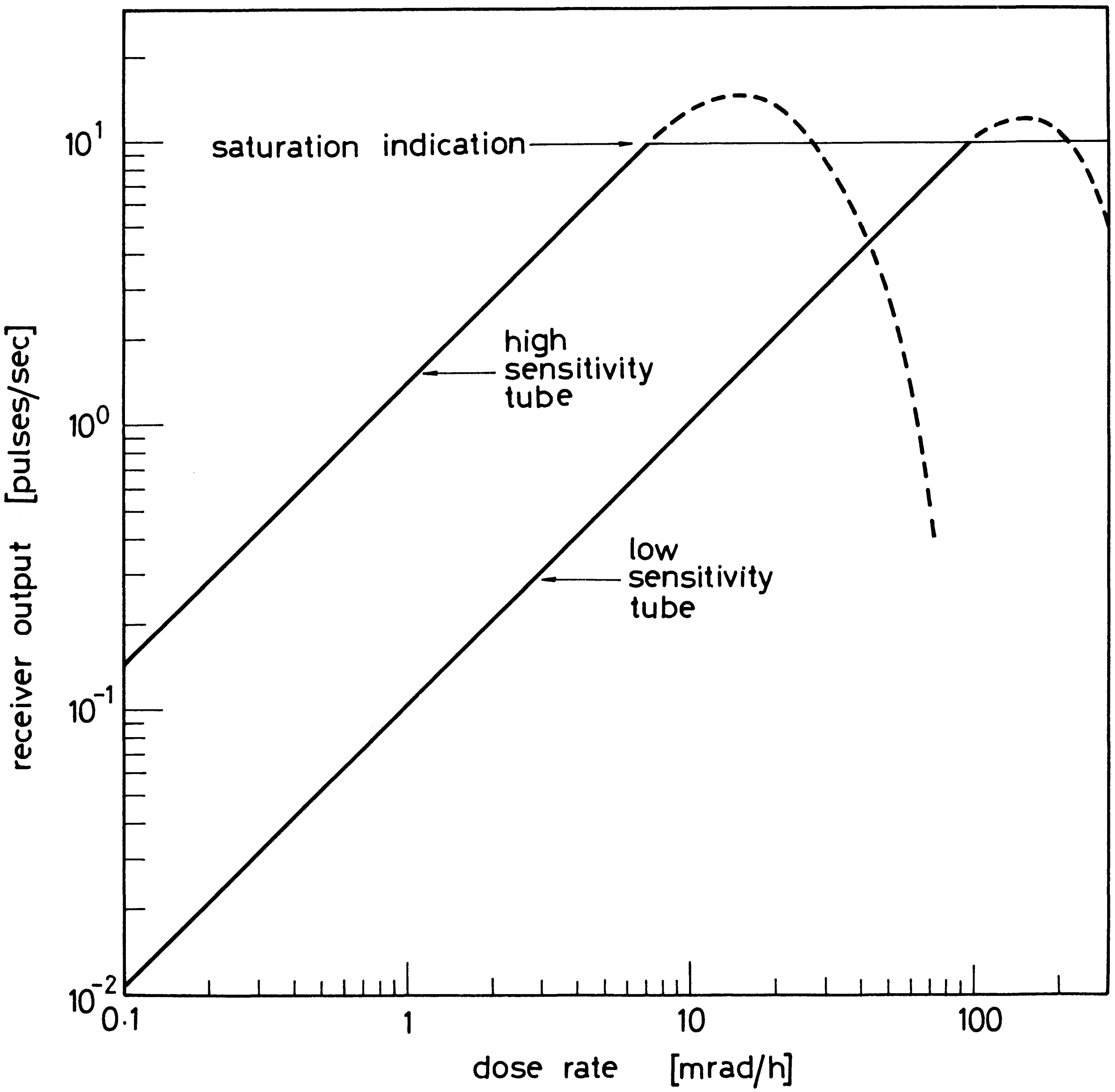

+30V
220Ω
10,000pF
1000V
10D10
4.7pF
5.6M
1W/2
BC184
1K
27K
150K
2N2243
LM 305
47pF
1K
22µF
35V
2N2662
IN914
2.2K
560Ω
150 pF
1M
ZF27
4.7µF
35V
3101
3101
Tr
Cpx
A
B
C
E
F
1K
0V

Fig. 2



saturation indication
high sensitivity tube
low sensitivity tube
10^1
10^0
10^{-1}
10^{-2}
0.1
1
10
100
receiver output [pulses/sec]
dose rate [mrad/h]

Fig. 3

Paper : A monitoring system for measuring the dose-rate from induced activity in high-energy accelerators

TESCH: What is the half-life of the activation of the GM counters? Do you expect troubles if there is a build-up of activation over long periods?

SCHÖNBACHER: The half-life of the isotopes created in the GM tubes depends on the irradiation time. Due to the short operation times during the running-in period of the ISR (up to 12 hours continuous irradiation) only short living isotopes have been induced so far). We do, however, not expect problems with the build-up of activation over long periods. Since the main components in the machine elements and in the tube are the same (iron) we expect approximately the same build-up for both the ambient environment and the tube.

HOEFERT: As we want to make an estimation of the dose-rate at 40 cm distance from the machine, it might be necessary to review, from time to time, the practical conversion factors allocated to each monitor reading.

COLEMAN: Could you tell me the dose-rates that you expect?

SCHÖNBACHER: I may refer to the paper of Dr Höfert in which he gives a value of 0.35 mrad/h at 40 cm distance several hours after the end of irradiation and states that this value may be a factor 10 higher or lower.

HOEFERT: The system was not built to look at dose-rates of 0.35 mrad/h at 40 cm distance. There are mainly two tasks:

i) To guide the health physics technician to places where unexpectedly high beam losses resulting in high levels of induced radioactivity have occurred.

ii) The system can give information on the behaviour of a circulating beam once sufficiently high proton-currents, usable for physics experiments, have been started.

COLEMAN: Could you tell me the price of this installation?

SCHÖNBACHER: On a basis of 200 detectors the price per detector per point is about SFr. 1'000.- including the cost for the multiplex components (transmitter receiver, power supplies, cables, etc.) and the analogue read-out system.

AWSCHALOM: It is possible to do better and arrive at a cost of about 10% of that.

SCHÖNBACHER: As mentioned, the choice of the system was influenced by the availability of the multiplex line in the ISR. The price of one transmitter receiver pair alone is SFr. 450.-. But we think we can justify the use of this method due to its proven reliability and flexibility. I am sure that you can make cheaper detectors, but that you get a similar performance of a system for only SFr. 100.- per detector point I would doubt. Let me also mention that the price for the electronics and mechanics of our detector as shown in Fig. 2 without the multiplex transmitter is about SFr. 300.-.

BAARLI: In cost estimates of the kind discussed here it is important to keep in mind the relation between staff cost and material cost. In our case I think the cost estimate for the system is justified on this basis since it also might have additional capabilities not yet explored.

OLIVER: Do the detectors continue to give full scale indication if the dose-rate considerably exceeds the intended operating level?

SCHÖNBACHER: During machine operation most of the detectors were working although usually at their limit; only in unfavourable conditions, such as close to the beam dumps, was the system completely saturated. In this condition the full scale indication was maintained. Remember also that the full scale indication is due to the transmission line, whereas the tube may still work properly. The tube only saturates when the counting rate is about 100 times higher than that counting rate which causes saturation of the multiplex system.

PARKER: Then, since your detectors are operable during machine operation, it is conceivable that they might be used to guide machine operation?
SCHÖNBACHER: The system was designed to measure only values of induced radioactivity. If additional information can be obtained, as proton losses, during machine operation this would be an advantage. It is, however, not intended to use the system to guide machine operation. For this purpose the dynamic range of the actual design (with a division factor of 16) is too low.

HOEFERT: As you may have noticed, in Figs. 4 and 5 of my paper, the system can give valuable information once a stable beam has been set up, for example, we can see deterioration of the vacuum and blow-up of the beam with time.

SHAW K.B.: Why have you installed this monitoring system in the ISR and not the PS where the radiation levels are more significant?

SCHÖNBACHER: In the PS the radiation control technicians are performing the survey measurements along the ring after any machine shut-down. Due to the complexity of the machine this seems to be the best method. Also the size of the machine (100 magnet units compared to more than 400 in the ISR) would probably not justify the installation of a monitor system.

SHAW K.B.: Does the use of this system mean that loss-induced activity surveys will be carried out on the ISR?

SCHÖNBACHER: No, with the system in operation the radiation control technician will only have to go to those places selected by observation of the system. At such places more precise measurements might have to be made.

MAUSHART: Kennen Sie die Form des γ-Spektrums? Die Primärenergien kürzen natürlich vor den induzierten Radioaktivitäten ab, aber es wäre sicher interessant zu sehen, wie das nun wirklich am Ort des Detektors aussieht, und wie es sich im Verlauf der Zeit ändert.

SCHÖNBACHER: Wir haben bisher keine Analyse des γ-Spektrums gemacht.

HOEFERT: Die einzelnen γ-Emitter, die gebildet werden, sind bekannt; ebenso gibt es mit der Formel von Sullivan eine gute Voraussage über den Aktivitätsanstieg. Wegen des grossen Abstands zwischen Radioaktivität und Detektor werden die β- und die weiche γ-Komponente weitgehend absorbiert; auf der anderen Seite wird das harte γ-Spektrum aufgeweicht. Eine spektrale Analyse am Messort wäre sicher interessant.