THE AGS MAGNET ENCLOSURE BEAM SPILL AND PERSONNEL SAFETY MONITOR*

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I. Introduction

The Alternating Gradient Synchrotron (AGS) magnet enclosure radiation monitoring system provides assistance in solving three radiation-related problems, viz., personnel safety monitoring, location and extent of beam loss ("spill" around the half-mile circumference of the synchrotron), and accumulated exposure of radiation-degradable machine components.

Personnel safety monitoring in a potentially lethal high energy accelerator facility must protect against inadvertent machine start-up, and provide means to measure residual radiation levels. The AGS in-ring monitor detects abnormal radiation fields at times when personnel are permitted in the enclosure and interupts machine functions in addition to those normally interlocked by machine security. During periods of non-acceleration, the monitoring system provides surveillance of residual radiation fields. The magnitude and decay rate of these fields can be used to optimize machine maintenance programs.

The beam spill monitoring capability of the system locates and evaluates the magnitude of beam spill in the magnet enclosure. This detection permits more rapid correction of undesirable beam loss and therefore provides for a higher utilization factor for the machine.

Unfortunately radio-sensitive components could not be eliminated from the beam handling and accelerating structure. Replacement can be delayed until failure or can be effected at a near failure dose. Radiation failures always seem to occur near the end of an important experiment so that urgency and high maintenance exposure ensue. In contrast, the spill monitoring system allows the administration of maintenance for minimum exposure and permits planning of the experimental shedule for maximum beam utilization.

II. Radiation Fields

Target areas comprise a very small protion of the AGS magnet enclosure to afford experimental floor economy. For this reason large portions of the synchrotron ring receive very little beam loss and are termed quiet areas. During normal accelerator operations the radiation levels experienced within the synchrotron magnet enclosure ring vary over an intensity range of about 10^4. Residual radiation intensities during periods of non-operation are similar in distribution, but lower in absolute value by a factor of about 10^3.

Any device capable of serving as a radiation monitor during machine operation, as a spill monitor, and as a personnel monitor must therefore be capable of following radiation intensity variations of about 10^7. The requirements are further complicated by the pulsed nature of the radiation. Normally, protons are injected into the synchrotron and are accelerated to full energy in about one second. At peak energy, the magnet current is held constant and the beam undergoes multi-turn targeting for an additional 200 to 600 msec. On the other hand, the proton beam is highly dynamic and takes on the radio frequency structure of the accelerating field. Deliberate or accidental beam impingement lead to rapidly fluctuating radiation intensities with periods in the order of nanoseconds. Fast external beam operations require the extraction of one-twelfth of the entire beam in a 2.5 nanosecond-wide bundle. This leads to a targeting time variation of 600 msec to about 3 nanosec and a radiation production duty cycle of .25 to 10^{-9}. Any reasonably accurate radiation spill monitor must have a dynamic range well in excess of 10^7 to follow the instantaneous dose rate variations or must be an integrating instrument.

III. Detector

Previous studies of the characteristics of the Integrating Pulse Discharge Ion Chamber (IPDIC)[1,2] suggested its use for the AGS in-ring spill and personnel monitor. Basically the device is an ionization chamber that integrates the charge caused by impinging radiation fields. Accumulated charge is stored on an internal capacitor which is reset at a given charge by the breakdown of a glow-discharge lamp. The sensitivity is determined at the time of fabrication by adjusting the filling-gas pressure, and the capacitor. Previous measurements[1] have shown that a single unit can reliably follow an intensity range of 10^5 and that IPDIC chambers can be constructed with a sensitivity variation of about 10^4. Proper utilization of the IPDIC chambers provides coverage over the range 0.0001 to over 5,000 rads/hr for continuous irradiations[1]. Calculations following the work of Boag[3] indicate that 80% collection efficiency will be maintained up to about 4 x 10^5 rads/hr.

Detector stability, as a function of time and radiation dose history, has been studied[1].

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A decrease of sensitivity of 2% to 5% per year is observed initially, with stabilization after 2 to 3 years. No degradation of performance was observed after ^{60}Co exposures of 5×10^6 rads.

The previously described AGS duty cycle imposes additional requirements on the dose rate response of the IPDIC. Detector efficiency is related to recombination losses which depend upon the applied voltage, nature of the impinging radiation, composition of the filler gas, geometry and size of the detector. The maximum dose rate response was calculated for a typical IPDIC unit for 80% and 90% collection efficiency using methods described by Boag[4]. The detector is cylindrical in geometry with a radius of 3.8 cm. The co-axial internal anode is 0.8 cm in radius and the outer container or cathode is about 30 cm long. The chamber is filled with argon gas to a pressure of 1 atm and is polarized to 1800 volts. The mobilities of the positive and negative ions are taken to be 1.8 and 1.3 cm/sec volt/cm respectively. Fig. 1 is a graphical presentation of the calculated result. The inflection point occurs when the ionic mobility equals the rate of charge formed. Further increases in the charge formation rate for the same dose have no effect and collection efficiency remains constant.

The limiting value, assuming 80% collection efficiency, is about 80 mr/AGS cycle for radiation periods shorter than about 10^{-3} seconds.

IV. Detector Assembly

To insure necessary detector dynamic range in various portions of the synchrotron ring, IPDIC sensitivities of 5,000, 100, 10 and 1 mrad/reset pulse were used. The detector's digital output requires simple low impedance circuitry. The IPDIC pulse amplitude is about 5 volts with a full width of about 50 μsec into 50 KΩ. Noise discrimination and pulse stretching to about 50 msec is accomplished by a low-gain univibrator. A level change from the univibrator drives a two-transistor, direct-coupled, heavily-saturated (for radiation degradation endurance) current amplifier. The amplifier operates a dry reed relay whose normally open contacts provide on output to the control unit located in the AGS control room. A regulated power supply in each remote unit furnishes 12 volts and 1800 volts. The 1800 volt chamber polarizing voltage is produced by a voltage tripler and regulated by a Victoreen Coronatron.

V. The Operational System

The monitoring system (Fig. 2) now consists of ten detectors located in the injection, quiet, and target areas within the magnet enclosure. Information from the detector modules is sent to the main monitoring system in the AGS Main Control Room and to a multi-pen event recorder in the Health Physics office. A register totalizes the pulse from each detector. An incandescent lamp is used, with each totalizing register, to afford a visual display of the spill pattern.

Basically, the personnel alarm feature samples all channels in analog summation manner (Fig. 3). The analog signals are generated by a flip-flop stage that is provided for each channel. A reset system sets all flip-flops so that the analog sum is initially zero. An IPDIC pulse causes its flip-flop to change state and current to flow in the analog buss. This current is monitored by an electronic relay meter. The alarm level is a function of the limit adjustment of the relay meter, current steps afforded by the flip-flop elements, and reset time. The flip-flops are reset periodically at selectable intervals of up to 64, 2.4-second increments.

The alarm feature is designed to be locked out during periods of normal accelerated beam operations. This is accomplished by requiring a signal from the personnel barrier security system to interrupt the alarm feature. Essentially the alarm circuitry is free to interrupt the acceleration system whenever excessive radiation levels exist and personnel access is possible.

VI. Operational Experience

A few months after the initial units were installed, the electronics associated with the detector in the principal target area, G-10 suffered radiation failure. The dose is estimated to be approximately 2×10^7 rads. The betas of the 2N2905 transistors used in the univibrator trigger pair had degraded from initial values of 125 to 150 to less than 10 at the time of failure. To counter this radiation degradation of performance, the electronics package was separated from the detector assembly and moved 20 feet upstream from the detector. The new location receives about 1/10 the exposure of the earlier location and no further failures have occurred. Germanium 2N414's have replaced the silicon transistors in all but the above mentioned unit. This unit is to be run to failure to further investigate the failure rate of silicon transistors in the AGS radiation environment. The use of Germanium transistors is expected to yield a life improvement[5] of a factor of about 4. Assuming immediate failure of the unit in test, a life of about 18 months would be indicated. No detector failures have been experienced.

The system is currently providing functional information on the AGS as a radiation source. The event recorder chart provides a record of machine operations with a time resolution of less than one minute, providing the means by which the radiation-producing activities are reconstructed. This "machine history" function is demonstrated in Fig. 4, wherein it may be seen that the following events occurred: Personnel access secured, 0858; end of "Linac only" operation, 0859; accelerated beam begins, 0902; begin use of F-20, G-10 targets, 0943; begin use of I-10 target, 0944. Quantitative changes in the radiation field patterns within the magnet enclosure are recorded for the beam and target changes. The display of radiation spill in the magnet enclosure has made possible knowledgeable curtailment or alternation of machine operation so as to avoid an unnecessary increase in the residual radiation field. This affects maintenance exposure reduction of the AGS facility that is somewhat maintenance-limited due to staff exposures.

The total number of pulses counted by a monitor channel is a calibrated function of the total exposure dose in the vicinity of the detector. For example, the G-10 monitor sensitivity is 5 rad/pulse, and 5 rads are consistantly delivered to the detector when 2.67×10^{14} protons have interacted with the G-10 target.

The system has found additional application in serving as a normalizing medium for extended radiation field surveys in inhabited areas outside the magnet enclosure. To achieve consistency amoung the data of a variety of detectors, it is necessary to normalize to a given radiation production rather than to a simple function of time or of total accelerated beam. The spatial distribution of beam loss within the half-mile circumference of the AGS is not sensed by any other calibrated machine monitoring system.

On several occasions highly sensitive portable versions of the detector system, viz., Integrating Radiation Monitors and Alarms (IRMA)[1] have been added to provide high temporal and spatial resolution of the decay of residual radiation fields in areas where maintenance is to be performed. The residual field is due to the activity of many isotopes and is a complicated function of the history of radiation spill in the area. The decay is typically a function of some negative power ($.5 \pm .3$) of time. The decay law for a given target area generally stabilizes a few hours after beam loss is ended; so that power function does not change markedly for the following several weeks. The ability to accurately project radiation field intensities has increased the efficiency of programing work in radiation areas.

VII. Summary

A synchrotron ring radiation monitoring system has been constructed that serves as a spill monitor, personnel safety monitor and radiation dosimeter for degradable machine components. One-third of the 30 detectors ultimately expected have been in service for about six months with full realization of all design concepts.

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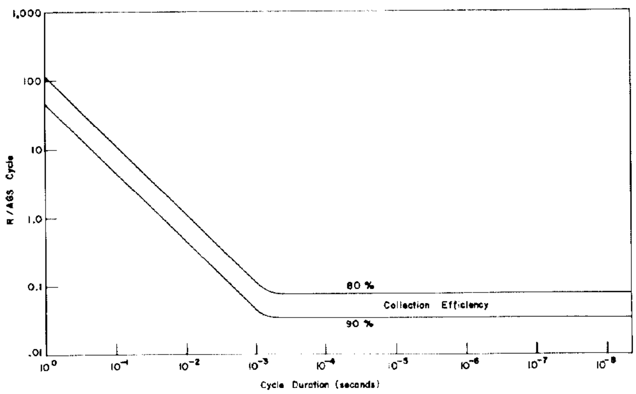

Fig. 1. Maximum Dose per AGS Cycle for 80 8 90% Detector Efficiency.

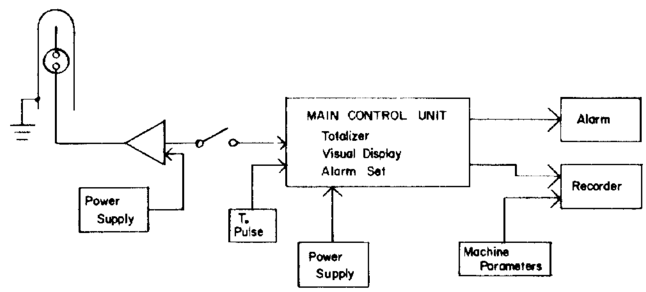

Fig. 2. General System Outline.

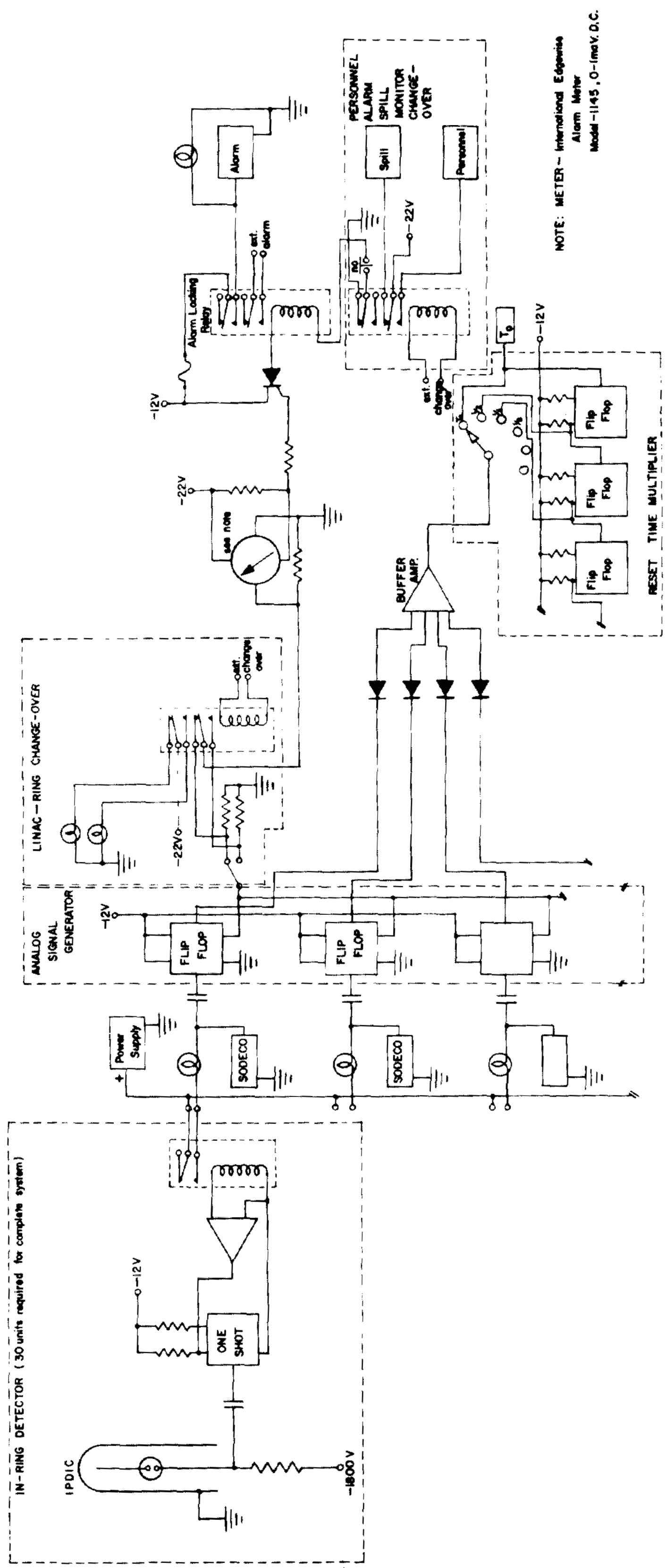

Fig. 3. In-Ring Spill 8 Personnel Safety Monitor.

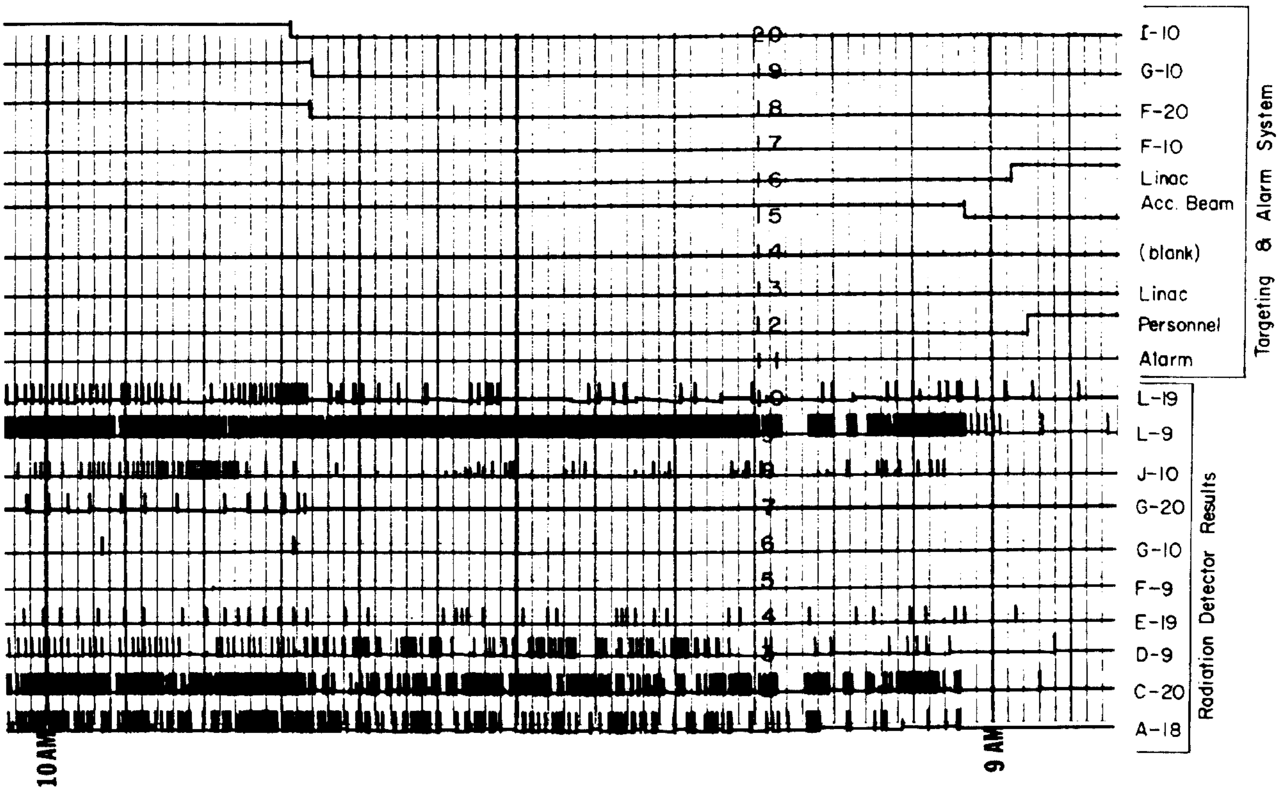

Fig. 4. AGS Radiation History Recorder.