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Computer-Controlled Radiation Monitoring System

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Abstract

A computer-controlled radiation monitoring system was designed and installed at the Lawrence Livermore National Laboratory's Multiuser Tandem Laboratory (10 MV tandem accelerator from High Voltage Engineering Corporation). The system continuously monitors the photon and neutron radiation environment associated with the facility and automatically suspends accelerator operation if preset radiation levels are exceeded. The system has proved reliable real-time radiation monitoring over the past five years, and has been a valuable tool for maintaining personnel exposure as low as reasonably achievable.

Introduction

The Physics Department of LLNL recently constructed a Multiuser Tandem Laboratory (MTL) to perform a variety of basic and applied measurement programs.[1,2] The laboratory and its research equipment were constructed with support from a consortium of LLNL divisions, Sandia National Laboratories Livermore, and the University of California.

Primary design goals for the facility were inexpensive construction and operation, high beam quality at a large number of experimental stations, and versatility in adapting to new experimental needs. To accomplish these goals, our main design decisions were to place the accelerator in an unshielded structure, to make use of reconfigured cyclotrons as effective switching magnets, and to rely on computer control systems for both radiological protection and highly reproducible and well-characterized accelerator operation. This paper addresses the radiological control computer system.

Accelerator

The tandem Van de Graaff accelerator is the former University of Washington FN tandem, manufactured by the High Voltage Engineering Corporation. We upgraded the accelerator from the traditional rubber charging belt to a metal and nylon pellet system, and we replaced the original accelerator tubes with tubes whose electric field design is optimized to suppress the generation and acceleration of secondary electrons. We also converted the insulating gas system from a mixture of nitrogen and carbon dioxide to sulfur hexafluoride. These changes allow a maximum terminal voltage near 10 MV and a reduction of ripple in the terminal voltage from several kV to below 750 eV. Table 1 contains a partial list of the ion beams that the MTL routinely produces, and Fig. 1 shows the facility layout.

Radiation Monitoring System

The Laboratory's radiation shielding design criterion for personnel radiation exposure is to ensure that the maximum annual personnel radiation dose does not exceed 500 mrem. This design policy can be implemented by controlling personnel exposure time, using physical shielding, and excluding personnel from radiation zones.

The maximum possible radiation level at the MTL facility is less than 100 rem/h, one meter from any unshielded accelerator component. However, most experiments at the MTL facility involve the acceleration of ions under conditions that result in radiation levels below 1 mrem/h in occupied areas. Occasionally, experimental conditions produce levels of several hundred mrem/h. These modest radiation levels and the 100-rem/h maximum allowed construction of a facility without the usual massive concrete shielding. A safe radiation environment is provided by local shielding around slits and beam dumps, access and operating controls, and a computer-controlled radiation monitoring system (RMS). This open architecture provides easy access for accelerator maintenance and modification, experimental configuration, and data collection.

The facility is divided into several radiation zones, as shown in Fig. 2. Each zone can be classified as Exclusion, Controlled, or Uncontrolled, depending on the expected ionizing radiation level. The radiation-level zone classification scheme is shown in Table 2.

The RMS continuously monitors the MTL work environment and automatically suspends accelerator operation if preset radiation levels are exceeded. The system consists of hard-wired radiation detectors and computer-controlled detectors. The hard-wired detectors turn on a rotating red light if the radiation dose rate exceeds 5 mrem/h and automatically terminate accelerator operation if the rate exceeds 100 mrem/h.[3] Three of the hard-wired detectors are in service. They are located at the ion source, the terminal region of the tandem tank, and the forward-beam experimental area. The computer-controlled system comprises photon and neutron detectors that monitor the instantaneous dose rate and hourly integrated radiation dose.

Safety Interlock System

Access to Zone 1 is controlled when the Exclusion Zone state is selected. An interlock chain monitors all entry and exit to Zone 1, including the basement and emergency exits. The status of access points is monitored using double, in-series microswitches. In addition to the microswitches, run-safe boxes are located throughout the area. These boxes are serially connected with the interlock loop and must be sequentially activated when configuring Zone 1 as an exclusion state. The interlock system signal is +24 volts direct current (VDC). If any microswitch is disabled (e.g., opening an interlocked door or gate or activating a run-safe box), accelerator operation is automatically suspended. The interlock loop is hard-wired into the accelerator control system and monitored by the main accelerator computer control system. In addition, the RMS also receives the +24 VDC interlock signal, and the presence of this signal automatically activates the Exclusion Zone computer logic.

Hardware

Figure 3 shows the RMS hardware configuration. The photon detectors consist of pressurized ionization chamber detectors and Geiger Mueller (GM) detectors. The neutron detectors are ^{6}Li solid-state detectors surrounded by a two-inch-thick polyethylene moderation jacket. Each detector assembly contains its own high-voltage power supply, charge-to-pulse converter (ionization chamber), low-voltage regulator, and line driver. The units are powered by +12 VDC at 85 mA and generate a nominal 3.4 VDC alternating polarity signal, whose frequency is proportional to the ionization chamber current, GM count rate, or neutron count rate as applicable.

The detectors are connected to the RMS computer system by a four-wire cable bundle consisting of a low-voltage power-and-ground pair and a coaxial signal cable. Maximum-rated signal cable length is approximately 300 m with 22 AWG wire. Each detector assembly is contained in a wall-mounted enclosure 24.1 cm high × 9.9 cm wide × 12.3 cm deep. The detector continuously sends signals to a cluster of Hewlett Packard HP 44715A 200-kHz totalizer modules. These plug-in modules are connected to an HP 3852S Data Acquisition and Control System. Each totalizer module accommodates 5 detector assemblies, and the HP 3852S can hold 8 modules: a total of 40 detectors. Expansion modules are available if more than 40 detectors are required.

The totalizer modules are sequentially polled every few seconds, and the current dose rate and hourly integrated dose are calculated. A color monitor displays the current dose rate and integrated dose along with the previous hourly integrated dose.

When Zone 1 is configured as a Controlled Zone, accelerator operation is automatically suspended if the instantaneous rate exceeds 100 mrem/h or the hourly integrated dose exceeds 1 mrem (neutron or photon). When Zone 1 is configured as an Exclusion Zone, accelerator operation is suspended if the integrated dose in Zones 2 or

3 exceed 1 mrem or the integrated dose in Zone 4 exceeds 0.25 mrem. The RMS continuously monitors Zone 1 and allows toggling between Controlled and Exclusion states without accelerator disruption. The hourly radiation level data are archived onto the RMS hard disk, which has a storage capacity of thirty years of hourly radiation data summaries.

To monitor for RMS computer malfunctions (e.g., if the computer's central processing unit locks up), a watchdog timer continuously confirms proper computer operation. The watchdog timer controls the power to the RMS computer and to the accelerator permissive signal. During each radiation monitor polling sequence, a +24 VDC signal pulse is transmitted to the timer. If the computer fails to provide this signal for more than 30 seconds, the watchdog timer automatically terminates computer power, which in turn terminates the accelerator permissive signal. After the watchdog timer stops the accelerator operation, the system must be manually restarted with a reset button.

We dedicated a detector for quality control of the detector power system and software. This detector continuously monitors an internal ^{137}Cs check source and automatically terminates acceleration operation if the signal falls below a specified value.

Software

We control the accelerator and beam transport systems through a distributed system of Hewlett Packard 9000 computers. The RMS software resides on an independent HP 9000 series 310 computer and monitors the radiation detectors and safety interlock system. The RMS software is written in HP BASIC 5.0 and is not accessible to the accelerator operator or experimenters. The current program is configured for up to 40 radiation detectors, which is more than adequate for the current accelerator environment. If we need to expand the system, we can easily modify the software and hardware.

Discussion and Summary

System Experience

We have used the RMS for over five years without any significant operating problems. The radiation monitors are calibrated every six months; the calibration constants [e. g., (pulse rate)/(rem/h)] have remained the same. Detector background levels are consistently of the order of 0.01 mrem/h.

In addition to providing real-time measurement of the MTL radiation environment, the system also serves as a predictive design tool. The RMS has been valuable in radiation safety planning for experiments involving new accelerator operating parameters or experimental configurations. Before operating the accelerator, the RMS is used to scope out the radiation environment at 1% or less of the proposed accelerator operating scenario. The actual radiation measurements are then used to design local radiation shielding or administrative barriers as needed.

Accelerator operation has been terminated automatically several times when the 1-mrem hourly integrated dose criterion was exceeded. In all cases, the termination was warranted; the experimenters merely configured Zone 1 as an Exclusion Zone and continued with their work.

Our watchdog timer has been effective on several occasions when large accelerator-tank sparks temporarily disrupted the RMS computer. As designed, the power to the accelerator permissive signal was terminated, and the accelerator operation was automatically suspended. In all cases, we easily reactivated the RMS by pushing the watchdog timer reset button. The computer then automatically rebooted and continued normal operation. Disruptive tank sparks are somewhat uncommon, but it is imperative that the monitoring system be designed to cope with any kind of computer failure.

In addition to providing a safe and documented radiation environment, the system has been beneficial in keeping radiation exposure as low as reasonably possible. The display of real-time radiation levels and warnings provides the accelerator operator a feedback loop for minimizing unnecessary radiation levels at slits, collimators, and other beam-line components.

All MTL operators, experimenters, and maintenance personnel wear thermoluminescent dosimeters. No MTL worker has ever been found to have a radiation dose measured above natural background level throughout the operating history of the accelerator. However, two employees did receive a dose of approximately 10 mrem while refurbishing an accelerator magnet. They received this dose from magnet components that had been activated when the accelerator was operated as a cyclotron by previous owners.

Summary

The RMS has proved to be a reliable system for real-time monitoring of the MTL radiation environment and maintaining personnel exposure as low as reasonably achievable. The RMS has demonstrated that a computer-based system can be used safely for monitoring the radiation environment and terminating accelerator operation if predetermined radiation levels are exceeded. Key to the reliability of the system is a watch-dog timer to detect CPU failure and independent hard-wired radiation monitors. A fault-tree analysis of the system has been performed, and the overall probability of the MTL accidentally exceeding the Laboratory guideline radiation levels has been estimated to be less than 10^{-9} per year. This probability value is well below the current goal of 10^{-6}.

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References

[1] J. C. Davis, I. D. Proctor, J. R. Southon, M. W. Caffee, D. W. Heikkinen, M. L. Roberts, T. L. Moore, K. W. Turteltaub, D. E. Nelson, D. H. Loyd, and J. S. Vogel, "LLNL/UC AMS Facility and Research Program," *Nuclear Instruments and Methods in Physics Research* **B52,** 269–272 (1990).

[2] J. R. Southon, M. W. Caffee, J. C. Davis, T. L. Moore, I. D. Proctor, B. Schumacher, and J. S. Vogel, "The New LLNL AMS Spectrometer," *Nuclear Instruments and Methods in Physics Research* **B52,** 301–305 (1990).

[3] Photon detectors are all calibrated with a ^{137}Cs source, and the assumption is made that 1 roentgen = 1 rad = 1 rem. The neutron detectors are calibrated using a ^{252}Cf-calibrated remmeter.

Table 1. Ion beams used at the MTL by the Accelerator Mass Spectrometry (AMS) Group and the Ion Micro Analysis Group (IMAG).

AMS	IMAG
Be	P
C	Li
Al	C
Cl	O
Ca	
Ni	
Se	
I	

Note: for non-molecular ions, $E_T = V_T (g+1)$
where g = charge state after stripping

Table 2. Radiation zone classification scheme.

Measured radiation level in:	Classification			
	Zone 1	Zone 2	Zone 3	Zone 4
Zone 1 or Zone 2				
Maximum hourly radiation dose equivalent does not exceed 1 mrem *and* maximum dose equivalent rate does not exceed 100 mrem/h	Controlled	Controlled	Controlled	Uncontrolled
Zone 2 or Zone 3				
Maximum hourly radiation dose equivalent does not exceed 1 mrem *and* maximum dose equivalent rate does not exceed 100 mrem/h	Exclusion	Controlled	Controlled	Uncontrolled

Definitions of Zones:

Exclusion	Any area accessible to personnel, in which there exists radiation at such levels that personnel could receive in any one hour a dose equivalent in excess of 1 mrem.
Controlled	A defined area in which the exposure of personnel to radiation or to radioactive material is under the supervision of a qualified operator. The maximum hourly dose equivalent to personnel will not exceed 1 mrem and the maximum dose equivalent rate will not exceed 100 mrem/h. Individual doses will be monitored to keep them below 500 mrem/yr.
Uncontrolled	Any area not meeting the definition of a controlled area. The maximum hourly dose equivalent to personnel will not exceed 0.25 mrem.

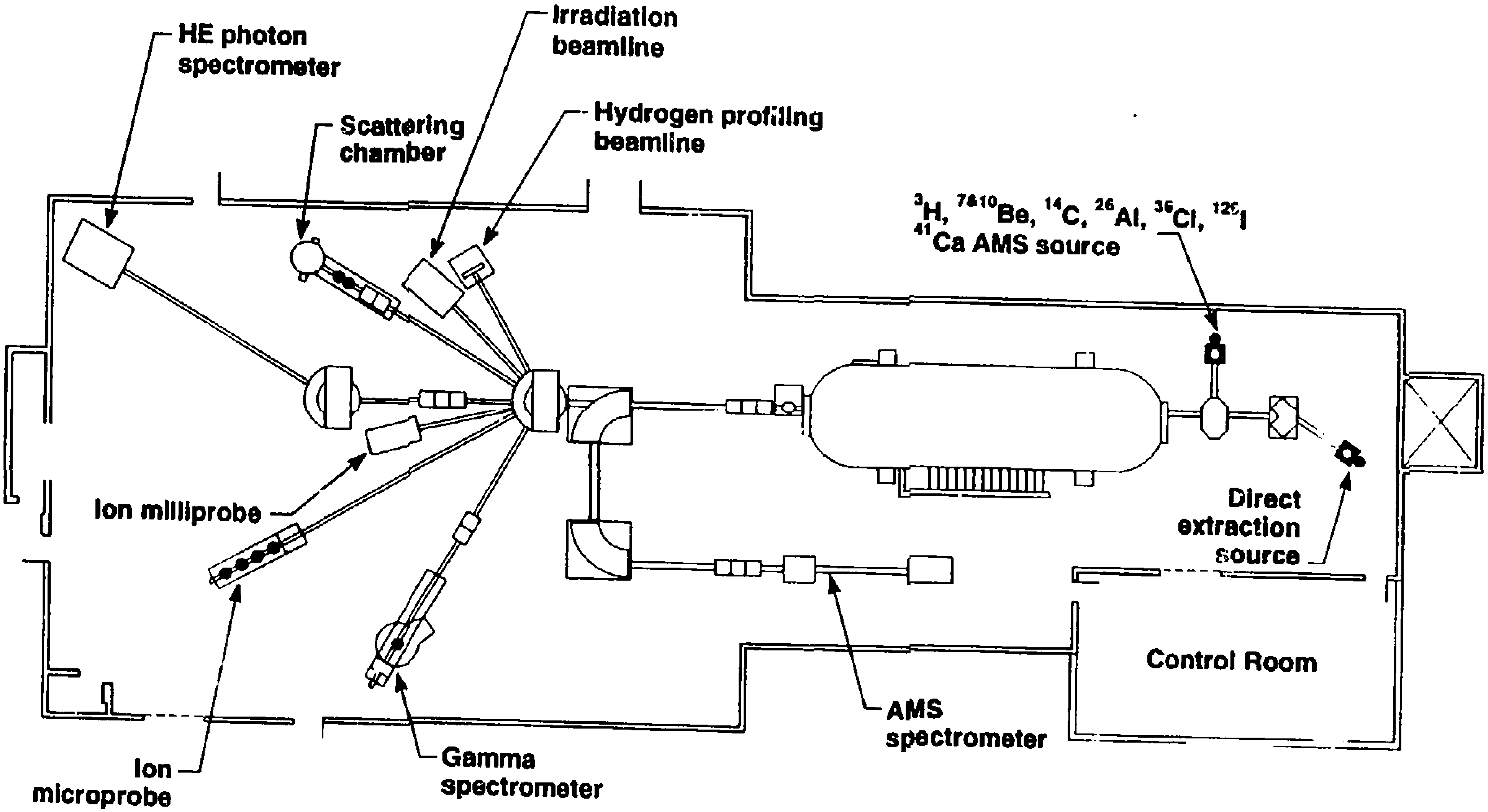

Figure 1. Overview of the MTL facility. The building is prefabricated steel construction with a 3-meter-wide service basement running full length under the central beamline. For scale, the experimental hall is 25 m long and 18 m wide.

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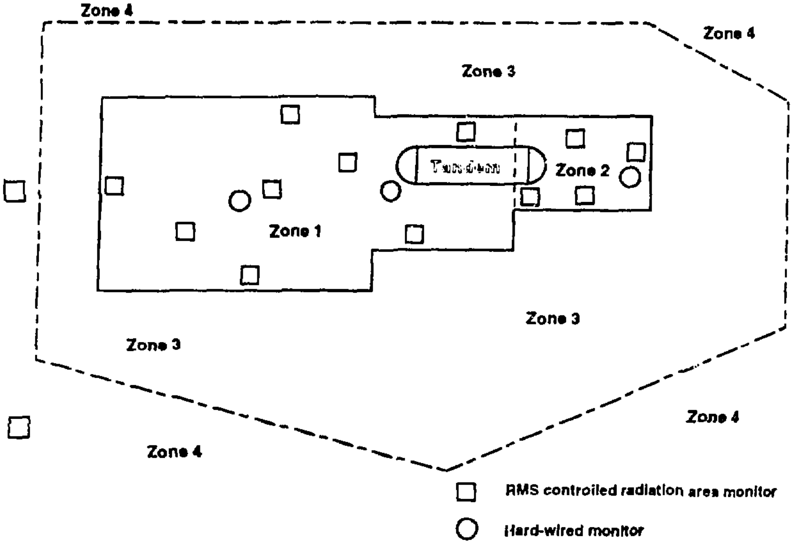


Figure 2. Radiation monitoring and control zones for the MTL facility.

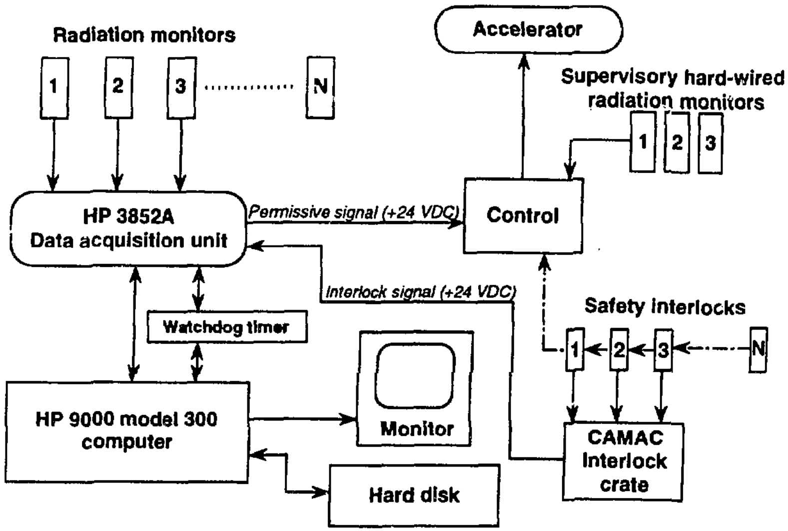
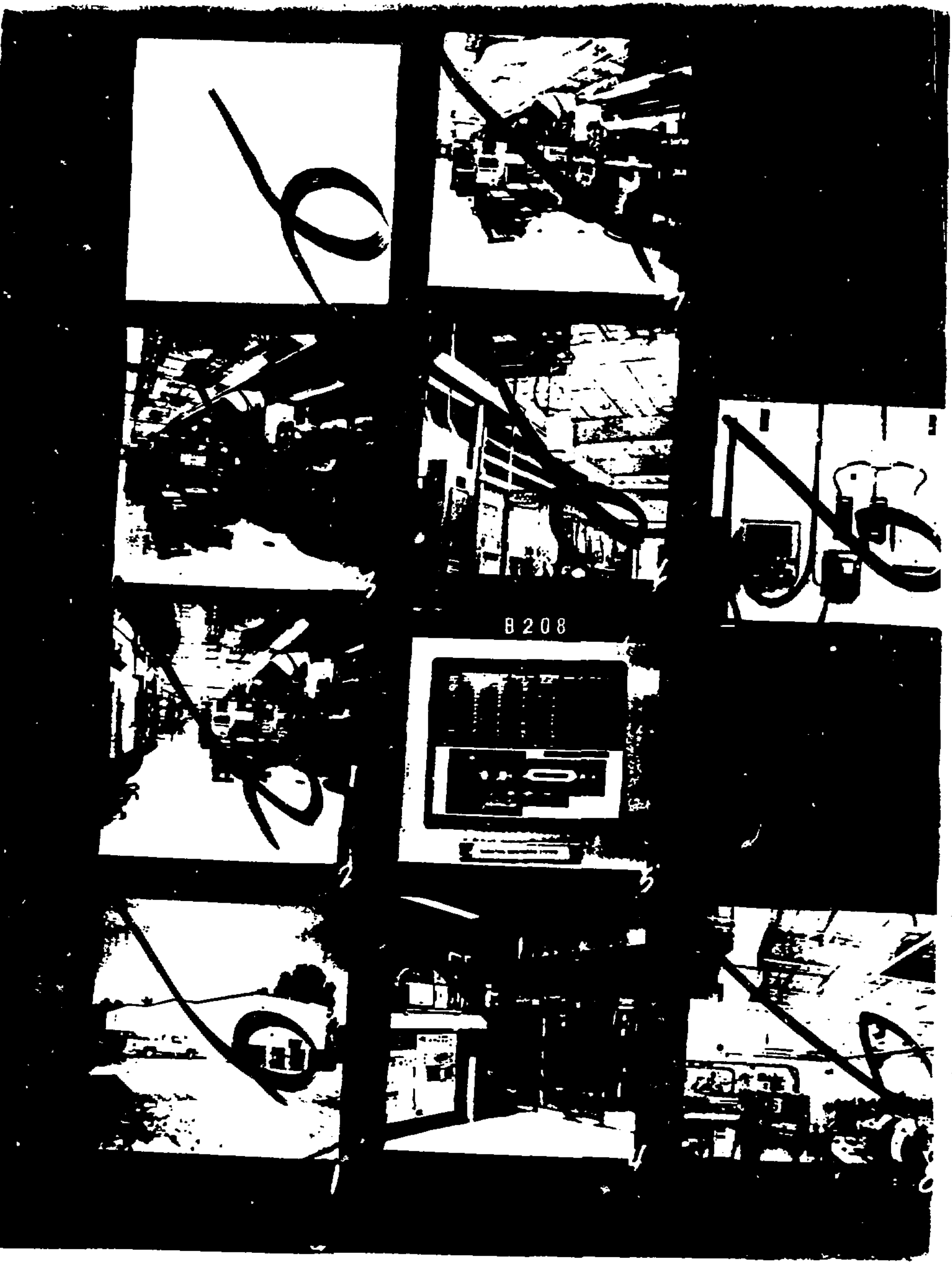


Figure 3. Radiation Monitoring System Hardware configuration.

Figure 4. Photograph showing the Radiation Monitoring System main display monitor.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