

THE SLAC PULSED X-RAY FACILITY*

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ABSTRACT

The Stanford Linear Accelerator Center (SLAC) operates a high energy (up to 33 GeV) linear accelerator delivering pulses up to a few microseconds wide. The pulsed nature of the electron beam creates problems in the detection and measurement of radiation both from the accelerator beam and the klystrons that provide the RF power for the accelerator. Hence, a pulsed x-ray facility has been built at SLAC mainly for the purpose of testing the response of different radiation detection instruments to pulsed radiation fields.

The x-ray tube consists of an electron gun with a control grid. This provides a stream of pulsed electrons that can be accelerated towards a confined target-window. The window is made up of aluminium 0.051 cm (20 mils) thick, plated on the vacuum side with a layer of gold 0.0006 cm (1/4 mil) thick. The frequency of electron pulses can be varied by an internal pulser from 60 to 360 pulses per second with pulse widths of 360 ns to 5 μ s. The pulse amplitude can be varied over a wide range of currents. An external pulser can be used to obtain other frequencies or special pulse shapes. The voltage across the gun can be varied from 0 to 100 kV. The maximum absorbed dose rate obtained at 6.35 cm below the target window as measured by a PTW ionization chamber is 258 Gy/h. The major part of the x-ray tube is enclosed in a large walk-in-cabinet made of 1.9 cm (3/4 in) plywood and lined with 0.32 cm (1/8 in) lead to make a very versatile facility.

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INTRODUCTION

The Stanford Linear Accelerator Center (SLAC) operates a high energy linear accelerator (energies up to 33 GeV) which is being upgraded to 47 GeV. The accelerator is capable of delivering electron pulses up to a few micro-seconds long. The fraction of operating time during which the beam is produced by the accelerator is called the duty factor (DF). The duty factor is the product of the pulse repetition rate (p in Hz) and the pulse length T_w (in seconds)

$$DF = p \cdot T_w$$

For example, the accelerator when operated at 22 GeV can produce a pulse of width $2.5 \mu s$ (microseconds) at a repetition rate of 360 Hz. This would result in a duty factor of 0.09%. Since the "prompt" radiation field (except thermal neutrons) outside the accelerator shielding is closely correlated with the time structure of the beam this small duty factor can impose severe limitations on radiation detection instruments. Instruments which have long dead times such as Geiger-Mueller and proportional counters tend to get saturated in such radiation fields (IAEA79). Ionization chambers are less influenced, and should be operated with adequate voltage to overcome recombination losses or else be calibrated in the pulsed field in which it is to be used (Pa73). Scintillation survey meters become non-linear at high dose rates for pulsed radiation, because the photomultiplier tube becomes overloaded during the short pulse duration. Thus the high energy and pulsed nature of the electron beam at SLAC creates problems in the detection and measurement of radiation both from the accelerator beam, and from the x-rays from the klystrons that provide the RF power for the accelerator. This and other problems unique to accelerator environments make most commercial instruments unsuitable for use at SLAC. Hence, SLAC has always designed and built its survey meters in-house.

A pulsed x-ray facility has therefore been built at SLAC mainly for the purpose of testing the response of different radiation detection instruments to

pulsed fields.

DESCRIPTION

Figure 1 shows a partially cut-away view of the SLAC pulsed x-ray facility. Figure 2 shows a block diagram of the pulsed x-ray electronics. Most of the x-ray tube is enclosed in a large walk in cabinet (1.2 m \times 1.2 m \times 2.2 m) made of plywood of thickness 1.9 cm (3/4 in) and lined with lead of thickness 0.32 cm (1/8 in), thus adequate shielding is provided.

The major part of the x-ray tube is the electron gun which provides a stream of pulsed electrons that can be accelerated to a target-window located directly below it. The window is composed of aluminum 0.051 cm (20 mils) thick, plated on the vacuum side with gold of thickness 6.4×10^{-4} cm (1/4 mil). This window is thick enough to stop all electrons that can be generated.

Part of the gun sits on top of the cabinet, and the rest of it including the target is enclosed within the cabinet. The gun consists of a cathode heated by a filament carrying a current of 1.5 A (amperes) and a control grid. The cathode is connected to a high voltage supply which can be adjusted to provide voltage from 0 to -100 kilovolts (kV). The control grid has an adjusted bias which is set to about 60 volts negative with respect to the cathode. The anode, i.e., the target-window, is at ground. Under these conditions the grid keeps the x-ray tube current to a minimum. In order to produce x-rays a negative pulse of increasing amplitude is applied to the cathode. As this pulse overcomes the grid bias, current flows to the anode. These electrons are stopped in the target-window. They produce a continuous x-ray (bremsstrahlung) spectrum with the maximum energy determined by the cathode high voltage.

A Varian 8 l/s sputter ion pump* operated at 5 kV maintains the vacuum in the x-ray tube. Since the cathode is pulsed, the control circuitry for the electron

* Varian Associates, 611 Hansen Way, Palo Alto, CA 94303.

gun must also be at high voltage. Signals from the controller are sent to the control circuitry via fiber optics cables to allow the controller to be at ground potential. The gun control circuitry consists of a pulser, a bias supply, a filament regulator and a bias monitor. The pulser translates the fiber optics signal to a cathode pulse. The bias supply provides the grid bias. The filament regulator and bias monitor are self explanatory. The entire electron gun control circuitry is packaged in a high voltage card cage. It is powered by a power supply also held at high voltage and fed by ac power through an isolation transformer. This circuitry is protected by a plywood box for safety purposes.

The output portion of the high voltage supply – a Spellman Model RHR-200N200[†] is also located in this wooden box. This is a 200 kV supply but it has been circuit limited to a voltage slightly above 100 kV. It is feedback regulated to provide a load regulation of 0.01% and stability of 0.02% per hour. Figure 3 shows the control panel for the pulsed x-ray facility.

The high voltage and gun controller (HVGC) provides power to both the isolation transformer and the high voltage power supply. It utilizes the feedback signal from the HV supply to display the high voltage on the x-ray tube digitally, and the x-ray tube current on an analog meter. It is also possible to set the pulse parameters and high voltage level from this unit. The power to the high voltage power supply (HVPS) is interlocked to the doors of the cabinet. The cabinet has three pairs of doors which can only be closed in sequence starting from the top. The gun will not operate if any of the doors are open. A lead lined sheet with an opening can be installed instead of one door and still maintain the integrity of the interlock chain. The opening permits the operator to test radiation detection instruments with remote read out systems.

Light emitting diodes (LED's) of various colors indicate the status of the doors and the high voltage. The functions of the various LED's are described below.

[†] Spellman, High-Voltage Electronics Corp., 1930 Adee Ave., Bronx, N. Y. 10469.

TOP OPEN. This means that any or all of the two pairs of top doors are open.

BOTTOM CLOSED. This shows that the bottom doors are closed thereby indicating that all doors are closed.

STATUS READY. This indicates that the system is ready for operation.

STATUS ON. This means that the HV is on. The HV can be controlled by the "HV ON" or "HV OFF" switches.

The function of the various dials are listed below.

HV LEVEL. This sets the amount of voltage to be sent to the cathode, and can be varied from 0 to 100 kilovolts (kV).

RATE. This controls the rate at which the x-rays are being pulsed. The rate selector has three settings. The variable setting offers a range of rates from 36 to 360 Hz. The 120 pps line provides a pulse that is synchronized with the incoming ac signal. The external trigger (EXT TRIG) setting can be used when one desires to use a range of rates provided by an external pulse generator. A pulse generator can be connected to the output marked "EXT TRIG".

DELAY. This will hold the pulse (that eventually pulses the cathode) from 200 nanoseconds (ns) to 2 microseconds (μ s) before sending it to the gun. This delay makes it possible to trigger equipment to synchronize with the gun pulse instead of the generated pulse. The "SCOPE TRIG" output can be used to trigger the oscilloscope. The "Beam Pulse Monitor" is a monitor point for the pulse going into the HV card cage.

WIDTH. This controls the width of the pulse measured in time, and can be varied from 360 ns to 5 μ s.

HEIGHT. This varies the voltage that is sent to the bias supply in the HV card cage. The bias voltage can be varied from 50 to 250 volts.

OUTPUT CURRENT. This measures the current produced by the HV stack going to the gun. This is monitored by an ammeter that has three range settings, 1000 μ A, 100 μ A and 10 μ A.

OUTPUT VOLTAGE. A digital voltmeter monitors the voltage sent to the HV.

DECK AC. This turns on the isolation transformer. The two LED's labelled "ON" and "OFF" indicate the corresponding status of the deck ac power.

FIL AND BIAS SETTINGS. The filament setting (FIL) sends information to the fiber optic cards in the card cage regarding the filament voltage. The bias (BIAS) setting sends information to the cards regarding the bias voltage.

ABSORBED DOSE RATE MEASUREMENTS

A PTW* precision ionization chamber (Farmer type) is mounted below the x-ray tube at a distance of 6.35 cm from the window. The ionization chamber is at a radial displacement of 2.5 cm from the center of the window. This facilitates remote read out of the radiation levels inside the cabinet. The PTW ionization chamber was checked for saturation and all the data was taken at saturation. Experimental data indicated that the output of this chamber was proportional to that of the Radcal Corporation ion chamber,[†] Model 20 \times 5-180 (used with a 2025 AC radiation monitor) on the axis of the x-ray tube at distances greater than 6.35 cm from the window. This proportionality was also observed at all x-ray energies. Thus the PTW ionization chamber can be used to monitor any drift in the x-ray tube output, and to reproduce dose rates wherever the machine is turned on and off repeatedly. It is not however used for the determination of dose rates at other points inside the cabinet.

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† Radcal Corporation, 426 West Duarte Road, Monrovia, CA 91016.

Measurements taken with a Radcal Corporation ion chamber, Model 20 × 5-180 (used with a 2025 AC radiation monitor) indicate that the pulsed x-rays follow an inverse square law rather closely within the cabinet, as seen in Figure 4.

Dose rate measurements were made with lithium fluoride thermoluminescent dosimeters (TLD) in the form of discs at 21 points distributed within the area of a circle of diameter 50 cm on the floor of the cabinet. The measured dose rate was found to be constant with a standard deviation of 10%. No particular pattern of distribution was evident in the low and high readings of the TLD's. The particular batch of TLD's that was used never showed a standard deviation of less than 6%. Thus the dose rate is believed to be uniform over this area. At these energies there is not much variation of x-ray intensity with angle. Hence it has been our intention to make dose rate measurements only within this area. However measurements were made out to the walls of the cabinet with the Radcal ionization chamber. Since the chamber is about 12 cm in diameter it was possible to make dose rate measurements out to a distance of 52 cm from the x-ray tube axis to the center of the chamber. The dose rate at 52 cm decreased by about 11% from that at the center for a pulse of width 2 μ s and frequency 120 Hz at 70 kV. However it must be pointed out that about 7% of this change can be attributed to the inverse square law effect.

Figure 5 shows the variation of absorbed dose rate (at a distance of 6.35 cm below the target window) with high voltage, as measured by the PTW ionization chamber, for a pulse of width 2 μ s, repetition rate of 360 Hz, and a cathode bias (i.e., pulse height) of 110 volts. The relationship between dose rate and high voltage as seen in the figure is different from that obtained with constant potential conventional x-ray machines, for example, Figures 1 and 2 in ICRP 33 (ICRP82). The reason for this is twofold. In conventional x-ray machines reflection targets are used whereas in this case a transmission target has been used. As the energy of the x-rays is increased the angular distribution of the x-rays becomes more peaked in the forward direction. In addition, the attenuation of the transmission target decreases as the high voltage increases. Both these

effects produce a greater dose rate increase with high voltage than shown in the reference above.

For a given high voltage the maximum dose rate obtained depends upon the pulse width, pulse repetition rate and the pulse height. The measurements taken indicate that the dose rate varies linearly with pulse widths ranging from 1 μ s to 5 μ s. The dose rate is also linearly dependent upon the pulse repetition rates between 60 Hz and 360 Hz.

Table 1 shows the maximum dose rates obtained at different energies for a pulse of given width, height and repetition rate. The maximum dose rate obtained is limited by breakdown of the vacuum. The maximum dose rate at 6.35 cm. below the target window as measured by the PTW ionization chamber is 258 gray/hour (Gy/h). Under these operating conditions the radiation field to which the operator is exposed does not exceed 10 μ Gy/h (1 mrad/h). The reproducibility of the x-ray tube is excellent, dose rates being easily reproduced within 1%.

CONCLUSIONS

The pulsed x-ray facility has been very useful in testing the response of different radiation detection instruments, both commercial as well as those built at SLAC, to pulsed radiation fields. The facility has proved to be very versatile offering pulsed dose rates as high as 258 Gy/h (at a distance of 6.35 cm from the target), pulse widths varying from 360 ns to 5 μ s and pulse repetition rates varying from 60 Hz to 360 Hz.

ACKNOWLEDGMENTS

The authors would like to thank Ron Koontz of SLAC and his associates for designing and building the pulsed x-ray facility.

REFERENCES

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- Pa73 Patterson H. W. and Thomas R. H., 1973, "Accelerator Health Physics," (New York: Academic Press).
- ICRP82 International Commission on Radiological Protection, 1982, "Protection Against Ionizing Radiation from External Sources Used in Medicine," *ICRP Publication 33* (Oxford: Pergamon Press).

TABLE 1

Voltage (kV)	Dose Rate (Gy/h)
100	258
90	225
80	192
70	175
60	125
50	72.9
40	25.8
30	6.46
20	3.90

TABLE CAPTION

Table 1. Maximum dose rates obtained on axis at different high voltages at a distance of 6.35 cm from the target for a pulse of width $2 \mu\text{s}$ and frequency 360 Hz.

FIGURE CAPTIONS

Figure 1. A partially cut-away view of the SLAC pulsed x-ray facility.

Figure 2. Block diagram of the pulsed x-ray electronics.

Figure 3. Control panel for the pulsed x-ray facility.

Figure 4. Absorbed dose rates measured on axis as a function of distance from the x-ray target for a pulse of width $1 \mu\text{s}$ and frequency of 360 Hz at 80 kV.

Figure 5. Absorbed dose rates measured on axis as a function of high voltage for a pulse of width $2 \mu\text{s}$ and frequency 360 Hz.

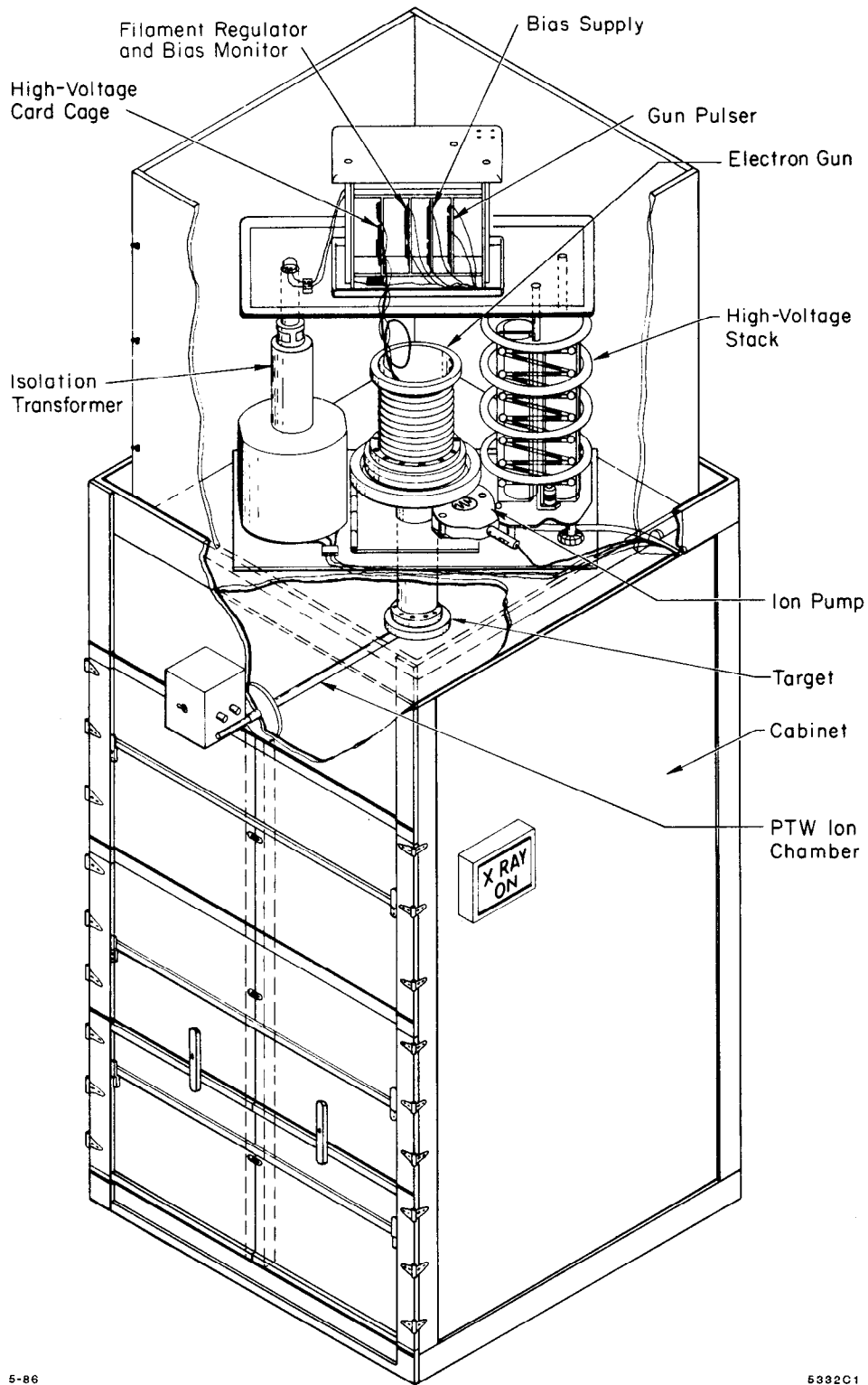
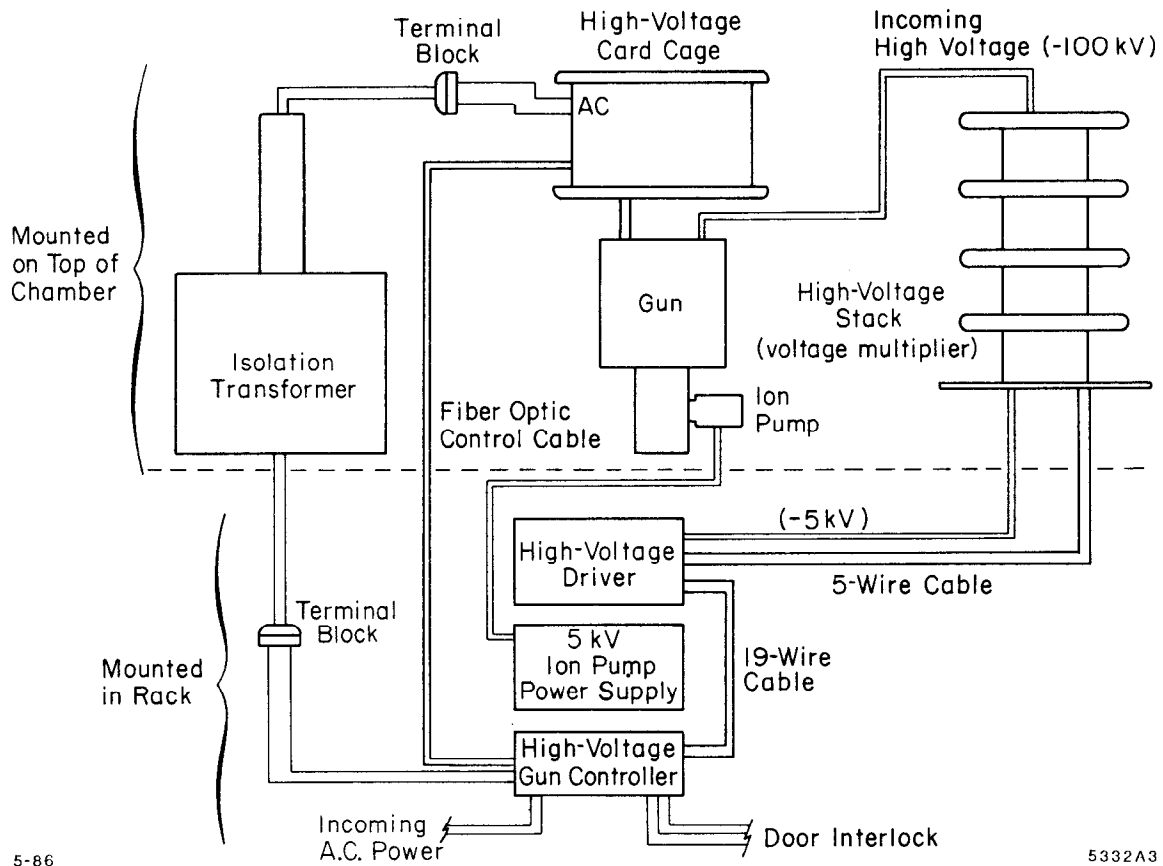


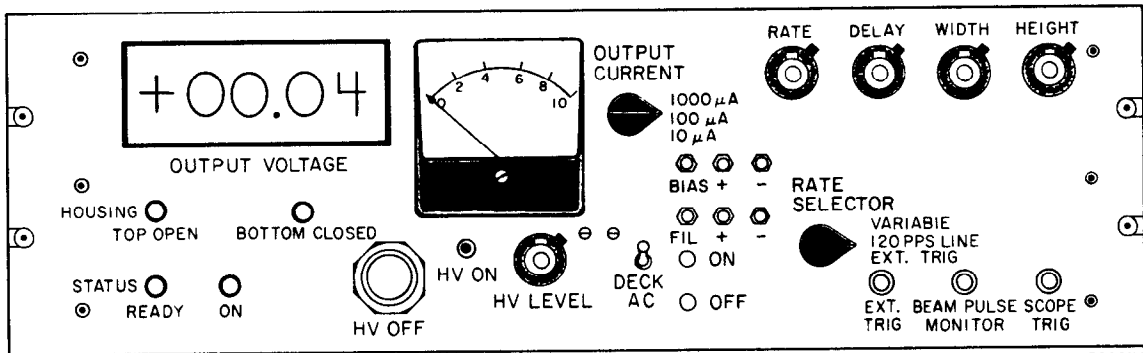
Fig. 1



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5332A3

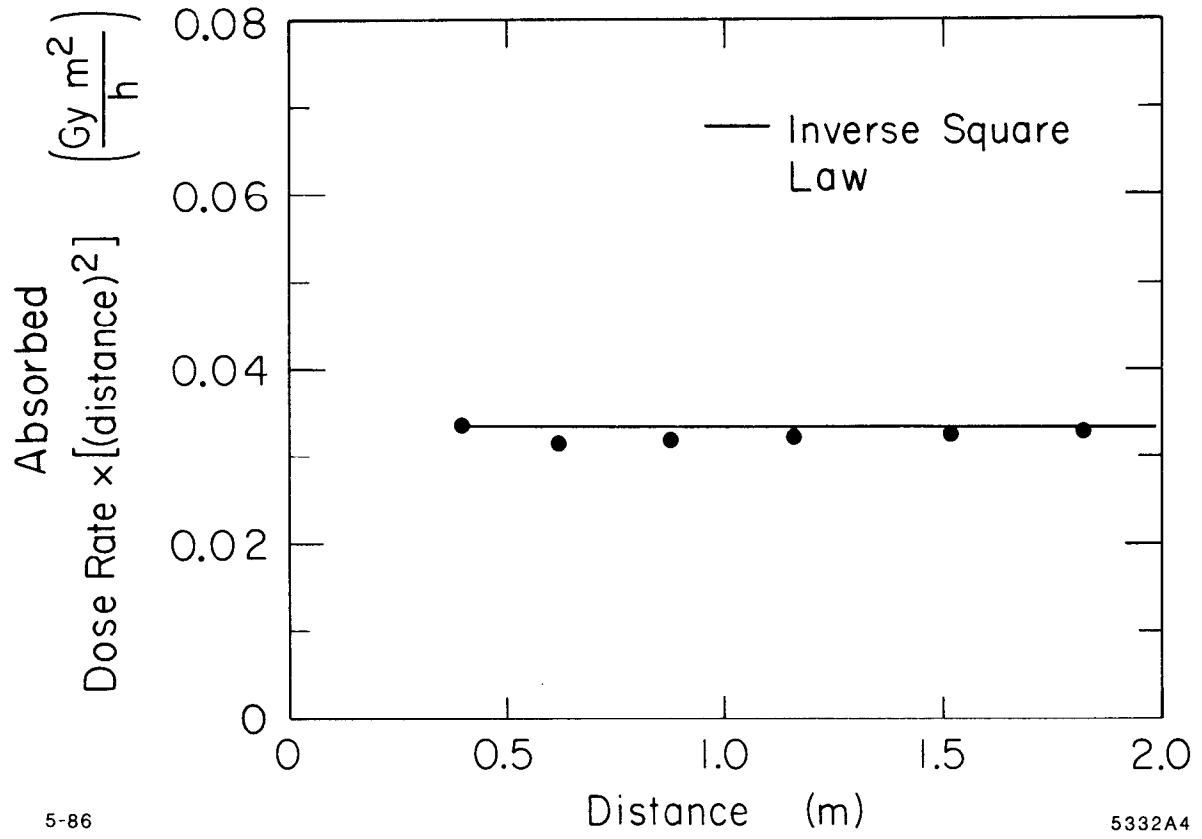
Fig. 2



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5332H2

Fig. 3



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5332A4

Fig. 4

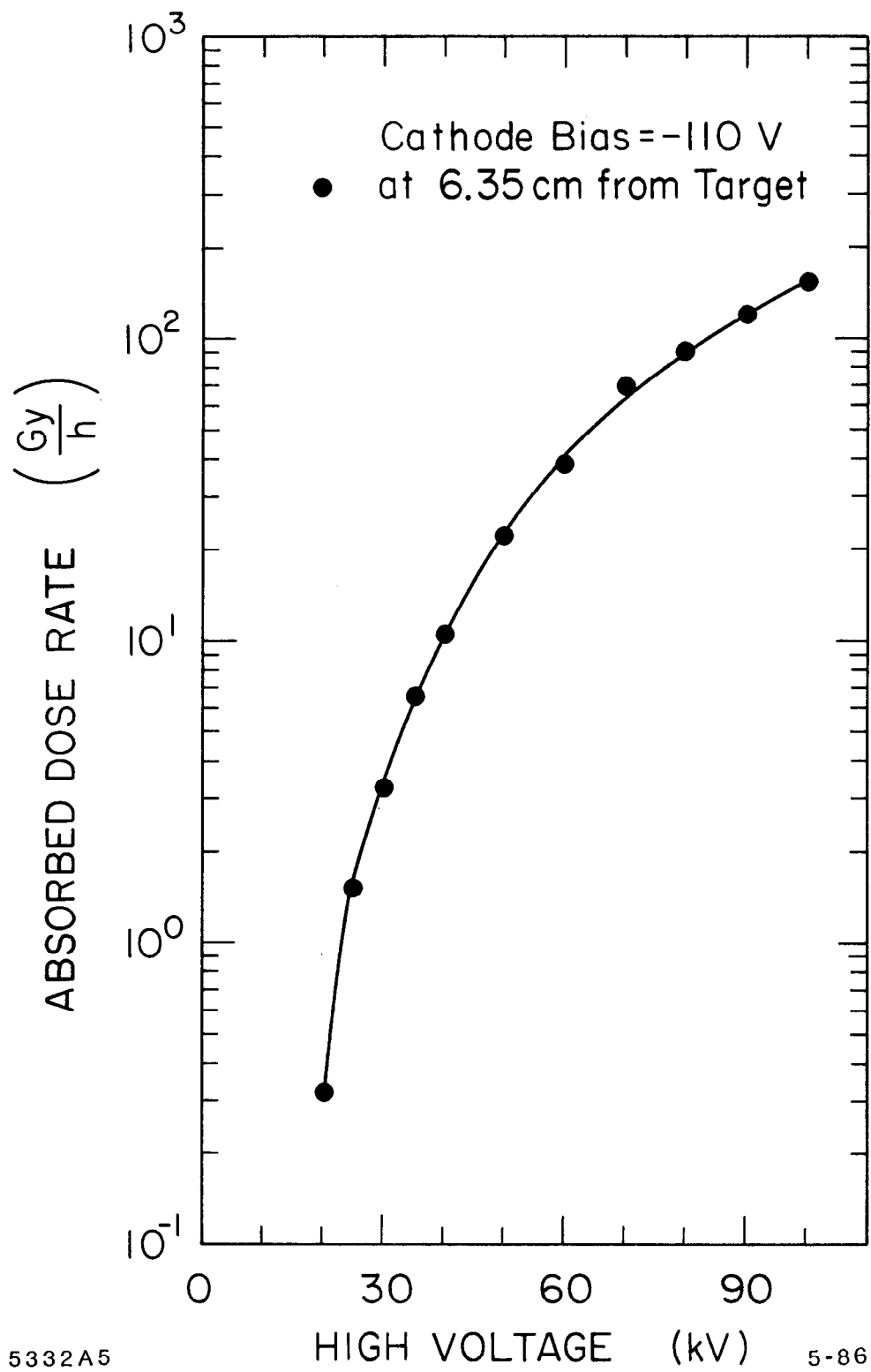


Fig. 5