RPN 110

Air Force Report No.
SAMSO-TR-73-362

Aerospace Report No.
TR-0074(4124)-1

DESCRIPTION AND OPERATION OF THE MARK 1B PLASMA FOCUS RADIATION FACILITY

Prepared by

Hugo L. L. van Paassen and Robert H. Vandre
Materials Sciences Laboratory
Laboratory Operations

73 NOV 3Ø

Development Operations
THE AEROSPACE CORPORATION

Prepared for

SPACE AND MISSILE SYSTEMS ORGANIZATION
AIR FORCE SYSTEMS COMMAND
LOS ANGELES AIR FORCE STATION
Los Angeles, California

FOREWORD

This report is published by The Aerospace Corporation, El Segundo, California, under Air Force Contract No. F04701-73-C-0074.

This report, which describes the physical arrangement and operation of the Mark 1B Plasma Focus Radiation Facility, was submitted on 30 July 1973 to Capt William E. Mercer, III, DYS.

The authors gratefully acknowledge V. Josephson for his active support and consultation from the inception of this program, M. H. Dazey for his efforts during the initial design and construction of the facility, and M. J. Bernstein for his participation in the creation of the Mk 1B facility and in bringing it to its present state of operation. Finally, we acknowledge the numerous individuals whose talent and ingenuity were vital in constructing the facility, in particular J. L. Snyder.

Approved

W. C. Riley, Director
Materials Sciences Laboratory
Laboratory Operations

V. Josephson, Associate Group Director
Development and Survivability Directorate
Technology Division
Development Operations

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

William E. Mercer, III, Capt, USAF
DYS Project Officer

ABSTRACT

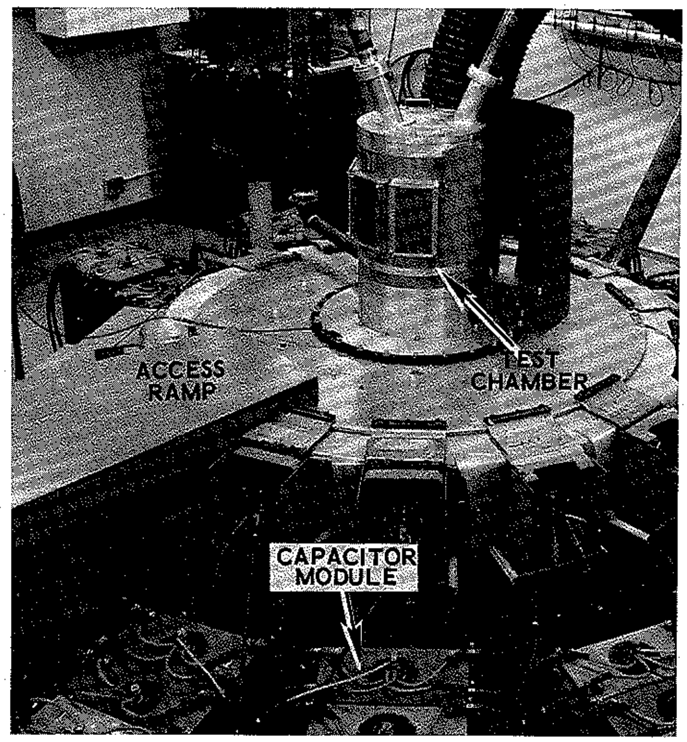
The 140 kJ plasma focus facility (Mk 1B) at The Aerospace Corporation produces x-ray fluences that are applicable to most radiation testing problems (e.g., integrated circuits or transistors). Although the facility has only one beryllium window for exposing 1.6-cm-dia samples to doses of 25 to 45 krad (Si) per shot, three more windows could be added and the additional samples exposed simultaneously. The facility is experiencing switch problems and is presently averaging 50 shots per week--15 shots per day for 3 or 4 days. The results of a comprehensive switch analysis should provide solutions that will significantly improve this repetition rate.

CONTENTS

FIGURES

I. INTRODUCTION

The Mk 1B high-energy (140kJ) plasma focus device (PFD) is the largest of several dense plasma focus apparatuses that have been designed and operated by The Aerospace Corporation. This effort began at Aerospace in 1965 with the design and operation of the paraboloidal-electrode Mk 1A device (Ref. 1). When operated at 18 kV, the Mk 1A had 13 kJ of energy stored in its capacitor bank. Subsequent devices -- Mk II (17 kJ), Mk III (68 kJ), and Mk IV (34 kJ) (Refs. 2, 3, and 4, respectively) -- tested several design variations and their effects on the radiation output. Since the size of the capacitor bank determines the radiation yield, the Mk 1B, which has the largest capacitor bank, has the highest radiation of any device in this laboratory.



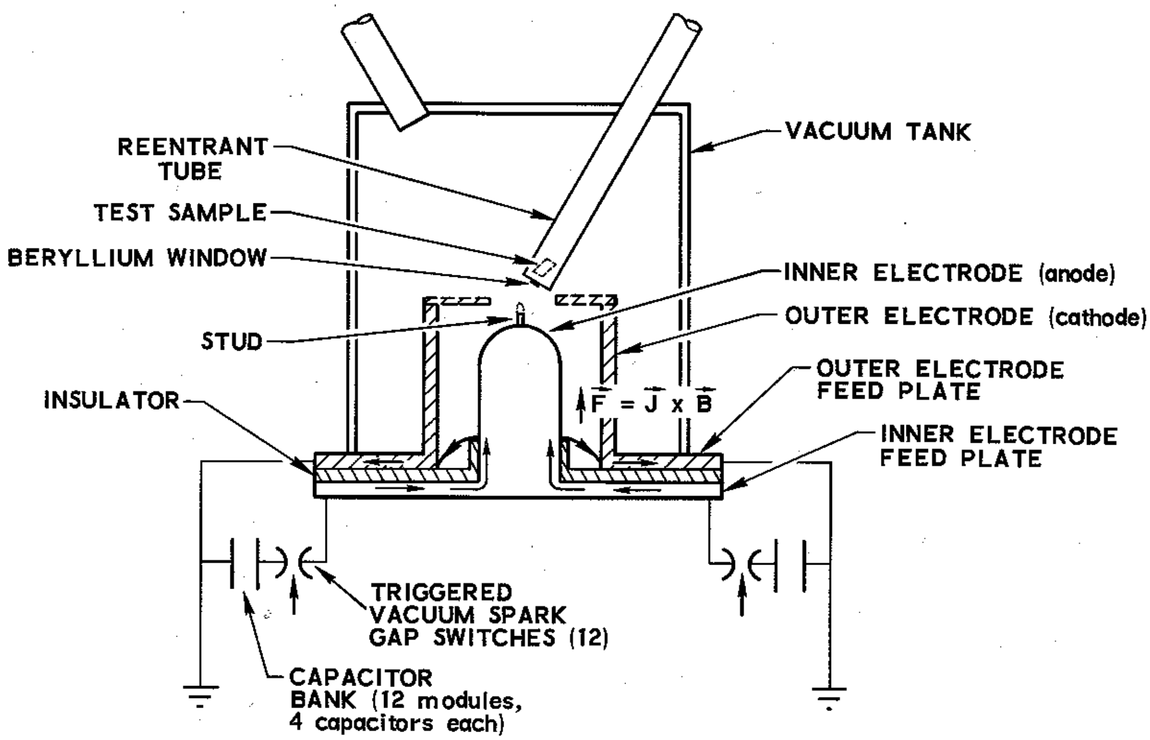


Fig. 1. Mk 1B Plasma Focus Radiation Facility

II. DESCRIPTION OF THE LABORATORY

A. PHYSICAL

A photograph of the laboratory and a schematic of the Mk 1B PFD are shown in Fig. 1. Two coaxial electrodes, a central anode (with 1.1-cm-dia tungsten or heavy metal rod), and a surrounding cylindrical cathode are separated by a Pyrex insulator in a deuterium atmosphere at a pressure of a few Torr. The device is centered inside a 16-in.-dia by 26-in.-long vacuum chamber that has two 5-cm-ID copper reentrant test pipes (Fig. 2) that penetrate the top surface of the chamber. The axes of these pipes, when extended, converge at the tip of the anode stud. The 1.6-cm-dia beryllium windows are mounted on axis and provide an airtight seal for the discharge chamber. The interior of the test pipes is maintained at atmospheric pressure.

The forty-eight 14 μF capacitors of the Mk 1B bank are arranged in 12 modules of four capacitors each. Each module is connected to the coaxial electrodes by a low-pressure switch and a current feed plate. The 12 low-pressure switches are fired simultaneously by a voltage from a trigger supply that is manually initiated by the operator. A switch monitor system indicates that all the switches fired within a prescribed interval or identifies any switches that misfired. The device is now being operated at 18 kV (110 kJ).

B. X-RAY MONITORS

Two time-resolved silicon x-ray detectors are used to determine the dose in rad (Si) for each shot. The time-resolved x-ray dose and the electronically integrated x-ray signal are displayed on an oscilloscope and photographed for reference. To determine if there is any unusual variance in the spectral distribution of the radiation, one detector normally has an attenuator so that, in effect, a two-point absorber measurement is made. Thermoluminescent detectors (TLD) are also used to measure x-ray dosage. Their output is combined with Ross filters to provide a time-integrated

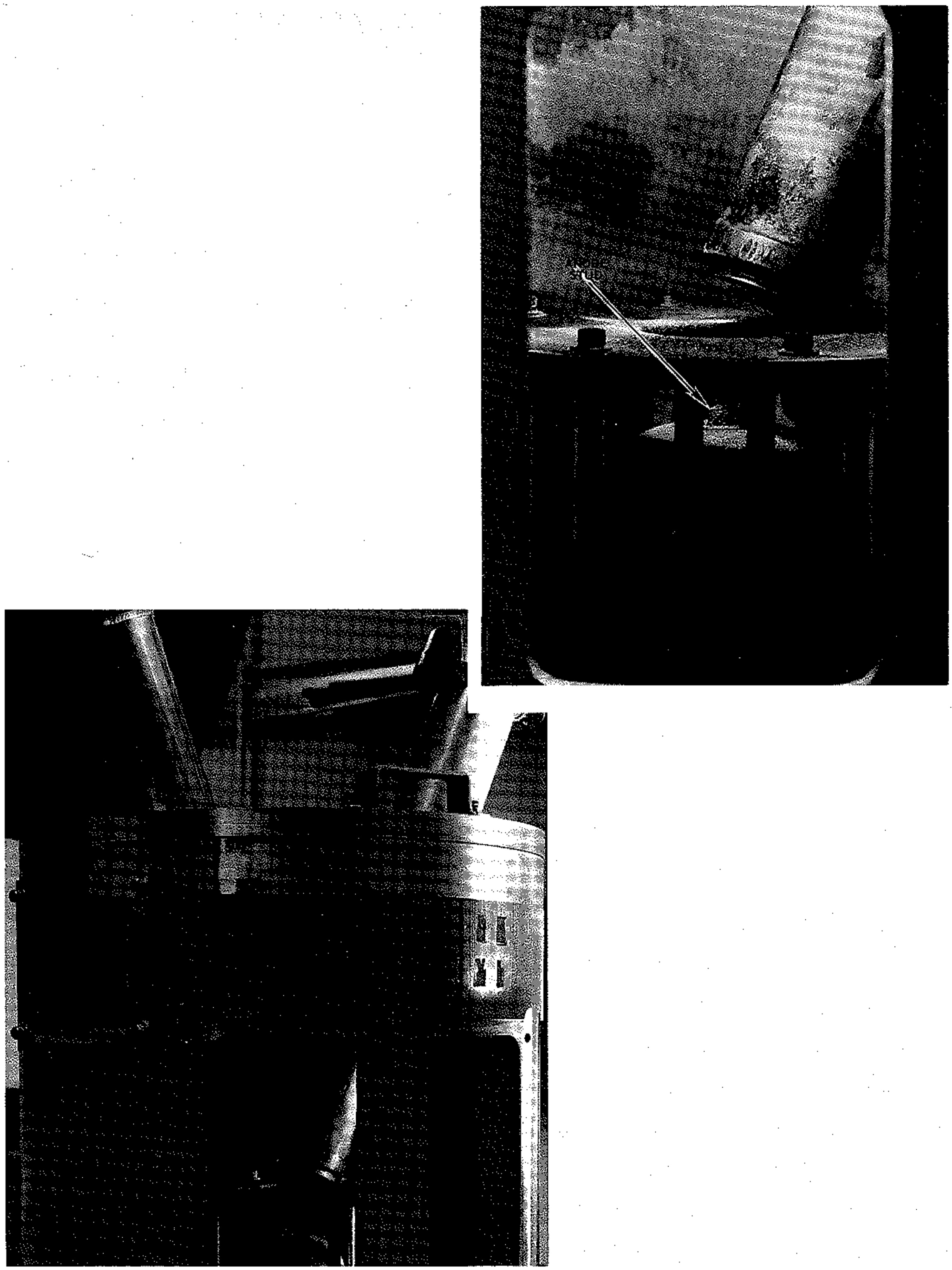


Fig. 2. Mk 1B PFD Test Chamber with Reentrant Test Pipe Detail

spectrum. The TLD diagnostic method is used to measure the spectrum only when a significant change (e.g., anode stud change or gas filling) is made in operating conditions.

C. SCREEN ROOM

A 100-sq-ft, double-walled, copper screen room (Fig. 3) is adjacent to the PFD and houses two dual-channel oscilloscopes and other monitoring equipment. There is ample room for three more oscilloscopes and additional test equipment. In addition to the cables necessary to operate and monitor the PFD from the screen room, there are 40 coaxial feed-throughs available for various diagnostic measurements.

D. ELECTRICAL NOISE

With a 1.5 MA electrical discharge changing at a rate (dI/dT) of $\sim 10^{12}$ A/sec at the time of pinch, high induced voltages could be expected in equipment in the proximity of the discharge. The radiation test area, which consists of a beryllium x-ray window mounted in the end of a copper pipe, is connected to equipment in the screen room by copper conduit leads and an electrically shielded junction box. With this technique, Aerospace has reduced the noise generated across a $50\,\Omega$ resistor in the test area and measured in the screen room to <3mV peak-to-peak. Double shielding techniques would provide a significant electrical noise reduction; however, they will not be used unless the energy output is increased.

E. PERSONNEL SAFETY

A safety barricade that is equipped with various interlocks separates the screen room and laboratory area from the PFD. The interlocks prevent the charging of the capacitor bank when the access door is open and will discharge the bank if the door is opened. The barricade is designed to minimize any possible hazard in the event that a capacitor or insulator explodes.

The large radiation dosages are produced only in those areas immediately adjacent to the beryllium x-ray windows. Because of the softness of the x-rays emitted, they are greatly attenuated by the thick walls of the

PFD vacuum tank. In addition, the safety barricade and the distance separating the radiation source from the area normally occupied by personnel operating the device combine to reduce the radiation level below the California safety requirements. All personnel who operate the facility are required to wear radiation-monitoring film badges, and the accumulated radiation dosages in various areas near the device are recorded by radiation-monitoring equipment.

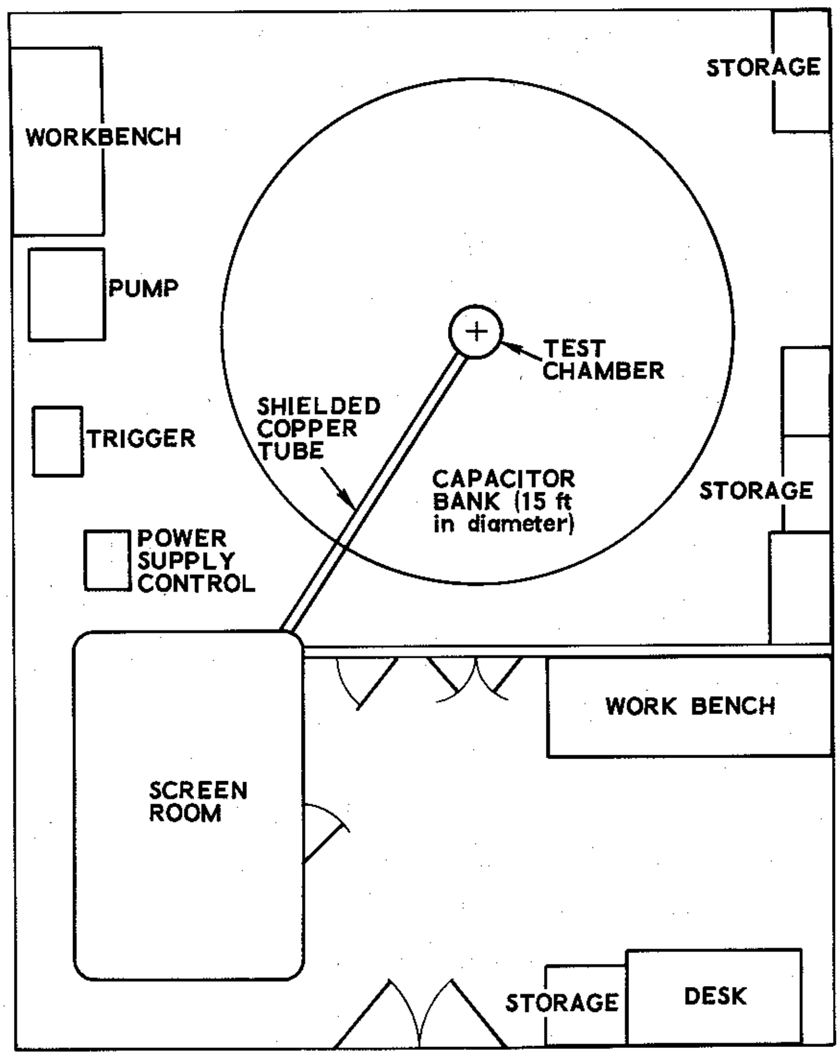


Fig. 3. Layout of Mk 1B Plasma Radiation Facility Showing Relationship of PFD Test Chamber and Screen Room

III. OPERATION

A. GENERAL

When the 12 low-pressure switches are triggered, the charged high-voltage capacitors are connected across the two coaxial electrodes. The current builds up in several microseconds to a maximum of 1.5 MA. The current sheet that is formed between the two electrodes reaches the end of the anode and collapses at the time of maximum current. At the instant of collapse there is a sudden large decrease in the current ($dI/dT \sim 10^{12}$ A/sec), and a burst of radiation is observed. This compression or "pinching" in the deuterium gas produces 2 to 4×10^{10} neutrons and a large dose of x-radiation [35 to 65 krad (Si) at 6 cm]. Heat, UV, high-velocity particulate matter (anode fragments), and a substantial shock wave are also produced around the tip of the anode. X-ray pinhole photography (Fig. 4) has permitted us to estimate that 80% of the radiation comes from a small area at the anode tip; the rest comes from a large area at the surface of the anode near the stud.

The radiation dose delivered from the 18 kV bank to a sample 6 cm from the radiation source averages 50,000 rads (Si) ±25%. At this distance, the beryllium window has a 1.6-cm-dia clear area. Samples usually are not placed against the window since the window is hot for a brief period after each shot. The x-ray flux is uniform and varies less than 5% over the area of the 1.6-cm-dia window. However, large asymmetries in the flux are observed when the anode stud becomes eroded; the ragged stud can preferentially shield one of the two windows from the x-ray flux. When the stud was worn, the highest ratio of flux intensity between the two windows was 2.8:1. X-ray pinhole photography can record stud wear without requiring that the test chamber be opened. The flux asymmetries can be corrected by replacing the worn anode stud.

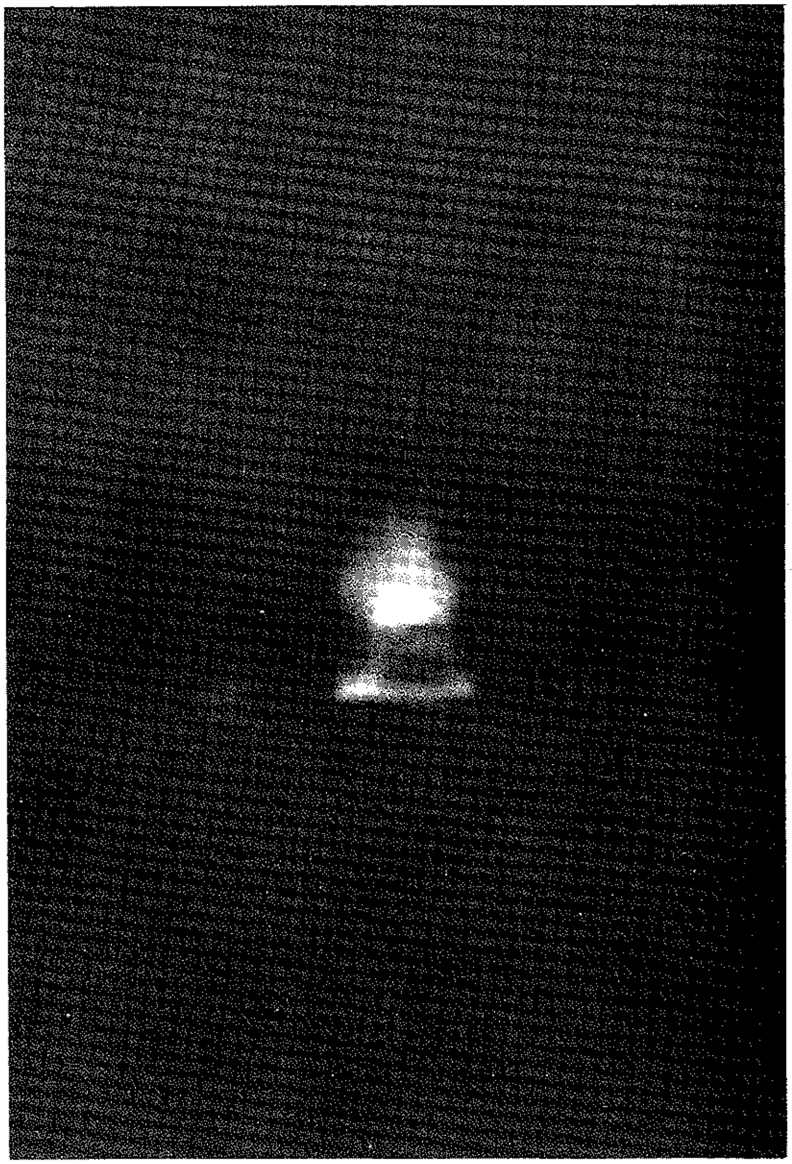


Fig. 4. X-Ray Pinhole Photograph
of X-Ray Source Area

B. DUTY CYCLE

The number of shots (typically 15 to 20) that can be made with the device in a day is limited by switch reliability. If the switches are operating properly, the normal warm-up period is less than 20 min.

About half the shots are fired at full voltage and produce from 35 to 65 krad. Since the chamber is not opened or the vacuum lost in order to adjust the samples, the various modifications in the test sample area (e.g., changing samples or detectors) do not disturb or delay operation of the device. Samples can be changed and operation resumed in an elapsed time of ~10 min.

It has been determined that the reentrant pipes can be brought to within 2.7 cm of the focus area without seriously affecting the operation of the discharge. Although the 0.37-cm-thick beryllium x-ray windows are cracked by either the first or second shot when they are positioned 4 cm from the pinch area, they will survive more than 100 shots at a distance of 5.9 cm. Window failures are detected by a slow rise in discharge chamber pressure. Inspection of the windows has shown the leaks were caused by hairline cracks across the face of the beryllium disc.

Since the Mk 1B PFD is working at high voltages (~18 kV) and currents ($>10^6$A), the switching problems are severe; therefore, switch maintenance is the major cause of operating delays. Possible solutions to these switch problems are being actively investigated, and a design change to increase reliability will be made when the analysis is complete.

C. X-RAY OUTPUT

The x-ray spectrum at the radiation test area, which is located 5.9 cm from the x-ray source, is shown in Fig. 5. Fluorescence emission from the anode and stud materials produces the significant increase of the continuum in the 7 to 9 keV range. Because of the peak at 8 keV, the spectrum (Fig. 5) will have essentially the same effect on a test sample as the radiation from a 3 keV backbody. Fluorescence lines can be added to the spectrum by changing the composition of the anode and stud material; this changes the

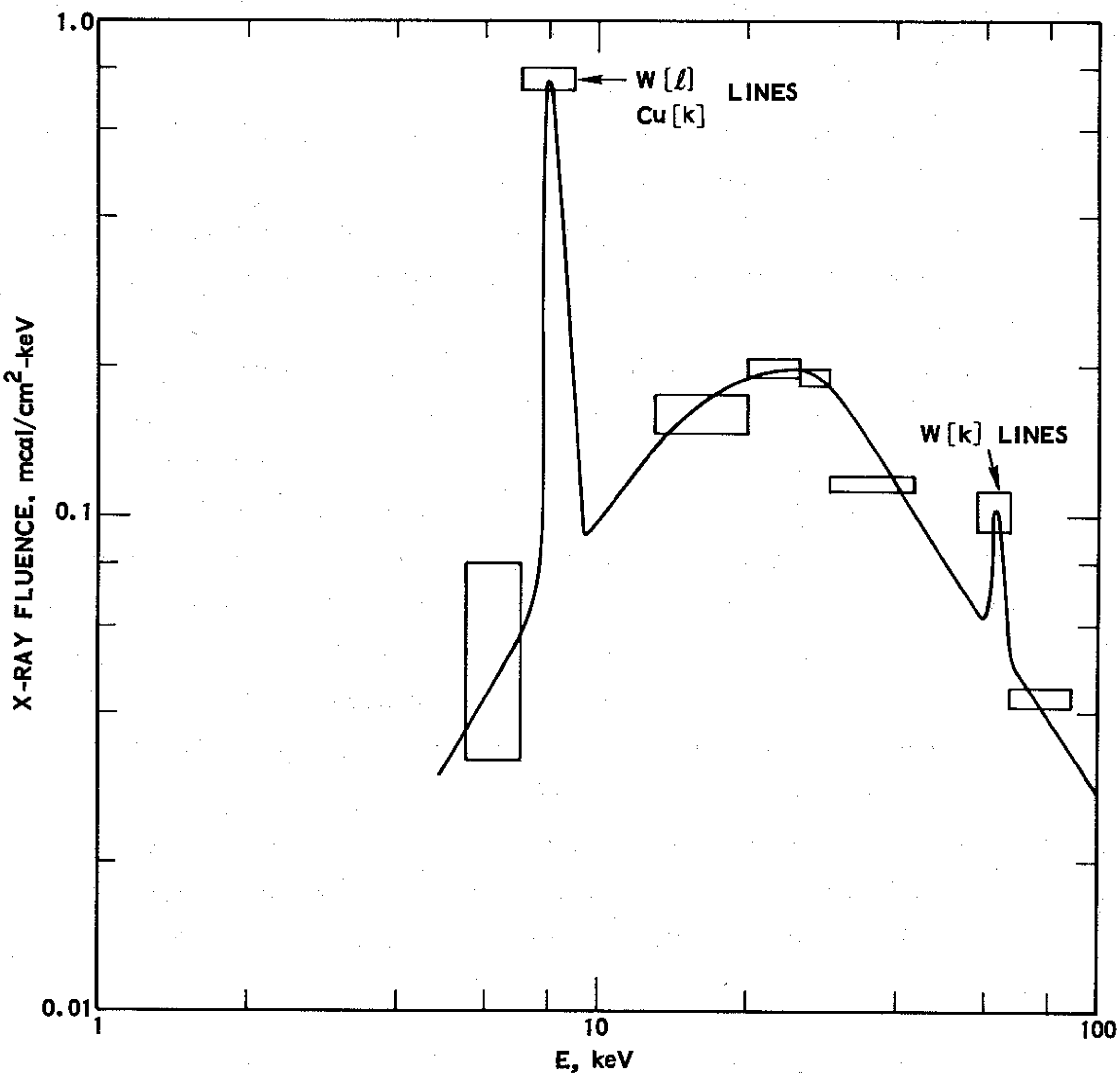


Fig. 5. X-Ray Spectrum from Mk 1B PFD -- Tungsten Anode Stud

effective hardness. Figure 6 shows the effect of a silver stud on the spectrum. This added fluorescence lines in the 20 to 25 keV range and made the spectrum similar to that of an 8 keV blackbody. The shape of the spectrum can be tailored to simulate blackbodies at temperatures from 2 to 10 keV by changing the stud and window material; this also changes the applied dose at the test area.

The maximum radiation doses in silicon [70 krad (Si)] are obtained with a spectrum shaped like the one in Fig. 5. The radiation doses for soft x-rays (i.e., those emitted by the Mk 1B) vary with test sample thickness. Table 1 shows the deposition of x-rays from the Mk 1B on thin silicon or gold samples. Because the soft x-rays are highly attenuated by the thin samples, the x-ray dose rapidly decreases with increases in sample thickness.[a] Although a flash x-ray device must be used to apply a large x-ray dose to a thick sample, there are many thin structures (e.g., integrated circuits) that may be tested with the Mk 1B. Since the Mk 1B device can deliver large doses of soft x-rays, it is well suited for integrated circuits or transistors where the radiation-sensitive portion is ~16 μ thick and the electroplated gold or aluminum paths are ~1 μ thick. The Mk 1B is especially useful for studying surface damage effects that require low fluence levels. In the Mk 1B device the average fluence in the radiation test area is 50 krad (Si) with a standard deviation of 18 krad (Si). Because of the complexity of the plasma focus formation, it is difficult to make a more accurate prediction of the yield from a shot. The fluence in the test area is modified by changing the distance from the x-ray source; the radiation from the source decreases as the inverse square of the distance.

The shape of the x-ray pulse is measured on every shot with silicon PIN photodiodes whose output is given directly in rads (Si). The average

---

[a] Dose $= \frac{\text{amount of absorbed radiation}}{\text{weight of test sample}}\left(1 \text{ rad} = \frac{100 \text{ ergs}}{1 \text{ gm}}\right)$; therefore, since almost all the soft x-rays are absorbed in the first few microns (on the surface of the sample), increases in sample mass or thickness produce a marked decrease in dosage. This effect is clearly shown in Table 1 for gold samples exposed to 7 to 9 keV.

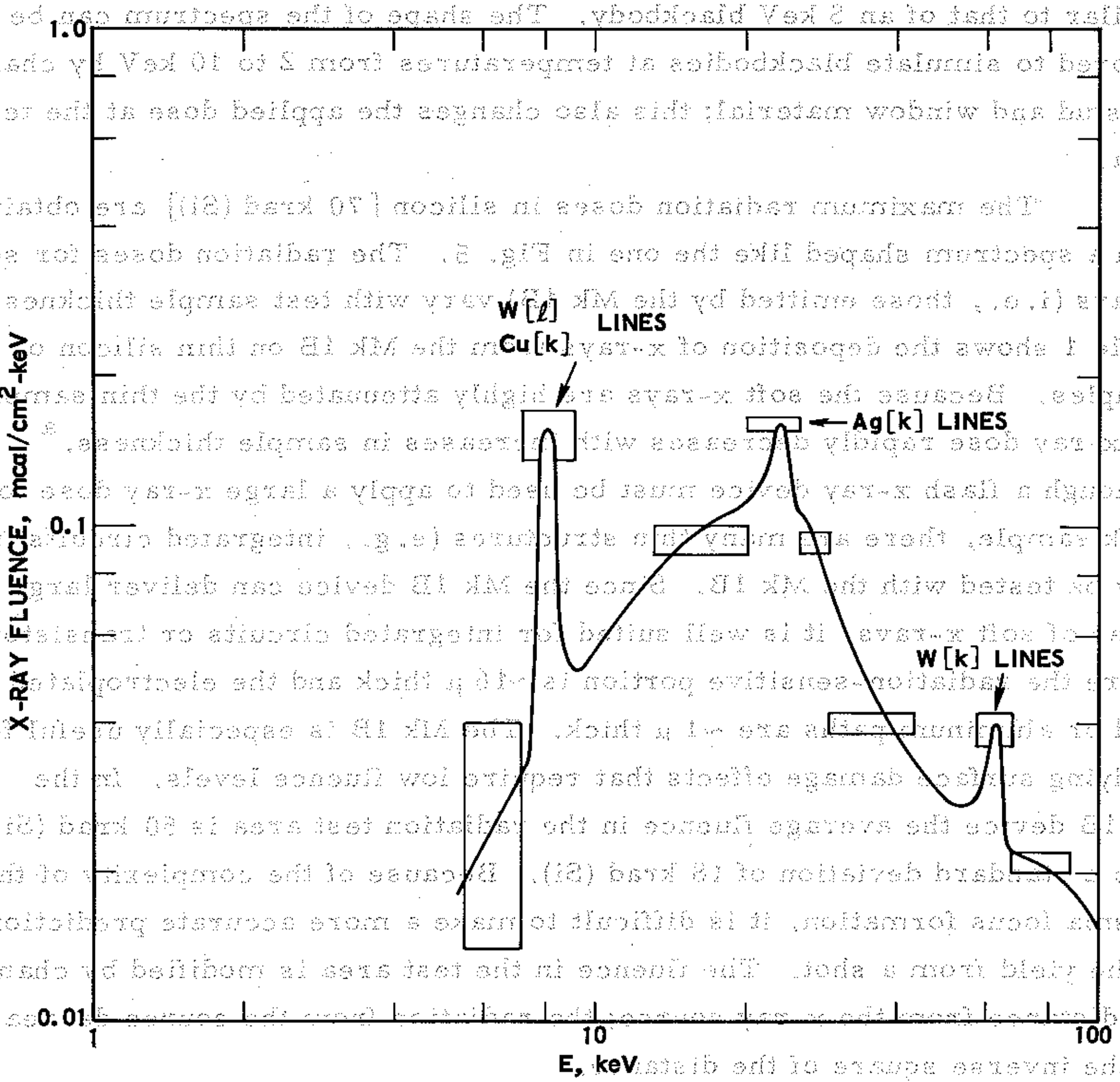


Fig. 6. X-Ray Spectrum from Mk 1B PFD -- Silver Anode Stud

Table 1. X-Ray Deposition in Thin Samples of Silicon or Gold

The x-ray fluence values were obtained from Fig. 3

E(keV)	Incident Fluence at 6 cm ($mcal/cm^2$)	Sample Thickness (μ) krad, Silicon			krad, Gold		
		5	16	125	1	10	100
7 to 9	1.52	40.0	37.0	16.2	107.6	32.3	3.3
9 to 13	0.59	6.2	6.0	4.4	20.6	10.6	1.3
13 to 20	1.14	3.3	3.2	3.1	49.5	22.0	2.5
20 to 25	1.07	1.2	1.2	1.1	22.5	14.8	2.3
25 to 29	0.70	0.4	0.4	0.3	9.7	7.3	1.5
29 to 43	2.58	0.6	0.6	0.4	16.7	14.6	5.3
43 to 57	0.75	--	--	--	2.0	1.9	1.1
57 to 67	1.01	--	--	--	1.5	1.4	1.1
67 to 88	0.69	--	--	--	0.7	0.7	0.6
Total	10.05	51.7	48.4	25.5	230.8	105.6	19.0

pulse width is 100 nsec and ranges from 50 to 300 nsec. The pulse width, like the fluence, cannot easily be predicted closer than 50 nsec. In addition, on approximately 30% of the shots a dual x-ray pulse is emitted -- the pulse separation is 200 ± 200 nsec. In most active x-ray tests these effects are of no consequence because the circuits cannot respond rapidly to such pulses and tend to integrate the x-ray pulse. Figure 7 shows a graph of the shot-to-shot pulse width variation.

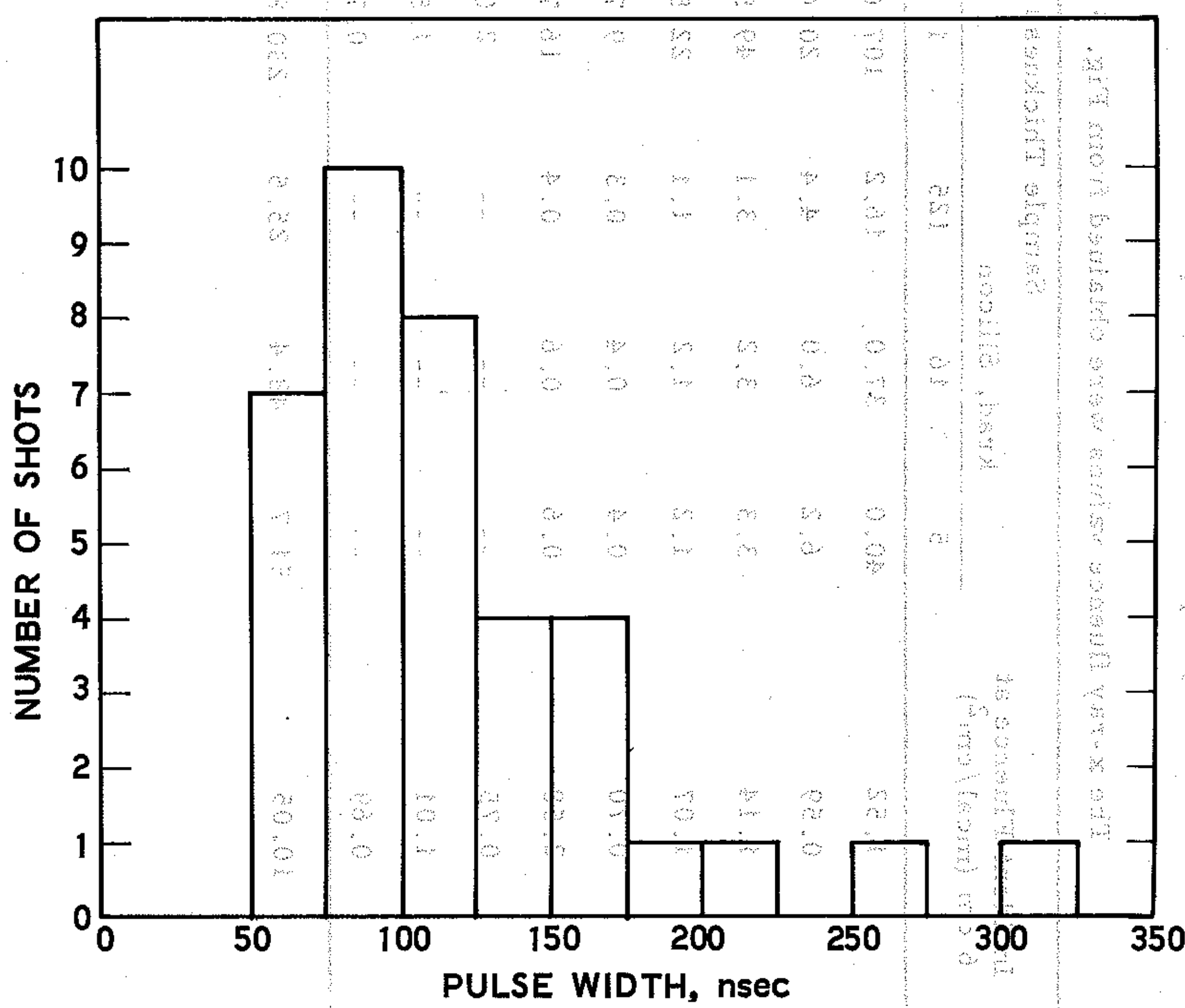


Fig. 7. Distribution of X-Ray Pulse Lengths for Mk 1B PFD

REFERENCES

1. M. H. Dazey and H. L. L. Van Paassen, Experimental Study of the Mk-1A Plasma Neutron Source, TR-0158(3220-50)-3, The Aerospace Corporation, El Segundo, California (April 1968).

2. M. J. Bernstein, R. C. Phillips, and G. G. Comisar, Investigation of a Three-Dimensional Plasma Pinch Device (Mark II), TR-1001(2220-50)-4, The Aerospace Corporation, El Segundo, California (May 1967).

3. H. L. L. Van Paassen, Mark III Plasma Neutron Source, TR-0059(6220-50)-5, The Aerospace Corporation, El Segundo, California (18 August 1970).

4. M. J. Bernstein, D. A. Meskan, and H. L. L. Van Paassen, Space, Time, and Energy Distributions of Neutrons and X-Rays From a Focused Plasma Discharge, TR-0066(5220-50)-4, The Aerospace Corporation, El Segundo, California (4 September 1969).