RECEIVED BY TIC MAR 24 1972

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

UCRL -72981
PREPRINT

CONF-710710--11

Lawrence Radiation Laboratory

UNIVERSITY OF CALIFORNIA

LIVERMORE

94550

**AN EVALUATION OF RADIATION HAZARDS
FROM HIGH-VOLTAGE VACUUM INTERRUPTERS**

N. A. Greenhouse

G. C. Peterson

August 16, 1971

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

**This paper was prepared for submittal to
Health Physics.**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

49

AN EVALUATION OF RADIATION HAZARDS
FROM HIGH-VOLTAGE VACUUM INTERRUPTERS*

N. A. Greenhouse

Brookhaven National Laboratory
Upton, New York 11973

G. C. Peterson

Lawrence Livermore Laboratory, University of California
Livermore, California 94550

(Received _____)

Abstract—High-voltage vacuum interrupters are electro-mechanical relays frequently used to control d. c., a. c., and r. f. currents at potentials up to about 100 kV. With high potential differences impressed across the open electrodes, these devices can become potent X-ray generators. The principle source of X rays is apparently field-emission of electrons from the cathode. Additional electrons may be produced by ionization of residual gas and subsequent ion bombardment of the cathode. X-ray fields of the order of tens of roentgens per hour at 1 m were produced from interrupters operated within their maximum voltage rating. The production of X rays is correlated with electrode condition and alignment, gap distance, and envelope pressure.

*Work performed under the auspices of the U. S. Atomic Energy Commission. The paper was presented at the 1971 Health Physics Society Annual Meeting, New York, July 12-15, 1971.

INTRODUCTION

Recently much attention has been called to electronic product radiation hazards, particularly to the possibility of X-ray production from devices not designed for that purpose.⁽¹⁾ HAYWOOD et al.⁽²⁾ investigated X-ray production from high-voltage vacuum interrupters and found them to be potent X-ray sources even when operated well within manufacturer's specifications. Since these devices are frequently used at the Lawrence Livermore Laboratory (LLL), the authors evaluated them with respect to potential radiation hazards.

X-RAY PRODUCTION MECHANISM

A typical vacuum interrupter is shown in Fig. 1. These devices are essentially solenoid-actuated relays (electro-mechanical switches) designed to transfer large currents at high potentials. Some models are insulated to withstand potentials in excess of 100 kV. New relays are evacuated to about 10^{-8} Torr by the manufacturer. A good vacuum is usually maintained during the life of the relay as a result of the "gettering" action of tungsten sputtered off the contacts during switching operations. The vacuum relays tested had tungsten contact points normally spaced $3/32$ to $5/32$ in. apart (0.24 to 0.4 cm). The contact diameters were $1/4$ or $3/8$ in. With applied potentials of 50 to 100 kV, the average electric field between the contacts is of the order of 2×10^5 V/cm. With fields of the order of 4×10^7 V/cm, field emission of electrons from tungsten can take place. Local fields of this magnitude are readily produced around burrs, whiskers or sharp edges with effective radii of 10^{-4} to 10^{-3} cm. Secondary processes such as positive ion bombardment of the cathode contact may contribute additional electrons. These electrons

are then accelerated across the gap and absorbed in the anode contact, where they produce bremsstrahlung and tungsten characteristic X rays.

One would expect X-ray production to be strongly dependent on contact-surface condition, contact alignment, and gap width, since these parameters affect the electric field strength at emission loci. Of the three, contact-surface condition is probably the most significant. With use, the relay contacts become eroded and pitted, particularly in high-current switching (Fig. 2). In addition, vapor deposition of sputtered tungsten produces surface discontinuities (as seen in Fig. 2b) that further increase emission efficiency.

The electric field strength between the contacts is a hybrid of two idealized geometries. If the contact surfaces are smooth and parallel, and if the contact diameter-to-gap width ratio is large, then the electric field strength is approximately uniform across the gap:

$$\epsilon \sim \frac{V}{d}$$

where:

V is the applied potential

d is the gap width

On the other hand, fine points and discontinuities on one contact approximate a sphere of radius r concentric to a larger sphere approximated by the opposing contact. In this case, a potential difference V applied between them results in a concentrated field

$$\epsilon \sim \frac{V}{r}$$

at the surface of the point.⁽³⁾ Actually, the relay contacts are very poor approximations of either of these geometries, but the observed X-ray intensities are ample proof that electric field strengths great enough for electron emission are produced.

Contact misalignment is significant because it tends to enhance electron emission from the edges of the contact surfaces and it promotes localized contact erosion by increasing current density, i.e., concentrating the switching current in a smaller area on the contact faces (Fig. 3). Perhaps the greatest radiological significance of contact misalignment is the reduction in self-shielding of the X rays. Strong attenuation of the X rays in the tungsten contact material limits external X-ray fields to essentially line-of-sight angles to the anode surface. Contact misalignment exposes more surface, hence increasing the size of the X-ray field.

Gap widths are essentially fixed by the manufacturer, but they can be reduced by shimming. This has been done on rare occasions to reduce contact closure time. Electric field strength is inversely proportional to gap width, so gap-width reduction generally enhances X-ray production.

EXPERIMENTAL METHODS

The relays were first cleaned with acetone to minimize surface leakage current and then mounted vertically on a lucite test stand for X-ray measurements. Potentials between 0 and 100 kV were provided by a 250-kV, 5 mA, d.c. power supply. When high voltage was applied to the open relay contacts, emission current was monitored with a log-scale milliammeter. A survey meter shielded against RF emission was used. The X-ray measurements were usually

made in the plane through the contact gap and perpendicular to the relay axis. However, additional measurements were also made for isodose curve data at 30, 60, 120, and 150 deg to the relay axis. For these measurements, the survey meter was hand-held with a 1-m-long spacer rod and an inclinometer attached for convenient distance and angle determination. A typical isodose curve is shown in Fig. 4.

RESULTS

One general statement that can be made about the results is that the X-ray output from these devices was extremely variable and unpredictable. Of the 18 relays tested, new ones, with notable exceptions (Fig. 5), were observed to pose less serious X-ray problems than used ones. This was expected, since the surface condition of contacts usually deteriorates with use. However, the manufacturer runs each relay through a rigorous testing program before release to the consumer, so even new relays may have pitted contact surfaces. The new relays tested having the highest standoff voltage rating were among the most potent X-ray generators (Fig. 5). In most cases, however, there was good correlation between X-ray emission and use history. Examples are shown in Figs. 6 and 7.

In all cases, X-ray output was found to be quite variable in time. Generally, for a given applied potential the X-ray output tended to decrease gradually (Fig. 8). This is probably due to contact erosion from backstreaming positive ions, and distortion of these emission points in the high electrostatic fields. Occasionally, an abrupt increase in X-ray output was observed, probably due to new metal whiskers being pulled out of the cathode surface.

Reduction of the gap width produced the expected increase in X-ray output (Table 1).

An interesting observation was the apparent polarity-dependence of X-ray emission (Table 2). This may be due to the selective erosion of one contact from unidirectional current flow in relays used to transfer d.c. power only.

CONCLUSIONS AND RECOMMENDATIONS

In making these measurements, we observed X-ray fields equivalent to several roentgens per hour at 1 m. These fields were produced by relays that were brand new or that were used but removed from properly functioning equipment. One used relay with excessive leakage current produced an estimated 20 R/hr at 1 m. Needless to say, the magnitude of these X-ray intensities and the unpredictable radiation production characteristics of the relays warrant an increased awareness of the hazard and the use of protective measures to prevent insidious exposures to personnel. The manufacturer includes an X-ray warning and shielding recommendation in the installation instructions. However, many units now in use were installed before the warning appeared, and in more recent installations the warning is frequently ignored. The X rays produced are generally quite soft (30 keV, effective) and therefore easily attenuated. Where shielding is impractical or impossible, the authors recommend a rigorous monitoring program for these and other vacuum high-voltage devices—and, in all cases, education of the users as to the potential radiation hazards.

REFERENCES

1. Electronic Product Radiation and The Health Physicist. BRH/DEP70-26 (October 1970).
2. F. HAYWOOD and D.R. WARD, HP RR and Accelerator Operations.
Health Physics Division Annual Progress Report for Period Ending July 31, 1970, Section 17, pp. 187-197. ORNL-4584 (October 1970).
3. R. JENKINS and W. TRODDEN, Electron and Ion Emission from Solids, Dover Publications, New York (1965).

Table 1. Effect of 50% reduction in contact gap

Model	<u>Exposure rate at 1 m (mR/hr)</u>	
	Rated gap	Reduced gap
R1G	25	60
R2G	2.0	150
R8A	1.4	130

Table 2. Effect of polarity reversal

Model	<u>Exposure rate at 1 m (mR/hr)</u>	
	Anode at top	Anode at bottom
R1G	25	150
R2G	2	200
R8A	100	9

FIGURES

- Fig. 1. High-voltage vacuum relay switch. The fiberglass rods inside the insulating supports at the base of the vacuum tube move the anode to close and interrupt the circuit.
- Fig. 2. (a) Typical cathode contact surface after switching. (b) Anode contact surface that has been severely pitted during switching (worst case found).
- Fig. 3. (a) Typical misalignment of contacts. (b) Resulting uneven pitting of cathode contact surface.
- Fig. 4. Isodose curve for R8G switch at 75 kV d.c. The exposure rate was 100 mR/hr at 1 m.
- Fig. 5. Exposure rates for three of the eighteen switches tested, showing unusually high rates for two new R8A switches.
- Fig. 6. Representative exposure rates for R1G switches tested.
- Fig. 7. Representative exposure rates for R2G switches tested.
- Fig. 8. Time variation of exposure rate.

Fig. 1 - Greenhouse

Fig. 2a - Greenhouse

Fig. 2b - Greenhouse

Fig. 3a - Greenhouse

Fig. 3b - Greenhouse

Fig. 4 - Greenhouse

Fig. 5 - Greenhouse

Fig. 6 - Greenhouse

Fig. 7 - Greenhouse

Fig. 8 - Greenhouse