SECTION D — Discussion: Flash X-Ray

Note: A participant's full name and address are given with the first contribution to the Discussion. Authors' full names and addresses are given with the title of each paper. For subsequent entries the addresses are omitted.

Paper D-1: A Fifty-Millimicrosecond Flash X-Ray System for Hypervelocity Research, *F. J. Grundhauser, W. P. Dyke and S. D. Bennett,* Field Emission Corporation, McMinnville, Oregon.

Dr. Gustav Thomer (Institut Franco-Allemand de Recherches, St.-Louis, France): What is the life (total number of flashes) of your tubes?

Dr. W. P. Dyke: The life is a function of anode loading. At the maximum peak powers described in this paper, the tube life obtained by users in the field seems to vary from 200 to 500 pulses. Life termination is due primarily to anode erosion in this range. At lower peak power, life is limited by cathode evaporation and is much longer.

Dr. G. Thomer: Can the tube be rebuilt and reused?

Dr. W. P. Dyke: It can, but there is no economic advantage because of the low initial cost of the tube.

Paper D-2: An Installation for Triple X-Ray Flash Photography at 600 kv, *Jean Viard,* Poudrerie Nationale, Sevran, France, and *Lucien Beaudouin,* Commissariat à l'Energie Atomique, 69 rue de Varenne, Paris 7, France.

Dr. G. Thomer: What is the delay between the trigger pulse and the x-ray flash?

Dr. L. Beaudouin: Two microseconds is the maximum.

Dr. G. Thomer: What is the dispersion of intensity in a series of x-ray flashes?

Dr. L. Beaudouin: The dispersion is a few percent.

Paper D-3: Megavolt Flash X-Ray Equipment, *E. W. Walker,* Atomic Weapons Research Establishment, Aldermaston, Berkshire, England.

Dr. Gabriel Nahmani (Ministry of Defense, P. O. Box 7063, Hakirya, Tel-Aviv, Israel): There seem to be two ideas behind the equipment described: (a) the generation of short-duration x-ray flashes, which is done by reducing the inductance of the equipment; and (b) increasing the penetration of the radiation by going to higher voltages.

I would like to ask Mr. Walker two questions: (1) was pressurizing the generator tried for reducing the size and hence the inductance; and (2) was an attempt made to increase the radiation output by building a generator with larger capacitors?

E. W. Walker: The inductance can certainly be decreased by pressurizing the equipment. We have not done this but believe that other laboratories are working on it. We have obtained a reduction of a factor of 2.5 in clearances by using a Freon (Arcton 12).

As regards improvements in energy, I am not entirely certain that I have followed the question. You can, of course, increase the energy by increasing the number of stages, or voltage per stage. I should mention here that the 1-Mv generator gives the equivalent of 5 to 600 kv x-rays. The other approach is to attempt to lower the generator impedance. This is quite difficult, but we believe that we know how to attempt this.

Paper D-4: Theory of Operation of Flash X-Ray Tubes, *J. S. McVeagh,* Armament Research and Development Establishment, Fort Halstead, Sevenoaks, Kent, England.

Dr. G. Thomer: Does this theory hold for all different forms of electrodes, for instance, for a pointed anode?

J. S. McVeagh: I agree that the pinch may not be the mechanism in all cases. In the WL 389 tube, the trigger arc is perpendicular to the main field. However, plasma is needed to neutralize the space charges in all cases, and this could be produced by vaporization of points.

Dr. G. Thomer: I feel that plasma-jets, and particularly pinches, will be the controlling factors only for some special electrode geometries. Especially for needle anodes, the evaporation of anode material will play a part.

Anonymous: Dr. Thomer suggested that the geometry of the electrodes may affect the current voltage characteristics. We found that in the case of point cathodes in a very high vacuum, the rise times are much faster and quite different from those indicated in the present paper. A paper in the 1953 *Physical Review* describes this work.

Dr. R. F. Saxe (Queen Mary College, Mile End Road, London E.1, England): J. S. McVeagh appears to be troubled to explain a plasma-jet moving from the trigger arc at velocity of 10^6 cm/sec. I suggest that he may find some explanation in the work of Bostick at the Stevens Institute, Hoboken, New Jersey.

J. S. McVeagh: I have not read Bostick's work, but I shall do so as soon as possible. However, I would point out that while jets of 10^6cm/sec may be produced by evaporation of the electrodes in the direction which the cathode faces, this is unlikely in a direction perpendicular to the axis of the spark.

Dr. Louis Zernow (Aerojet General Corp., Downey, Calif.): (1) Do the doubly-peaked current pulses which you show imply a double x-ray output? (2) Can you suggest ways in which the double output can be reproducibly controlled? The WL-389 at low voltage is well known for its multiple outputs, and these would be very useful if they could be controlled.

J. S. McVeagh: (1) I have, indeed, had multiple exposures in the pictures obtained from the low-voltage circuit; and I think that they correspond to peaks in the current. (2) I think that the multiple outputs are a function of the oscillation of the trigger arc, and it is this which would have to be controlled. However, this is not so easy. I have tried to control it by the addition of capacitance to the trigger circuit, with mixed success. It is possible that trigger oscillation may actually be a plasma oscillation in the trigger arc.

Dr. Frank Frügel (Dr.-Ing. Frank Frügel GmbH., Sülldorfer Landstrasse 400, Hamburg-Rissen 24(a), Germany): We found similar results, though we had not developed a theory. With our demountable x-ray tubes, there is no difference in the diameter of the anode spot, whether we take a conical anode or a Zuckermann needle anode. A bigger conical anode seems to be better than the needle. Only a pinch discharge mechanism could explain this.

Also, we found that a very brief discharge often doesn't cause an x-ray flash. The anode voltage must be maintained for a time sufficiently long that the discharge pinches enough to cause the emission of the x-rays.

Since it is possible for a pinching plasma to emit gamma rays, it would seem possible that one might obtain a higher x-ray quality with higher voltage, as the driving voltage allows a higher speed of the pinching needle.

J. S. McVeagh: I agree that the tube's failure to fire is most easily explained by the anode voltage pulse being of insufficient duration to allow time for the plasma-jet to get across the tube.

X-rays can be produced by the pinch effect, but the brehmstrahlung produced by a plasma, even at several million degrees Centigrade, is very soft.

Paper D-7: Application of Image Intensifier in Flash Radiography, *Gustav Thomer and Rudi Schall,* Institut Franco-Allemand de Recherches, St.-Louis, France.

Dr. Lawrence W. Jones (Department of Physics, University of Michigan, Ann Arbor, Michigan): (1) Dr. Perl and I, together with radiologists at the University of Michigan, have shown that the addition of a two-stage image converter (RCA type C73458), optically coupled to a Philips X-ray intensifier, permits observation and photographic recording of single x-ray quanta converting in the zinc sulfide screen of the Philips tube, thus bringing this device to the quantum limit of sensitivity. These studies were made under nonpulsed conditions.

(2) We have also proposed that more efficient detection of quanta at higher energies (e.g. to one Mev and greater) can be achieved using filaments of transparent x-ray scintillator oriented parallel to the incident x-rays. This permits a high conversion efficiency of the penetrating x-ray quanta, while maintaining resolution through the light-piping of the filaments. Using such a filament bundle in place of the conventional x-ray screen with an

image converter system again results in a detector approaching the quantum limit, for very high energy quanta. Dr. Perl and I are pursuing this development in cooperation with industrial laboratories in this country.

Paper D-8: Measurements of the Density of Gas in an Argon Discharge by Soft X-Ray Flashes, *Karl Vollrath*, Institut Franco-Allemand de Recherches, St.-Louis, France.

Dr. Werner Müller (*Erprobungsstelle der Bundeswehr, Meppen, Ems, Germany*): I assume that the arc discharge produces a shock-wave propagation similar to the exploding-wire phenomena. I made an attempt to explain these shock-wave propagations qualitatively by adapting Wecken's theory of the spherical detonation to the cylindrically symmetrical case. Wecken calculated that the lowest pressure is not located in the center of the sphere. In our case, it would not be on the axis of the cylinder. This result is apparently confirmed by the present arc-discharge study.

Dr. K. Vollrath: Shock-wave laws, following the papers of Lin and Wecken, may serve as initial conditions of the equation for the heat transfer. I preferred to use experimental initial conditions. Evaluation of the differential equations used always indicates minimum density in the center of the kernel.

Dr. R. F. Saxe: Could Dr. Vollrath tell us the energy discharged into the spark, and the approximate duration of the spark?

Dr. K. Vollrath: Total energy stored in the condenser was about 4.5 joules. As a certain loss in the triggering spark gap occurred, it was necessary to determine the energy in the argon spark under test. This was done — neglecting radiation losses — following the shock-wave laws. This gave about 0.6 joule/cm of spark length.

Paper D-9: High-Speed Measurement of Shock Compressibility of Solids in the 1-Mb Range, *Rudi Schall*, Institut Franco-Allemand de Recherches, St.-Louis, France.

J. S. McVeagh: Has this method been used to record the velocity of the retreating rarefaction wave from a free surface?

Dr. R. Schall: Flash radiographic density measurements may be useful also for rarefaction waves provided that sufficiently great density variations occur (at least of the order of 20%).

J. S. McVeagh: How have you, Dr. Schall, associated the density of the film with the x-ray transmission at these short times?

Dr. R. Schall: Film density was calibrated by a step-wedge photographed with the flash.

Dr. David C. Oakley (*University of California, Lawrence Radiation Laboratory, Livermore, California*): How do you take into account the two-dimensional density distribution in the experiment to obtain a single-density point for the curves?

Dr. R. Schall: Because of the cylindrical symmetry, the density field can be determined from a densitometer record perpendicular to the axis. The result can be checked and corrected taking mass conservation into account. We are particularly interested in the density repartition along the shock axis.

Dr. D. C. Oakley: On the axis you'll have a rarefaction as the cylindrical wave expands. Do you measure the photographic density near the edge or in the center where the rays go through regions of varying density?

Dr. R. Schall: We measure along the axis and perpendicular to the axis, so that we get the whole density field.

Dr. D. C. Oakley: But don't you then have to assume a certain distribution of density with radius?

Dr. R. Schall: No. We need not assume anything about the density distribution.

J. William Gehring, Jr. (*Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland*): I have a comment regarding Dr. Oakley's question. We think, at Aberdeen, that the assessment of the densitometer measurements can be improved if one considers the target in three zones, and thereby takes into account the x-ray absorption vs. thickness of the zone being penetrated. The description of this technique and the associated relationships are given in the Appendix to my paper, "High-Speed Radiographic and Optical Techniques Applied to Hypervelocity Impact Studies," published in these *Proceedings*.

Paper D-10: High-Speed Radiographic and Optical Techniques Applied to Hypervelocity Impact Studies *J. William Gehring, Jr.*, Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland.

Dr. D. C. Oakley: Do you have the dynamic yield points for other materials?

J. W. Gehring, Jr.: We have determined material densities under dynamic compression for Al, Mg, and two plastics. The data obtained agree in general with an extrapolation of other data (i.e. the results published by R. Schall and the work done at Los Alamos). However, there is not yet sufficient data to arrive at any exact conclusions as to the true dynamic yield point of materials.

Winston O. S. Johnson (*Mechanical Research Laboratory, E. I. du Pont de Nemours & Co., Wilmington, Del.*): Will the data be published?

J. W. Gehring, Jr.: We do plan to publish the data as soon as possible. We are presently limited in our choice of materials to those having low density. We are now having a higher-voltage radiographic unit built. It will, of course, permit the extension of this work to more dense materials.

W. O. S. Johnson: What is the validity of the dynamic strength as determined by hypervelocity impact on plastics?

J. W. Gehring, Jr.: That's a difficult question to answer. I'd like to say that the results are reliable, but I don't know of any other experiments quite like this; therefore, I don't know of any data with which to compare my results.