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THE STATUS OF FLASH RADIOGRAPHY IN THE U.S.A. TODAY AND FUTURE POSSIBILITIES

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A sample of presently employed flash x-ray generators is given including low-energy, commercially available systems and high-energy very specialized installations in government laboratories. These flash x-ray sources are compared as to radiographic characteristics. Imaging techniques and materials are surveyed and compared as to their advantages and limitations. A variety of applications of flash radiography are cited including explosive, ballistic, diffraction, crash injury, and fuel injection. Probable near term advances in special techniques are mentioned in cine radiography and film image enhancement. Possible future developments are speculated upon such as flash radiographic applications of computerized axial tomography. The recent recognition of flash radiography at professional society conferences is reviewed.

FLASH X-RAY GENERATORS

TABLE I - SAMPLES OF FLASH X-RAY GENERATORS IN THE U.S.A IN 1978:

X-Ray Energy & Type	Designer & Builder	Radiation Intensity at 1 m/Pulse	Focal Spot Size - mm	Pulse Duration ns	Portability
85 kV[1] Blumlein	Lawrence Livermore Laboratory	30 mr	1.1	50	Yes
150 kV[2] Marx	Hewlett Packard	2 mr	3	70	Yes
450 kV[3] Marx	Hewlett Packard	20 mr	5	25	Yes
1 MeV[4] Marx	Hewlett Packard	55 mr	5	25	Yes
9 MeV[5] Marx/Blumlein	Physics International	500R	< 5	60	Limited to Rails
30 MeV Linac	Los Alamos Scientific Laboratory	100R	3	40, 100, 200	No
[illegible] MeV Linac	Lawrence Livermore Laboratory	60R	2.8	300	No

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FILMS AND INTENSIFYING SCREENS FOR FLASH RADIOGRAPHY

This primarily concerns the smaller flash x-ray generators with minimal radiation output which require fast films and screens. The more intense radiation sources have a much wider choice of imaging materials.

The fastest intensifying screens commercially available for flash x-ray energies from 150 kV to 1 MeV are given in Table II.

The fastest intensifying screen readily obtainable for a 2-MeV flash x-ray energy is a Dupont NDT High Plus-3 screen, a relatively thick phosphor of $CaWO_4$. It can offer additional speed gains as a back intensifying screen at lower energies. Its thicker layer means some loss of resolution.

The two films which find widest application where speed is paramount are Kodak X-Omat Type R film (XR) and Dupont's Cronex 2DC Medical X-Ray Film. For the flash x-ray energies mentioned above, the Kodak film is faster and of higher contrast while the Dupont film gives finer definition.

APPLICATIONS OF FLASH X-RAY

To Fuel Injector Sprays[6]

Messrs. Kerry Bahl and Harry Vantine of Lawrence Livermore Laboratory, Livermore, California have reported a low-energy, flash x-ray diagnostic technique for determining [illegible] of a spray of fuel droplets as one aspect of a study of combustor design. These combustors include directly injected, reciprocating and rotary engines; gas turbines; and industrial furnaces.

In the past, optical methods have been used in the experimental characterization of fuel sprays; however, optical techniques have certain limitations. Thick fuel sprays are often opaque to light. When thermal gradients are present, holographic techniques are affected by phase shifts.

An 85-kV flash x-ray technique overcame these limitations and yielded information about the pattern and density of the fuel sprays and their droplet distribution.

To Diffraction Systems for Materials Testing[7]

Professor Robert Green, Jr. of The John Hopkins University has used flash x-ray systems to achieve flash x-ray diffraction patterns from materials undergoing rapid dynamic loading. The flash x-ray equipment was from Hewlett Packard and operates at 150 kV with either tungsten or molybdenum target, beryllium window x-ray tubes. An electro-optical device incorporating a three-stage image intensifier acted as a detector.

In 1975 Green recorded the first x-ray diffraction photograph of an aluminum, shaped-charge jet, which had a cross sectional diameter of approximately 5 mm as determined from a separate flash radiograph at 300 kV of the metallic jet. Analysis of the transmission, flash x-ray diffraction pattern of the aluminum jet indicated that it consisted of a particulated solid with a grain size distribution ranging from about 1 mm down to about 0.01 mm.

Ballistic Events[8]

[illegible] Finfera of the U.S. Army, Aberdeen Proving Ground in Maryland has supervised flash radiography of many experiments that could be categorized as imaging

1.) at the muzzle of a gun tube,
2.) at the target, and
3.) of a shaped charge.

In the second case the purpose

TABLE II - SCREENS FOR FLASH RADIOGRAPHY

Screen	Designation	Manufacturer	Type
Radelin	T1-3	U.S. Radium/GAF	$CaWO_4$
Trimax	Alpha 8	3 M Co	Rare Earth Oxide
Radelin	BG High Speed	U.S. Radium/GAF	Rare Earth Oxide
Cronex	Quanta III	Dupont	Rare Earth Oxide

of the flash radiography is to qualitatively and quantitatively monitor the behavior of the projectile, armor, and related fragments as the projectile approaches, penetrates, and exits the target. This is done at Aberdeen Proving Ground using flash x-ray generators ranging from 150 pkV to 2.3 MeV. Radiographs of projectiles impacting armor have revealed defeated rounds due to premature disintegration and a tendency to pitch upward. Redesign of the projectile and subsequent testing gave flash radiographs that confirmed complete penetration of the round.

Crash Injury[9]

Capt. Stanley Shatsky, M.D. at the Armed Forces Radiological Research Institute in Bethesda, Maryland has used low-energy flash x-ray equipment to study lateral head impact of anesthetized primates. This technique has revealed internal organ motion and damage which are caused by severe collision impact. Low persistence x-ray image intensifiers produce a small output image, which has been recorded at 1000 frames per second with a pin registered framing camera. Injection of iodine-based contrast media in the appropriate blood vessels just prior to impact provides an effective method for mapping the motion of internal organs during and after impact.

In Insensitive Explosive Studies[10]

Dr. Richard Dick of Los Alamos Scientific Laboratory has reported the use of PHERMEX to diagnose the behavior of insensitive explosives consisting of mixtures of TATB and Kel-F binder. A typical experiment is to obtain a series of film radiographs at varying times after detonation to observe the corner turning and unreacted zones of insensitive explosives. High resolution flash x-ray techniques are employed with Kodak AA and KK industrial x-ray film placed between 1 mm thick lead screens and radiation levels of 10 to 20 R at 1 m for a pulse duration of 40 ns. Target to film distance was 3.05 m and object to film distance was 1.22 m with the film protected by a conical aluminum film cassette. Interpretation of the resulting films reveals a dead and probably unreacted zone which seems to persist for many microseconds and may never detonate in the normal sense. Also, the decrease in detonation velocities as determined from these dynamic radiographs as the front turns the corner indicates a reduction in detonation pressure.

NEAR TERM ADVANCES

A design team consisting of Lockheed Missiles and Space Company, Pratt and Whitney Aircraft, and Varian Associates has proposed a cine-radiographic system for imaging internal components of an operating gas turbine aircraft engine. This imaging will occur while the engine is undergoing simulated maneuvering acceleration and gyroscopic loads.

The cine-radiographic system includes a pulsed linear accelerator operating between 8 and 15 MeV, both film and electronic imaging systems and a remotely operated positioning and alignment system. These components will be designed to remain functional in an outdoor environment under a randomly oriented load of up to 21 g in some cases.[11]

Another high-energy cine-radiographic system has been described at this Congress. It is intended to provide imaging of large scaled burning rocket motors, undergoing static test. The imaging rate is to be in excess of 100 frames per second at an energy level of 10 MeV or greater with fluorescent screen imaging, large light amplification and high-speed camera recording of results. Effort will be needed to protect the radiation source and recording systems from flame, vibration, and possible detonation.

Gains in commercial flash x-ray equipment from the McMinnville Division of Hewlett Packard are anticipated in the following areas.[12]

1. Voltage doubler tube [illegible] and [illegible] capacitance [illegible] storage [illegible] cables. Both lead to more intense radiation per pulse or smaller size equipment or a combination of both features.

2. Computerized, radiographic technique selection utilizing mi-

Flash x-ray films which have less than desirable quality are now frequently subjected to various techniques of image enhancement to improve contrast, or definition or both. One typical technique begins with a microdensitometer scan of the original negative. The scanned image is digitized in terms of position (X and Y) and film density. Computer programs are employed to flatten the film density variations of the background and then extreme film density stretching is performed by using histogram equalization techniques. The manipulated data is then played back in a visual display and recorded on film for viewing.

FUTURE DEVELOPMENTS

Computer assisted tomography is an outstanding medical x-ray diagnostic technique. Studies are now being conducted on industrial and scientific applications of this technique. One possible application would utilize multiple flash x-ray tubeheads discharged simultaneously to generate the several images which would be recorded on x-ray film. The film would be scanned by a microdensitometer, digitized, and by computer manipulation the side views would be converted to a single cross-sectional image. A specific application could be to study turbulence of coolant flow in nuclear reactor piping.

RECOGNITION FROM TECHNICAL SOCIETIES

The technique of flash radiography has recently received recognition from the American Society for Nondestructive Testing (ASNT), a technical society, which traditionally has given conventional radiography for static inspection of materials a significant emphasis. The ASNT sponsored a full-day session comprising 18 papers on flash radiography at their annual fall conference in Houston, Texas during September 1976. In August 1977 in Wilmington, Delaware the ASNT sponsored a one-half day session on flash radiography featuring six papers as part of the Conference on "Innovative and Advanced NDT Radiography." These meetings have provided a wider forum for exchange among the users of flash radiography than has previously existed in the United States. The 18 papers from the Houston meeting have been published as the Proceedings of the Flash Radiography Symposium, which is the first hard cover book exclusively concerning flash radiography published in the USA.

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