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Edge Blurring in Stacked X-Ray Film Screen Combinations

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Edge Blurring in Stacked X-Ray Film Screen Combinations

Abstract

The Advanced Experiments Group of B-Division, LLNL, has been seeking to improve the sensitivity and spatial resolution of stacked film screens for bremsstrahlung flash radiography of imploding, dense metal shells. In the work reported here, we experimentally measured the spreading of the x-ray shadow of the edge of a uranium block in two film-and-screen combinations. We also used the SANDYL code, which models photon and electron scattering, to calculate the theoretical edge spreading in an array of films and screens. Experimentally, the uranium edge was spread to a width of 1.7 mm in the combination 0.15-mm-Ta/NDT9-XAR5, and 1.5 mm in the combination 0.25-mm-Ta/NDT6-XAR5. The theoretical calculation agreed with these results.

Introduction

In flash radiography for nuclear weapons design, there is a technique called core-punching. The term was coined by the British, and much of the technology rests upon the pioneer efforts of the Aldermaston pulsed power group. The word "core" refers to the gas cavity of an imploded non-nuclear hydrodynamic experiment. The word "punching" refers to the transmission of an intense burst of x rays through the cavity and the formation of an image on photographic film. What is sought is the shape of the gas cavity, a quantitative measure of any mixing of metal and gas, and the profile of shocks in the surrounding materials.

The gas cavity is located in the middle of a substantial quantity of compressed high-density metal produced by the detonation of a chemical explosive. A typical experiment with compressed uranium has an areal density in the neighborhood of 250 g/cm² and an unscattered 4-MeV x-ray transmission of a few tens of parts per million. A very intense dose of x-rays is required to penetrate such a core and to prevent motion-smearing of the image; the pulse width must not exceed several tenths of microseconds.

The dose requirements have been met by a new generation of electron accelerators at the several laboratories, and considerable effort has been made to improve the image-forming components on the other side of the experiment. This has taken the form of a search for the most sensitive emulsions available and the "fastest" light-emitting intensifying screens, the use of multiple films (this practice is called "stacking"), the use of pushed development in chemicals offering the least danger of fogging, and design of bullet-like cassettes to get the films as close to the explosions as possible.

This paper concerns a static exposure of several stacked combinations of film screens to a flux of 8-MeV x-ray bremsstrahlung to measure the amount of blurring or spreading of an object edge. In addition, this paper presents the results of a computer calculation of blurring and of energy deposition by x-ray photons and electrons (arising from Compton scattering or pair production) in a stack of eight typical films and their screens.

Experimental

A pack of 5 XAR5* films and tantalum-and-NDT† screens was assembled and exposed at the 8-MeV radiographic linac. The details of the film pack are given in Appendix A. The experiment included two collimators, a lead filter, and a uranium block located quite close to the film so that its x-ray shadow could be used as a measure of the edge blurring or spreading. The geometry is shown in Fig. 1. The accelerator was operated for 23.25 seconds. This elapsed time corresponds to a metered unfiltered dose of 970 rads at one meter from the source. The 15-cm thickness of lead had a 4-MeV transmission of 0.0755%; applying the

inverse square law to this filtered flux yields a value of 9.4 mrad at the film cassette.

The films were processed for 5 minutes at 20° C in Kodak GBX developer. A microdensitometer produced density vs distance curves, which were converted to percentage exposure values using the density-exposure relationship for the films used. Reduced data are shown in Fig. 2. For 25%-75% exposure, the edge was blurred to 1.7 mm for the combination 0.15-mm-Ta/NDT9 and to 1.5 mm for the combination 0.25-mm-Ta/NDT6. Note that although the areal density of the 0.15-mm-Ta/NDT9 combination is 18% greater than that of the 0.25-mm-Ta/NDT6 combination, the latter combination requires 58% more exposure to reach the same film density as the former.

* Trademark of the Eastman Kodak Company.

† Trademark of the E. I. DuPont Company.

Experimental geometry

Figure 1. The experimental layout. A lead filter is located between the two collimators. The x-ray shadow of the uranium block is used to measure edge blurring.

Edge spreading for
XARS Film No. 2 and XARS Film No. 4

Figure 2. Reduced densitometric data showing edge spreading in two film/screen combinations. For 25%-75% exposure, the edge was blurred to 1.7 mm for the combination 0.15-mm-Ta/NDT9 and to 1.5 mm for the combination 0.25-mm-Ta/NDT6.

Calculation

The SANDYL¹ code was used to calculate the scattering of photons and electrons in an array of eight film-screen unit cells. Figure 3 illustrates the first of these cells and shows, in addition, a thick tantalum front filter which is used to absorb low-energy photons. A point source of 4-MeV γ rays was located 1.5 m distant on the left, and its radiation was distributed conically to illuminate a 1-cm-radius circle at the first film. The first and eighth films were radially zoned in 0.2-mm increments for editing purposes. This is shown in Fig. 4. In this calculation, knock-on electrons and bremsstrahlung photons were followed, while fluorescence and Auger particles from photoelectric events and electron-induced atomic ionization were not followed. The major portion of the film exposure comes from the light emitted by the CaWO_4 phosphor screens, but this physics is not

included in the SANDYL code. Therefore, this calculation is only useful to the extent that it shows what fraction of the film-pack blur is due to the scattering of electrons and x rays. In addition, the distribution of energy deposited by photons and electrons was calculated. Appendix B contains the complete material parameters that were used in the calculation.

SANDYL calculates too narrow an angular distribution in thin foils when the default values are used for the number of electron substeps.² The number of substeps for this calculation was increased according to Table 1. These values are adequate for foils as thin as 0.05 mm. Other SANDYL calculations show that for thinner foils, the substep number should be increased still further. These latter results have not yet been compared with experimental data.

The first of eight unit cells in the calculation

Figure 3. The SANDYL code calculated scattering of photons and electrons in an array of eight film-screen unit cells, the first of which is shown here. This figure also shows the thick tantalum front filter used to absorb low-energy photons.

In the zoning of the problem we tried to simulate as closely as possible the film pack that was used in a recent dynamic experiment. In that event, there were 13 unit cells of 8 layers each which, when added to the editing regions, exceeded the code-imposed maximum of 110 zones. The following compromises and assumptions were made because of this zone limit:

1. The calculation was made for 8 films, which was sufficient to show the effect of pack blur.

2. The film base and its two gelatin/halide emulsions were considered to be a single material. The gelatin was modeled as pure carbon. The gelatin and the AgBr were distributed throughout the base, which was assumed to be DuPont Mylar.

With the chemistry thus established, the atomic fractions were adjusted from measured densities. A value of 52% was used for the fraction of AgBr in the emulsion. Since the emulsion is only 3% of the total film thickness, it was unnecessary to calculate the scattering in the emulsion separately from scattering in the base. However, a previous SANDYL calculation of energy deposited in such a film distributed 40% of the deposited energy in the emulsion and 60% in the Mylar base.

3. The light-emitting screens were treated as two layers: the base was treated as Mylar, and the active light-emitting portion was treated as expanded CaWO₄, without binder, but with a measured density of 3.803 g/cm³.

The first and eighth emulsions
were divided into 13 edit zones

Figure 4. In the SANDYL code calculation, the first and eighth films were radially zoned in 0.2-mm increments for editing purposes, as shown here.

Table 1. Electron substep values.

Material	Highest atomic numbers	Default number of electron substeps	Number of electron substeps in this calculation
Tantalum	73	16	150
Mylar	8	3	24
CaWO ₄	74	16	150
Film	47	11	135

Calculational Results

A series of CaWO_4 screens are available with different thicknesses and fluorescence characteristics. The most sensitive combination uses NDT9 screens with XAR5 film. In the NDT9 screen, the phosphor is 0.53 mm thick. In the NDT6 screen, it is 0.25 mm thick. The thinner phosphor may yield less edge blur without too great a loss of film density. To investigate the effect of phosphor thickness, an additional film pack was calculated, composed of 0.2-mm-Ta/NDT6 screens. Each unit cell of the 0.15-mm-Ta/NDT9 combination has an areal density of 0.751 g/cm^2 , while the 0.2-mm-Ta/NDT6 combination cell density is 0.637 g/cm^2 .

Figures 5 and 6 show the results of the calculation for 0.15-mm-Ta/NDT9 screens. In those figures, we have plotted the energy deposited in the edit zones as a function of radius for the first and eighth films. We took the 25%-75% range as a measure of edge blurring; this yielded values of 0.6 mm for the first film and 0.8 mm for the eighth. Similar curves for the 0.2-mm-Ta/NDT6 screens yielded statistically the same results: 0.7 mm for the first film and 0.8 mm for the

eighth. However, the energy deposited due to electrons in the CaWO_4 for this latter combination was 50% less. Consequently there was less density in the emulsion for the same exposure.

The standard deviation in these calculations ranged between 3% and 110%, depending on which editing zone was examined. Nonetheless, the mean standard deviation for all 13 editing zones in a film was 31%. The magnitude of these errors is shown on Figs. 5 and 6. The problems ran slowly on the CDC 7600 computer because of the greatly increased number of substeps in the electron transport section. Each problem took nearly 16 hours of machine time.

Table 2 lists the distribution of energy deposited by photons and electrons in the various components of the film pack. Thickening the tantalum screens from 0.15 mm to 0.21 mm resulted in 19% more energy deposition in the tantalum, while decreasing the CaWO_4 thickness resulted in a 20% drop in energy deposited in them. This calculated result compares favorably with the experimental findings given earlier.

Figure 5. SANDYL calculation of the energy deposited in the first film (0.15-mm tantalum, NDT9 screens, XAR5 film, 4-MeV photons). The energy deposited in the edit zones is plotted as a function of radius. Taking the 25%-75% range as a measure of edge blurring yields a value of 0.6 mm for this film.

Figure 6. SANDYL calculation of the energy deposited in the eighth film (0.15-mm tantalum, NDT9 screens, XAR5 film, 4-MeV photons). The energy deposited in the edit zones is plotted as a function of radius. Taking the 25%-75% range as a measure of edge blurring yields a value of 0.8 mm for this film.

Table 2. Summary of calculated energy deposits.

Materials	0.15-mm Ta/NDT9 screens		0.21-mm Ta/NDT6 screens	
	Deposited energy, MeV/source γ	% of total	Deposited energy, MeV/source γ	% of total
Tantalum screens	0.257	40	0.329	59
Bases of CaWO_4	0.058	9	0.058	10
CaWO_4	0.308	47	0.153	27
Bases of the films	0.014	2.4	0.014	2.4
Emulsions	0.010	1.6	0.010	1.6
Total energy deposited, MeV/source γ	0.647		0.563	
Areal density, g/cm ²	0.751		0.637	

References

1. H. M. Colbert, *SANDYL—A Computer Program for Calculating Combined Photon-Electron Transport in Complex Systems*, Sandia Laboratories, Livermore, CA, SLL-74-0012 (May 1974).
2. D. R. Goosman, *Comparison of the SANDYL Monte-Carlo Code Calculations of 20.9-MeV Bremsstrahlung with Published Experimental Data*, Lawrence Livermore National Laboratory, Livermore, CA, UCID-19791 (April 27, 1983).

Appendix A

Film-and-Screen Combination for Experimental Exposure

Table A1. Film-and-screen combination for experimental exposure.

Film No.	Material	Thickness (mm)	Background fog after exposure, diffuse density	Diffuse density	
				Dark region	Light region
1	Tantalum	0.51	0.15	1.36	0.81
	NDT9	0.53			
	XAR5	0.19			
	NDT9	0.53			
	Tantalum	0.15			
2	NDT9	0.53	0.15	1.29	0.73
	XAR5	0.19			
	NDT9	0.53			
	Tantalum	0.15			
	NDT6	0.25			
3	XAR5	0.19	0.14	0.59	0.34
	NDT6	0.25			
	Tantalum	0.25			
	NDT6	0.25			
	XAR5	0.19			
4	NDT6	0.25	0.15	0.55	0.31
	Tantalum	0.25			
	NDT9	0.53			
	XAR5	0.19			
	NDT9	0.53			
5	Tantalum	1.02	0.14	1.30	0.72

Appendix B

Material Parameters for the SANDYL Calculation

Table B1. Dupont calcium tungstate screens.

Item	Total thickness (mm)	CaWO ₄ and binder thickness (mm)	Density (g/cm ³)	Composition, at.% (wt%)				
				H	C	O	Ca	W
Base	0.24	—	1.4	36.36	45.45	18.19	—	—
CaWO ₄	—	—	3.82	—	—	66.67	16.67	16.67
[CaWO ₄]	—	—	—	—	—	[22.22]	[13.92]	[63.86]
NDT4	0.47	0.24	—	—	—	—	—	—
NDT6	0.49	0.25	—	—	—	—	—	—
NDT9	0.77	0.53	—	—	—	—	—	—

Note that the chemistry of the base was not determined. The numerical values used here to describe the base are those for the Dupont polyester Mylar, because that material is considered representative. Also note that the measured density of the active portion of the screen was 3.803 g/cm³, while that of pure CaWO₄ is 6.06 g/cm³. The composition of the binder was neglected in this calculation because its contribution to scattering and energy absorption was considered small compared to that of the CaWO₄.

Table B2. Eastman Kodak XARS film.

Base thickness, mm	0.178
Emulsion thickness (one side), mm	0.006
Total thickness, mm	0.190
Base density, g/cm ³	1.4
Fraction AgBr in emulsion, wt%	52%
Film density, g/cm ³	1.46
Composition (including base), at.%	
H	34.84
C	47.24
O	17.61
Br	0.26
Ag	0.26

Note that the gelatin was assumed to be totally carbon, and any superlayers were neglected. As in Table B1, the chemistry of the base was not determined, and the values used here are for Mylar, a representative material.