PREPRINT UCRL-78835

CONF-761006--17

Lawrence Livermore Laboratory

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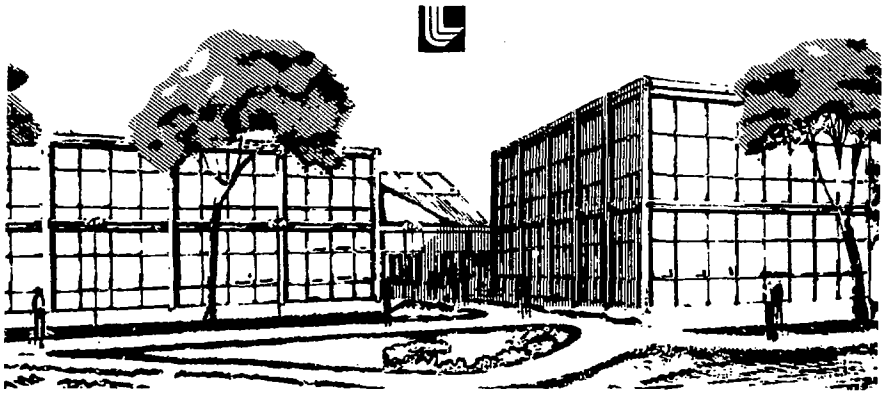
November 17, 1976

MASTER

This paper was prepared for submission to
IEEE Transactions Nuclear Science Symposium
New Orleans, LA, October 11, 1976



SUB-NANOSECOND PLASTIC SCINTILLATOR TIME RESPONSE STUDIES USING LASER PRODUCED X-RAY PULSED EXCITATION*

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ABSTRACT

The light emission time response of quenched NE111 plastic scintillators has been measured using a streak camera (20 ps resolution) and 100 to 180 ps, 1.06 μm, laser-produced, pulsed, low energy x-ray excitation. Each light output pulse was obtained by deconvolution from the film data using the x-ray temporal response measured with an x-ray sensitive streak camera (10 ps resolution). Time response parameters are presented for benzophenone and acetophenone, quenching agents which most effectively reduce the decay time of the singlet component. Full width-half-maximums ≤ 260 ps were observed for NE111 samples quenched with ≥ 2% benzophenone. Results are given for unquenched samples consisting of different concentrations of butyl-PBD in PVT and for the phosphor ZnO doped with Ga.

INTRODUCTION

Plastic scintillators are used in many types of particle and photon detection systems to convert the incident ionizing radiation to light. Extremely fast plastic scintillators are needed for many applications such as plasma diagnostics. Quenched plastics will fill this need for those applications which do not require maximum sensitivity but which require superior time response. The development of these scintillators and results of related measurements are presented in another paper.[1]

Because of time resolution limitations of other methods, we have developed a streak camera technique for measuring fluor emission time response. Excitation is with single, laser-produced, low energy x-ray pulses. Since the basic resolution of the streak camera[2] is 20 ps, the measurement is limited by the 100 to 180 ps FWHM of the x-ray emission. However, by simultaneously recording the x-ray emission response with an x-ray sensitive streak camera[3], we are able to obtain the light output pulse by deconvolution. This technique provides better basic time resolution than other methods. For example, the single photoelectron method using fast photomultiplier tubes typically has 600 ps system resolution.

With low energy x-ray excitation, thin polished samples can be used and various geometrical effects can be greatly reduced, e.g., self absorption and reemission in the scintillator. Moreover, the Cerenkov background component observed in electron linac excitation is avoided.

A significant decrease in the decay time of the singlet state has been observed after quenching agents are added to the fastest commercial plastic, NE111 (PBD (40mg/ℓ) in a PVT matrix).[4] Two of the most effective quenching agents include benzophenone and acetophenone. We have, therefore, chosen to study NE111 quenched with these compounds in concentrations ranging from 1/2% to the onset of polymerization failure (approximately 15%).

In addition, a group of plastics was studied to investigate the effect of varying butyl-PBD concentration in PVT. Butyl-PBD was chosen for its resemblance to PBD and for its higher solubility. It was hoped that a faster time response would result from increased solute concentrations as was observed by Birks in his study of PBD in PVT.[5]

EXPERIMENTAL PROCEDURE

The experimental arrangement is shown in Fig. 1. A 1.06 μ, 1 J, 150 ps laser pulse in focused on an iron slab at the center of an evacuated chamber. As the result of the plasma interaction, an x-ray pulse is produced with FWHM in the 120-180 ps range and a spectral shape as shown in Fig. 2. (The x-ray energy distribution was measured with a 7-channel P-I-N diode array with appropriate K-edge filters.)

Two streak cameras are mounted symmetrically with respect to the laser beam and target to detect similar portions of the emitted x-ray pulse. Three plastic scintillator samples (3mm x 9mm x 62mm) were assembled in a 3-channel vacuum light guide (3-shooter). X-rays transmitted through a 25 μm Be light shield interact with the scintillators. The light emitted from each is guided to separate sections of the photocathode of an UV sensitive S-20 ultrafast streak camera. A light guide is necessary to provide sufficient recordable light intensity. Material dispersion was avoided by using an evacuated guide with silvered walls for high reflectance in the fluor emission wavelength region (≈ 3800 A). The three shooter permits more accurate measurements of relative total light output because the three scintillators sample a nearly identical portion of the x-ray pulse. A photographic view of the light guide, sample holder, mounted scintillators, and Be shield is shown in Fig. 3. The sides of the samples are blackened and each glass sample retaining well is coated to suppress internal sample reflections.

X-ray pulse shape information was recorded on each shot to take into account variations in laser pulse duration. The x-ray streak camera was operated at approximately 40 ps/mm compared to 100 ps/mm for the optical streak camera.

DATA ANALYSIS

The scintillator raw data is a convolution of the fluor time response, the light guide time dispersion, and the input time response of the x-ray pulse. The light guide time dispersion is required to deconvolve the time response of the light emitted from the scintillator. The x-ray time response is required to deconvolve the scintillator time response due to an instantaneous x-ray input. The general data analysis procedure is outlined in Fig. 4.

Typical raw data for both the x-ray streak camera and the 3 shooter are shown in Fig. 5. The raw film data is scanned by means of a micro-densitometer. Several scans are made to reduce the data noise level and are recorded on tape for computer processing. The step wedge technique is used to generate a D-log(E) film calibration curve in order to obtain relative intensities from the film data. Results for a single scan are shown in Fig. 6.

*Work performed under the auspices of the U.S. Energy Research And Development Administration W-7405-eng-48

This data is corrected for the non-linear streak speed of each camera. The optical streak camera distance-time conversion curve was based on accurately known dimensions of an etalon. The etalon was used to develop a laser pulse train with a known pulse separation which was fed directly to the S-20 entrance slit. A laser-generated, double x-ray pulse was used to calibrate the x-ray streak camera. Additional data were obtained by using the x-ray streak camera deflection circuitry coupled to an optical streak camera of the same internal design and employing the standard optical camera calibration technique.

Relative intensities were corrected to account for the linear dependence of film exposure on the streak camera sweep velocity. An example of an x-ray time response thus derived is shown in Fig. 7. The calculated time dispersion of the light guide, which is discussed in Appendix A, is also shown for comparison.

As can be inferred from Fig. 7 the deconvolution is relatively insensitive to the uncertainty in the light guide calculation. Prior to the unfolding procedure the corrected scintillator data was smoothed as shown in Fig. 8. A typical resultant time response is compared to the filtered input in Fig. 9.

RESULTS

The experimental results are summarized in Table 1. The time response measurements of the benzophenone quenched samples are shown in Fig. 10. The 10% to 90% rise times were roughly 100 ps for all samples. Except for the total light output, the time response parameters for the butyl-PBD samples were remarkably consistent over a wide range of solute concentration. The time response of each sample in this group is faster than that of NE111. The lack of a trend for the time parameters and the inconsistent values for total light emission suggest an uncertainty in the composition of the sample surfaces. (Note that the x-ray deposition occurs mainly in the first 30 μm).

As shown in the table, the quenching effect of acetophenone is similar to that of benzophenone. We observe a decrease in the FWHM with increasing quencher concentration to a limiting value ≈ 200 ps. The percentage of peak intensity measured 400 ns after the peak decreases monotonically as does the total light output of the benzophenone quenched samples.

The measured time response of ZnO phosphor doped with Ga was found to be independent of thickness. Averages were therefore tabulated. The FWHM values obtained for samples produced by Westinghouse were all about 250 ps. The observed decay constant is also relatively short (340 ps). Nuclear Enterprise samples, possibly due to impurities, yielded a FWHM greater than 2 ns.

DISCUSSION

The observed ~400 ps FWHM for each of the NE111 control samples is not in agreement with values of 1.05 ns obtained using the electron linac. This does not appear to be due to problems with the streak camera technique. Tests with the laser have ruled out light transmission through the Be filter, a possible cause for a fast component. The streak speed calibration is considered good to within 10% on an absolute basis. The validity of the intensity correction is indicated by good agreement between results obtained for shots differing greatly in raw data intensity.

Most probably the disagreement is due to differences in sample excitation. High energy electrons excite the total sample volume. X-rays excite a thin surface layer, that part of the sample which is most susceptible to contamination. Instability or contamination of quenched plastic fluor surfaces may be a serious problem. Thus, a detailed comparison of measured light pulse shapes with theoretical models is not yet warranted.

APPENDIX A

LIGHT GUIDE TRANSIT TIME DISPERSION CALCULATION

The time dispersion of the light guide was calculated assuming uniform isotropic emission of light from the scintillator. Rays reflected from the silvered interior surfaces were traced from the scintillator to the streak camera entrance slit over the light guide geometry in order to determine the distribution of path lengths. The dependence of the reflectance on the angle of incidence was taken into account.[6] Optical constants were used that have been measured for vacuum evaporated silver with some exposure to air.[7] Preliminary calculations were made for a range of wavelengths covering the spectal emission region of NE111. We determined that results obtained for the NE111 peak emission wave-length (3800 A) would provide a good average. Calculations at these wavelengths were repeated using a large number of rays to obtain the results shown in Fig. 7.

We wish to thank Dr. D. Attwood for the use of the Laser facility. We appreciate the advice and assistance of Dr. R. Harding in the data reduction. Data analysis computer programs developed by Dr. J. Weaver were invaluable. We thank C. R. Hurlbut for his efforts in producing the scintillators.

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TABLE I

Measured Time Responses of Scintillators to Pulsed Low Energy X-ray Radiation

SCINTILLATOR	Rise Time (10-90)% ps	FWHM ps	Intensity[a] Peak + 400 ps %	Decay Constant ns	Total[b] Light Output
PVT, Butyl-PBD(50g/ℓ)	110 ± 25	330 ± 30	33 ± 5	0.7 ± 0.2	(100)
PVT, Butyl-PBD(75g/ℓ)	120 ± 40	290 ± 40	35 ± 4	0.8 ± 0.2	32
PVT, Butyl-PBD(125g/ℓ)	110 ± 25	260 ± 50	25 ± 5	0.7 ± 0.2	69
PVT, Butyl-PBD(150g/ℓ)	110 ± 40	320 ± 40	30 ± 5	0.7 ± 0.2	27
PVT, Butyl-PBD(175g/ℓ)	120 ± 50	280 ± 40	22 ± 5	0.8 ± 0.2	--
PVT, Butyl-PBD(200g/ℓ)	110 ± 50	360 ± 60	28 ± 4	0.8 ± 0.2	56
NE111	100 ± 25	400 ± 40	38 ± 5	0.7 ± 0.3	(100)
NE111 + 5% Acetophenone	100 ± 25	230 ± 30	8 ± 3	0.6 ± 0.3	2
NE111 + 15% Acetophenone	90 ± 25	240 ± 30	<5	0.5 ± 0.3	9
NE111 (control)	110 ± 30	400 ± 40	35 ± 5	1.4 ± 0.5	(100)
NE111 + 0.5% Benzophenone	110 ± 40	360 ± 60	27 ± 5	0.7 ± 0.3	35
NE111 + 2% Benzophenone	100 ± 30	260 ± 40	21 ± 4	0.7 ± 0.3	10
NE111 + 5% Benzophenone	110 ± 40	260 ± 40	8 ± 3	0.7 ± 0.3	6
NE111 + 10% Benzophenone	100 ± 30	220 ± 30	3 ± 2	>1.5	6
NE111 + 15% Benzophenone	100 ± 30	230 ± 40	2^{+3}_{-1}	>2.5	4
ZnO(Ga)[c]	100 ± 25	250 ± 25	21 ± 6	0.34 ± 0.10	

[a] Percentage of peak intensity 400 ps after the peak.

[b] Total light output relative to that of the first sample in the group.

[c] Average of four samples ranging in thickness from 1/2 to 6 mg/cm^2.

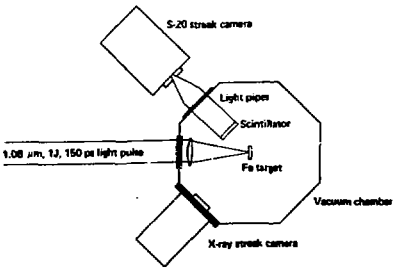

Fig. 1. Experimental arrangement used to measure scintillator time responses.

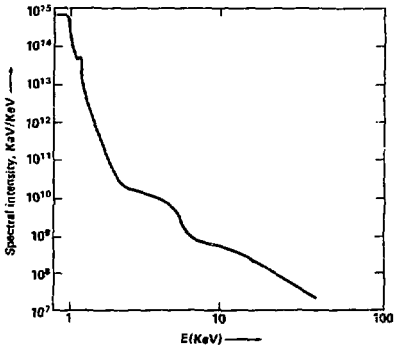

Fig. 2. Energy distribution of x-rays emitted from the iron slab target.

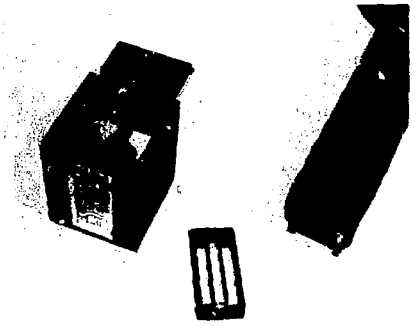

Fig. 3. View of the light guide, scintillators, sample holder and Be light shield.

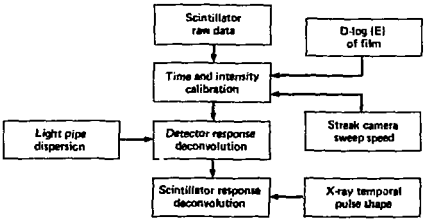

Fig. 4. General data analysis procedure.

Fig. 5. Raw experimental film data for both the x-ray and optical streak cameras.

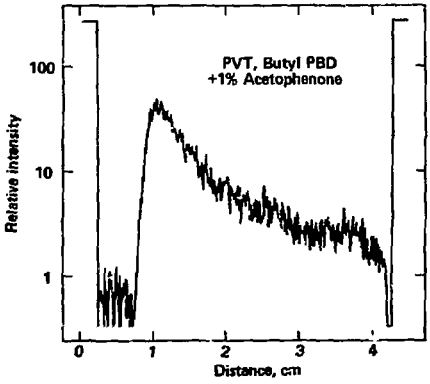

Fig. 6. Single micro-densitometer scan of the optical streak camera data. A step wedge generated D-log(E) curve has been used to obtain relative intensity vs film distance.

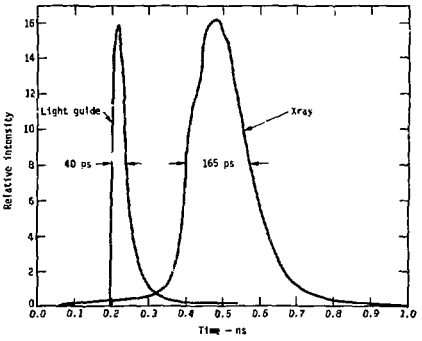

Fig. 7. Typical measured x-ray time response compared to the calculated fluor emission transit time spread in the vacuum light guide.

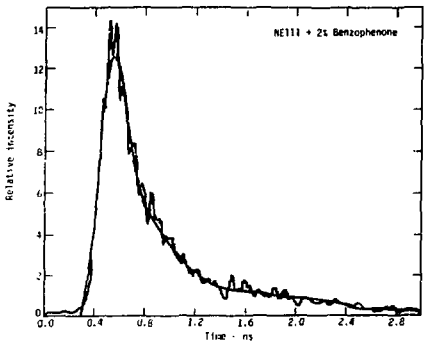

Fig. 8. Corrected scintillator streak camera data before and after Fourier smoothing.

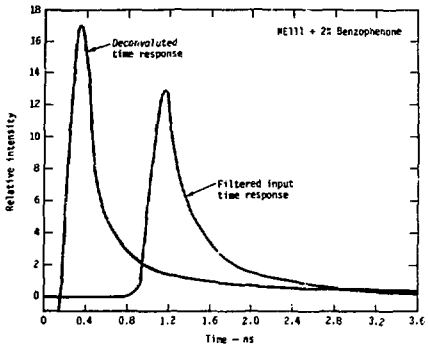

Fig. 9. A typical unfolded time response compared to the filtered input.

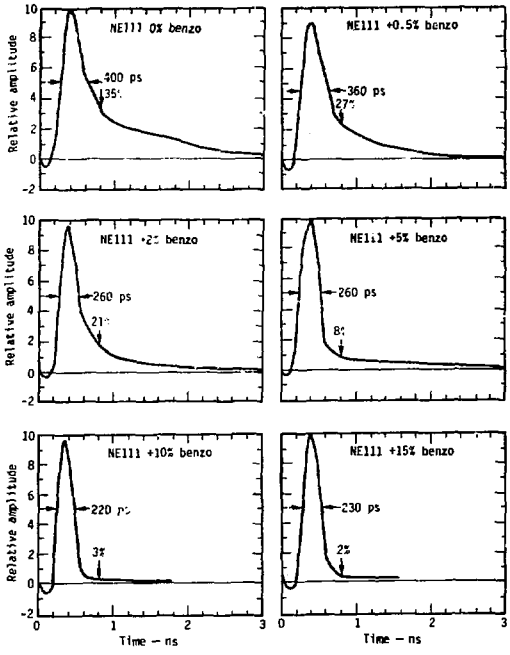

Fig. 10. Measured time responses of NE111 scintillators to low energy x-ray excitation. Benzophenone quencher concentration ranges from 0 to 15%. Initial negative excursions result from unfolding and are not real.