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PULSE WIDTHS EFFECTS ON SCINTILLATOR SATURATION

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PREFACE

Presented herein is the final report submitted to the University of California (LLL) by the Lockheed Palo Alto Research Laboratory (LPARL) for contractual research performed under Contract (PO 9451903). The work involved an investigation into the pulse-width effects on scintillator saturation using bursts of low energy (≤ 2 keV) x rays.

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Section 1
INTRODUCTION

Organic scintillators are playing an ever increasing role in the detection of short, intense bursts of x rays. Consequently, it is important that the response characteristics to low-energy x rays be ascertained accurately. One of the properties which is of major importance in evaluating data taken at high intensities is that of nonlinear saturation effects. A study of these effects was performed at the Lockheed Palo Alto Research Laboratory (LPARL) (Ref. 1) using a 200-ps pulse of x rays ($E_x \lesssim 2$ keV). No nonlinear effects were observed in the response of NE102 and NE111 at irradiances $\leq$ 15 mJ/cm^2-ns. These measurements provide the only data available regarding nonlinear effects at high x-ray doses.

Stevens and Knowlen (Ref. 2) have conducted similar saturation studies using pulsed high-energy electrons with pulse widths $\geq$ 6 ns. The point at which they observed nonlinearity was dependent not only on total dose but on dose rate as well. The extrapolation of their data to the 0.2-ns width used in the LPARL experiments, however, indicate an apparent inconsistency between the two sets of data. The results of Steve and Knowlen predict the occurence of nonlinear saturation effects at irradiances two orders of magnitude lower than the 15 mJ/cm^2-ns employed in the LPARL experimen s. Other investigations (Refs. 3 and 4) with electron-beam pulses $\geq$ 6 ns support qualit tively the results of Stevens and Knowlen.

The present experiment was therefore undertaken to uncover the source of the discrepancy between the x-ray and electron-beam saturation measurements so that future x-ray diagnostic packages can be designed for optimum performance.

The experiment involves measuring nonlinear effects on a number of organic scintillators at x-ray pulse widths equivalent to those used in the electron-beam measurements. The LPARL high-powered pulsed Nd (Glass) laser facility was configured into a long-pulse ($\leq$ 10 ns) mode for the present investigation. The preliminary procedures, such as configuring the laser cavity for long pulses, obtaining x-ray irradiance calibrations, and fabricating monitor systems are described in Section 2.

Section 3 describes the characterization of the x-ray spectrum used in the saturation studies through a series of spectrometer measurements. The actual performance of the saturation experiments using x rays from a copper target is described in Section 4. Measurements were performed, using a 6.5-ns-wide x-ray pulse, on NE111 and NE102 organic scintillators as well as on NE111 doped with benzophenone, acetophenone, and piperidine. In addition, NE111 was investigated at x-ray pulse widths of 2 and 4 ns. A summary of the present study is given in Section 5.

Section 2
PRELIMINARY EXPERIMENTAL PROCEDURES

Previous studies conducted at LPARL on the saturation properties of organic scintillators to low-energy x rays were performed at a laser pulse width of 0.2 ns. To continue similar studies but at longer pulse widths (≥ 1 ns) it was necessary to reconfigure the laser cavity from mode locking to a giant pulse mode. A Pockel cell switching system was set up to switch out prescribed segments of the main giant pulse using charged clipping cables.

The temporal profile of the laser pulse was monitored by a photodiode that detected a small sample of the laser beam reflected from a pellicle positioned just before the entrance to the target chamber. This same detector monitored a sample of the unswitched portion of the laser oscillator pulse. The latter pulse was delayed through the appropriate optical path such that both pulses could be displayed on a single oscilloscope trace. This system provided an online monitor of the laser pulses so that an optimization of the pulse switching system could be maintained as well as providing a record of the laser beam energy for each shot.

The x-ray irradiance was monitored by two detectors positioned at 45 deg to the target on either side of the laser beam. One detector was an x-ray diode (XRD) the other was a scintillator photodiode (FW 114). For the NE111 measurements, the scintillator on the monitor detector was NE111 while, for the NE102 sequence, the monitor scintillator was NE102. Both the XRD and scintillator-photodiode monitors were calibrated against a "standard" tantalum foil calorimeter. During the calibration measurements and actual saturation experiment, identical (12.7 or 25.4 μm) beryllium foils were used on all detectors. This ensured that all detector systems experienced the same incident low-energy spectrum.

A typical laser output with a 7-ns clipping cable was approximately 10 to 15 J. For a copper target this translated into a 6.5-ns-wide burst of x rays at levels up to 10 mJ/sr; at a distance of 0.6 cm from the target this corresponds to an irradiance of 4.5 mJ/cm^2-ns. Using the appropriate clipping cable, similar irradiances were achieved for a 2-ns-wide x-ray pulse.

Section 3
SPECTROMETER MEASUREMENTS

Intense bursts of x rays can be generated from targets with a z near 30; consequently, copper targets ($z = 29$) were used in the present measurements. Unfortunately the x rays emanating from a laser-induced copper plasma are not monoenergetic. If one is to analyze the data in terms of dose rates, it is necessary to characterize the x-ray spectrum well enough so that an average penetration depth for the spectrum can be determined. A spectrometer designed to fit inside the target chamber in the close-coupled geometry was used with no screen film and a curved KAP crystal. A series of data runs were taken with 12.7 and 25.4 μm beryllium windows. Figure 1 illustrates a densitometer trace of a typical spectrum taken with 51-μm beryllium foil. The low energy end is cut off by the beryllium foil while, on the high energy side, the drop off is due to the lack of radiation in this energy region. It is difficult to measure the spectrum above 2 keV with this spectrometer arrangement; consequently, a foil transmission experiment was performed using two calorimeters and various thicknesses of beryllium foil on one of the calorimeters. The results indicated that not more than 5 percent of the total emitted x-ray energy lies above 2 keV.

For the analysis of the spectral data, 12 energy bins were selected and an energy histogram was constructed. This histogram is illustrated in Fig. 2 and contains corrections for film and crystal efficiency as well as all geometrical factors. The mean of this frequency distribution is at 1.25 keV. Using known cross-sectional data, a sum of energy deposition as a function of deposition depth was performed for the 12 bins in the histogram. The results of this investigation are illustrated in Fig. 3; as shown, 63 percent ($1-e^{-1}$) of the energy contained in the spectrum of Fig. 1 is deposited in the first 10 μm of the scintillator. In addition, the total energy contained in the spectrum (after efficiency corrections) agrees very well with the monitor data taken for that shot. This again is an indication that very little energy is contained in the spectrum above 2 keV. Nonetheless, to test how sensitive the average deposition depth might be to high-energy x rays, a calculation was performed where a 13th

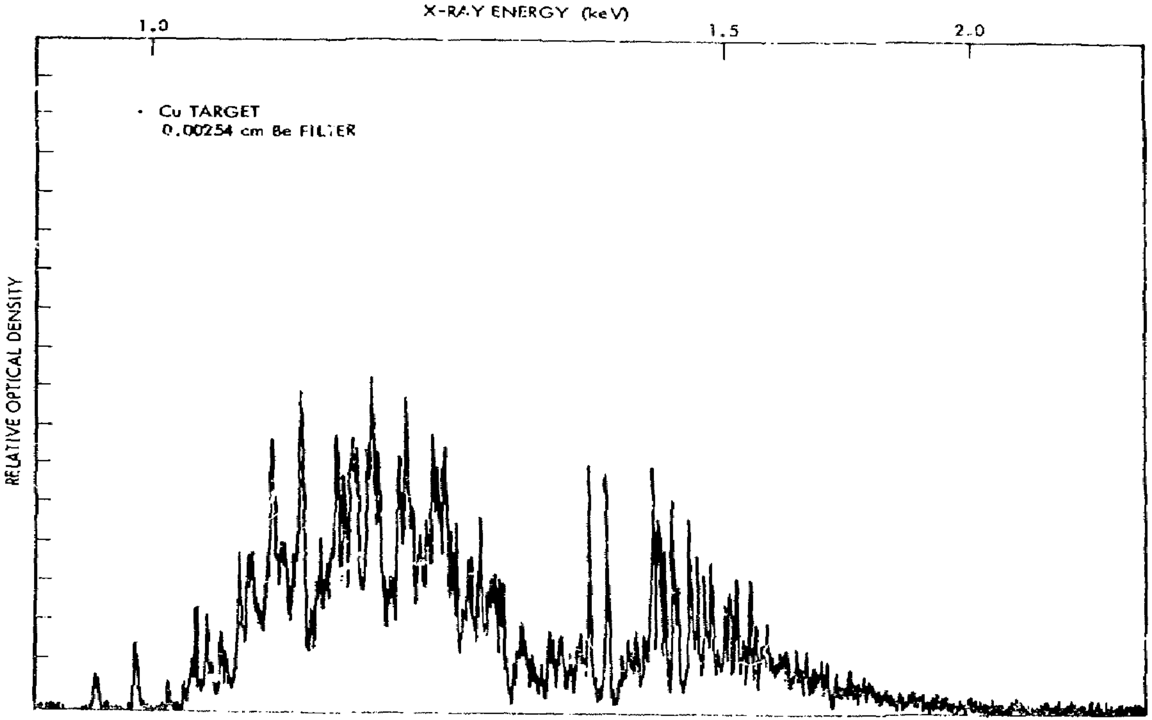

Fig. 1 Microdensitometer Analysis of Typical Spectrographic Data Taken With No Screen Film and a Cu Target Using Curved-Crystal (KAP) Spectrometer. Laser pulse characteristics are similar to those used in collection of scintillator saturation data presented in this report

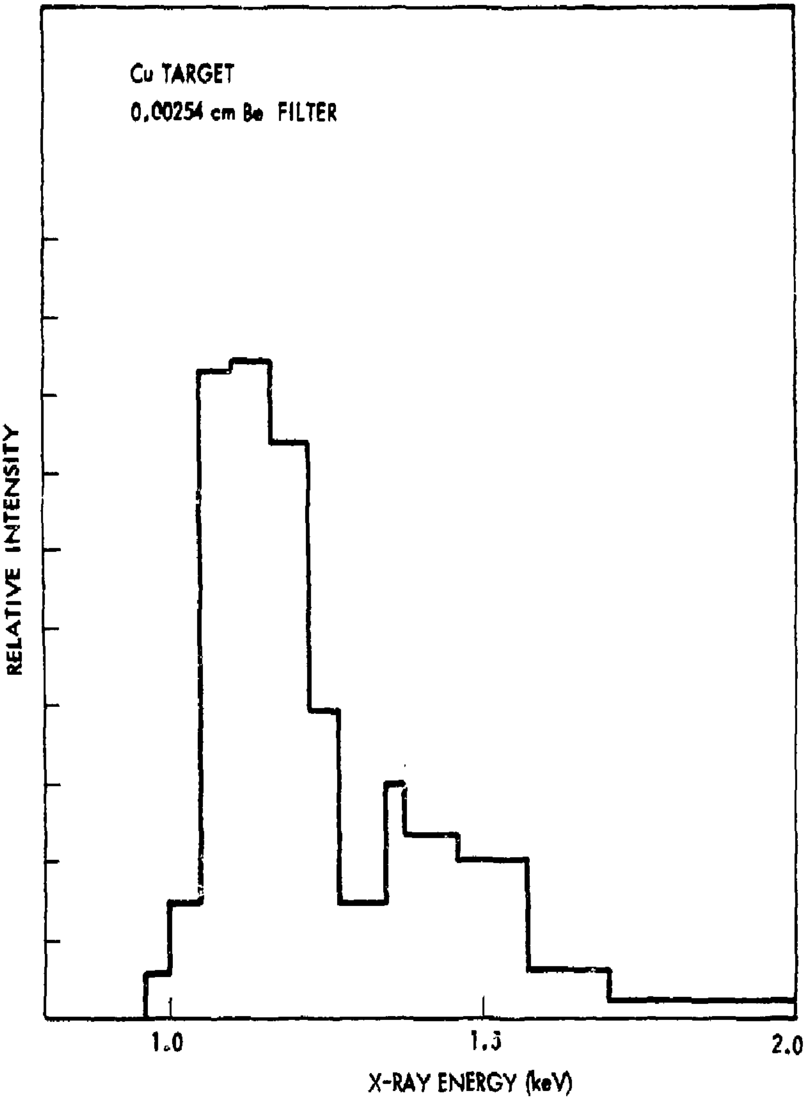

Fig. 2 Histogram Constructed From Spectrum Presented in Fig. 1 and Corrected for Geometric, Film, and Crystal Efficiencies. Relative intensity is proportional to units of photons/cm^2-keV. Mean energy value of this distribution is 1.25 keV

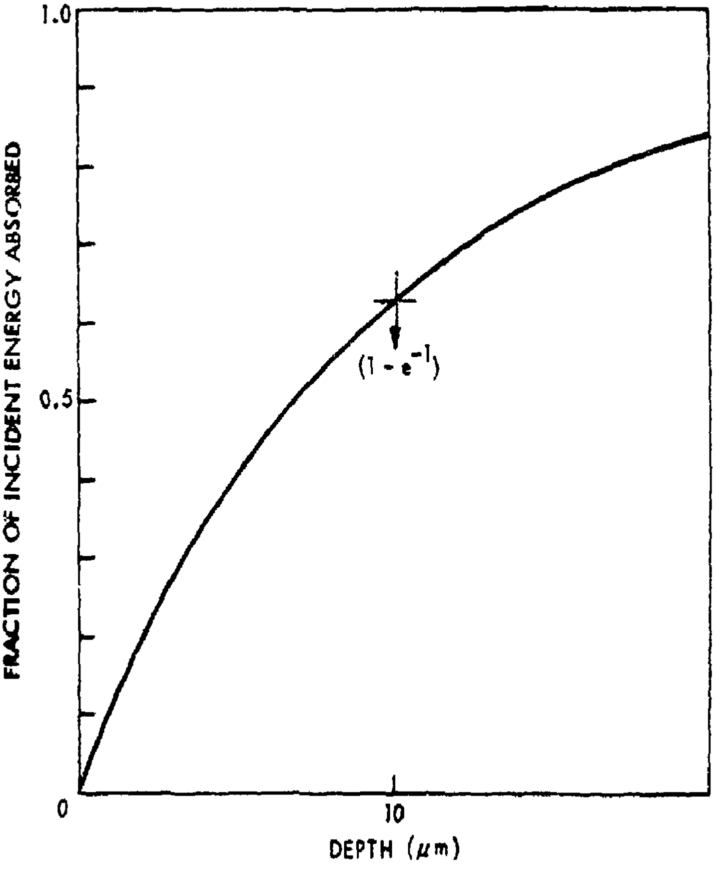

Fig. 3 Plot of X-Ray Deposition Depth in NE111 as Function of Total Incident Energy Absorbed. Curve was constructed from x-ray absorption integration of histographic data of Fig. 2

bin was added and covered the region of 2 to 8 keV. It was found that to increase the deposition depth by a factor of 2, it is necessary to assume that 30 percent of the total energy lies in this bin. As pointed, such a percentage is not consistent with present measurements.

Spectograph data were also taken using 12.7-μm beryllium foil. The average energy of a photon in this case was found to be 1.22 keV.

Section 4
SATURATION EXPERIMENTS

The saturation properties of NE111 were studied at x-ray pulse widths of 2, 4, and 6.5 ns. Those of doped NE111 and NE102 were only investigated at 6.5 ns. In principle, the experiment involved the monitoring of changes in scintillator output with respect to systematic changes in x-ray irradiance. The scintillator samples were disks 0.32 cm thick and 4.13 cm in diameter, which were coupled to an ITT FW114 photodiode through a light pipe and optional neutral density filter (OD1). The neutral density filter was used with the undoped scintillator, otherwise the scintillator light output might, at the highest irradiances, saturate the phototube through space-charge limitation. The purpose of the light pipe was to bring the scintillator (via a special holder through the chamber lid) closer to the target than was previously possible (Ref. 1).

Four factors determined how close to the target the scintillator could be placed: (1) blowoff damage to the beryllium foil, (2) partial occlusion of monitor detectors, (3) introduction of x-ray scattering surfaces that made it difficult to obtain reliable monitor data, and (4) interference with the incoming converging laser pulse. It was found that, at a target spot-to-scintillator distance of 6 mm, any effects due to the above would be avoidable or at a negligible level. However, at distances so close to the target spot the majority of the x rays would pass obliquely through the beryllium foil covering the scintillator and thus suffer a loss of intensity due to the effective increase in foil thickness. To prevent this, a half angle of ≤ 180 deg was ensured by fabricating a series of brass collimators (aperture diameters from 0.254 to 1.27 cm) any of which could be placed over the beryllium foil.

The laser pulse energy was held at approximately a constant level for these measurements so that no changes in the spectral characteristics (described in Section 3) would take place. The normal to the target was at 45 deg to the plane formed by the beam and monitor detectors. The scintillator-diode package was positioned above the target at 45 deg to the normal. See Fig. 4 for a schematic illustration. The diode

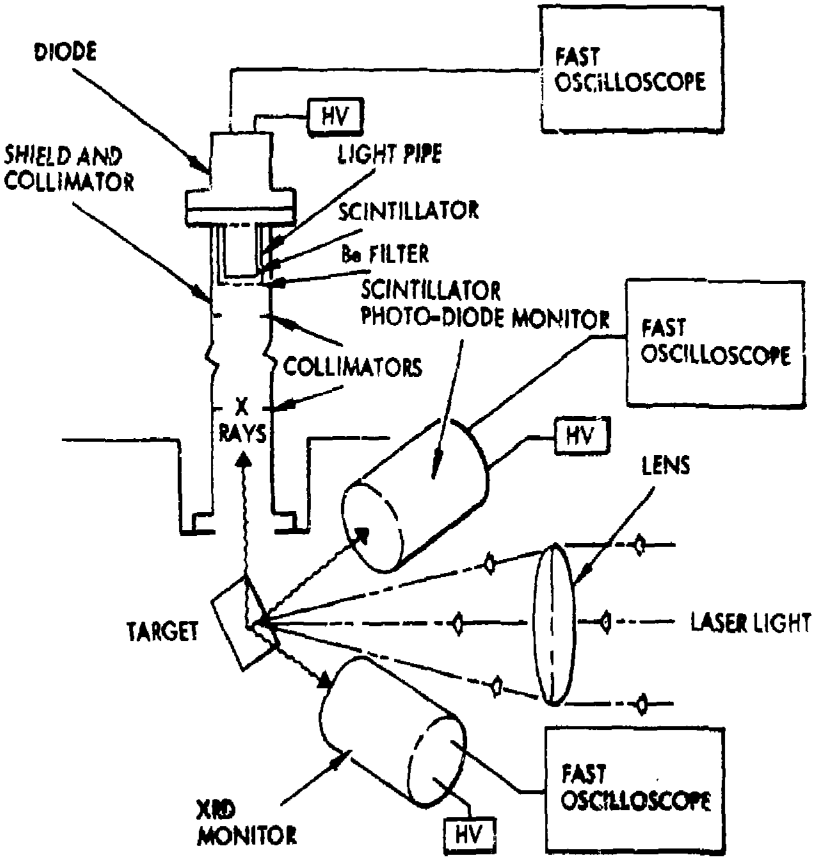

Fig. 4 Schematic Representation of Experimental Arrangement Used in Present Experiment

package was positioned in a well in the chamber lid so that the scintillator and light pipe could be passed through the base of the well and form a vacuum seal. As was pointed out earlier, the closest scintillator-to-target distance was 6 mm. The amount of energy deposited on the surface of the scintillator could be reduced by positioning the diode package at the end of evacuated pipes of different lengths positioned in the well. A series of different length pipes was available, the longest of which placed the surface of the scintillator at a distance of 148 cm from the target spot. To eliminate the possibility of x rays being reflected into the scintillator off the walls of the pipes it was necessary to place apertures of the appropriate diameter in the four longest pipes. Using the system described above the scintillator could be exposed to levels of irradiance covering approximately 5 orders of magnitude.

A series of data runs was taken at x-ray pulse widths of 2 and 6.5 ns for the NE111 scintillator sample. The scintillator used had been purchased from the manufacturer (Nuclear Enterprises) more than a year ago. In order to test the possibility of a surface dead layer having formed during that period, 6.5-ns-wide data were first taken and then the sample was returned to the manufacturer and a 51-μm layer was removed from the surface. The sample was immediately placed in vacuum and returned to the laboratory whereupon saturation measurements were repeated at 6.5 ns and in addition, data were taken at 2 ns. For some of the above measurements, data were collected using a 12.7 μm instead of the 2.54 μm beryllium foil.

From the onset of the experimentation there appeared to be no noticeable difference between the data taken with the unpolished and the polished sample. Although a number of runs were made with different foil thicknesses and pulse widths, only the cases for which a continuous set of data points, covering the nearly five orders of magnitude in irradiance, will be presented for the two x-ray pulse widths. This range was determined, at the high end, by the maximum possible irradiance achievable at a target-spot-to-scintillator distance of 6 mm and, at the low end, by the maximum pipe distance that could be used before the signal was lost in the background noise.

Detector pulses from the XRD monitor were displayed on a 519 Tektronix oscilloscope and were recorded photographically using Polaroid 410 film. The signals from the sample and monitor photodiodes were recorded in a similar fashion but using 7904 Tektronix oscilloscopes. The photographic data were then digitized using TI 980A laser-based computer system and a two-dimensional X-Y table. Using the appropriate computer program, areas under the digitized waveform could be obtained for the formal analysis.

It was necessary to measure the target-spot-to-scintillator distance quite precisely since a small error at such close distances could be quite serious. With the chamber and detector system under vacuum the target-spot-to-scintillator distance for the closest gap was measured by viewing the gap through a glass chamber port with a telescope having calibrated a prism translator.

Since the NE111 detector system has a time resolution ≤ 1 ns, it is not necessary to obtain data experimentally at different x-ray pulse widths in order to make an analytical comparison of nonlinear yields as a function of pulse width. The same analysis can be performed by taking data at a long pulse width (e.g., 6.5 ns) and then integrating over specific temporal portions of the recorded pulse. For the present analysis the 6.5-ns pulse waveforms were integrated over the first 2 ns, first 4 ns and entire 6.5 ns. In each case the time reference was the half height point on the leading edge. Figures 5 through 7 illustrate a plot of the waveform areas over each of these time regions as a function of x-ray irradiance. The error bars on each data point were estimated to be approximately 10 percent. The solid lines through the data points are a least squares fit to the function

$$y = \sum_{0}^{3} a_k x^k \quad . \tag{1}$$

The test for saturation was based on the search for evidence of a nonlinear relationship between yield and x-ray irradiance. Table 1 lists the resulting expansion coefficients from the least-squares fit to the data.

In the case of the 2-ns data the quality of the fit (as indicated by the value of χ^2) does not improve when terms of order higher than $k = 1$ are included. However, in the case of the 4- and 6.5-ns data, the fit quality is improved slightly by the inclusion

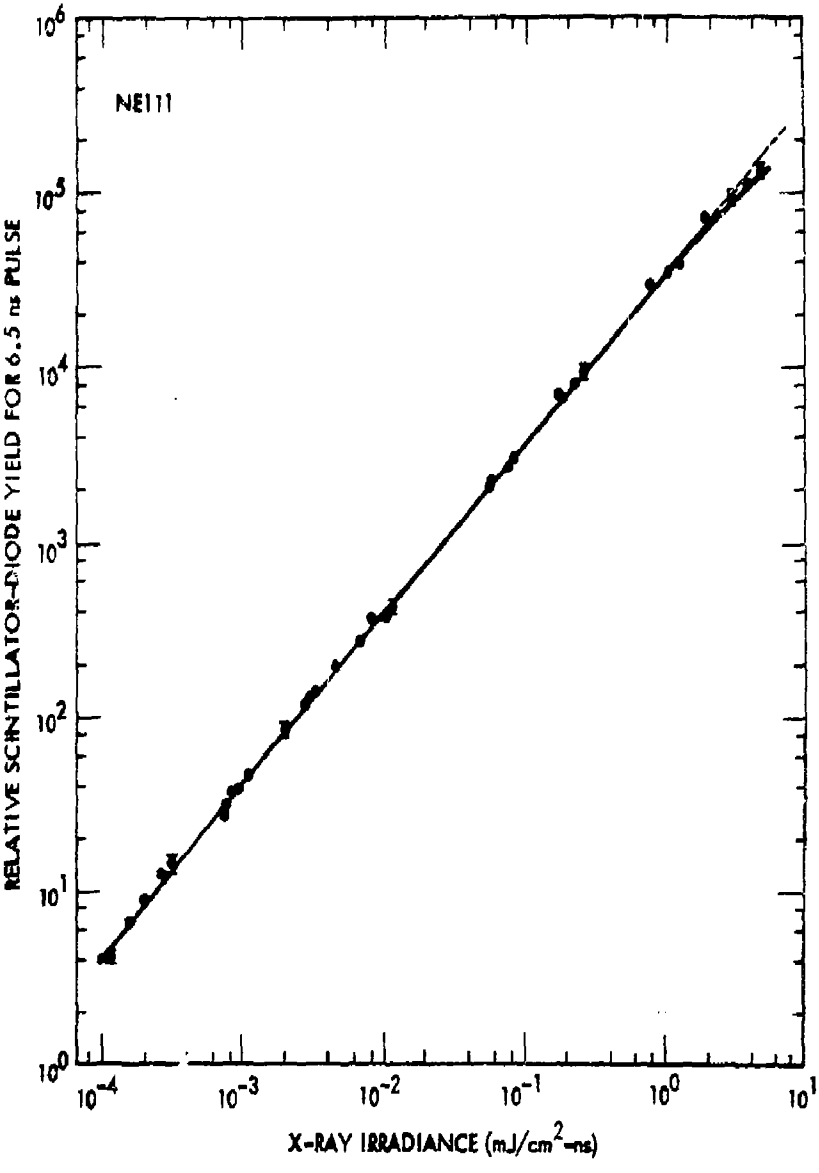

Fig. 5 Plot of Relative Scintillator-Diode Yield, Obtained From Pulse Area, Versus X-Ray Irradiance for Given Laser Shot. These data are for 6.5-ns-wide x-ray pulse. Solid line through data points is best quadratic fit to data while dashed line represents best linear fit. Experimental error on each datum point is approximately 10 percent

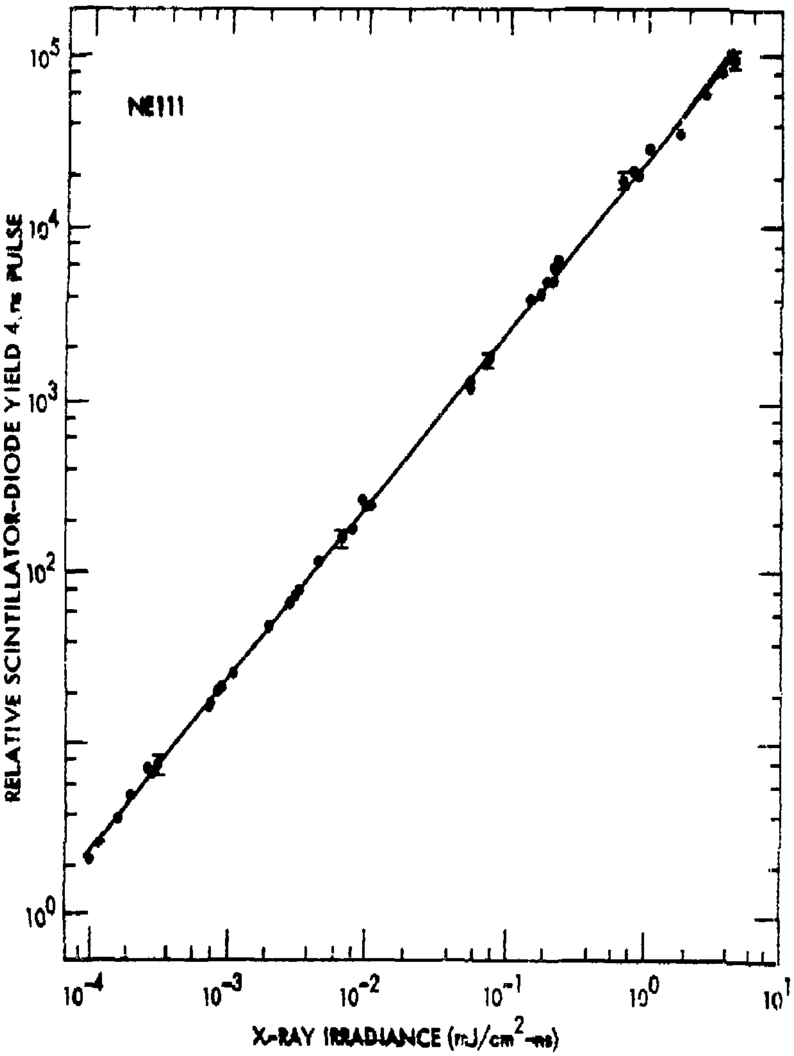

Fig. 6 Plot of Relative Scintillator-Diode Yield, Obtained From Area of First 4 ns of 6.5-ns Data, Versus X-Ray Irradiance for Given Laser Shot. Solid line through data points is best quadratic fit to data while dashed line represents best linear fit. Experimental error on each datum point is approximately 10 percent

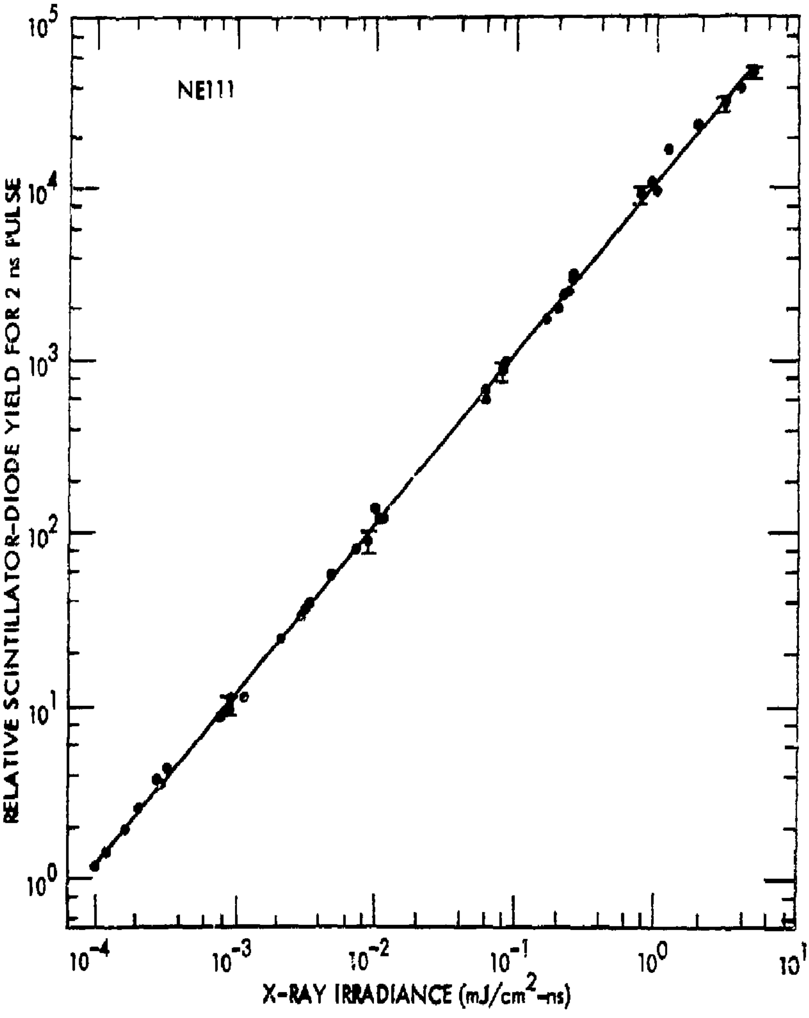

Fig. 7 Plot of Relative Scintillator-Diode Yield, Obtained From Area of First 2 ns of 6.5-ns-Data, Versus X-Ray Irradiance for Given Laser Shot. Solid line through data points is best quadratic fit to data. Experimental error on each datum point is approximately 10 percent

Table 1

RESULTS OF SCINTILLATOR SATURATION DATA ANALYSES USING X RAYS FROM Cu TARGET AND NE111 SCINTILLATOR

Pulse Width (a) (ns)	a_0	a_1	a_2	a_3	χ^2
2(b)	0.11 ± 0.06	11088 ± 159	(d)	(d)	0.82
	0.09 ± 0.06	11192 ± 176	-170 ± 130	(d)	0.81
	0.11 ± 0.06	11078 ± 186	+590 ± 490	191 ± 119	0.79
4(c)	0.08 ± 0.10	22162 ± 258	(d)	(d)	0.67
	0.0 ± 0.08	22641 ± 240	-728 ± 172	(d)	0.55
	0.01 ± 0.09	22690 ± 265	-1031 ± 644	77 ± 157	0.55
6.5	0.456 ± 0.224	38329 ± 566	(d)	(d)	0.84
	0.261 ± 0.167	39502 ± 470	-1651 ± 322	(d)	0.61
	0.255 ± 0.175	39536 ± 527	-1839 ± -1242	47 ± 298	0.63
2	0.20 ± 0.11	11382 ± 330	(d)	(d)	1.53
	0.16 ± 0.11	11738 ± 372	-940 ± 567	(d)	1.40
	0.17 ± 0.11	11622 ± 440	+116 ± 2106	-658 ± 1262	1.43

(a) The values of the data points were based on pulse area.

(b) The values of the data points were taken from the first 2 ns of the 6.5-ns data.

(c) The values of the data points were taken from the first 4 ns of the 6.5-ns data.

(d) For this case the a_k coefficient was assumed to be zero.

of higher-order terms. This is particularly true of the 6.5-ns data and is vividly demonstrated in Fig. 7 at the highest irradiances. The dashed line is a continuation of the linear fit. In the case of the 4-ns data this deviation, although there, is not as pronounced as in the case of the 6.5-ns data. The implication is that saturation is occurring at the highest irradiances for the 6.5-ns wide pulse but not as significantly as for the shorter pulses. As a means of further verifying this notion, the experiment was repeated using a 2-ns-wide burst of x rays. The results are shown in Fig. 8 and Table 1. Although the fit is not as good as the former case, there is no evidence for any serious nonlinearities.

A further evaluation of this situation can be obtained from Fig. 9. This figure compares the monitor and signal pulses for three levels of x-ray irradiance. The solid curve is the monitor pulse while the dashed curve is that of the signal pulse. To make this qualitative comparison, the pulses were normalized to each other by a visual overlay of the leading edges. The waveforms at 6.35 mJ/cm^2-ns were obtained with the scintillator as close as 4 mm. However, as pointed out earlier, data collected that close to the target could not be included in the nonlinearity analysis because of normalization difficulties.

At the lowest level of irradiance illustrated in Fig. 9 the monitor and signal pulse have similar shapes. For intermediate levels the trailing edge of the pulse suffers from what appears to be saturation. At the highest level of irradiance it appears that a major portion of the pulse undergoes some form of saturation.

For the case of NE102 and the doped NE111 samples, data were collected only at an x-ray pulse width of 6.5 ns. The doped samples consisted of 2, 5, and 10 percent benzophenone; 5 percent acetophenone; and 10 percent piperidene. These were all similar in shape and size to the undoped NE111 described earlier in this section. It was known from the studies of NE111 that it would take the highest available irradiance to cause saturation; consequently, data were collected mainly at the high end of the available five orders-of-magnitude range in irradiance. Figures 10 through 15 illustrate the data collected for this portion of the experiment. The error bars on each data point were estimated to be approximately 10 percent. The solid lines through

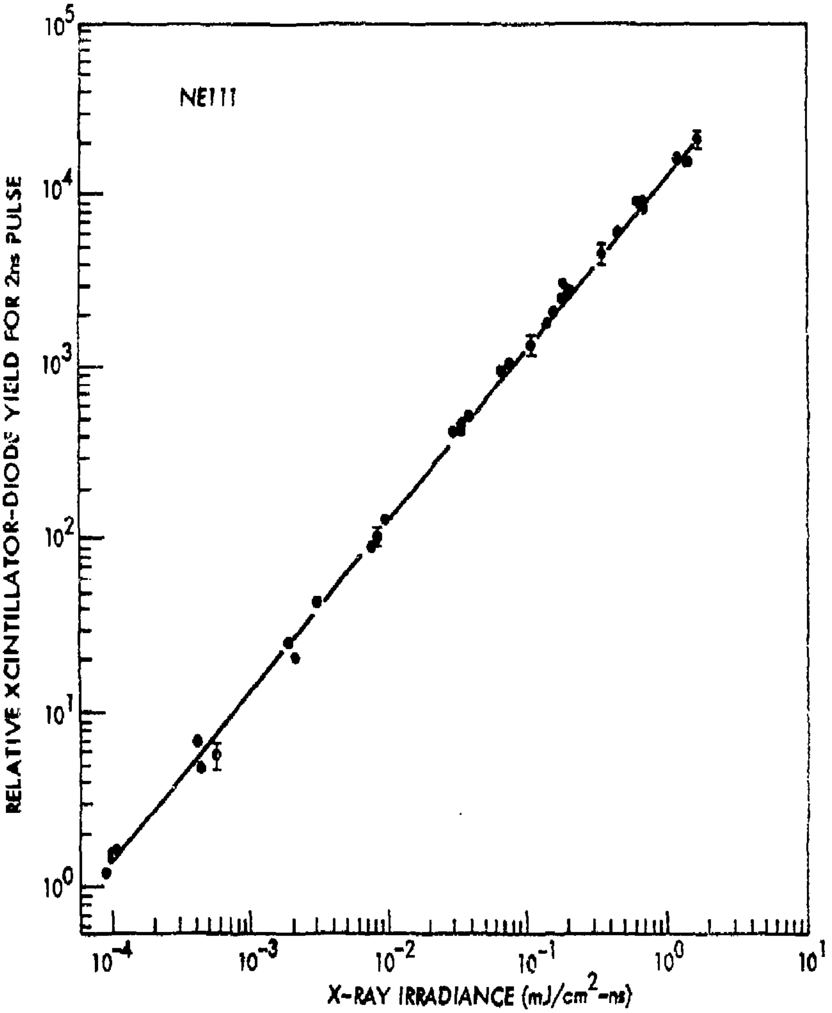

Fig. 8 Plot of Relative Scintillator-Diode Yield, Obtained From Area of Pulse, Versus X-Ray Irradiance for Given Laser Shot. Data are for 2-ns-wide x-ray pulse. Solid line through data points is best quadratic fit to data. Experimental error on each datum point is approximately 10 percent

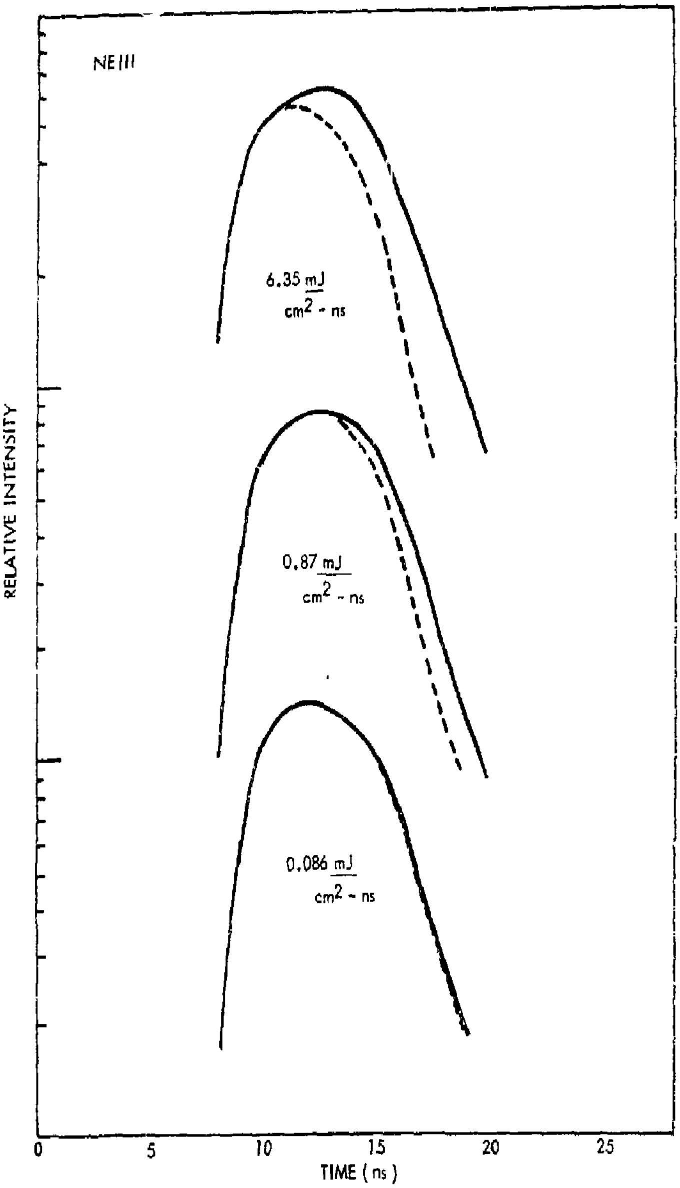

Fig. 9 Comparison of Shape of Monitor and Signal Scintillator-Photodiode Pulses for Three Levels of X-Ray Irradiance. Solid curve is monitor pulse while dashed curve is signal pulse. Pulses were normalized to each other by visual comparison of leading edges

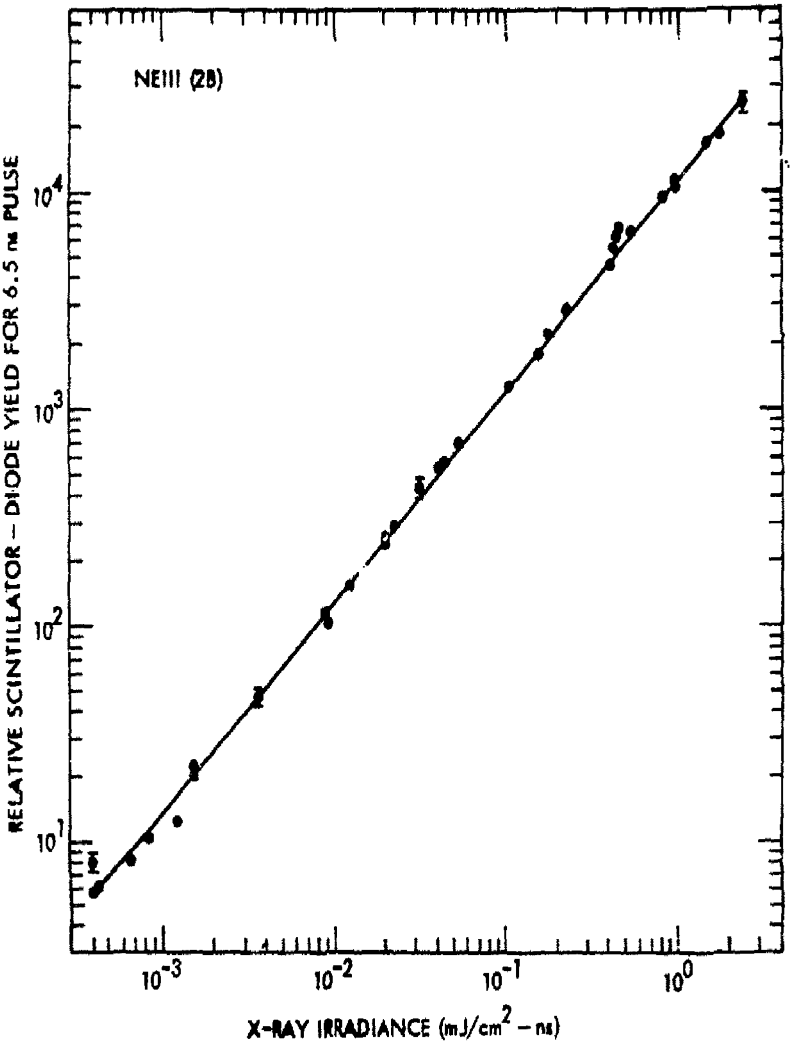

Fig. 10 Plot of Relative Scintillator-Diode Yield, Obtained From Pulse Area, Versus X-Ray Irradiance for Given Laser Shot for NE111 Doped With 2 Percent Benzophenone. Data are for 6.5-ns-wide x-ray pulse. Solid line through data points is best quadratic fit to data. Experimental error on each datum point is approximately 10 percent

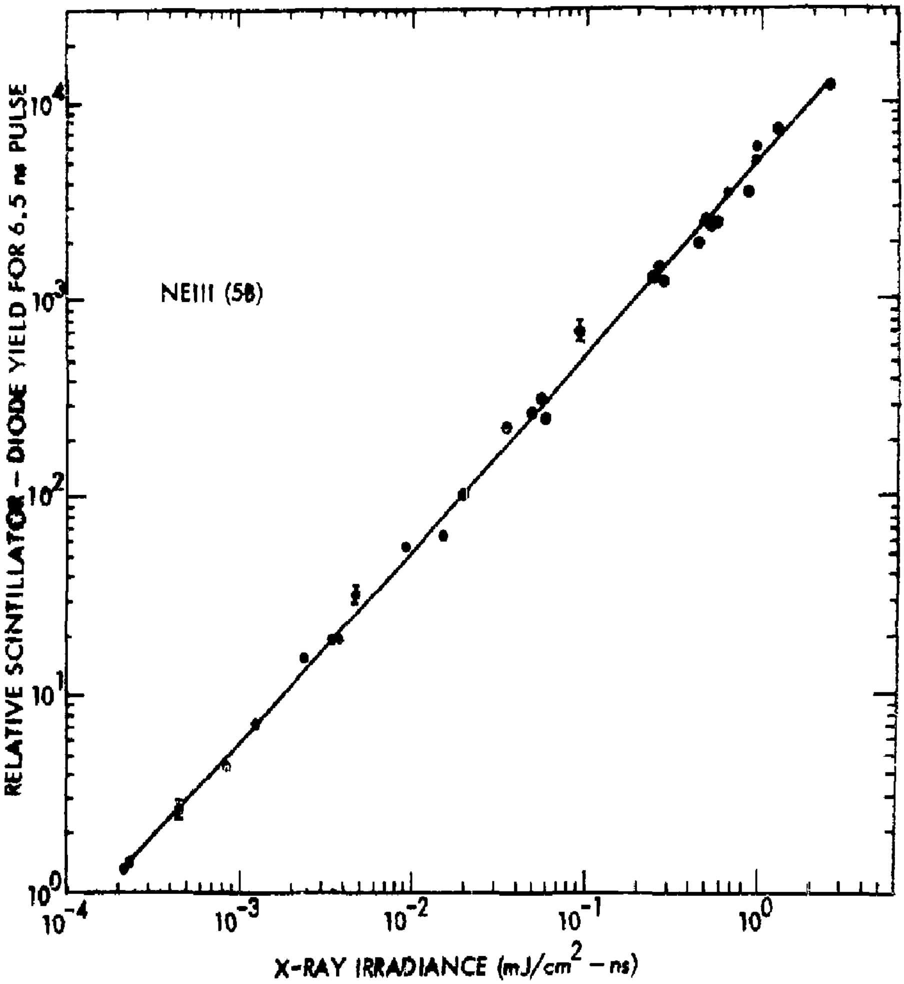

Fig. 11 Plot of Relative Scintillator-Diode Yield, Obtained From Pulse Area, Versus X-Ray Irradiance for Given Laser Shot for NE111 Doped With 5 Percent Benzophenone. Data are for 6.5-ns-wide x-ray pulse. Solid line through data points is the best quadratic fit to data. Experimental error on each datum point is approximately 10 percent

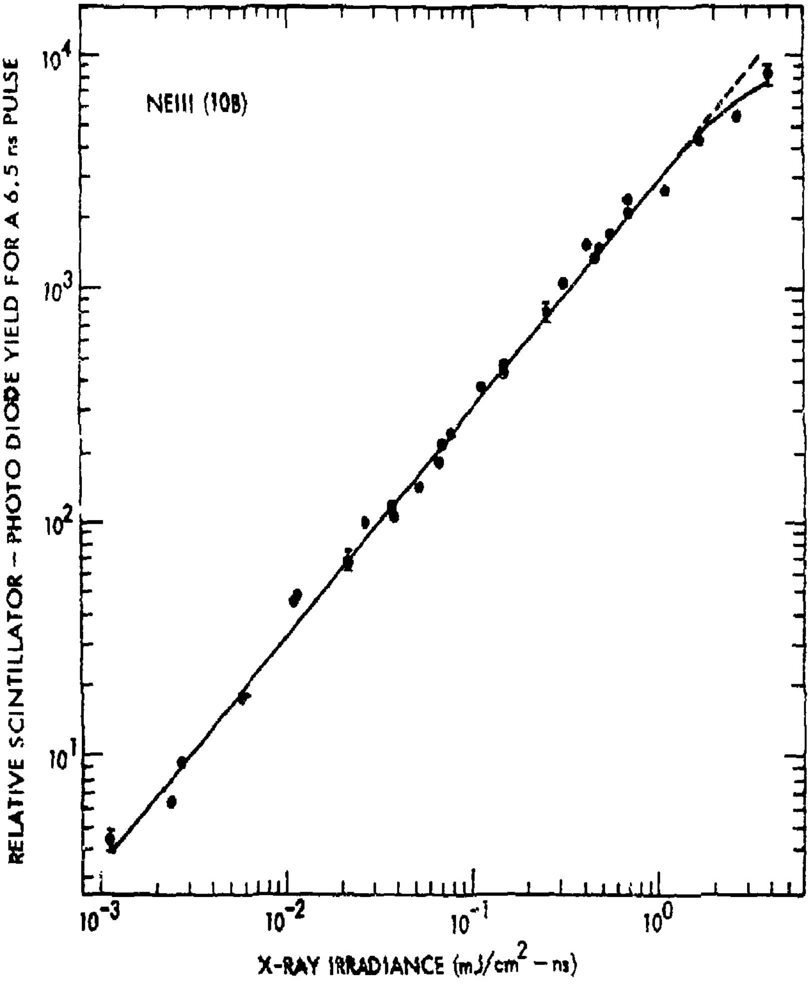

Fig. 12 Plot of Relative Scintillator-Diode Yield, Obtained From Pulse Area, Versus X-Ray Irradiance for Given Laser Shot for NE111 Doped With 10 Percent Benzophenone. Data are for 6.5-ns-wide x-ray pulse. Solid line through the data points is best quadratic fit to data. Experimental error on each datum point is approximately 10 percent

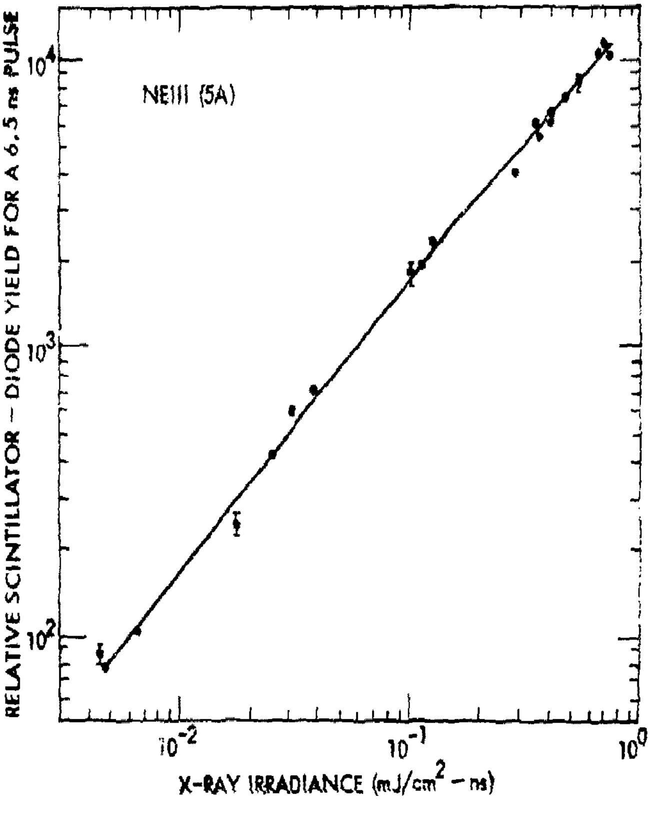

Fig. 13 Plot of Relative Scintillator-Diode Yield, Obtained From Pulse Area, Versus X-Ray Irradiance for Given Laser Shot for NE111 Doped With 5 Percent Acetophenone. Data are for 6.5-ns-wide x-ray pulse. Solid line through data points is best quadratic fit to data. Experimental error on each datum point is approximately 10 percent

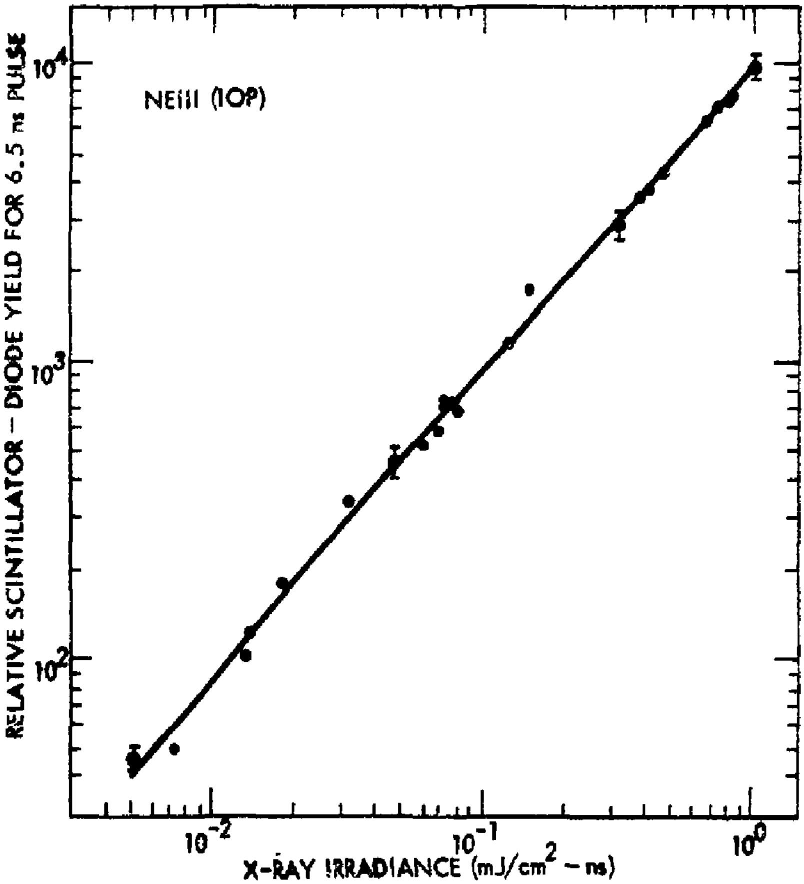

Fig. 14 Plot of Relative Scintillator-Diode Yield, Obtained From Pulse Area, Versus X-Ray Irradiance For Given Laser Shot for NE111 Doped with 10 Percent Piperidine. Data are for 6.5-ns-wide x-ray pulse. Solid line through data points is best quadratic fit to data. Experimental error on each datum point is approximately 10 percent

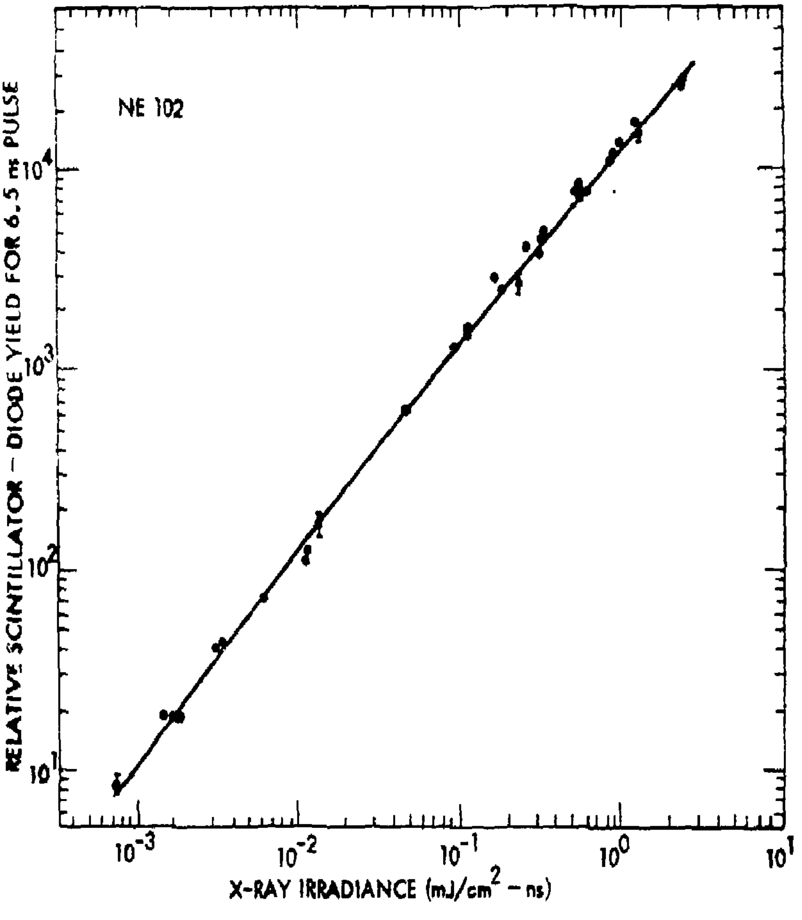

Fig. 15 Plot of Relative Scintillator-Diode Yield, Obtained From Pulse Area, Versus X-Ray Irradiance for Given Laser Shot for NE102. Data are for 6.5-ns-wide x-ray pulse. Solid line through data points is best quadratic fit to data. Experimental error on each datum point is approximately 10 percent

the data points are a least-squares fit to the function of Eq. (1). Table 2 lists the resulting expansion coefficients from the least-squares fit to the data for NE102 and doped NE111 samples. As is evident from these figures and Table 2 there is no evidence of nonlinearity except at irradiances above 1 mJ/cm^2-ns. This is most evident in the data shown in Fig. 12 where the highest irradiance achieved was approximately 4 mJ/cm^2-ns. The dashed line represents the best linear fit to the data. Since the monitor scintillator was NE111 and not identical to the sample under investigation, a direct comparison between the line shapes of the monitor and signal FPD could not be made. However, a comparison between signal data taken at low and high irradiances can be made. Figure 16 illustrates scintillator data taken at irradiances of 0.5 and 4.0 mJ/cm^2-ns. The XRD monitor associated with these two laser shots indicated that the temporal profiles of the x-ray pulse were nearly identical. As illustrated in Fig. 16, there is obvious distortion in the trailing edge of the pulse taken at the higher irradiance.

Table 2

RESULTS OF SCINTILLATOR SATURATION DATA ANALYSES USING 6.5-ns-WIDE PULSE OF X RAYS FROM Cu TARGET

Sample (c)	a_0	a_1	a_2	a_3	χ^2
NE111 (2B)	1.0 ± 0.36	12009 ± 243	(b)	(b)	1.05
	0.8 ± 0.34	12396 ± 282	-715 ± 326	(b)	0.95
	0.8 ± 0.36	12373 ± 333	-569 ± 1068	-74 ± 516	0.98
NE111 (5B)	0.3 ± 0.2	5243 ± 201	(b)	(b)	1.98
	0.2 ± 0.18	5408 ± 220	-225 ± 177	(b)	1.86
	0.2 ± 0.2	5412 ± 290	-239 ± 701	4.0 ± 195	1.92
NE111 (10B)	0.7 ± 1.0	2937 ± 169	(b)	(b)	2.77
	0.2 ± 0.6	3187 ± 122	-205 ± 86	(b)	1.64
	0.1 ± 0.6	3217 ± 148	-420 ± 318	32 ± 86	1.68
NE111 (5A)	-17.9 ± 9.4	3281 ± 135	(b)	(b)	1.58
	-2.1 ± 6.0	2850 ± 117	235 ± 51	(b)	0.83
	3.7 ± 5.4	2615 ± 122	656 ± 147	-101 ± 34	0.66
NE111 (10P)	-16.2 ± 6.9	1672 ± 75	(b)	(b)	1.82
	-6.4 ± 5.1	1516 ± 69	82 ± 25	(b)	1.19
	-4.0 ± 5.0	1417 ± 77	236 ± 80	-27 ± 14	1.04
NE102	-2.2 ± 1.1	12559 ± 359	(b)	(b)	1.48
	-2.4 ± 1.2	12669 ± 476	-192 ± 530	(b)	1.52
	-1.4 ± 1.0	11905 ± 471	3364 ± 1372	-1560 ± 573	1.21

(a) *The values of the data points were based on pulse area.*

(b) For this case the a_k coefficient was assumed to be zero.

(c) The notation refers to the percentage of concentration and doping material: B - Benzophenone, A - Acetophenone, P - Piperidine.

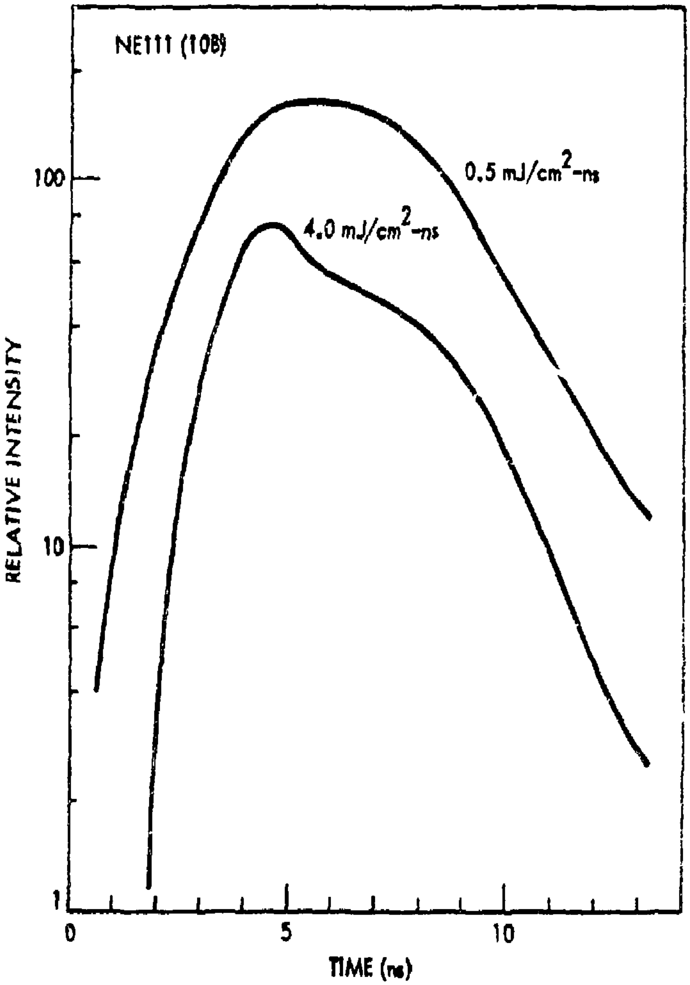

Fig. 16 Shapes of Two Signal Scintillator-Photodiode Pulses Taken at Different Irradiances. Scintillator is NE111 doped with 10 percent benzophenone. Pulse heights are on a relative scale and not normalized to each other

There have been studies (Refs. 2 to 4) of the nonlinear response of the organic scintillator NE102 using high-energy electrons. These data suggest that the point at which nonlinearity occurs is dependent not only on total dose but dose rate as well. The effects observed in the present experiment also suggest that this dose-rate dependence does indeed exist. When converting the irradiance from the present experiment, at which 10 percent nonlinearity occurs, into a corresponding dose rate, one obtains a value of 2×10^{14} rads/s. This calculation assumes a 10 μm $(1 - e^{-1})$ deposition depth as described in Section 3. This dose rate is approximately two orders of magnitude greater than the equivalent level obtained from the electron data. However, it is consistent with what one would expect for a 6.5-ns pulse, based on previous *LPARL* x-ray saturation data (Ref. 1) taken at 0.2 ns.

The apparent discrepancy between the x-ray and electron data still exists. However, assuming that the nonlinearity effects are dose-rate dependent, the results of the earlier LPARL experiment (Ref. 1) and the present experiment are consistent. One possible explanation is that there is a significant deadlayer on the surface of the scintillator. As pointed out earlier, this possibility was tested by performing saturation tests before and after a 51-μm layer was removed from the surface. No change had been observed in the linearity over the region tested. Should there indeed be other surface effects not taken into account, they are probably the result of intrinsic properties of the scintillator. If this be the case, the measurements presented in this report empirically set the level of nonlinearity for scintillators being used under similar spectral and irradiance conditions.

Section 6
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