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ADDITIVE ENHANCEMENT
OF SHORT PULSE FLASHLAMPS

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ADDITIVE ENHANCEMENT OF SHORT PULSE FLASHLAMPS

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FOREWORD

The work reported here was performed under Contract Number E(04-3)-1149 for the Division of Laser Fusion of the Energy Research and Development Administration.

Work was carried out in the Advanced Products Division of ILC Technology, Inc., which is under the direction of Dr. Leonard Reed.

Dr. Paul Lovoi directed the initial stages of the program and Dr. James Shaw was responsible for completion of the effort. Radiometric measurements and data reduction were performed by Mr. R. Maynard. Lamp fabrication was directed by Mr. Charles Major.

The authors wish to thank Dr. Michael Gusinow and Dr. Richard Palmer of Sandia for their technical advice during the program.

SUMMARY

Sandia Laboratories developed a short pulse flashlamp for pumping iodine photodissociation lasers that provided spectral enhancement in the laser pumping band compared with that obtained from a pure xenon-filled lamp. Additives of zinc and cadmium were credited for the enhancement. Lamp lifetime was limited by "clean up" of the additive. The objective of this program was to reproduce the enhanced spectral output in a lamp having a useful lifetime.

To meet this goal a unique molybdenum cup-sealed lamp was produced. This structure minimized additive loss from the active lamp region and provided an acceptable lamp lifetime (more than 1000 shots).

However, only modest and erratic peak enhancement was found in the lamps tested at ILC when filled according to Sandia instructions. Joint investigations with Sandia staff eventually disclosed that:

1) Sandia enhancement measurements were time-integrated and were not peak measurements.

2) Phosphorous was an accidental additive in Sandia lamps.

With this information ILC was able to produce phosphorous doped lamps with significant spectral enhancement. It was found that most of the enhancement was due to a longer output radiation pulse rather than an increase in peak output.

Laser pumping efficiency is pulsewidth dependent so that the time-resolved spectral output of these doped lamps is critical in determining their performance in a laser. Investigation of the present additives should be continued using time-resolved spectrophotometry, and a fresh look taken at the other possible approaches to achieving peak spectral enhancement within short pulses.

1.0 INTRODUCTION

A key factor in the development of iodine photodissociation lasers is the improvement of pump lamp efficiency in the 250 to 300 nm pump band at pulsewidths of about 10 μs. Previous work by Gusinow* showed that certain metal additives appeared to enhance pump lamp output in the 250 to 300 nm region by as much as a factor of three. This had been determined by comparing microdensitometer traces of spectrograms of doped and undoped lamps. The principal problems noted with these lamps were a shot-to-shot variability of more than 30 percent and an effective life of only 20 shots (a result of migration of the dopants from between the electrodes to the colder regions behind the electrodes).

1.1 Objectives

The present program was intended to remedy these problems with emphasis placed upon developing a lamp with relatively small volume behind the electrodes. Principal tasks in the program were the following:

1. Develop a molybdenum cup seal with the design criteria of a minimum non-active volume, power loading to 2 kJ per meter, and reasonable production cost. Eight lamps were to be fabricated during this task.
2. Optimize the type and amount of dopant to produce maximum pump band radiation in the lamp design developed in 1.1.1 above. Six development lamps and two control lamps were to be fabricated during this task.
3. Measure and record time-resolved spectral data of the radiation produced by the lamps developed in 1.1.2 to indicate effectiveness for pumping iodine photodissociation lasers.

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*Gusinow, M.A., "The Spectral Enhancement of Near UV Xenon Flashlamps", Applied Optics, Vol. 14, No. 11, pp. 2645-2649 (November 1975).

4. Perform life test studies on the lamps developed in 1.1.2 at several power levels to determine their explosion energy and their life as limited by dopant migration. Six more lamps were to be fabricated during this task.

1.2 Approach

As originally conceived, most of the effort was intended to go toward seal development and life testing. In fact, as the program developed, most of the effort, with technical guidance from Sandia, went into the optimization task for reasons that will be discussed later.

Seal development efforts consumed the equivalent of five lamps in piece parts. Control lamps S/N 1, 2, and 4 represent the last three lamps devoted to seal development tests. Eight lamps were built as planned but only the last three survived the fabrication and testing process and received serial numbers. This activity is described in Section 2.

Four lamps were built initially for optimization testing and were used up without resolving the lack of observed enhancement. A total of six more lamps (S/N 2 and S/N 5 through 13A) were built and devoted to solving the problems associated with the optimization tests. As described in Section 3 this effort culminated in the identification of phosphorus as a key additive. At this point it was decided to scale down further development efforts to match remaining program resources. Accordingly S/N 14 was built to serve as a control lamp. S/N 15 and 16 were committed to the final set of optimization tests. Thus a total of twelve optimization lamps and one control lamp were built.

Spectral data were taken using lamp S/N 15 as described in Section 4. Lamp S/N 16 was the one lamp used for life testing and these test results are described in Section 5. Section 6 shows the effect on radiation output of running pure xenon lamps in a simmer and non-simmer mode. Section 7 presents conclusions and recommendations.

2.0 ADDITIVE LAMP DESIGN

The key problem of lamp design as indicated from previous lamp testing was to keep the additives from condensing in the nonactive, cooler regions behind the electrodes. Condensation of the additives outside the active region was limiting lamps tested at Sandia to a few tens of shots. Figure 2-1 shows the seal design evolved to remove this restriction. A molybdenum cup seal is used as the central feature of the design that allows a tungsten plug to be used as the electrode. A molybdenum foil is wrapped around the plug and the quartz envelope is shrunk around the assembly. The foil provides enough elasticity to prevent the differential expansion of the tungsten from cracking the quartz at the seal when the lamp is in operation. This assembly proved to be a significant improvement over conventional flashlamp geometry in minimizing cold volume near the electrodes.

Molybdenum exposed to air will oxidize at temperatures of approximately 400^{o}C. The seal described above would allow molybdenum to contact air if measures were not taken to prevent this from occuring, so an outer sealed region is formed to protect the molybdenum. The electrical feedthrough on the outer seal envelope is a standard ILC flashlamp rod seal. The electrical connection between these two seals is complicated by requiring a flexible connection to allow for thermal expansion of the envelope material.

Table 2-1 shows the lamps that were built in the course of this program. The goal of the program was to develop an effective 100 cm long additive lamp operating at 2 kJ/meter. Seal development efforts consumed the equivalent of five lamps in terms of piece parts and electrode assemblies. The first lamp seal designs were manufactured in short sections. This

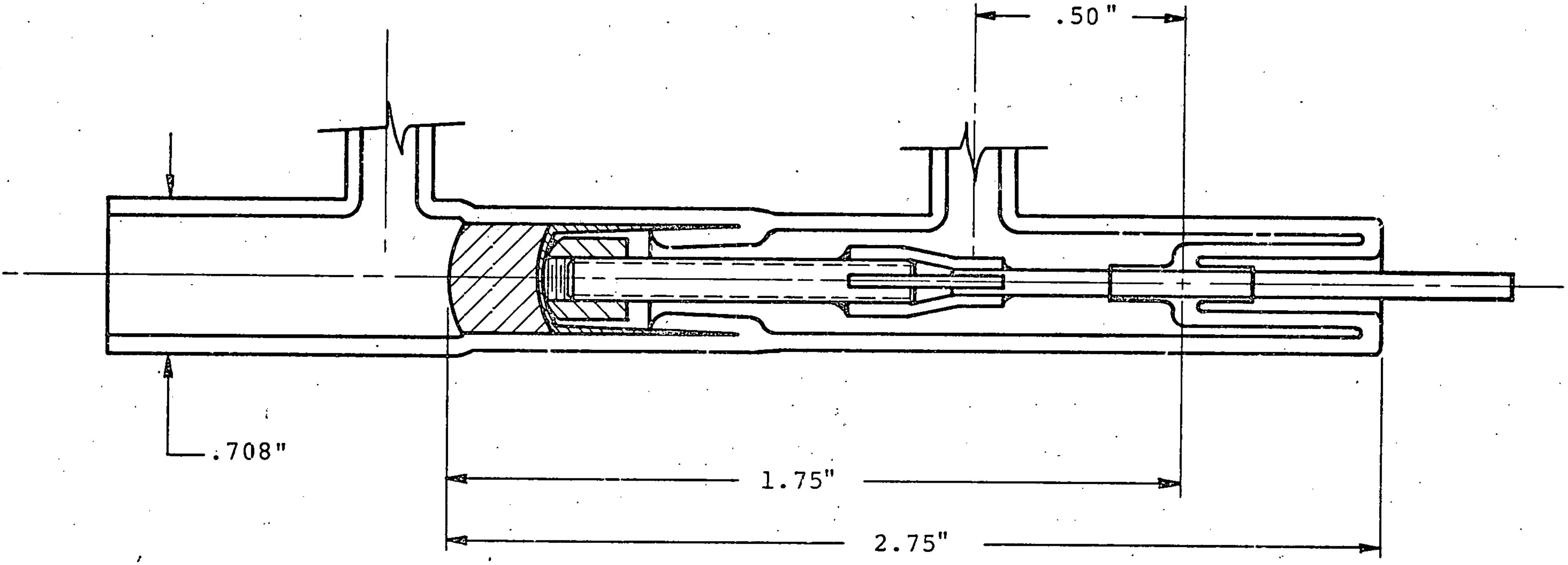

Figure 2-1 16mm Bore Molybdenum Cup Seal Lamp Electrode Assembly

Table 2-1 Summary of Lamp Types Constructed

Serial Number	Electrode Type	Arc Length (cm)	Xenon Pressure (torr)	Additive		Intended Use	Status
				No. 1	No. 2		
1	moly cup	100	20	-	-	Control	broken seal
2	moly cup	100	20	150mg Zn	-	Pretest	
3	moly cup	100	20	-	-	Control	
4	moly cup	100	20	-	-	Control	
5	moly cup	100	20	150mg Cd	-	Opt*	see 9
6	moly cup	100	20	1.5g Zn	-	Opt	
7	moly cup	100	20	-	-	Control	failed
8	std flashlamp	30	20	-	-	Opt	
8A	std flashlamp	30	20	150mg Cd	-	Refilled	
9	moly cup	30	20	150mg Cd	-	Opt	shortened No. 5
10	Sandia std	30	20	-	-	Opt	stopped triggering
11	Sandia std	30	20	150mg Cd	-	Opt	
12	moly cup	30	30	-	-	Opt	shipped to Sandia
13	moly cup	30	30	1.5mg Zn	-	Opt	shipped to Sandia
13A	moly cup	30	30	150mg Zn	-	Opt	
14	moly cup	30	30	-	-	Control	broken near electrode
15	moly cup	30	30	150mg Zn	10mg P	Spectral	o.k.
16	moly cup	30	30	150mg Zn	10mg P	Life	failed
17	moly cup	30	30	150mg Zn	20mg P	Spectral	broken in processing

*Optimization Tests

allowed various fabrication techniques to be investigated to determine the one most suitable for producing a reliable lamp.

Once successful seals were being produced they were integrated into lamps for testing. This technique rapidly converged on a producible seal design. The three lamps filled with pure xenon, S/N 1, 3 and 4, represent the first completed seal qualification lamps to be processed. Figure 2-2 shows the results of early seal quaification tests.

The first question was whether the molybdenum cup seal design would hold up without serious degradation at the design energy of 2 kJ per meter. Figure 2-2 shows the relative light output with age for one of the xenon-filled lamps. This is a normal aging curve for a flashlamp and shows no signs of early lamp failure mechanisms.

From Figure 2-1 it is clear that there is a small cold volume behind the electrodes that allows dopant deposition. The dopant will always collect at the coldest locations within a contained volume. The cold locations are areas, even on the electrodes surfaces, that are heated less by the discharge than surrounding areas. Dopant that collects in these areas is less likely to be reintroduced into the active regions during subsequent lamp discharges than dopant that condenses on surfaces that are heated during each lamp discharge.

Once the inactive volume is minimized, the amount of dopant to achieve a desired vapor pressure during lamp discharges must be experimentally determined, since some of the material introduced into the lamp is lost to the colder regions. The next step in the program was to try different dopants and amounts to determine the optimum for output enhancement using the required lamp size and the newly developed seals.

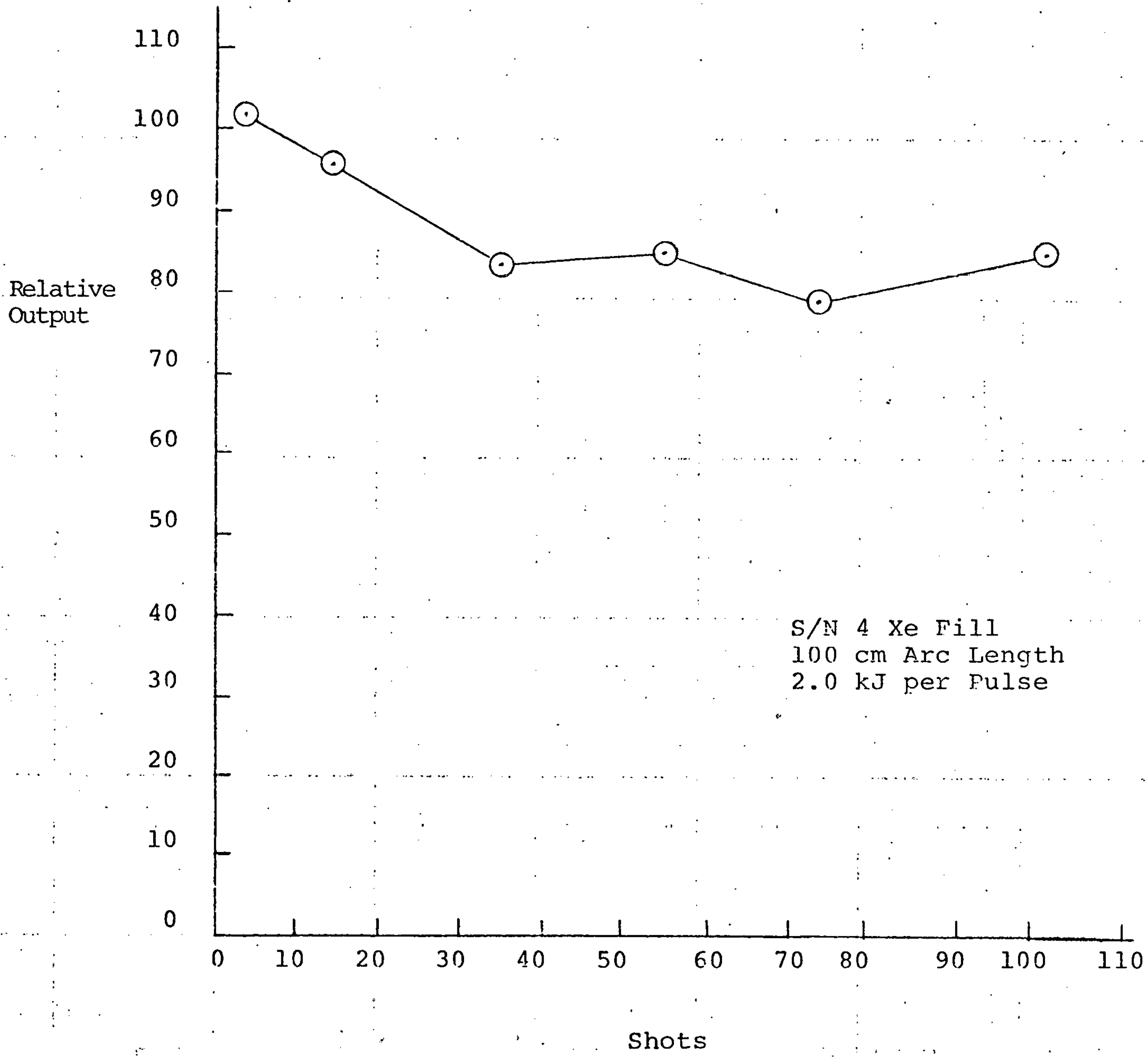

Figure 2-2 Seal Qualification Aging Tests

3.0 OPTIMIZATION TESTS

3.1 Test Facility

3.1.1 Electrical

The electrical test facility is illustrated schematically in Figure 3-1. The lamps were operated from a single section pulse forming network (PFN) consisting of one or more capacitors in parallel and the residual inductance associated with the coaxial current return structure. Capacitance values were 8.4 and 13.6 μF. A triggered spark gap was used as the high voltage switch. Both the lamp and spark gap were mounted coaxially within a current return structure consisting of four symmetrically spaced copper rods. Lamp ignition was accomplished for both simmer and non-simmer modes of operation by "overvoltage" techniques, i.e., the associated capacitor voltage or open circuit simmer voltage was high enough to break down the gas without employing other high voltage trigger pulses.

Two power supplies were used; a variable voltage simmer mode power supply with the capability of operating the lamps at currents of 20-50 mA, and a variable voltage capacitor charging supply that employed a resistive/reactive scheme for current limiting.

Typical test results are shown in Figure 3-2, where current pulses for high and low energy operation are displayed. Both pulses are moderately underdamped with a base width of 16 μs. Figure 3-3 shows the measured peak currents as a function of capacitor energy. These pulse widths and peak currents agree closely with the experimental results produced by Sandia and show

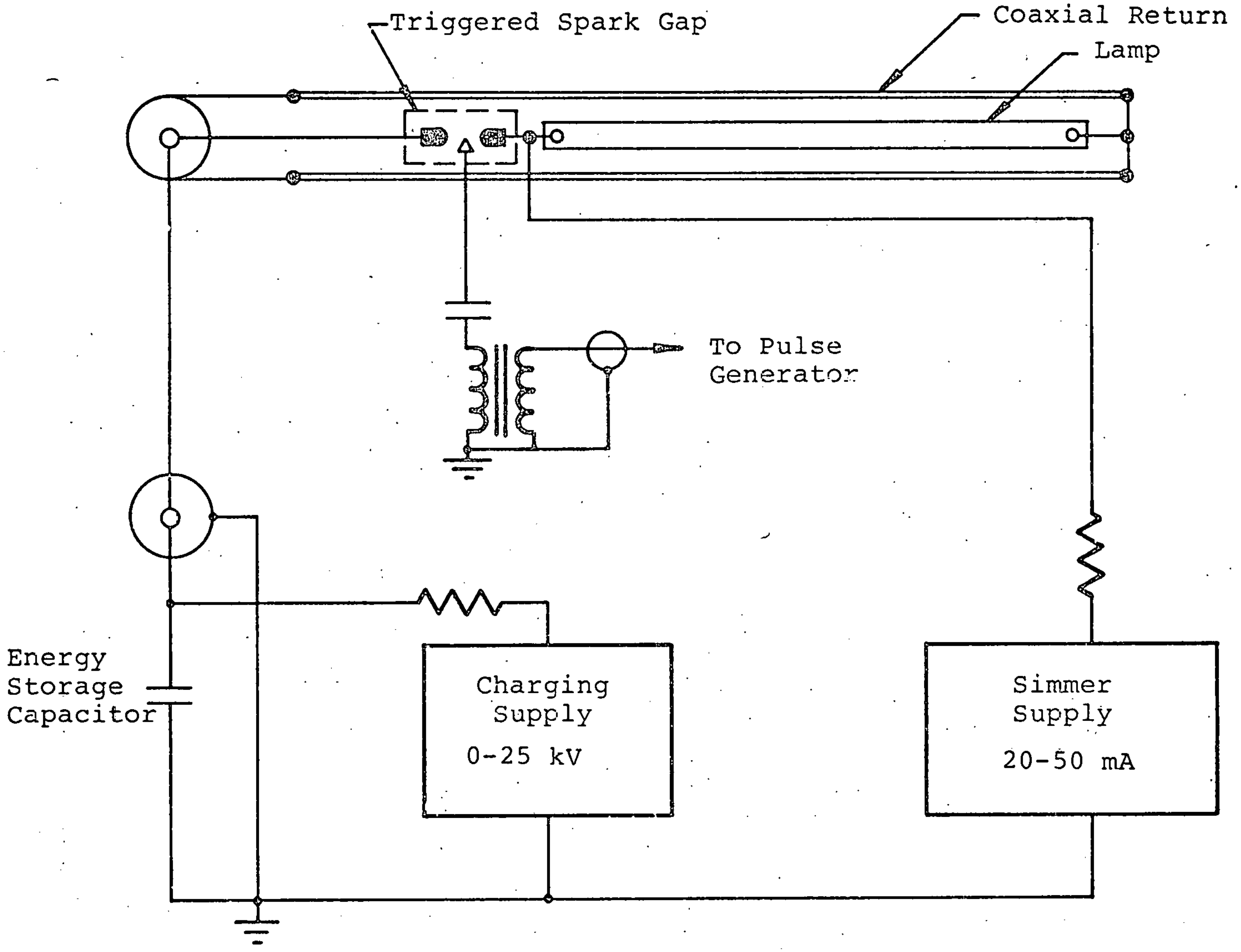

Figure 3-1 Additive Lamp Electrical Test Circuit

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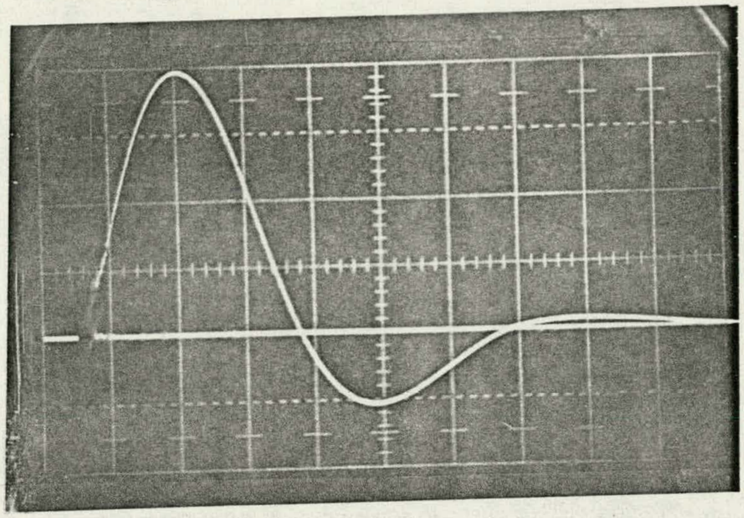
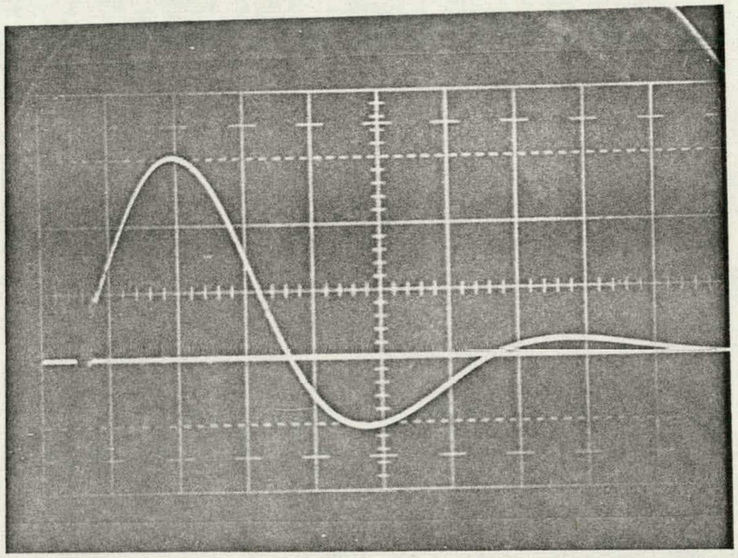


5 kA/cm
5 μsec/cm

E = 780 J
V = 10.7 kV
C = 13.6 μF



10 kA/cm
5 μsec/cm

E = 1612 J
V = 15.9 kV
C = 13.6 μF

Figure 3-2 Typical Lamp Current Traces

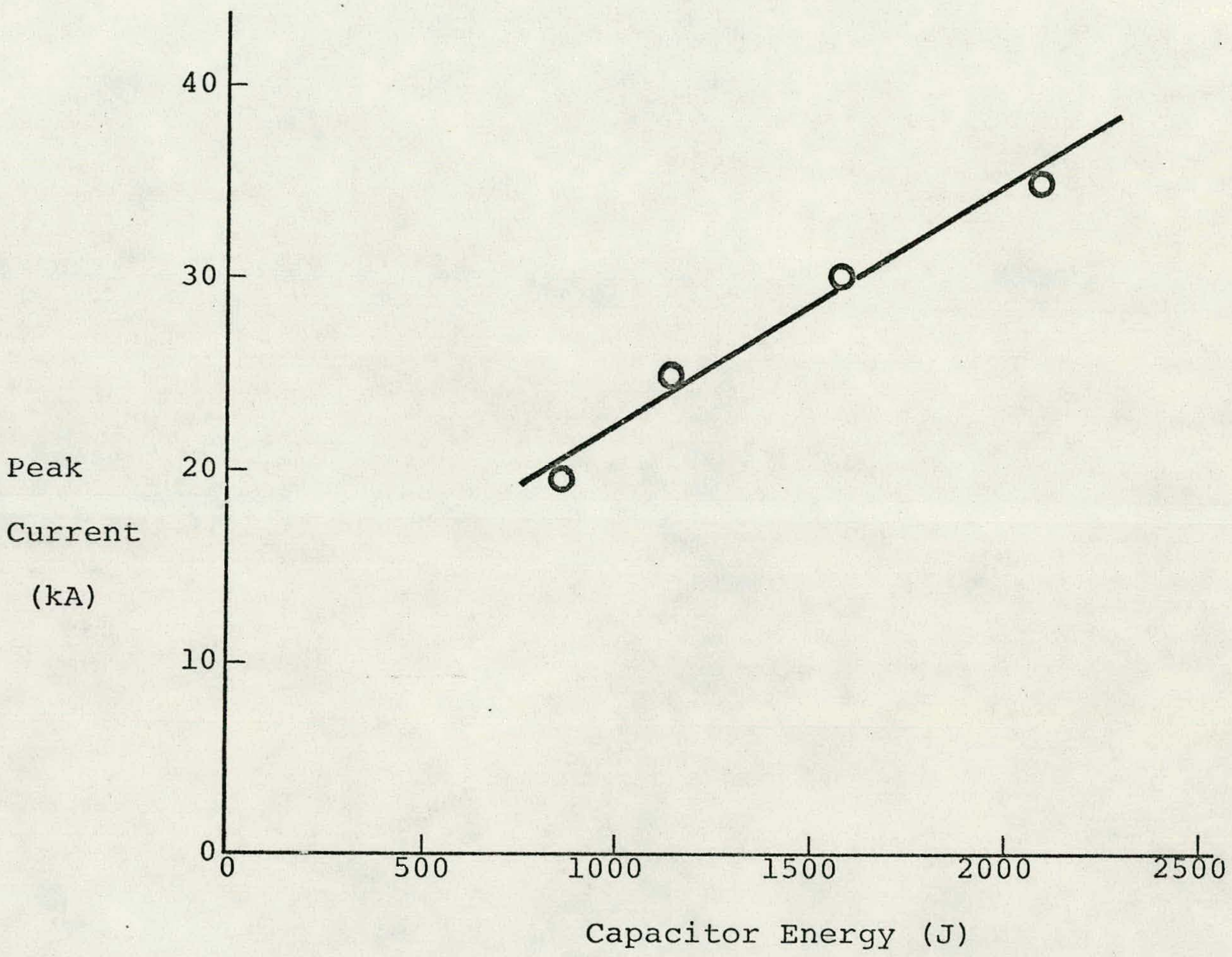


Figure 3-3 Peak Current Versus Bank Energy

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that both facilities drive lamps in the same manner.

3.1.2 Mechanical

The lamps were run horizontally in a totally enclosed box that incorporated a variable rectangular aperture for viewing various arc length lamps or different portions of a particular lamp. To prevent spurious reflections, a "flat black" coated strip was positioned behind the lamp. The power supply and pulse forming network (PFN) were mounted directly under the test box. This apparatus is shown in Figure 3-4.

3.1.3 Radiometry

The lamps were evaluated for optical performance by monitoring irradiance at particular wavelengths. A series of control lamps were used for maintaining system calibration and for detailed comparison of electrical and spectral characteristics of the various lamps.

Routine evaluations were performed by taking oscilloscope photographs of the light output waveform using narrow band interference filters in front of a submicrosecond-response ITT F4018 photodiode. The transmission characteristics of the interference filters are shown in Figure 3-5 and the photodiode spectral response is shown in Figure 3-6. The lamp to detector distance was maintained at 12 feet. Data reduction was accomplished by either reading the peak light output off the photograph or integrating the first 35 μs of the light output waveform from the photograph. The integration was done using a Tektronix graphic tablet digitizer in conjunction with a computer program.

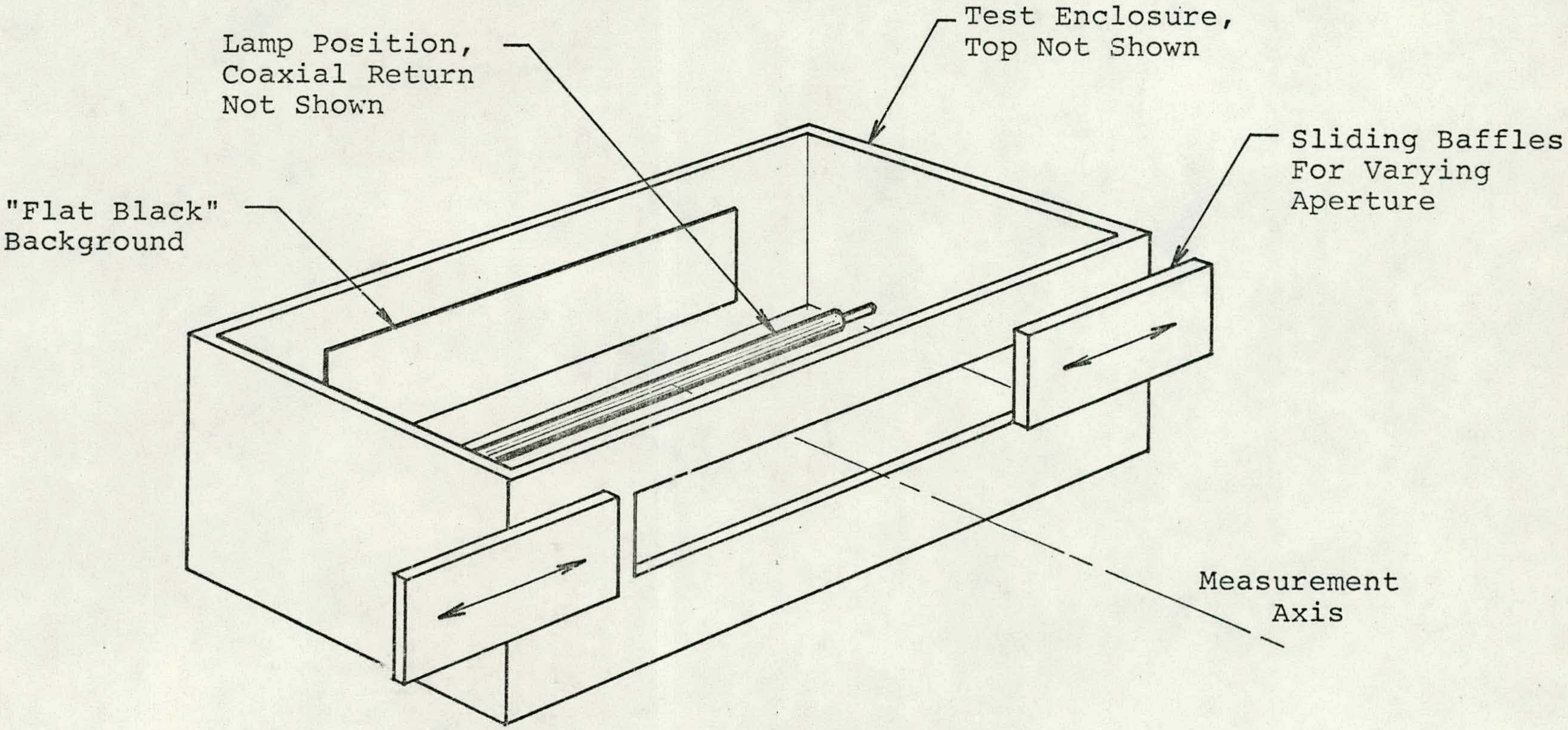

Figure 3-4 Lamp Test Enclosure

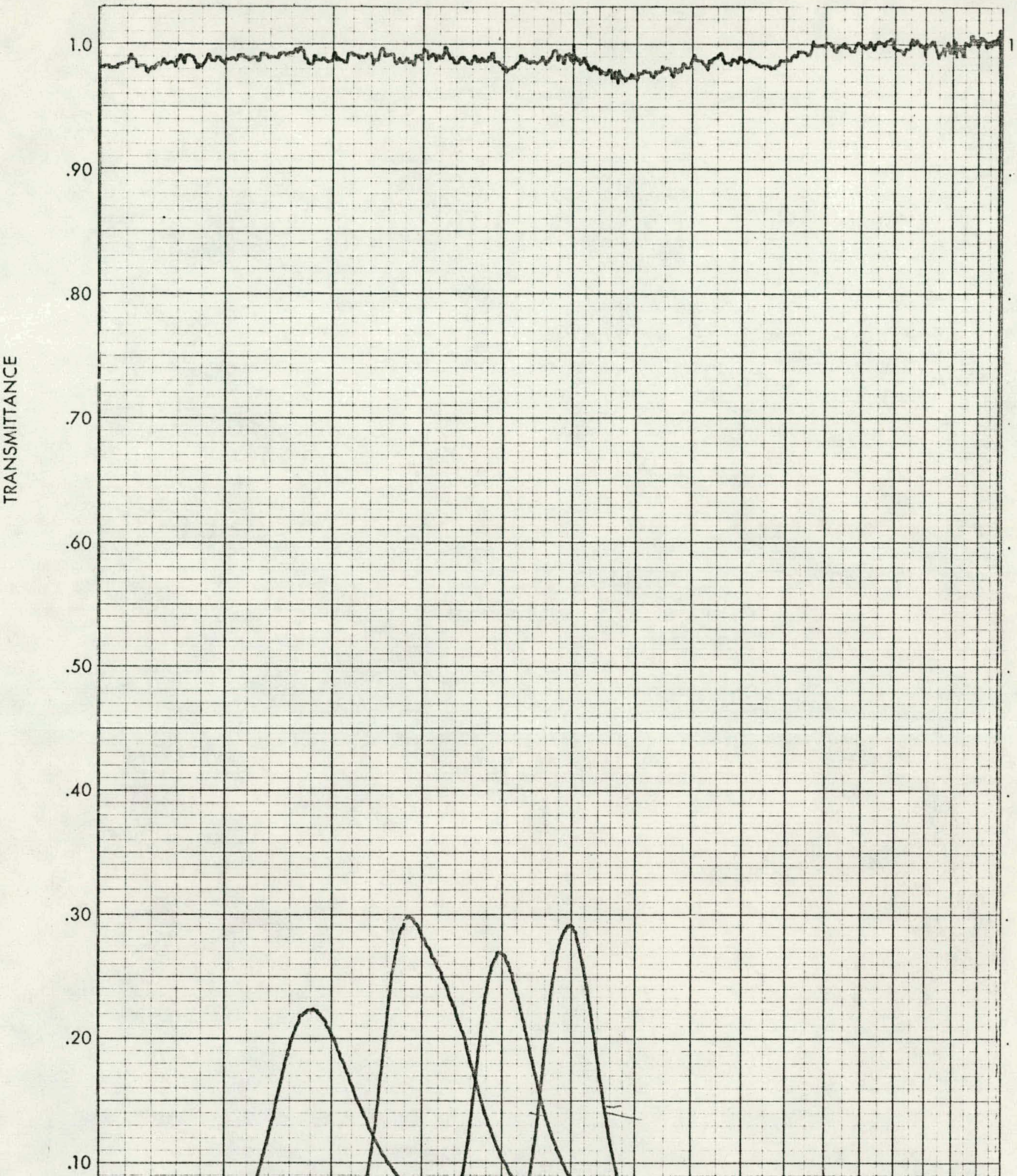

Figure 3-5 Radiometer Filter Transmittance

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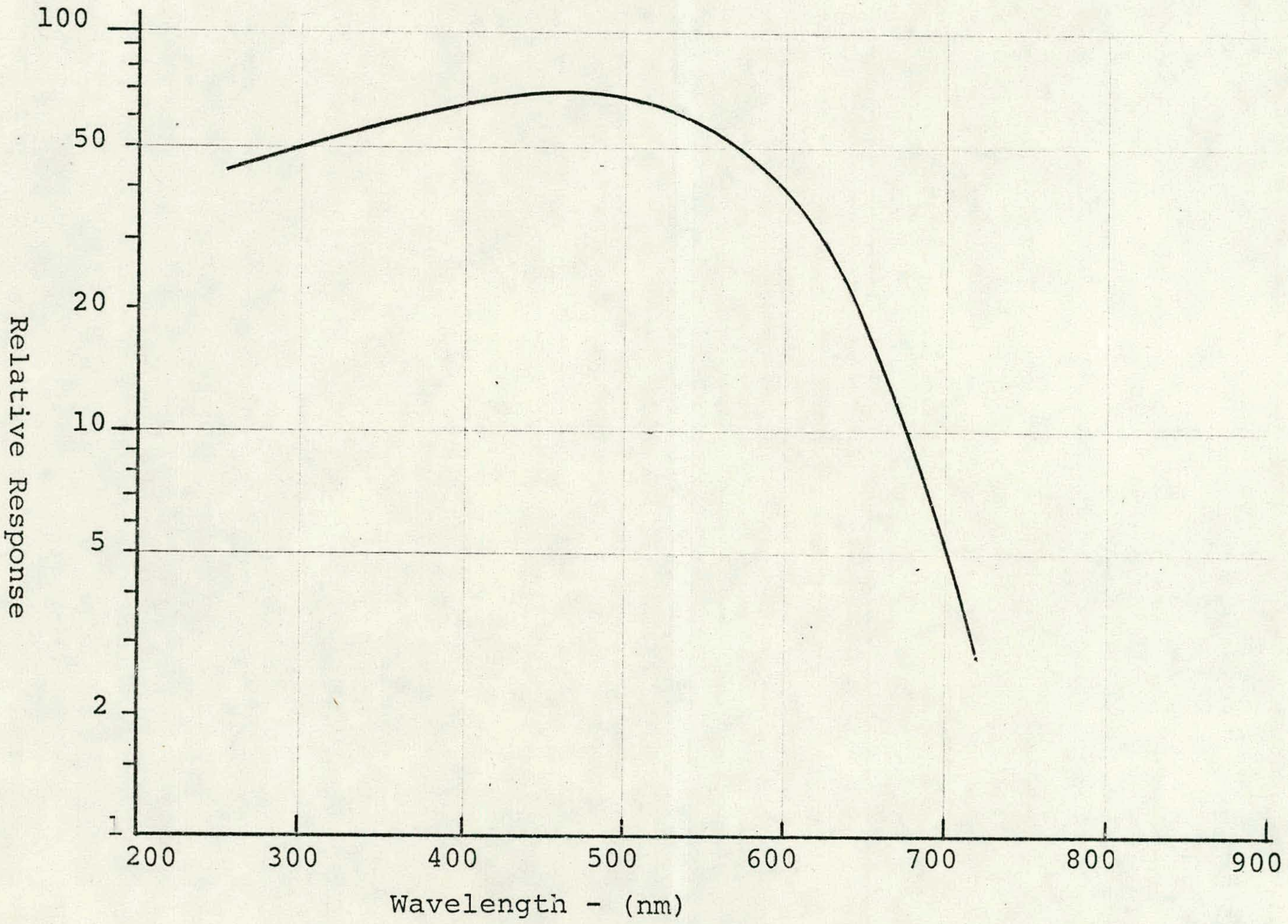
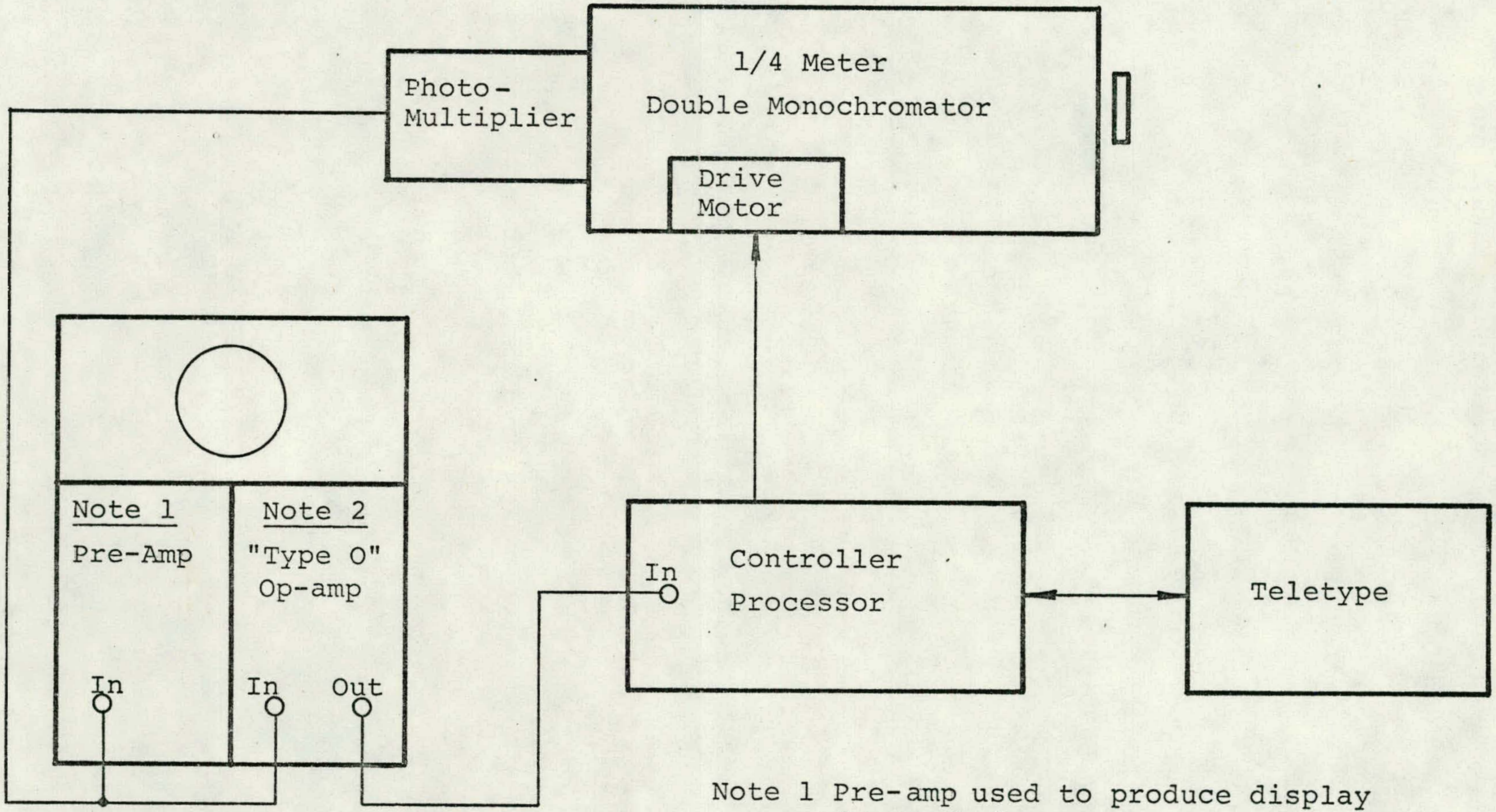


Figure 3-6 ITT F4018 Photodiode Spectral Response

Spectral measurements were performed on selected lamps using an ILC digital data acquisition and processing system. This system is illustrated in Figure 3-7 and consists of the following subsystems:

1) a double pass ¼ meter monochromator with digital stepping motor wavelength drive
2) a control and signal processing module
3) a teletype terminal for input/output functions
4) a UV-sensitive photomultiplier tube with associated signal conditioning.

Spectral measurements were taken in a serial fashion, i.e., the lamp was pulsed once for each wavelength, so that to take N wavelength points, the lamp was fired N times. The spectral data were taken in such a manner that both time resolved and integrated information was available simultaneously. As shown in Figure 3-5 the monochromator output was detected by a high speed UV-sensitive photomultiplier tube and fed to two preamplifiers. The first preamplifier was conventional in that it was used in conjunction with an oscilloscope to produce photographs of the waveform, which were then used to make time resolved measurements. The second preamplifier was used to integrate the light output waveform. The peak of the integrated signal was then inputed into the digital data acquisition system, digitized, and stored on paper tape for subsequent correction for system spectral response. System response information was derived by referencing to an NBS-traceable standard of spectral irradiance. Time-resolved spectral data could be derived from the recorded oscilloscope waveforms using the graphic tablet but this was not required, as will be discussed later.



Note 1 Pre-amp used to produce display for peak data.

Note 2 Op-amp used for integrating signal.

Figure 3-7 Digital Data Acquisition And Processing System

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3.2 First Test Series

At this point it had been established that lamp behavior was fairly stable between 20 and 80 shots for a pure xenon lamp. It remained to be seen whether the same was true for an additive lamp. Figure 3-8 shows the output of lamp S/N 2 run for 118 shots at 2 kJ per shot with 150 mg of zinc dopant. At the end of the test the lamp appeared to have cleaned up half the zinc, but its radiometric output had remained stable for 100 shots. Therefore, it was concluded that it was possible to make a one to one comparison between Zn-doped lamp output and control lamp output between 20 and 100 shots.

Table 3-1 is a summary of the optimization test results. In the first set of tests lamp S/N 2 was compared with control lamp S/N 1 but showed 13 to 37 percent less peak output than the control lamp. Even the integrated intensity was lower than the control lamp. At this point S/N 5 was run to try the effect of cadmium; a slight enhancement of 6 percent peak and 11 percent in integrated energy was found. Since a factor of two increase was expected and the largest enhancement seen was 11 percent it was felt that some parameter was substantially different from the Sandia work. The first attempt at a solution was to load ten times more additive into lamp S/N 6. It was theorized that since these lamps were three times as long as the originals that they should have a bigger additive load. The result was a uniform opaque metal coating of the lamp which reduced light output by a factor of three!

Molybdenum cup lamps are more expensive than standard flashlamps, so further attempts to determine the reasons for a lack of enhancement were attempted with standard lamps. (It was recognized that the dopant would "clean-up" rapidly in a standard

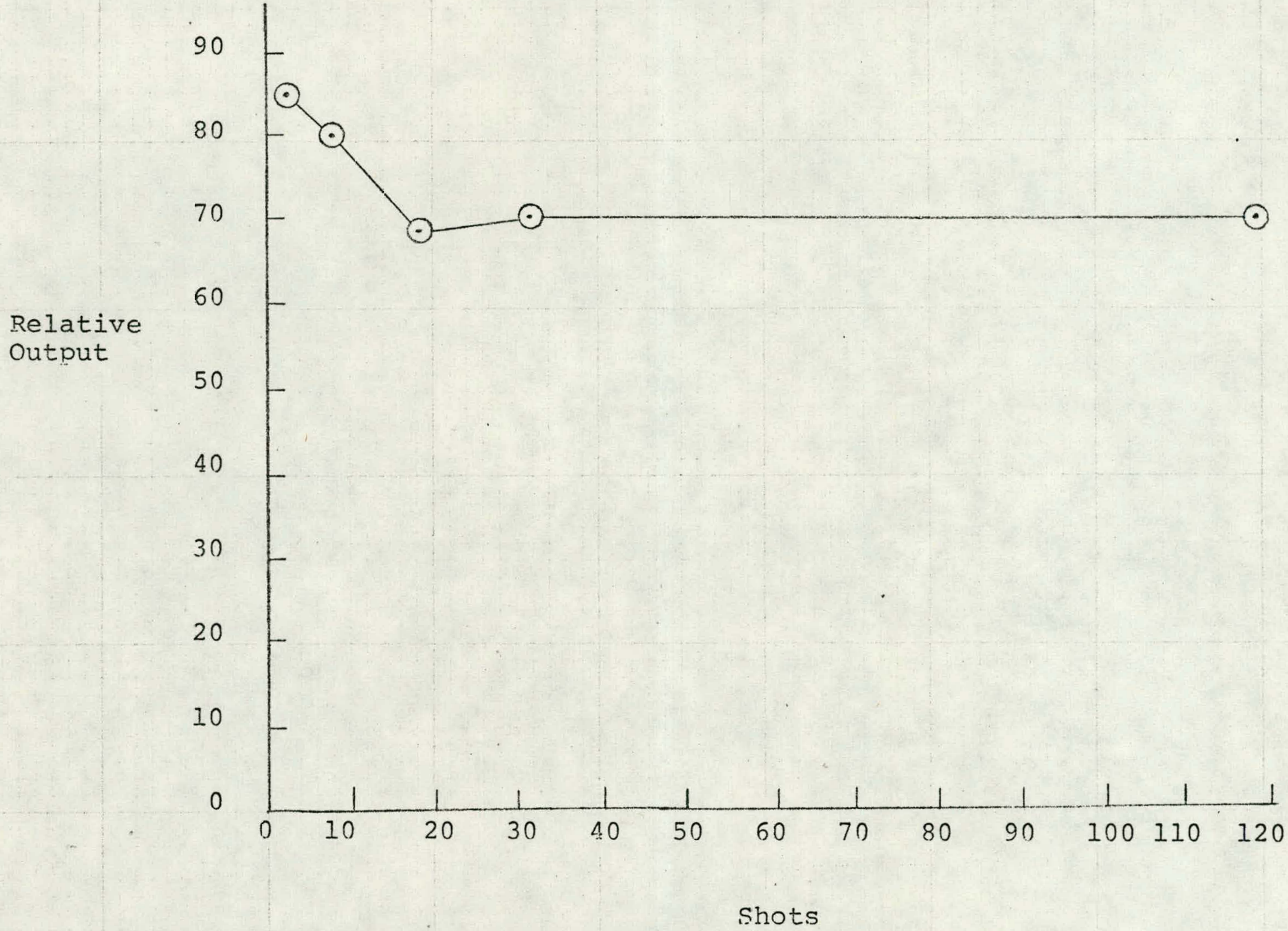


Figure 3-8 Pretest Results for Lamp S/N 2

Table 3-1 Early Lamp Optimization Test Results

Test S/N	Lamp Shots	Control S/N	Lamp Shots	Pulse Energy (J)	Wavelength (nm)	Trigger Mode	Percent Enhancement Peak	Percent Enhancement Integrated
2	13	1	23	2000	290	Simmer	-13	-6
2	14	1	24	2000	290	External	-37	-
5	113	4	110	2000	270	Simmer	+6	+11
6	1	4	130	2000	270	Simmer	-68	-62
8A	3	8	8	800	270	Simmer	+20	+11
8A	9	8	14	1240	270	Simmer	-8	+27
8A	5	8	10	800	280	Simmer	+9	+7
8A	7	8	11	1240	280	Simmer	-4	+20
11	10	10	2	800	280	Simmer	+4	+1
13	8	12	1	2100	280	External	-1.5	-
13	9	12	1	2100	280	External	-7	-
13A	2	12	7	2100	280	External	-46	-

flashlamp, but it was decided after consultations with Sandia that first priority be given to determining the cause of the discrepancies in spectral enhancements.

3.3 Second Test Series

Lamps were built to conform as much as possible to the lamps used at Sandia. This was an effort to remove as many variables as possible from those that could account for the lack of enhancement. A 30 cm lamp with 16 mm bore and conventional electrodes was built. Radiometric data were taken with a pure xenon load, and then 150 mg of cadmium was added and the lamp was retested. Performance at peak output was about 4 percent above the control value and integrated output was about 16 percent above the control level. These results did not close the discrepancy between the ILC work and that done at Sandia.

A detailed comparison of PFN values, pulsewidths, and radiometric instrumentation was begun to try to account for the lack of large enhancement ratios in ILC lamps. New tests were undertaken at Sandia and enhancement was confirmed using spectrograms, integrated monochromator output, and integrated output through interference filters. It was found that the observed enhancement ratios varied somewhat with the measurement technique used, and that while monochromator output showed a 100 percent enhancement a ratio of 50 percent was more typical of the interference filter data. In addition, it was discovered that the results were not fully repeatable. Data taken in the original experiment and that taken in this new series, while both showing enhancement, differed in the peak current required to produce this enhancement. Also changing vacuum stations caused a shift in optimun operating conditions. While this fact was to prove very significant eventually, it was taken into account, at the time, as just one more puzzling feature of the situation.

3.4 Third Test Series

Dr. Paul Lovoi of ILC visited Sandia to discuss the situation with Sandia personnel. The only parameters that then appeared to differ between ILC and Sandia lamps were: the Sandia lamps used epoxy seals and ILC lamps used glass-to-metal seals; Sandia filled the lamps on their pump and fill station while ILC used in-house station; and ILC used metal dopants from solid stock while Sandia used powdered metal. Two of the Sandia-type lamps were returned to ILC and filled and pumped in the standard manner. The dopants remain in the lamp region long enough to verify that there was no enhancement. Thus lamp design was ruled out as a possible variable.

New lamps were now made with molybdenum cup seals, but 30 cm long. These lamps were identical to lamps used at Sandia except for the seal design. The lamps were filled and tested with the now-usual disappointing results. These lamps, S/N 12 and 13, were delivered by Dr. James Shaw of ILC to Sandia and the situation was further discussed.

At this time some further differences in the two programs were identified. The most obvious was the fact that the ILC lamps looked different from the Sandia tubes. The ILC lamps had a gray white cast while the Sandia lamps had a dark reddish black color. It was apparent in side-by-side comparison that there were different additives in the two tubes. Also, it was noted that all Sandia data were time-integrated and that ILC was measuring peak intensity.

At this point it appeared that the differences in additives were probably responsible for the difficulties. Four additional flashlamps were manufactured to try to determine the differences between ILC dopants and those in the Sandia experiments.

3.5 Fourth Test Series

Using these new lamps it was found, at Sandia, that small amounts of phosphorus were crucial to the enhancement process and that between 5 and 20 mg of phosphorus along with cadmium or zinc yielded the best enhancement. In the initial tests at Sandia, phosphorus was present as a contaminant in the vacuum system and had been present in the lamps even though it had not been deliberately added. It also was shown that a 10 percent enhancement ratio was about the best that could be expected without phosphorus.

It now became clear how to use the last four lamps on the program. One would be used as a 30 cm control lamp, one would be used for life tests, and two would be used to obtain optimization data. This was done and the most convincing evidence of enhancement was shown by lamp S/N 15. Figures 3-9 through 3-12 show the integrated enhancement effects of lamps S/N 15 and 16 for four different wavelengths. Both lamps had 30 torr xenon, 150 mg zinc, and 10 mg phosphorus. Lamp S/N 17 with 20 mg phosphorus failed in its first ten shots before quantitative data could be taken. It can be seen that there is a considerable difference between lamp S/N 15 and 16, which supposedly have identical fill material. It is clear, however, that the integrated output of S/N 15 is clearly above that of control lamp S/N 14. The average for the 1200, 1600 and 2000 J points is a 14.0 percent enhancement ratio. This is not a large ratio and on a single point basis would fall within the range of experimental error, but for the average of 16 points it is convincing proof of enhancement. However, figures

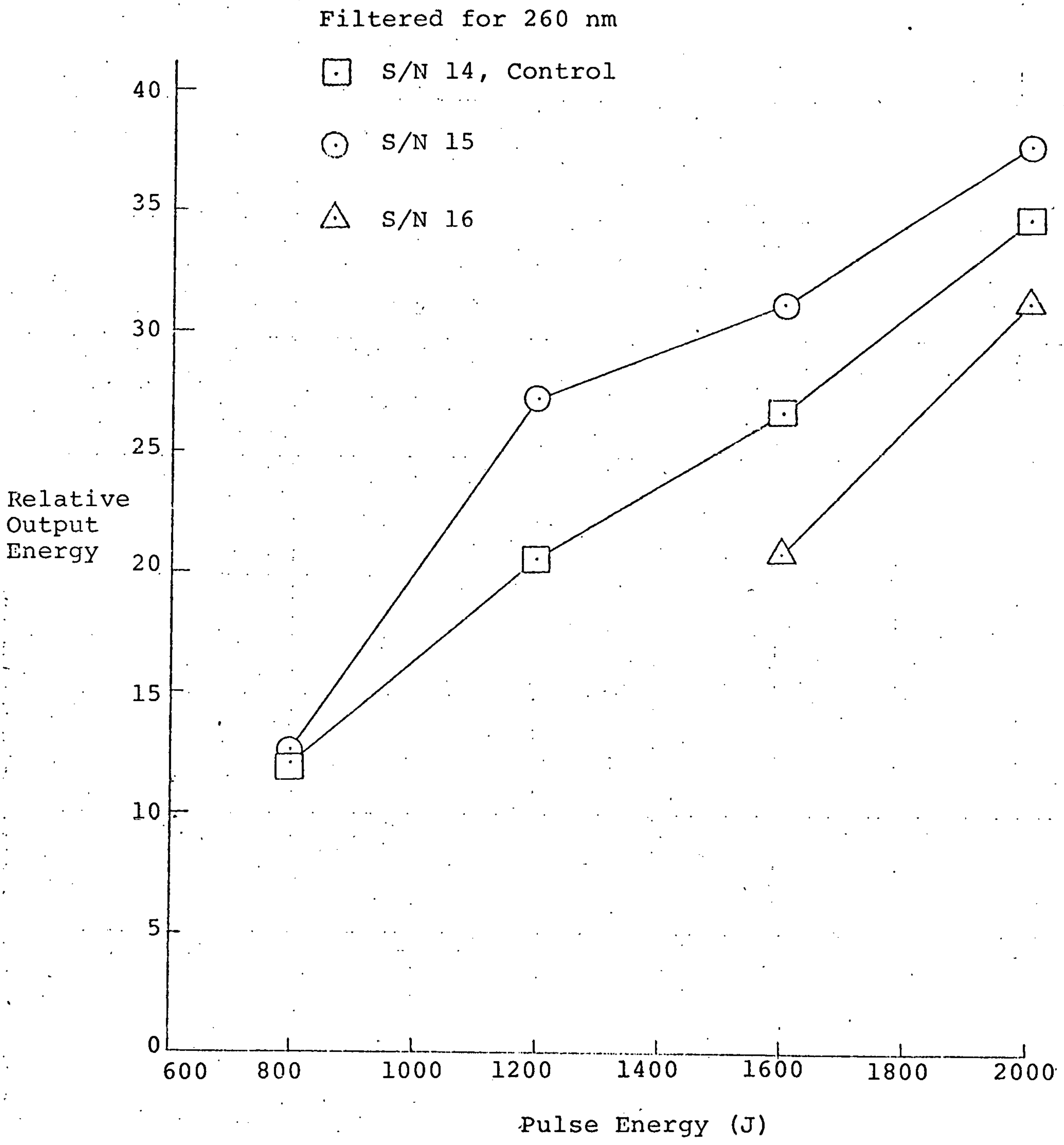


Figure 3-9 Integrated Output Energy at 260 nm versus Input Energy

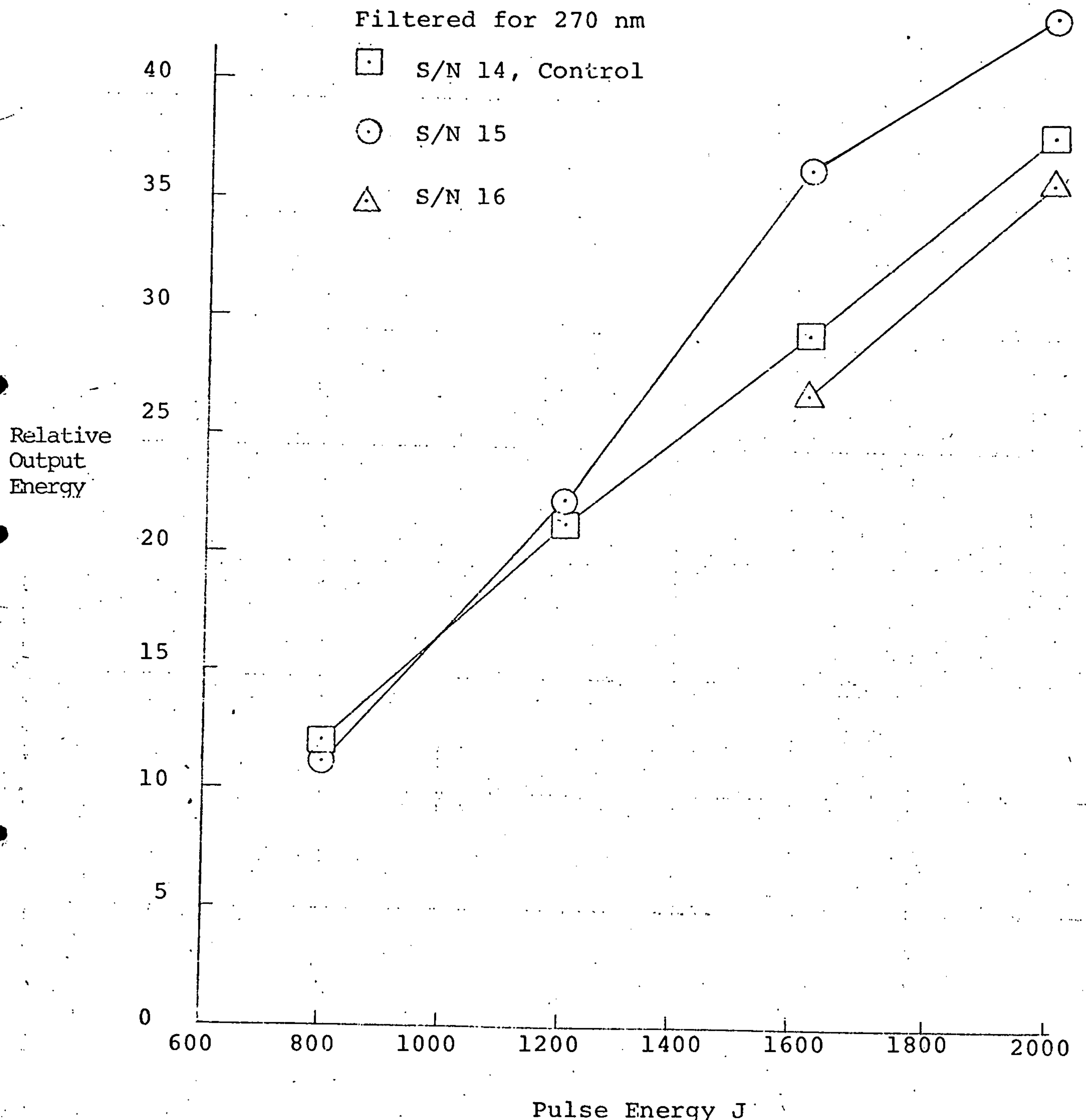


Figure 3-10 Integrated Output Energy at 270 nm versus Input Energy

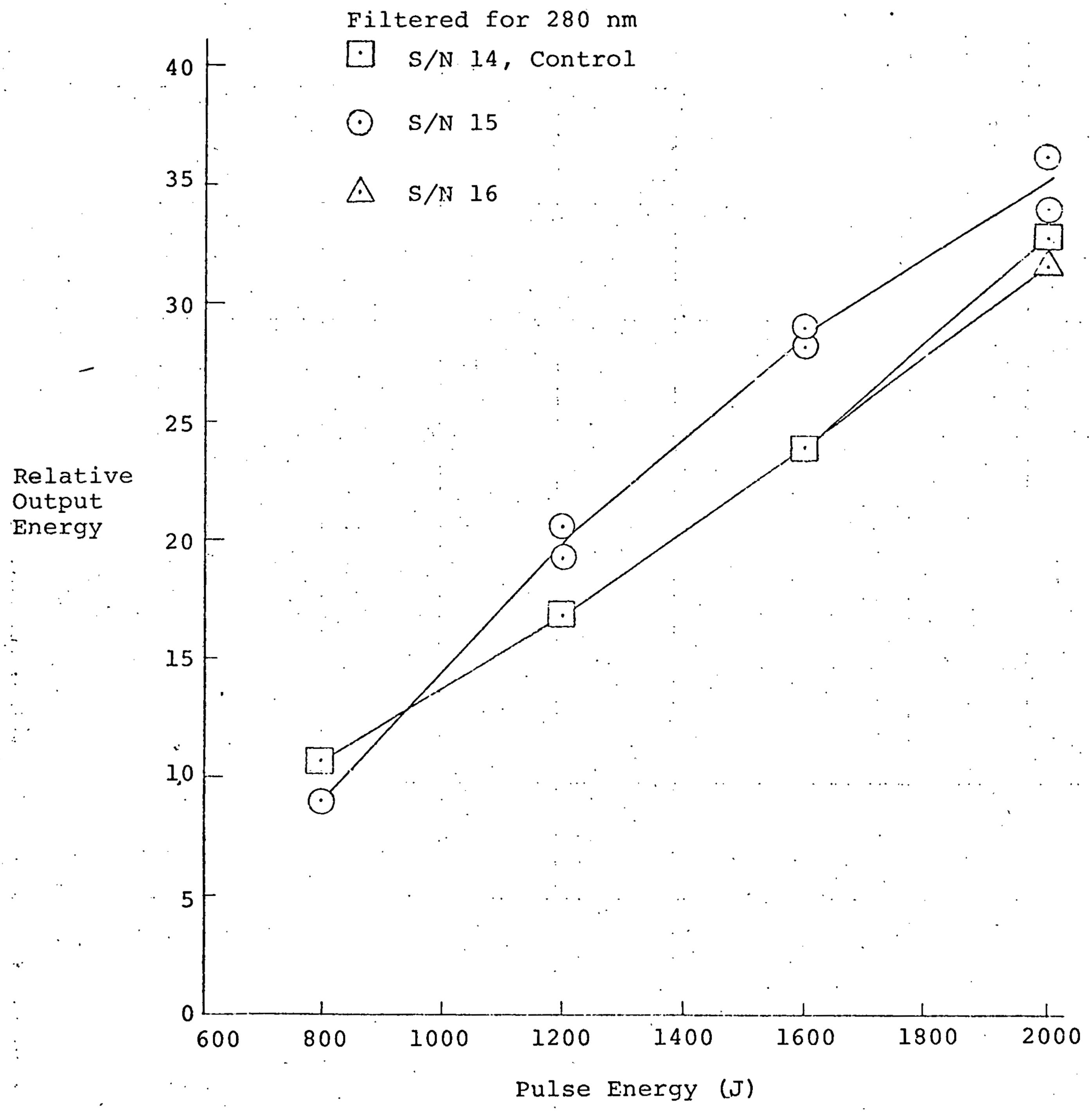


Figure 3-11 Integrated Output Energy at 280 nm versus Input Energy

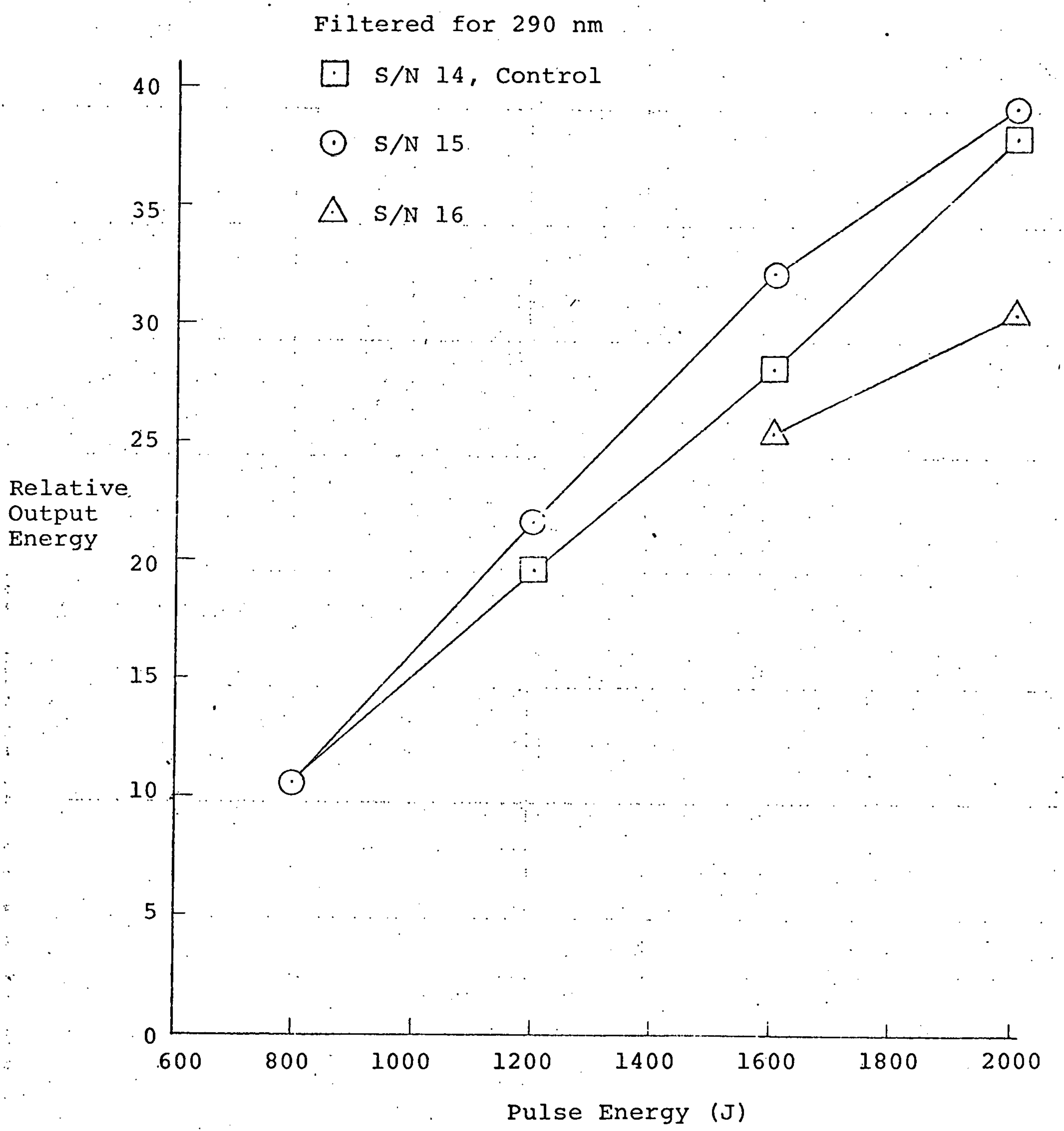


Figure 3-12 Integrated Output Energy at 290 nm versus Input Energy

3-13 through 3-16 show a different trend. Here the peak output of lamp S/N 15 is always lower than the control lamp and the comparable average is 12.2 percent below the control lamp.

Thus, the resolution of the mystery is that while the additives decrease the peak output by 12 percent they lengthen the output pulse by about 26 percent to give enhanced integrated output. This is, in fact, confirmed in time resolved oscilloscope traces. Similar tests at Sandia have shown a few percent increase in peak output.

The addition of phosphorous apparently enhanced integrated light output but not necessarily peak output. Developing lamps with higher enhancement ratios still depends upon determining the optimum additive load, with particular emphasis on the amount of phosphorous. Processing problems still exist and there are still large variations in lamp to lamp output.

The goal of this optimization task of the program was to determine the best dopant material and the optimum amount. The effort to identify the unknown factors took precedence over the optimization task since the optimization would have been meaningless without substantial enhancement. It should be emphasized that the identification of phosphorous as a key additive is probably the principal experimental result of this program. It required the cooperation of both laboratories, over 1000 miles apart, and took many months of effort. Without its identification any further useful lamp development would have been impossible.

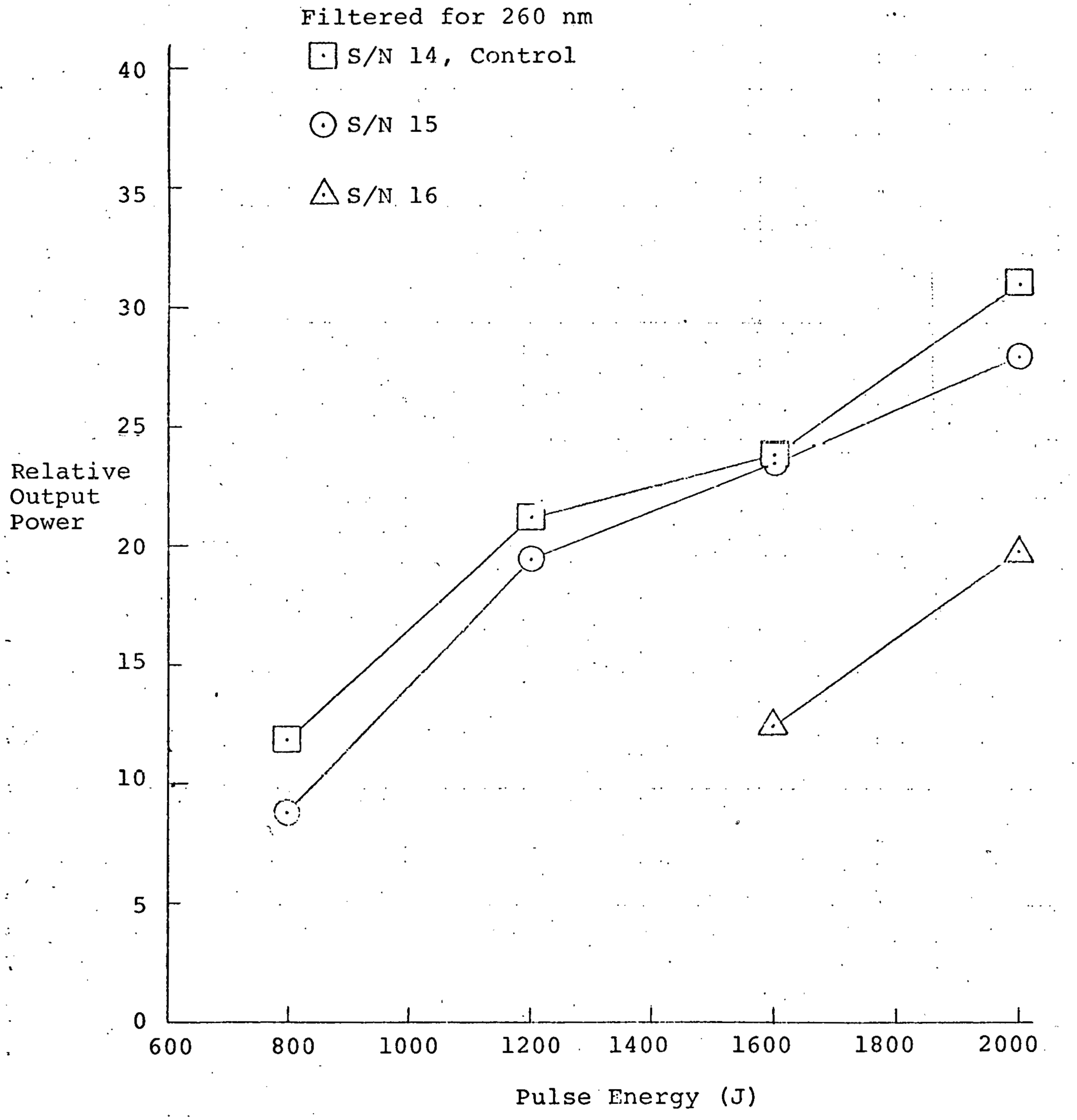


Figure 3-13 Peak Output Power at 260 nm versus Input Energy

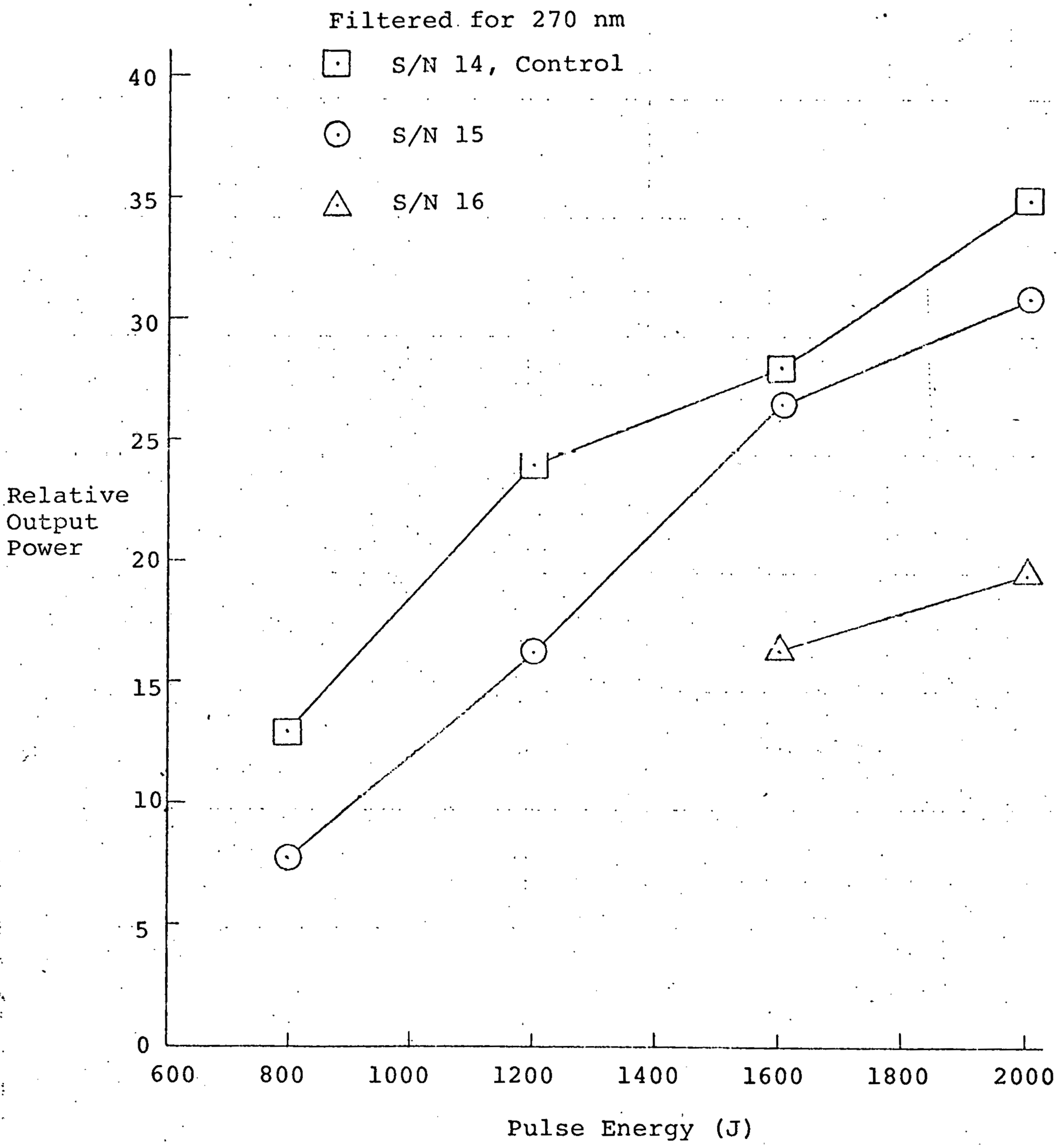


Figure 3-14 Peak Output Power at 270 nm versus Input Power

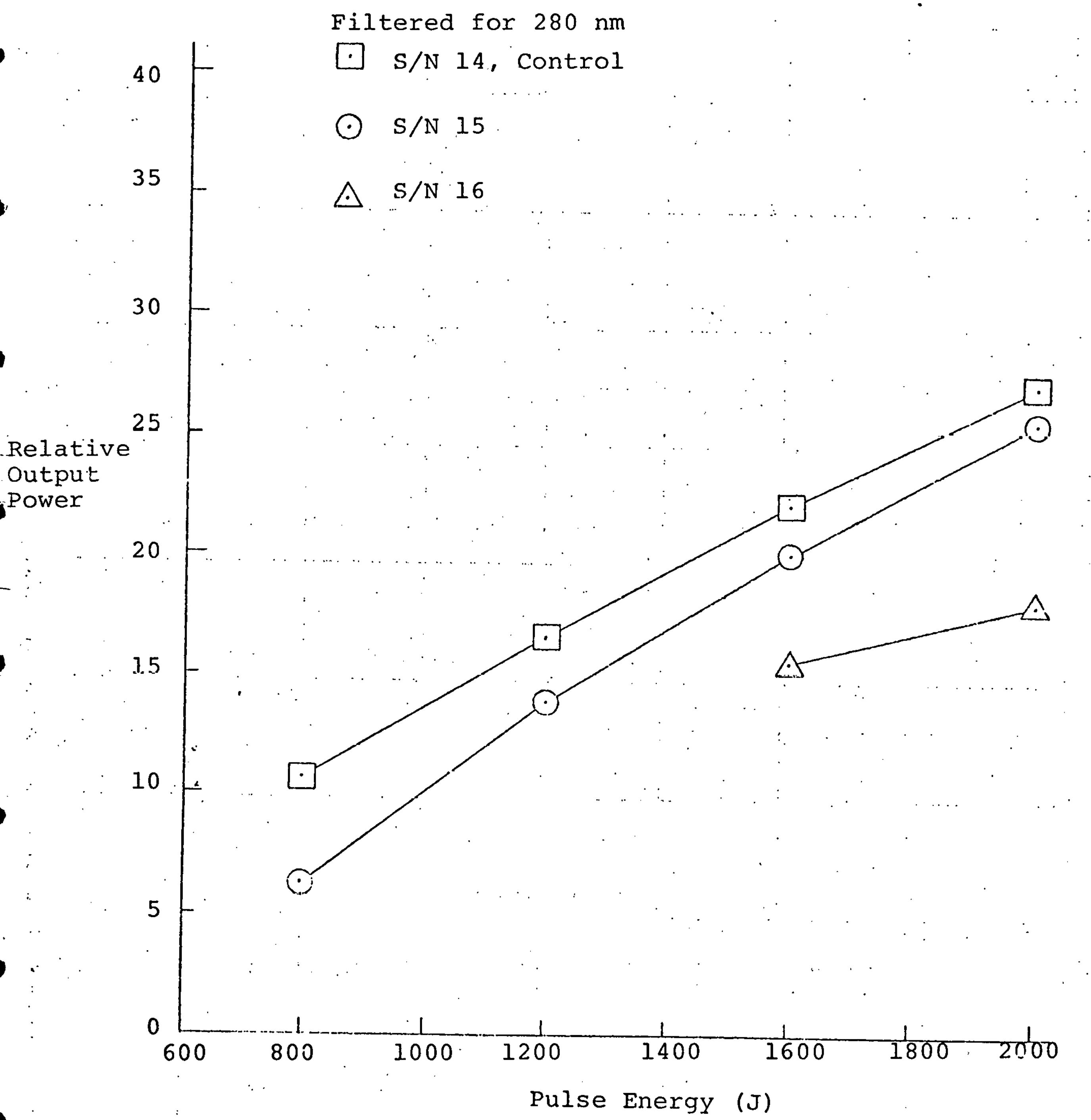


Figure 3-15 Peak Output Power at 280 nm versus Input Power

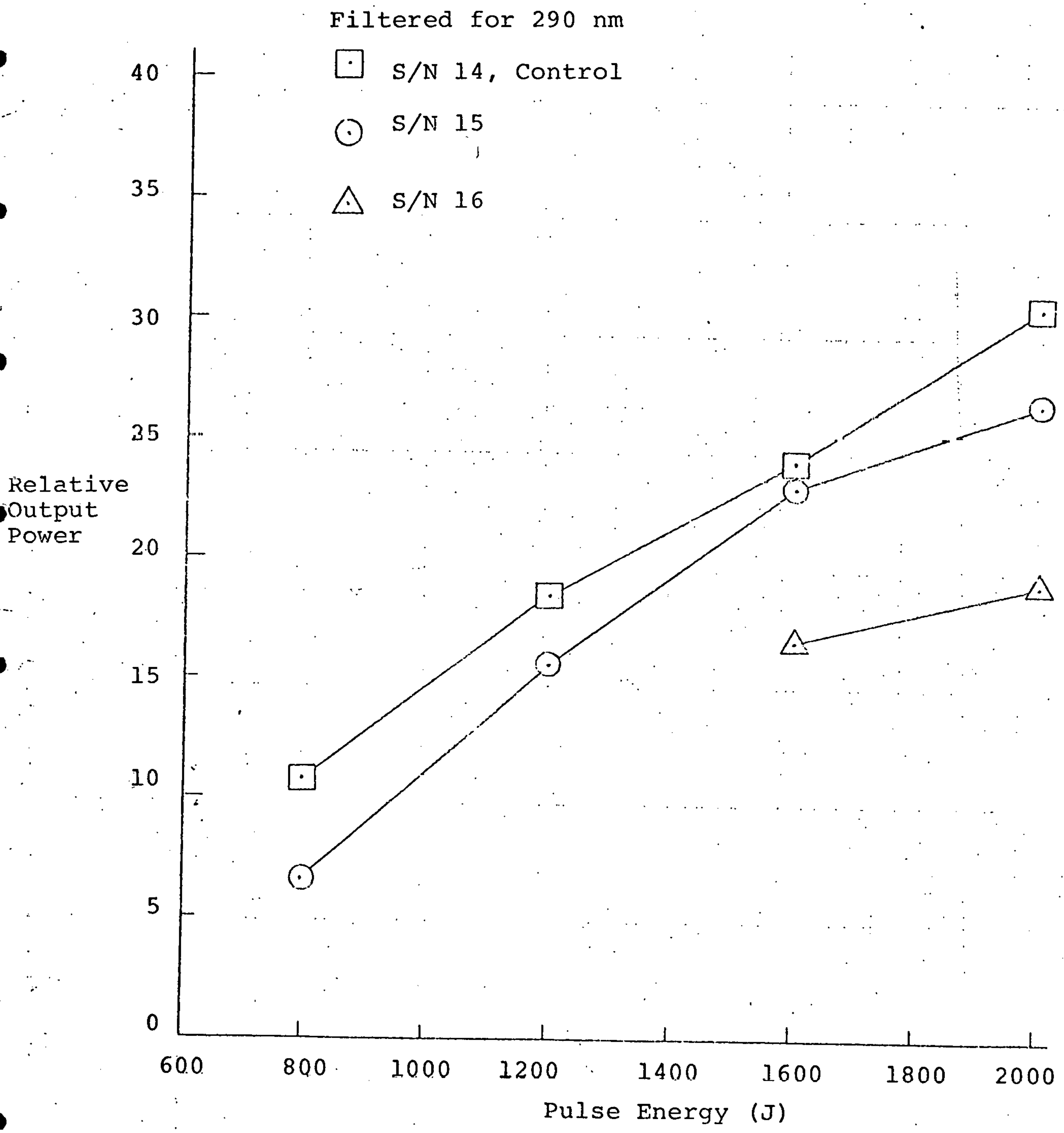


Figure 3-16 Peak Output Power at 290 nm versus Input Energy

4.0 SPECTRAL DATA

Detailed spectral data were taken early in the program on various additive lamps but suffered from two problems. First, the ILC lamps did not contain phosphorus and consequently showed only minimal enhancement effects. Second, these runs took well over 100 shots, and as a consequence lamp cleanup effects had an appreciable effect on the relative spectral curve as determined by the later shots. The spectra recorded for xenon control lamp S/N 1 are shown in Figure 4-1. At the end of the program a coarse spectral trace was run on lamp S/N 15 and completed in 20 shots to minimize aging effects. This lamp had shown significantly enhanced output in previous tests. Output for this lamp is shown in Figure 4-2 for the band 250 to 300 nm. It basically shows the same features as the xenon spectra with apparent self absorbtion at 255 nm and high output at 260 nm. The additive lamp appears to have a relatively higher output between 285 and 300 nm but the coarse resolution makes any conlusion tentative.

What is suggested by these results is that the enhancement effect is probably not due to the instantaneous increase of plasma emmissivity but is due primarily to a longer pulsewidth. There is also the curious fact that the enhancement effect depends upon two elements and that either zinc or phosphorous by itself will not yield a significant improvement in lamp performance. One plausible explanation for this is that phosphorus is an element with higher vapor pressure and probably vaporizes early in the pulse. Phosphorus emits radiation in four strong spectral lines with one pair at 253 nm and the other pair at 255 nm. This line radiation then excites the main additive atoms, which emit over a broad spectrum from 260 to 300 nm. Phosphorus by itself would be restricted to line emmission from a single spectral line whereas the presence of the secondary element allows efficient energy

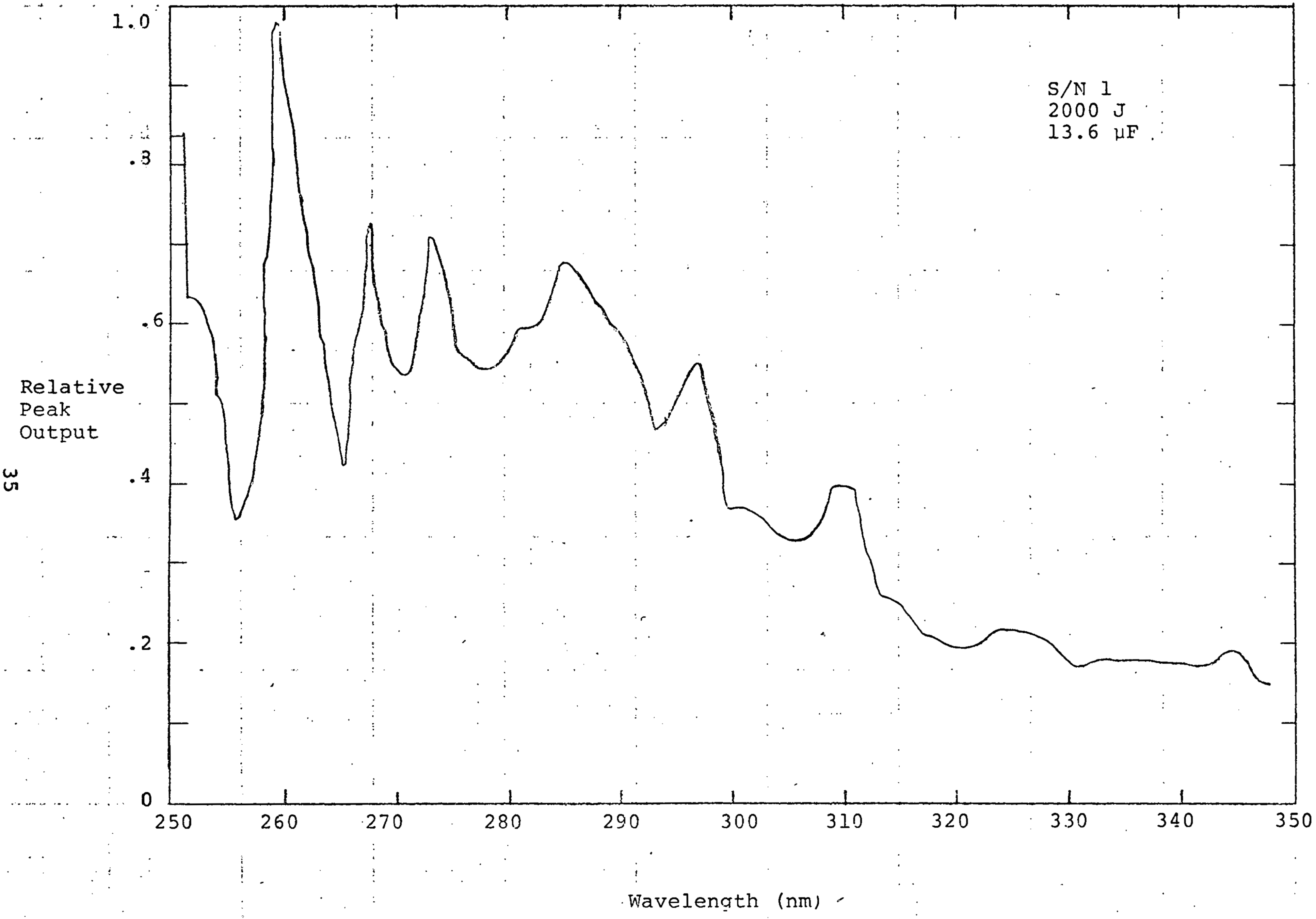


Figure 4-1 Spectral Output of Control Lamp S/N

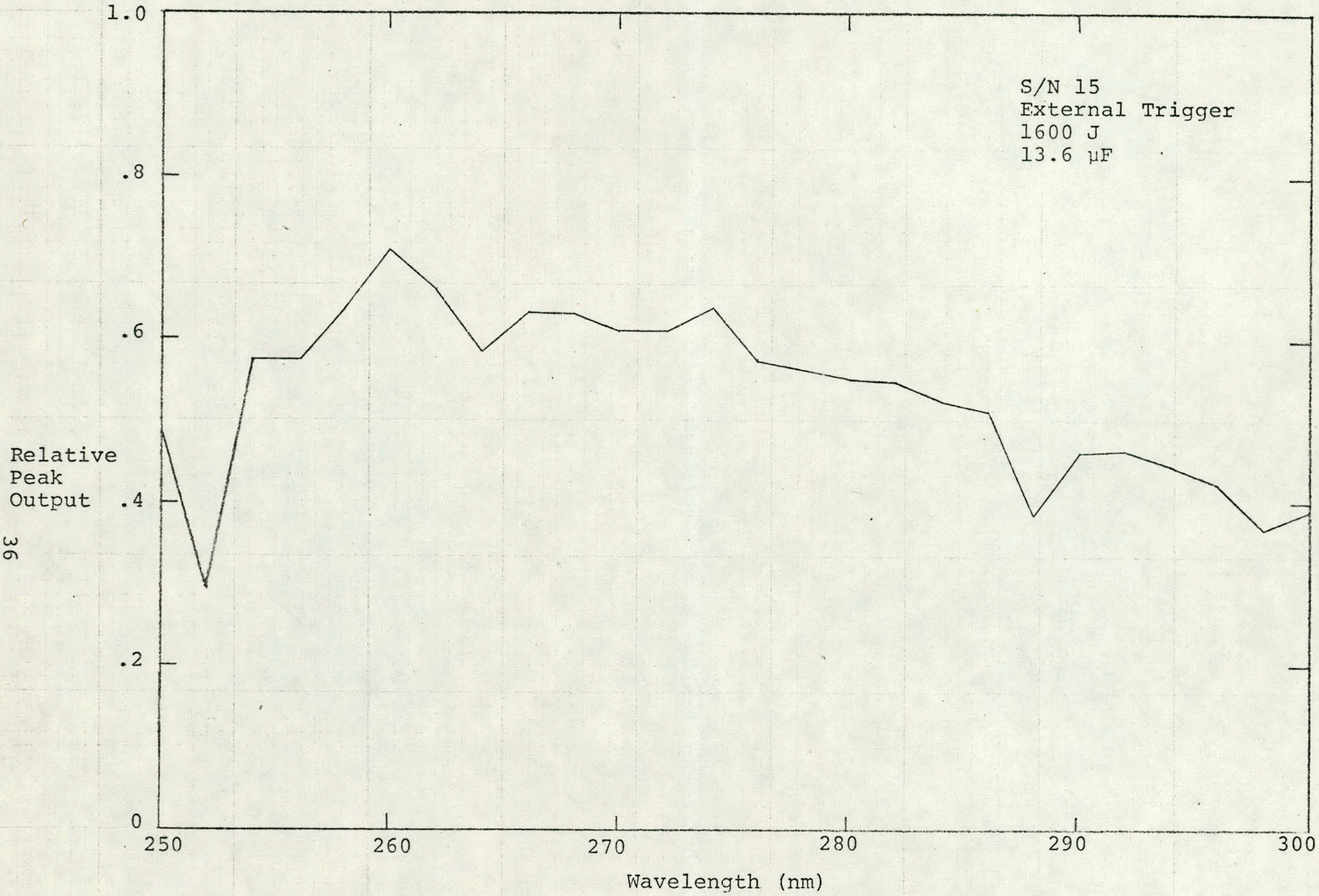


Figure 4-2 Spectral Output of Lamp S/N 15

transfer to a medium able to radiate over a broader spectrum.

These results, while tentative, offer some explanation why two additives are required. Any further experimental programs should investigate this phenomena further and try to arrive at a conclusive explanation for the observed effects of these additives on lamp spectral behavior.

5.0 Life Tests

At this point it was decided to life test at least one lamp at fairly high pulse energies to obtain a measurement of the usage that would result in removing the majority of the dopant from the active region.

The conventional formula for explosion energy, E_x, is:

$$E_x = 6250 \cdot S \cdot d \cdot T^{-\frac{1}{2}}$$

where E_x is in joules, S is the arc length in inches, d is the diameter in millimeters, and T is 1/3 the pulsewidth in seconds. For this case S is 11.8, d is 16, T is 5 μsec and E_x is 2638 joules. At 1600 joules, the lamp is being run at 60 percent of the conventional explosion energy and the lifetime L from the equation

$$L = \left(\frac{E_x}{E_o} \right)^{8.5}$$

is 70 shots. It was known that lamps survive longer than predicted when pulse durations are short so a test on the order of 1000 shots was expected.

A life test was carried out on a molybdenum cup seal lamp incorporating the most promising fill mixture. The lamp, S/N 16, had a 30 cm arc length and a 16 mm bore diameter. The fill consisted of 30 torr Xe, 150 mg Zn, and 10 mg P. The lamp was operated at 1600 J input energy (13.6 μF at 15.3 kV) in the non-simmer mode. The repetition rate was one pulse per minute.

The irradiance of the lamp was monitored during the course of the test with a ITT F4018 photodiode using a 258 nm bandpass filter. This data is hown in Figure 5-1. The data show considerable spread that is thought to be associated with migration

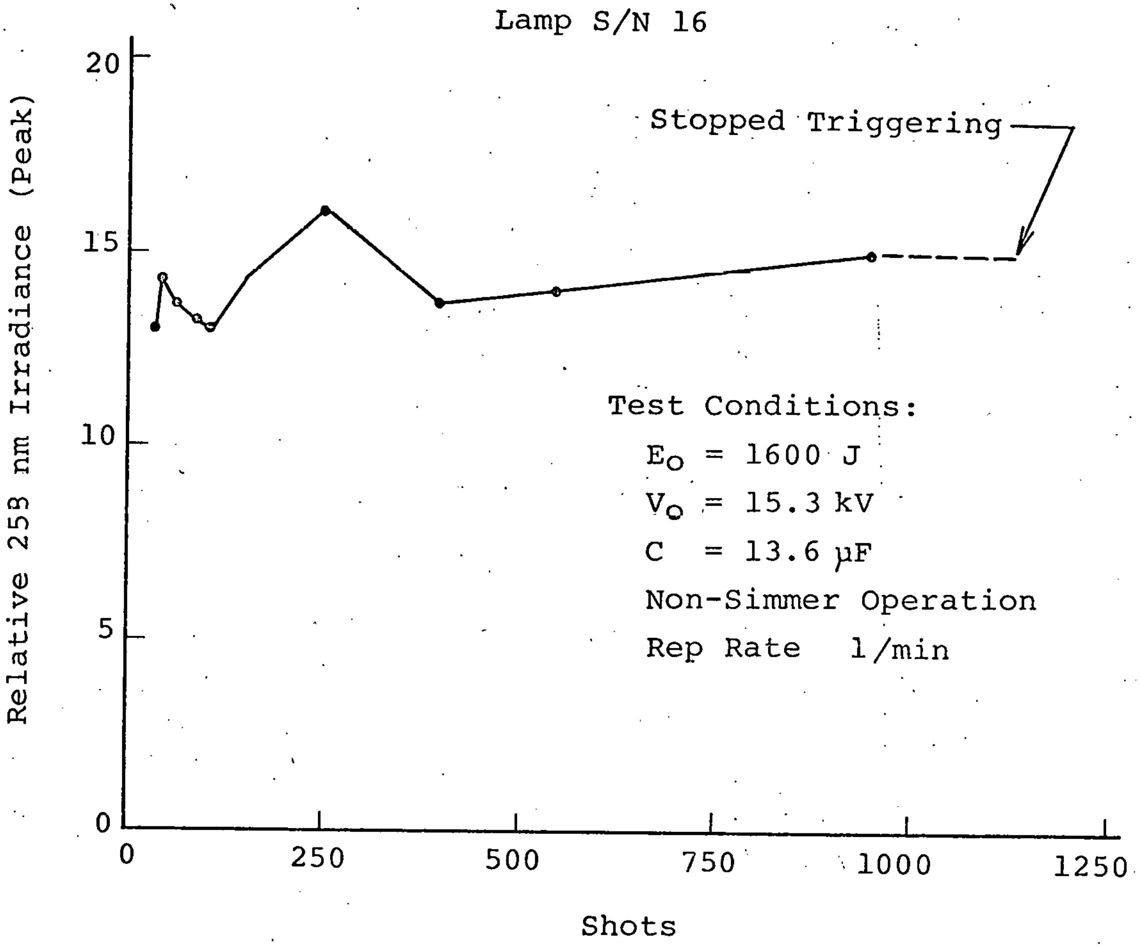


Figure 5-1 Life Test Peak 258 nm Output Of Lamp S/N 16

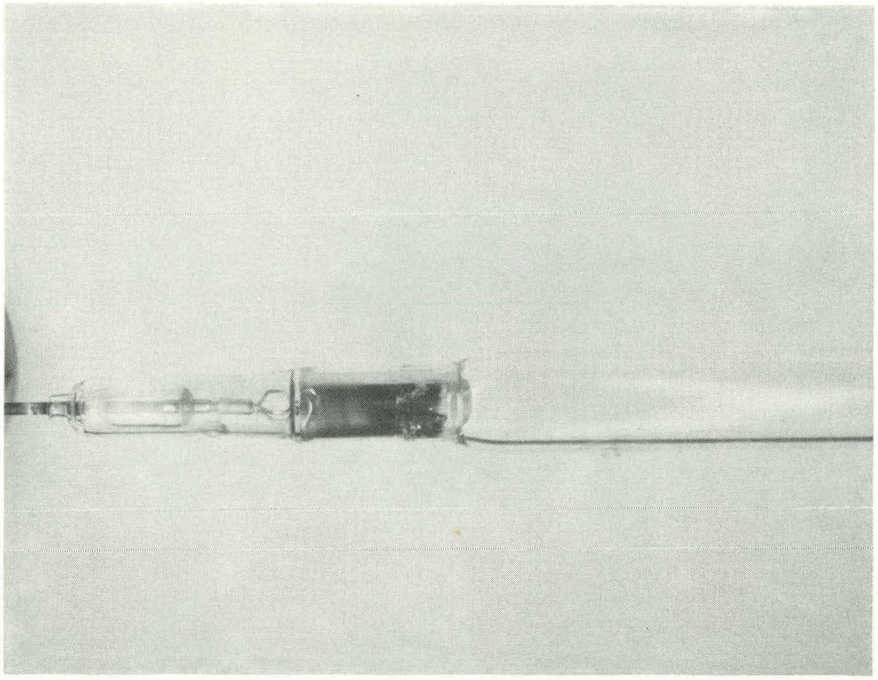
5496

of the dopant, which changes the overall transmission of the lamp walls. After the first few shots on the lamp, the dopant completely coated the inside wall of the lamp. Subsequent shots caused a gradual but nonuniform migration of the dopant towards the electrode ends of the lamp such that by approximately 50 shots considerable "clean up" of the central portion of the lamp had occurred and by approximately 1000 shots the only dopant left was at the extreme ends of the lamps. In addition, a number of metallic gray clumps were loose in the lamp. These clumps would not vaporize under normal operating conditions. The electrode area of this lamp as well as that of an otherwise identical non-doped lamp is illustrated in Figure 5-2.

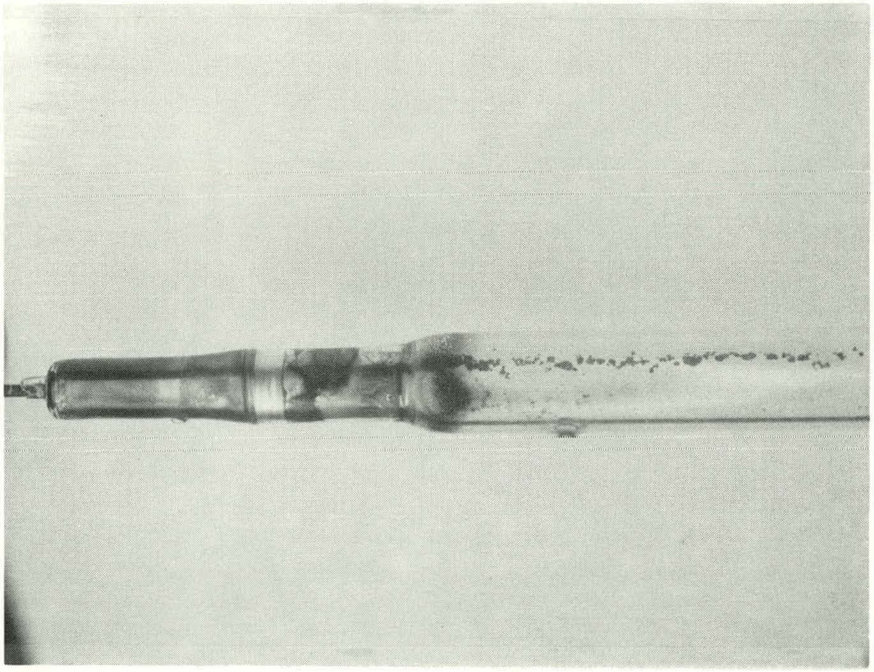
The lifetime of this lamp was 1170 shots. At this point, the lamp would no longer trigger at the normal operating voltage or at higher voltages up to 24 kV. The reason for this inability to trigger is unknown.

An attempt was made after 1170 shots to move the dopant material by externally heating the lamp envelope. It was expected this would be difficult but in fact proved impossible to do. The agglomerations of material appeared to be essentially chemically inert, with a very high boiling or melting point. It appears that these clumps of material are a chemical combination of oxygen and the fill material although much more testing would be required for conclusive proof.

There are apparently three separate life-limiting mechanisms at work in these lamps. The first is migration of dopant to the ends of the lamp due primarily to thermal effects. The second is ablation of the wall material due to the intense heating during a pulse. The third is the chemical reaction of the wall material with the lamp dopant to form an inert compound. For lamps of this type, it seems that chemical reaction with the dopant will occur before catastrophic



S/N 14 Undoped Lamp



S/N 16 Doped Lamp after 1170 Shots

Figures 5-2 Effects of Aging on Electrode Structures failure due to wall ablation. The effect of pulse heating is probably very energy sensitive, so that a slight decrease in pulse energy would be expected to increase lamp life considerably.

The dopant migration problem is probably less sensitive to energy level and will limit effective life at lower energies. There are several approaches to altering the thermal conditions in order to prevent this migration. One simple approach is to wrap the electrode region with foil to reflect radiation back into the lamp and to provide some insulation from the ambient air.

A similar approach would be to use reflective paint. Another approach would use resistive heaters in the electrode region to preheat the glass and prevent condensation in this area. (These had been proposed for this program but problems with achieving enhancement properly took priority.)

6. Effect of Simmer Current

Early in the program two tests were run to confirm the effect of simmer current on lamp performance. Tests were run on two xenon control lamps with 100 cm arc gaps at a loading of 1 kJ per pulse. Results of the tests are shown in Table 6-1; as expected, simmer operation produces an enhancement of the relative light output. Both lamps show an enhancement in output of roughly 60 percent in all wavelength bands of interest. During these tests the control lamp and the dopant-filled lamp were either both simmered or both non-simmered. (Since Sandia already simmers the flashlamps, any useful enhancement must be compared to a simmered control lamp.) It was noted that when both lamps were simmered, the output increased for the additive lamp as well as the control lamp. This would lead to the conclusion that the two effects are independent, and enhancement seen a non-simmered additive lamp will also be observed when the lamp is simmered.

Table 6-1 Enhanced Light Output of a Simmer Lamp Relative to an Externally Triggered Lamp

Serial Number	Wavelength (nm)	Relative Output		Percent Enhancement
		External	Simmer	
1	260	580	960	165
	270	700	1140	162
	280	540	860	159
	290	560	890	159
3	260	585	865	148
	270	690	1100	159
	280	540	840	155
	290	570	850	149

100 cm Arc Length
2000 J per pulse

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Lamp Structure

The main goal of this program, that of developing an electrode and seal structure with minimum non-active (cold) volume, has been met. The molybdenum cup seal and plug electrode have proven to be reproducible.

7.2 Additive Behavior

Phosphorous has been identified as being an accidental additive in Sandia-made lamps. The identification of phosphorus as a key additive element has converted previously puzzling experimental spectral enhancement results in to a reasonable pattern. While this is no small step forward, several fundamental questions concerning lamp behavior remain. Enhancement ratios are still not well defined in a quantitive way. The physics behind enhancement phenomena are not well defined. It is not clear whether the enhancement is due to different electrical conductivity properties of the additive mixture, or whether the radiative properties of the elements are the crucial factor. If the effect is due to resonance radiation of the additive, the decay time for the process is not yet known and, in particular, it is not clear whether additives will have significant value for short pulse durations.

7.3 Life Tests

More development work is required to produce lamps with lifetimes in excess of 1000 shots at high per-pulse energies. The observed chemical reaction problems can probably be minimized by running at lower energies per pulse. Dopant migration problems can probably be alleviated by adding heat shields in the electrode regions. If necessary, these shields may have to be heated to drive dopant away from the electrodes.

7.4 Recommendations

Further work on dopant optimization should be based on time-resolved spectral data and should include work on extending lamp lifetimes. The combination of xenon, zinc and phosphorus that has proven effective (if probably not optimal) in this program should be further investigated, as should other approaches to spectral enhancement in the desired band at short pulse durations.