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TECHNICAL REPORT ARCSL-TR-79065

IGNITION OF ARTILLERY TRACERS MANUFACTURED WITH KNOWN DEFECTS

by

Gerald C. Holst, Ph.D.

Research Division

November 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
Chemical Systems Laboratory
Aberdeen Proving Ground, Maryland 21010

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Acknowledgment

Mr. Thomas Doris recommended that the M13 tracer capsule be tested. He provided the rationale for choosing the particular defects used in this study and was instrumental in obtaining the defective tracers from Lone Star Army Ammunition Plant. The literature he supplied was the basis for the experiments performed in this study.

Henry J. Bielecki
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The need exists for a reliable, inexpensive method of testing artillery tracers for ignitability and burn rate prior to expensive field tests. In this study, a 1-kw CO_2 laser was used to ignite tracers having known defects. The most sensitive measure appears to be the energy required for ignition. Results indicate that tracers manufactured with variations in the igniter percent of graphite exhibit a large dispersion in energy required for ignition. Tracers manufactured with variations in the tracer magnesium granularity also exhibit

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20. ABSTRACT (Continued)

large dispersion. However, there appears to be a direct relationship between energy required and consolidation pressure. Low consolidation pressure tracers require more energy than do standard tracers.

PREFACE

This work was initiated at Frankford Arsenal in October 1976. Because those tracers manufactured with known defects were not available until after Frankford Arsenal closed in October 1977, the project was transferred to Chemical Systems Laboratory where it was completed in February 1979.

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IGNITION OF ARTILLERY TRACERS MANUFACTURED WITH KNOWN DEFECTS

I. INTRODUCTION.

Tracers for artillery rounds are pyrotechnic compositions housed within steel containers that are affixed by various means to the base of the projectile. These tracers are ignited by the hot gases in the gun chamber, and the smoke and flame produced allow personnel to perceive the trajectory of the projectile. The need for a reliable method of testing these tracers for ignitability and burn rate prior to field tests was made obvious by the number of rejections that appeared. The current quality-control acceptability criteria is that a single failure in a 10-round test lot, blind or short trace, is sufficient cause for rejecting the entire lot. If a double-sample method is used, then the lot may be accepted if an additional 25 rounds are tested and all perform satisfactorily. The trade off is between the cost of testing an additional 25 rounds and the cost associated with rejecting an entire lot.

The purpose of this study was to evaluate a method of testing the tracers during manufacture so that any deviations in the process may be corrected before the entire lot is completed. As a result, this type of test would, hopefully, significantly lower the scrap rate and lead to a high acceptance rate during expensive field trials.

The possible causes of blinds and short burn rates must be considered before a laboratory measurement is attempted because ignition in free air is a radical departure from the gun-chamber environment. Within the chamber, it may be assumed that the tracer is uniformly irradiated by a blackbody heat source. Furthermore, only a finite amount of energy is available for ignition. If the tracer has a manufacturing defect such that more energy is required, then the tracer will not ignite within the chamber. To detect this type of deficiency in the laboratory, it is necessary to uniformly irradiate the tracer with a controllable heat source. To this end, a 1-kw CO_2 laser was used. It is recognized that the energy absorbed depends upon the reflectivity of the surface; and since the reflectivity is a function of wavelength, the incident energy required for ignition from a CO_2 laser may be different from the broadband energy available within a gun chamber. However, for comparative results, the CO_2 laser will suffice.

Short burns may result from improper stoichiometric mix: voids within the tracer or a heterogeneous mixture. The effects of these defects will depend upon the spin rate. Initially, in this study the tracers were placed in an air-driven rotor capable of spinning up to 30,000 rpm to simulate actual firing conditions.

The use of a CO_2 laser to ignite tracers is not new. Several other investigators*, ** have attempted to ignite tracers with this controllable source and to study the effect of spin rate, burn time, and ignitability. Although the results indicate that there is a correlation between ignitability and stimulus intensity, no comprehensive test has been performed with tracers having known defects. The test procedure used by Platt* to ignite 5.56-mm tracer bullets is similar to the test procedure used in this study. However, the defective tracers used by Platt were listed only as 100%, 86%, 62%, and 50% weapon performance level lots. The performance level was obtained by grouping all defects (blinds, short traces, long-ignition burns) together. It is not known why these particular tracers were defective in terms of chemical composition, consolidation pressure, etc.; therefore, it is not known how to avoid these unidentified manufacturing defects. Furthermore, to ignite the tracer Platt had to focus the laser down to a 2.5-mm-diameter beam to increase the laser power density. Any small surface irregularity could cause a significant difference in ignitability.

As already mentioned, the amount of energy absorbed depends upon the reflectivity. It has been experimentally observed that a pyrotechnic composition containing a high percentage of magnesium requires more energy for ignition than does a low percentage composition.** Supposedly, this was caused by the high reflectivity of magnesium at $10.6\,\mu m$.

In an in-depth study, Puchalski*** sought to maximize burn time and candlepower output. He also studied the relationship between burning time and spin rate. Although he tried to optimize the composition, it can be inferred from his data how burn time may be affected by what we classify as an improper mixture; but to insure ignition 100% of the time, he affixed an electrosensitive composition onto the tracer igniter and used a Telsa coil to start the reaction. Therefore, there is no way of determining how sensitive the various compositions were to thermal energy.

In this study, we tried to avoid the possible errors discussed above. Tracers manufactured with known defects were uniformly irradiated by a 1-kw CO_2 laser. A parametric study was conducted with burn time, spin rate, and delay time as variables. Delay, defined as the time from initial laser irradiation to ignition, is related to the incident energy required for ignition.

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*Platt, W. G. Remington Arms Company, Bridgeport, Connecticut. Final Summary Report, Phase I. Contract DAAA25-71-C0069. Tracer Simulation Study. April 1972.

**Ward, J. R., Pahel, R. K., and White, K. J. Laser Ignition of Pyrotechnic Compositions Being Tested As Drag Reducing Fumers. AD 765415. July 1973.

***Puchalski, W. J. Frankford Arsenal Report FA-TR-74011. The Effects of Angular Velocity and Composition on Pyrotechnic Performance. August 1974.

II. EXPERIMENTAL PROCEDURE.

For these tests, the M13 tracer was chosen. It consists of a steel cup 1.9 cm in diameter and 1.75 cm long. It is charged with tracer composition R-508 and igniter I-527. Eight lots of the tracers were manufactured by the Lone Star Army Ammunition Plant, Texarkana, Texas. Seven lots had known defects; the eighth was manufactured in the normal manner (table 1).

Table 1. Description of M13 Tracers

Lot	Lot number	Consolidation pressure kpsi	Igniter percent graphite	Magnesium sieve size**
1.	LS-78F001S096	50	*	*
2.	LS-78F001S097	75	*	*
3.	LS-78F001S098	25	*	*
4.	LS-78F001S099	*	0	*
5.	LS-78F001S100	*	4	*
6.	LS-78F001S101	*	*	All fine (200/325 only)
7.	LS-78F001S102	*	*	All coarse (100/200 only)
8.	LS-52-10 sublot 5	100	2	100/200 and 200/325

*Standard pressure, graphite or magnesium, as given by standard tracer LS-52-10 sublot 5.

**200/325 Represents particle sizes that pass through No. 200 sieve but are retained by No. 325 sieve.

Lots 1, 2, and 3 were designed to evaluate the effects of consolidation pressure. Lots 4 and 5 evaluate possible irregularities in the igniter, and lots 6 and 7 are possible irregularities in the tracer magnesium particle size. Lot 8 is a standard tracer. The chemical composition of a standard tracer is given in table 2.

Table 2. Pyrotechnic Compositions of M13-Type Tracers

Charge	Chemical	Weight
		%
Tracer R-508	Magnesium 100/200*	21
	Magnesium 200/325*	21
	Strontium nitrate	44
	Vinylalcohol acetate resin	7
	Dechlorane	7
Igniter I-527	Barium peroxide	77.5
	Magnesium 200/325*	15.5
	Calcium resinate	5
	Graphite	2

*100/200 Represents particle sizes that pass through a No. 100 sieve but are retained by a No. 200 sieve.

The experimental setup is shown in figure 1. The relative brightness of each tracer was obtained with a silicon diode-filter system which had a spectral response equivalent to the standard photopic observer. Each tracer was irradiated for 1 second by a 1000-watt CO_2 laser. The $1/e^2$ beam diameter was equal to the tracer diameter (1.9 cm). The average power density was approximately 350 w/cm^2. The entire exposed area (2.84 cm^2) of the tracer was irradiated. No attempt was made to increase the absorption of the CO_2 laser. The air-driven spinner could rotate up to 30,000 rpm.

Initially, the following parameters were investigated: (1) delay time between initial laser irradiation and tracer ignition time, (2) tracer burn time, (3) tracer intensity, and (4) effects of rotation.

Preliminary tests indicated that the intensity was approximately equal for all tracers (standard and defective). Furthermore, at any particular spin rate the burn time for all tracers was also approximately equal. The duration of the burn time depended upon the spin rate, and a "cone" of the unburned pyrotechnic material was usually ejected. The effects of rotation and "cone" ejection are discussed in detail by Puchalski* and will not be repeated in this report. Only the delay time was sufficiently sensitive to warrant further investigation. Therefore, this test applies only to the determination of possible blind tracers.

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*Puchalski, W. J. Frankford Arsenal Report FA-TR-74011. The Effects of Angular Velocity and Composition on Pyrotechnic Performance. August 1974.

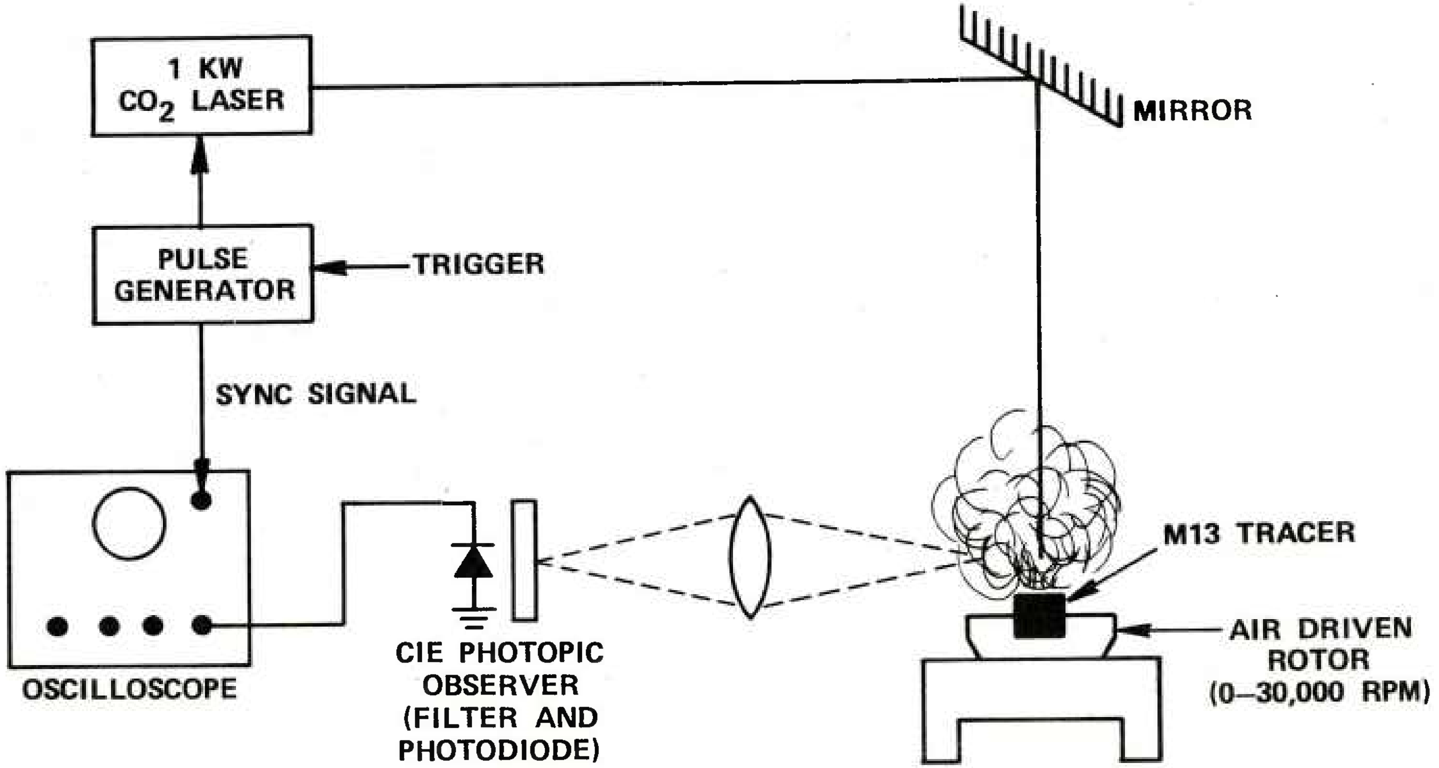

Figure 1. Experimental Setup Used for Igniting M13 Tracers

III. RESULTS.

The delay time between initial laser irradiation and ignition is given in table 3. Since the laser is on for 1 second, the total energy required to ignite the tracer is simply

$$E = PT \qquad (1)$$

where P = the laser power (1000 watts)

and T = the delay time

Table 3. Delay Time Measured for Each Tracer Lot

Standard	Lot numbers						
	S096	S097	S098	S099	S100	S101	S102
	msec						
200; 380	440	500	600	300	280	280	240
240; 400	680	520	640	400	300	300	440
240; 400	700	600	760	520	300	300	600
240; 400	700	640	760	600	440	400	640
240; 400	700	650	760	620	600	400	640
260; 400	760	700	760	640	600	400	700
300; 400	850	700	800	640	600	600	700
300; 440	880	800	800	700	800	600	800
300; 440	900	800	840	760	800	750	820
300; 440		800	860		820	800	840
300; 440							
300; 480							
360; 500							
380; 500							

Table 4 gives the mean and standard deviations of the delay time for each lot. The data are assumed to be normally distributed, and the probability of ignition for each lot as a function of delay time is shown in figures 2 through 4. The curves are drawn so that the total area under the curve is equal to unity. The brightness of each tracer seemed to be independent of the lot and appeared to be constant.

Table 4. Average Ignition Delay Time and Standard Deviation

Lot number	Number tested	Average delay time	Standard deviation of delay time
		msec	msec
S096	9	734	140
S097	10	671	111
S098	10	758	81
S099	9	576	149
S100	10	554	215
S101	10	483	191
S102	10	642	185
Standard	28	356	87

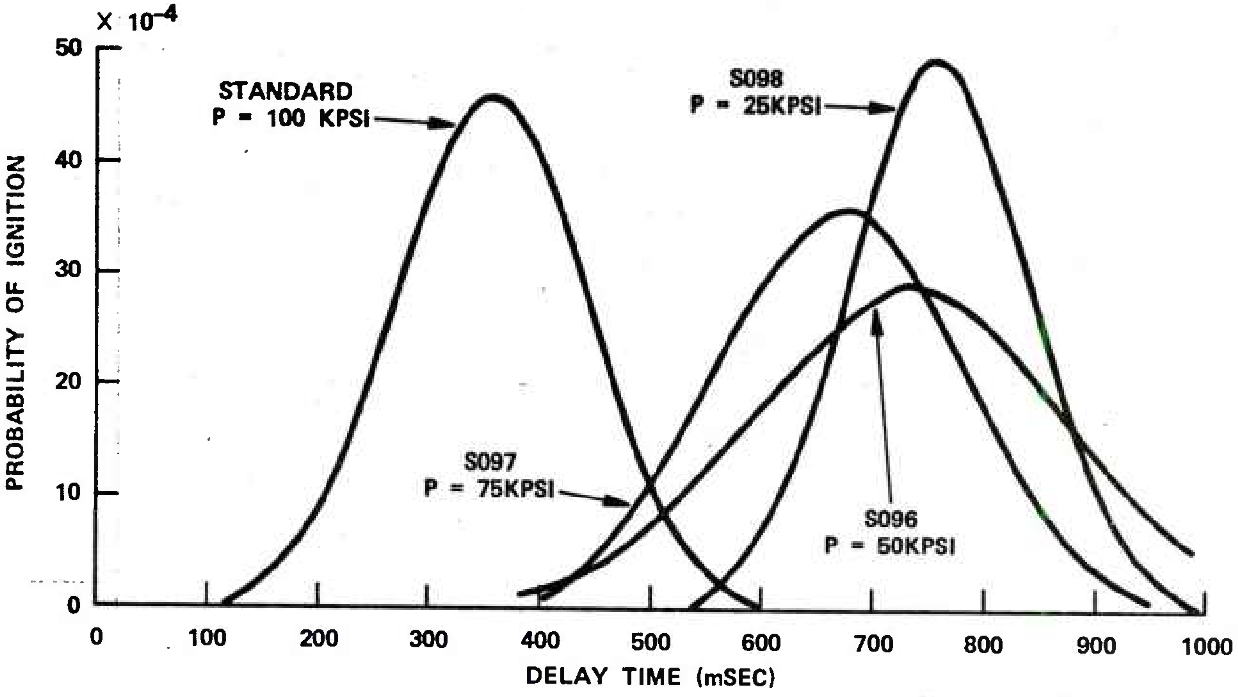

Figure 2. Probability of Ignition As a Function of Consolidation Pressure

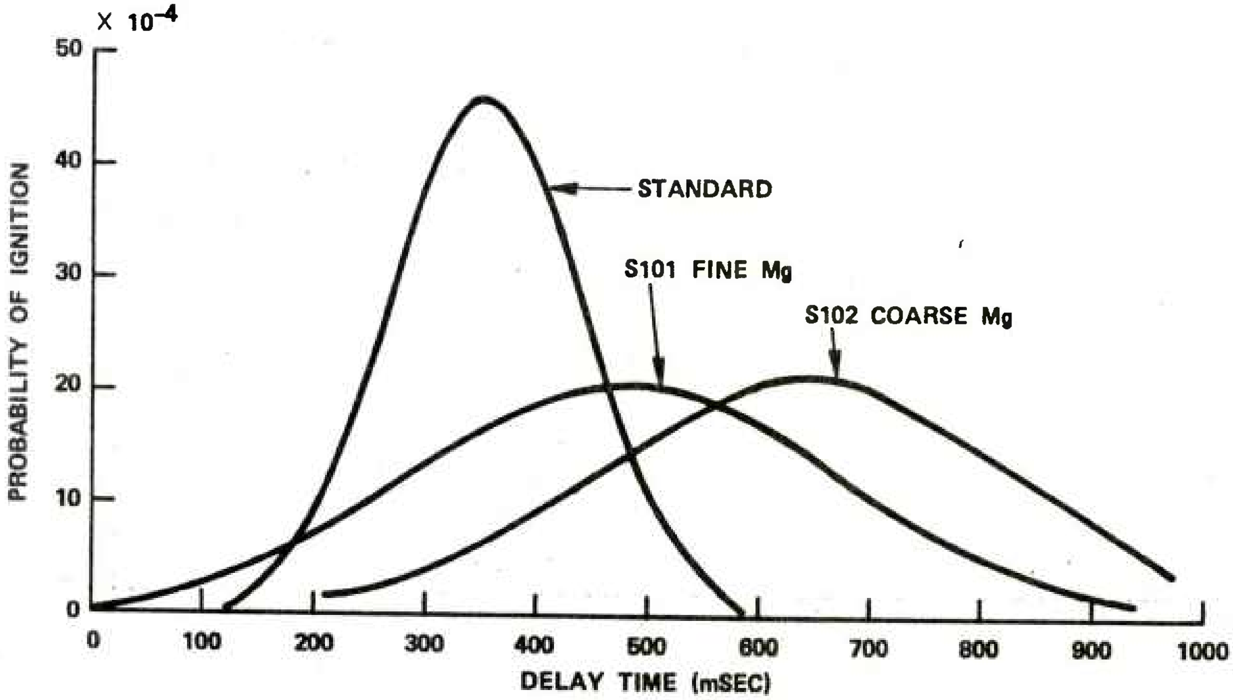

Figure 3. Probability of Ignition As a Function of Magnesium Granularity

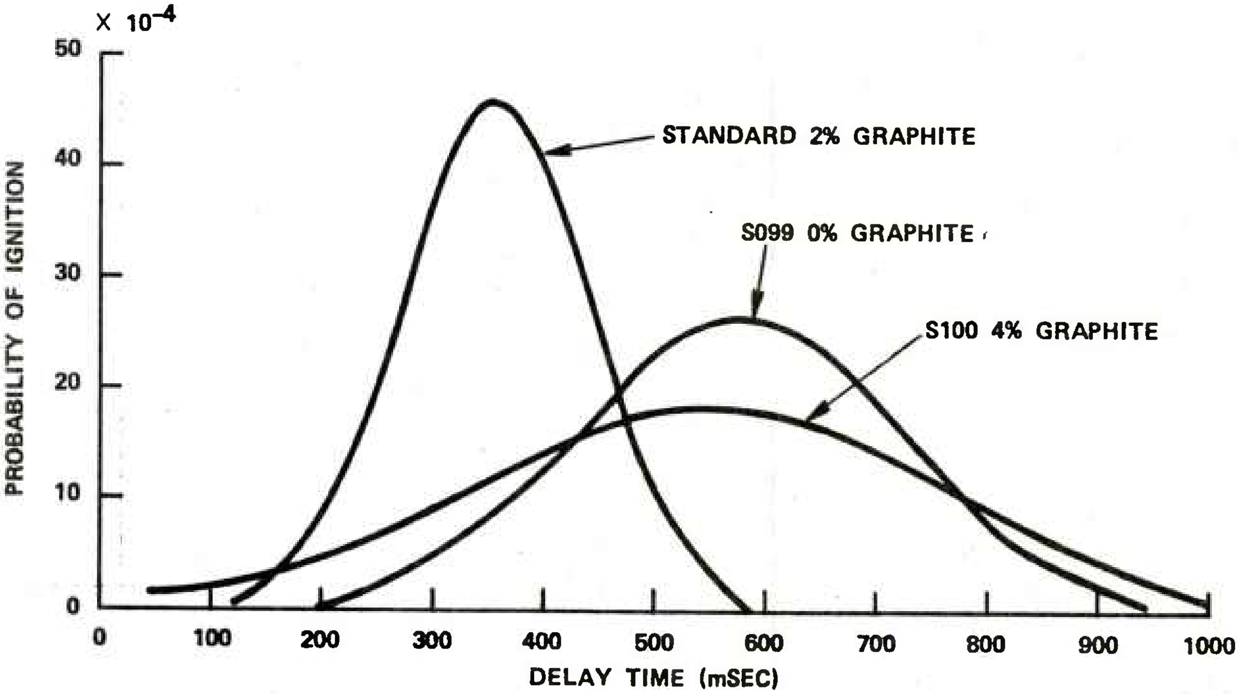

Figure 4. Probability of Ignition As a Function of Percent by Weight of Graphite

IV. DISCUSSION OF RESULTS.

It may be argued that the total number of tracers sampled was not sufficient to apply reasonable statistics. On the other hand, when tracers are fired in the field, only 10 rounds are fired and the results of those 10 rounds are sufficient to accept or reject an entire lot. If this type of test is used during manufacturing to control processing, only a few would be tested. The delay-time determination appears to be a sensitive method of evaluating consolidation pressure. Figure 5 is a plot of the average delay time versus consolidation pressure. If it is arbitrarily stated that the maximum delay time of 500 msec would be acceptable then, on the average, any tracer with a loading pressure below 90 kpsi would be rejected. If this method is considered for manufacturing control, statistical analysis would be used to determine the maximum allowable delay time. The critical assumption in these experiments is that the reflectivity of the exposed surface at 10.6 μm is not affected during the manufacture of the defective tracers. Since delay time is related to total energy, the total energy given to the tracer is 500 joules for a 500-msec delay. If heat conduction is not significant, the relationship between incident laser power and delay time (table 5) can be calculated from equation (1). Thus, if a lower-powered laser is used, the expected delay time increases.

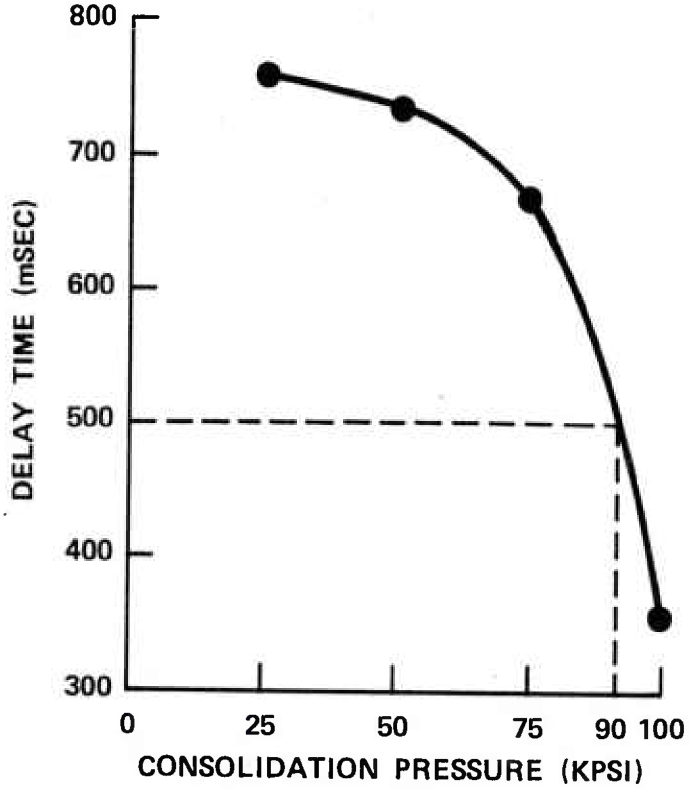

Figure 5. Average Delay Time As a Function of Consolidation Pressure

Table 5. Expected Delay Times

Laser power	Ignition delay time
w	sec
1000	0.5
500	1.0
250	2.0

It may be possible to reduce the laser power even further by focusing down to a smaller laser spot. However, surface irregularities and imperfections may lead to inconsistent data.

The percent of graphite and the granularity of magnesium exhibited a large dispersion in delay times which are quite difficult to explain. The standard deviations of these tests were much larger than the consolidation pressure defectives. Since the defects required a special manufacturing process, it may be exactly this process that leads to blind tracers.

When any upper bound is used to separate good items from bad items, and only a few items are tested, there is always a probability that a good lot may be rejected and a bad lot may be accepted. It is recognized that an insufficient number of tracers have been tested to accurately define the mean or the standard deviation of the overall population. The standard deviation is very sensitive to the sample size; and in this study, the sample size was rather small. Nevertheless, if the statistics obtained are representative of the population and if the delay time was truly the reason for blind tracers, then we can estimate the percentage of tracers that will ignite out of the total population for each type of defect for various incident energies (table 6). For example, if 4.7% of lot S096 ignited during field tests, then we would expect 6.2% of lot S097, 0.1% of lot S098, and so on to ignite. On the other hand, if 97.1% of lot S096 ignited then all other lots would also exhibit a high probability of ignition. If this is the case, then the energy available within the chamber is sufficient to ignite all tracers tested in this study.

Table 6. Percent of Tracers Ignited for Various Incident Energy Levels

Energy available for ignition	Lot number							
	S096	S097	S098	S099	S100	S101	S102	Standard
Joules				%				%
500	4.7	6.2	0.1	30.5	40.1	53.6	22.1	95.2
600	16.9	26.1	2.8	56.4	58.3	72.9	40.9	99.8
700	40.5	60.3	23.9	79.7	75.2	87.3	62.2	99.9+
800	68.1	87.7	69.8	93.3	87.3	95.2	80.2	99.9+
900	88.3	98.0	96.0	98.4	94.6	98.5	91.9	99.9+
1000	97.1	99.8	99.9	99.8	98.1	99.7	97.4	99.9+

V. CONCLUSIONS.

These data show that more energy is required to ignite low consolidation pressure tracers. If blinds are caused by low consolidation pressure, then ignition testing with a CO_2 laser is a viable method to control manufacturing. It is economically feasible to subject a large number of tracer capsules to laboratory tests to obtain a significantly large statistical sample size for quality-control purposes.

For us to understand why such a large standard deviation appeared in the delay-time data, we should carefully evaluate the process which was used in the manufacture of the percent of graphite and magnesium granularity defectives. Since the defects required a special manufacturing process, it may be exactly this process that leads to blind tracers.

The known defects tested (consolidation pressure, percent of graphite, and granularity of magnesium) do not appear to significantly affect burn intensity or burn time. Other possible defects, such as inhomogeneous mix or voids, should be tested by this method to determine how they might affect burn intensity or burn time.

VI. RECOMMENDATIONS.

It is recommended that samples from the eight lots tested here be subjected to field tests to verify the findings presented here. In particular, lot S098 should be tested first because it is the most sensitive to the energy available for ignition. If this lot does not exhibit any blind tracers, it suggests that the energy within the chamber is greater than 1000 joules. Table 6 shows that at 1000 joules, all defective lots have a high probability of ignition. Therefore, if lot S098 ignites each time, no further field testing is recommended. It indicates that laboratory test procedures are more sensitive to the defects tested in this study than are field tests.

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