ARMY RESEARCH LABORATORY

Laser Ignition of Standard and Modified 155-mm Howitzer Charges

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Army Research Laboratory
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Abstract

Laser ignition experiments have been performed using the M198 towed howitzer as the test bed. The first component was to evaluate the performance of two modified M3A1 bag charges, each of which had the standard igniter pad replaced with a propellant-filled tube designed to pressurize rapidly and generate sufficient gas and pressure for prompt ignition. These experiments were successful but not remarkable, with ignition times faster than the average for clean-burning igniter (CBI) pad ignition. Along with these rounds, standard rounds were fired to gain more experience with laser ignition of the M198 in preparation for interfacing a digital fire control computer with the laser ignition system. All these experiments were done with a pulsed neo-dymium: ytterbium aluminum garnet (Nd:YAG) laser similar to the one developed for the XM297 cannon. In the third part of the program, a continuous semiconductor diode laser was used to ignite five Zone 3 modular artillery cannon system (MACS) charges. Delay times from 355 to 733 ms were recorded. No degradation of the laser was noted from shock/vibration effects.

ACKNOWLEDGMENTS

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LASER IGNITION OF STANDARD AND MODIFIED 155-MM HOWITZER CHARGES

1. INTRODUCTION

The experiments described in this report have three purposes. The first part is as a first step in transferring laser ignition technology, which was originally developed for self-propelled (SP) artillery, to towed artillery. The second goal was to complete the in-cannon study of a concept of charge ignition which does not use conventional igniter materials (clean-burning igniter [CBI] or black powder). The third goal was to explore the use of continuous lasers as cannon ignition sources.

Two lasers were used here. The first was a traverse breech-mounted neo-dymium ytterbium aluminum garnet (Nd:YAG) flashlamp-pumped (pulsed) laser. The laser is optically identical to the breech-mounted laser that has been successfully used for more than 400 firings of the 155-mm M284 and XM297 cannons. The second was a commercial continuous diode laser that was adapted to the cannon by Quantic, Inc. These lasers are described in more detail later in this report.

Currently, the M82 percussion primer is used for igniting propelling charges on the M198 155-mm towed howitzer. A primer failure results in a misfire of the howitzer, requiring a lengthy set of procedures to be followed before the howitzer can be fired. It is anticipated that laser ignition will reduce the chance of a misfire while enabling higher firing rates and thereby enhancing the capabilities of the M198 and its crew.

Several improvements in the M198 155-mm towed howitzer are currently being explored. One improvement is an automated digital fire control (ADFC). With an ADFC system, fire missions are sent to the ballistic computer on the howitzer. Integrating laser ignition with ADFC results in a system that can only be fired when the correct gun azimuth and elevation are set on the howitzer. This arrangement reduces the chance of firing the weapon on the wrong position.

In addition to improving the present generation of towed howitzers, there is a strong requirement for lighter weight high performance cannons for lightweight, highly mobile forces. It is possible that laser ignition might well play a role in reducing overall logistics weight by removing the requirement for primers, especially if power requirements to the laser can be minimized. The most efficient lasers for converting electrical energy to light energy are the semiconductor diode lasers. Low power versions used in many consumer devices have shown them to be both rugged and long lived. Thus, they appear as a possible source of ignition which might require much less input power than conventional laser ignition but with many of the same attributes. Although they have been used in many pyrotechnic applications and in laboratory laser ignition experiments, they have not previously been studied as large caliber gun igniters.

2. Nd:YAG LASER

2.1 The Laser

The Nd:YAG breech-mounted laser (see Figure 1) used in these experiments was optically identical to the breech-mounted lasers used in the Crusader XM297 tests.**[1]** It has an output of 10 joules of energy in a 5-millisecond (ms) pulse. Beam diameter at the laser output was approximately 5 mm. Referred to as the "brick" design, this laser was designed and built by Kigre, Inc., under a Small Business in Research contract. The laser rod and optical cavity are transverse to the axis of the cannon; the beam is directed through the breech and breech window to the charge by a reflecting prism mounted near the end of the laser rod. No other intermediate optics were used.

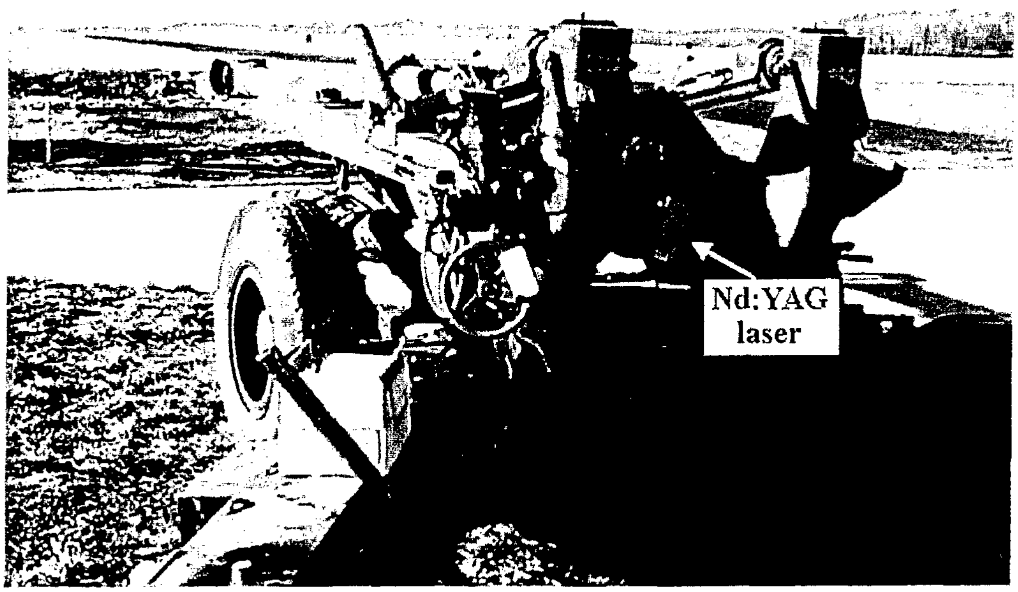

Figure 1. "Brick" Nd:YAG Pulsed Laser on M198 Cannon Breech During December 1997 Study.

2.2 Propelling Charges

Firing was conducted with the M3A1 and M4A2 propelling charges. The M3A1 or "green bag" is used for firing minimum range in Zones 1 through 5. It consists of 5.50 pounds of M1 propellant in five charge increments, three flash reducer pads, and an igniter pad. The M4A2 or "white bag" is used for firing minimum to medium range in Zones 3 through 7. It consists of 13 pounds of M1 propellant in five charge increments, one flasher reducer, and an igniter pad. For all rounds, M107 inert projectiles with M557 fuze assemblies (empty) were used.

Two standard M3A1 propelling charges were modified by removing the standard igniter pad, cutting the cloth bag leading to the base charge increment, and pushing the igniter tube into the base charge increment. The tube was centered in the charge so that it would align with the sapphire window on the spindle assembly. The tube assembly protruded approximately 2 inches beyond the base of the charge. In order to maintain optical alignment between the igniter and the sapphire window, the tube assembly was supported by a corrugated cardboard collar. The alternate igniter has been described in detail earlier.**[2]** It consists of a tube of acrylic approximately 1 inch in diameter and 6 inches long. It has a thin walled aluminum tube over most of the exterior length. In its interior, it has a series of chambers that promote gas generation and flame transfer the length of the tube before venting out the radial vents near the forward end of the device. The tube assembly contains a total of 26 grams (g) of M44 and JA2 double-based propellants. A schematic diagram of the igniter and the geometry of the modified M3A1 charge is shown in Figure 2.

2.3 Modified Spindle Assembly

A standard spindle assembly that was earlier modified for fiber-optic coupled laser ignition in this cannon was used. The modifications consisted of machining the primer port on the chamber side of the spindle to allow the sapphire window case to be screwed into the spindle. This case is about 1 inch long and 1 inch in diameter. A standard design 10-mm aperture window was used. The primer port on the outside of the spindle was originally threaded for the insertion of an optical "collimator" to refocus the light after transmission through the fiber optic. These same threads were used without modification to attach the brick laser assembly. Although this design laser has been used in earlier laser ignition gun studies,**[3]** these were the first that were fired at an elevation; all earlier rounds had been fired with the gun tube horizontal. With the laser mounted vertically on the breech, as in the previous design, interference between the right trunnion and the laser was encountered when the breech was opened. The laser was rotated in the spindle until no interference was noted.

2.4 Facilities

Firing was conducted at the U.S. Army's Aberdeen Test Center (ATC) at Aberdeen Proving Ground (APG), Maryland. The firing position was at ATC's main front range, Barricade 3. Data acquisition and firing support were provided by ATC personnel.

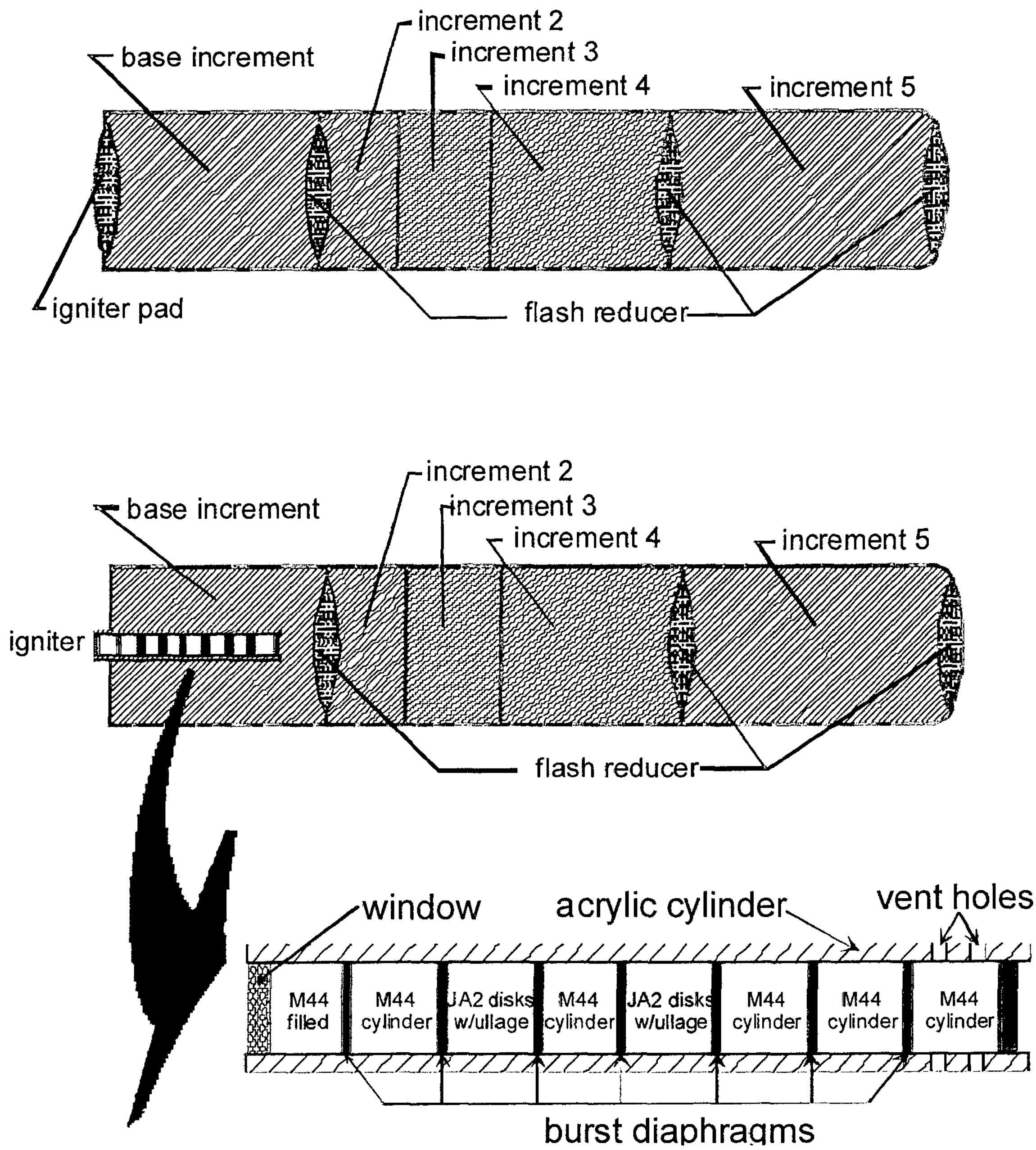

Figure 2. M3A1 Charge in Standard Configuration (upper) and With Modified Igniter (lower).

Copper crusher gauges were used to record chamber pressures during the firings with the experimental igniter tubes. A Weibel, W-680 Doppler radar system with a 3-watt head was used to record muzzle velocity for all the firings. A Kodak model 4540 camera was used for studying gun tube movement. The camera was synchronized to the laser firing pulse so that ignition delay times could be estimated. The delay times recorded are based on first motion of the gun tube. Since the tube may not move until the projectile is well in motion down the tube, this measurement of the "ignition" time is off by a fixed amount of 10 to 20 ms, compared to pressure-based times. Because the times were much longer than this error, no corrections have been made.

3. Nd:YAG LASER RESULTS

A total of nine rounds was fired. All rounds fired on trigger without anomaly. The results are summarized in Table 1.

Chamber pressures were measured only for the two modified charges. The values obtained were 7.90 kilo-pounds per square inch (kpsi) for Round 3 and 14.95 kpsi for Round 4. Standard values **[4]** for these charges are 7.90 kpsi and 15.40 kpsi.

Table 1. Results of Pulsed Laser Cannon Firing Experiment

Round No.	Propelling Charge/Zone	Elevation (mils)	Muzzle Velocity (m/s) measured	standard [ref]	Delay (ms)
1	M3A1/3G	567	276	277	418.8
2	M3A1/3G	567	266	277	444.4
3	mod M3A1/3G	567	258	277	344.0
4	mod M3A1/5G	300	364	375	301.0
5	M3A1/5G	300	370	375	440.8
6	M3A1/5G	300	370	375	426.1
7	M4A2/7W	140	576	565	329.6
8	M4A2/7W	140	574	565	415.2
9	M4A2/7W	140	575	565	370.7

4. DISCUSSION

4.1 Ignition Delays

The ignition delays for both the M3A1 and M4A2 charges are well known to be slow with laser ignition (compared to black powder ignited charges) because of the relatively slow flame spread through the CBI material from the point of ignition. Although limited firing records are available, ignition delay times near 400 ms are typical for laser-ignited bag charges with CBI base pads. In one data set of 45 rounds where M4A2/7 charges were fired as warmer rounds for XM297/MACS experiments, an average ignition delay of 431 ±120 ms was reported.**[5]** All but Round 4 of the sequence fell within one standard deviation of that value.

Since the shortest ignition delay was from one of the modified rounds, one might want to declare that the confinement and subsequent increased rapid gas generation rate of the modified igniter had shortened the ignition delays of these charges. With such a limited set of values, this is probably not justified. It is true that both of the measured delays with the modified igniter were well below the average ignition delay value.

The ignition delay for a bag charge using a M82 primer is typically from 125 to 150 ms.

4.2 Muzzle Velocity

The values of the muzzle velocities do not compare well with the "standard" values. Although these experiments were conducted in mid-December, the ambient temperature was above the seasonal average. The temperature of the rounds from storage is unknown. Because of the uncertainties, only relative values can be evaluated here. The groups of three M4A2/7W and M3A1/5G are each reasonably self-consistent. The velocity value for the modified igniter is slightly lower than the rest of this group of three.

The group of M3A1/3G rounds shows a decrease with each round fired. This effect may be random variation. However, once again, the lowest value of this set is from the round with the modified igniter.

This slight decrease in velocity with the modified igniters is perhaps partially accounted for in the decrease in energetic material in the charge. Both of these bag charges in standard configuration contain a base pad with 3.5 ounces (99 g) of CBI. We have replaced that with 26 g of propellant with approximately the same impetus. Because of the very limited number of values available, no attempt has been made to calculate the predicted decrease in muzzle velocity from this igniter decrease.

No sense was found in the pressure values. The one that was lower than expected (Round 4) had a muzzle velocity consistent with similar rounds. Round 3 had a nominal peak pressure and was low in muzzle velocity.

5. THE CONTINUOUS DIODE LASER

5.1 The Laser and Optics

The semiconductor diode laser used in this series of experiments was purchased from Applied Optronics Corporation by Quantic Industries and was evaluated as a potential cannon igniter in a series of range experiments using black powder and propellant samples. This laser has a nominal output power of 60 watts near 980 nanometers (nm) from a 600-mm diameter optical fiber. It is expected that the fiber will have a connection at the outside of the breech spindle. Thus, an important part of this evaluation was to determine the effect of the relatively high standoff (more than 6 inches) between the fiber and the material to be ignited at the base of the charge. Based on these experiments, it was determined that ignition of black powder might reasonably be expected in less than 100 ms; while this time does not correspond directly with gun ignition time, it is not unreasonable.

An optical system to relay the energy between the end of the fiber, which is attached at the outside surface of the spindle, and the charge was designed. It consists of two relay lenses mounted inside the spindle and the convex high pressure surface of the sapphire window. This design was the first in a large cannon to use a sapphire window with a curved surface. A flat surface is normally preferred for both cost effectiveness and cleaning. Because of the high numerical aperture of the optical fiber (i.e., divergence of the emerging light beam), it was necessary to machine a spindle to significantly larger opening from the rear of the window case to the outside surface in order to accommodate the required optics. With this optical design, a spot size of slightly less than 6 mm diameter was obtained at the charge position. This position was inadvertently designed to be approximately 1 inch away from the normal charge position. Charges were carefully placed accordingly during the firings.

No estimate was made of the possible decrease in strength of the spindle because of the additional machining. No damage was noted, but only modest charges were fired here.

The laser was attached to the gun mount as shown in Figure 3. This provided sufficiently close location that the 1 meter of optical fiber available was sufficient for recoil with these charges. The current supply for the laser was located in the control area.

5.2 Propelling Charges

Three XM232 modular artillery cannon system (MACS) charges were used for each of these rounds. These charges were chosen because they have black powder base pads and were expected to yield more reasonable ignition delay times than would CBI bag charges.

5.3 Experiment Facilities

Firing was conducted at the U.S. Army ATC at APG, Maryland. The firing position was at ATC's railroad range. Data acquisition and firing support were provided by ATC personnel. Because only delay times were to be studied in this experiment, instrumentation was limited to a Kodak model 4540 camera which was used for studying gun tube movement. As with the pulsed laser experiments, delay times were recorded, based on first motion of the gun tube. Again, no correction has been made for the delay between ignition and first gun tube motion.

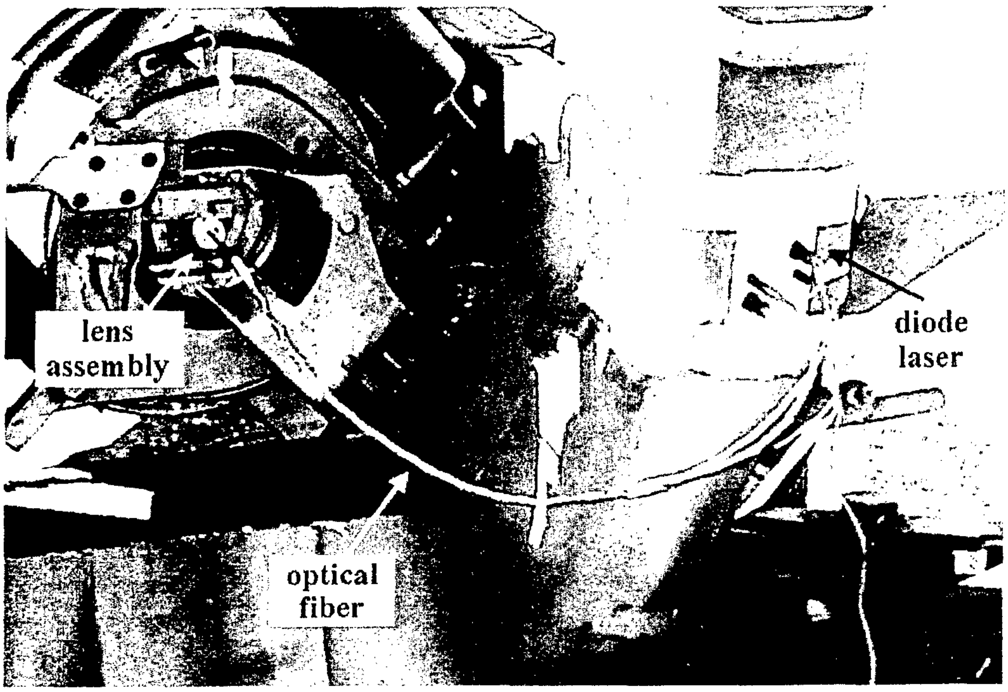

Figure 3. Diode Laser and Optical Fiber Cable to Breech During October 1998 Study With M198 Howitzer.

6. DIODE LASER RESULTS

Five rounds were fired with this setup. All five fired on the first try. In each case, the laser was turned on until the cannon firing was noted. The length of the delay was apparent to the operator in some cases. The measured delay times are recorded in Table 2.

All laser and optical components were functional and showed no indications of damage from shock and vibration at the end of the experiments.

7. DISCUSSION

Because this was the first application of this type of laser to gun firings, it was evaluated at a somewhat different level. The survival of the laser components is critical. The diode industry standard for shock/vibration experimenting is far below that routinely encountered in a gun experiment. This element alone makes this experiment very encouraging.

Table 2. Delay Times for Diode Laser Ignition

Round	Time (ms)
1	526
2	733
3	444
4	522
5	355

While the delay times are somewhat high, these were not unexpected. It had been hoped that reasonable consistency could be obtained. The differences vary over a range that certainly needs improvement; however, there are many ways in which this early design can be readily improved. The first is that the power density can be made much higher at the normal charge location by correctly imaging the energy at the position. It is estimated that improvements of at least a factor of four can be made in energy density, which will translate into shorter ignition delays. The second change that will be available shortly is a much higher brightness diode laser of comparable power. These lasers will allow higher power densities or similar densities over a much longer focal (ignition) region.

8. FUTURE STUDIES

As mentioned in the introduction, this report has three elements of laser ignition that are connected by their common use of the M198 howitzer as a experiment platform. The experimental charge ignition concepts, while fully successful, will not be pursued further in the immediate future. The principal difficulty is that with the present emphasis on modular charges, the rapid inter-modular transfer of ignition is more important to function than initial ignition of the charge. The concept as developed here does not appear to lend itself well to modular charges.

The second element present here is the transition of pulsed laser ignition to lightweight cannons, especially future systems that might have very limited power and weight budgets. If funding is available, the goals of this element will be to gain experience with digital control of laser ignition and to evaluate the potential of reducing the power requirements of the Nd:YAG laser through more efficient use of the light energy for ignition of the charge. In particular, in the XM297 cannon, ignition over an extended stand-off range is required. This need limits the possibility of focusing the laser beam, which would provide prompt ignition with much less total energy. A careful study of the real energy density requirement at the charge for ignition as well as system stand-off requirements for future lightweight cannons may provide the basis for attractive laser ignition options. The significant decrease in both power required and weight of the ignition package is expected.

The third element of this series of experiments was to explore the possibility of making a major step toward reducing weight and power by changing the more efficient diode lasers. The present results are encouraging. Future work is required to narrow the distribution of delay times, either through the use of higher brightness lasers or by redefining the focal plane (location of the charge) to an optically favorable position. While there are many possible avenues of improvement with these lasers, a source of funding has not yet been identified to make serious progress possible.

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13. ABSTRACT *(Maximum 200 words)*

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