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Title: PROCYON HIGH EXPLOSIVE PULSED POWER EXPERIMENTS

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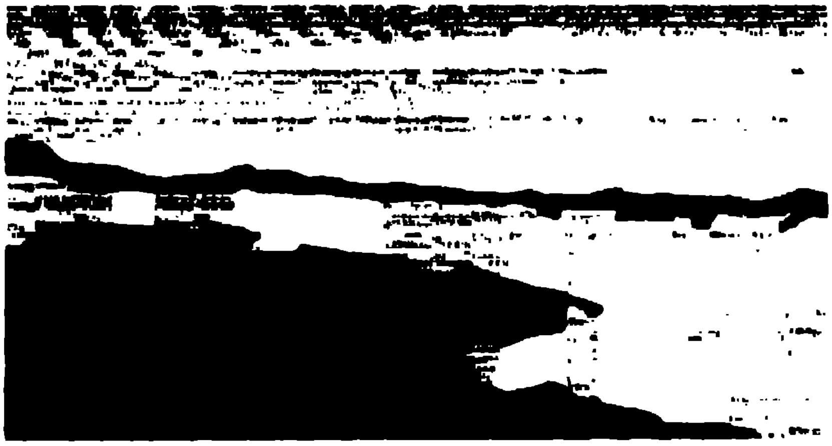

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PROCYON HIGH EXPLOSIVE PULSED POWER EXPERIMENTS

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Introduction

Procyon is a two-stage explosive pulsed-power system, consisting of a MK-IX helical generator[1] and an explosively formed fuse[2] (EFF) opening switch. A complete assembly including load and diagnostics is shown in Fig. 1. The system was originally developed for the purpose of powering plasma z-pinch experiments and, in its original concept, was coupled to the plasma z pinch load through a third pulsed power stage, a plasma flow switch (PFS)[3]. We have performed plasma z-pinch experiments both with and without a PFS, and we have now conducted our first heavy liner experiment. In this paper, we will summarize the results obtained to date with the system, and briefly discuss future applications.

PFS Tests

Our original design goals for Procyon were driven by the belief that to obtain the radiation temperature desired, a sub-microsecond plasma implosion would be required. From previous experiments[4], we know that we could make an EFF that would satisfy this need, but transmission line voltages appeared excessive, and our baseline design included a slower opening EFF along with a plasma flow switch for an intermediate stage opening switch between the EFF and the implosion. Several tests were performed in this configuration, and we achieved significant results on two of these. We reported the results of our initial static load test in the 1993 IEEE Pulsed Power Conference Proceedings[5]. Currents measured on our most successful z-pinch load test are given in Fig. 2. On this test we delivered 15 MA from the storage inductor to the PFS, and the pinch occurred at over 14 MA. The PFS did not employ a conventional $1/r^2$ gun plasma mass distribution, but varied as 1/r, causing the switch to open while plasma was still in the barrel, as in Fig. 3a. Only minimal radiation was detected by external diagnostics, because of the mass of PFS plasma that filled the detector viewing port at the critical time, as shown in Fig. 3b. From an energy analysis using the currents shown, we conclude that ~1MJ was dissipated on a time scale of interest for radiation[5]. Based on experience from other experiments, we believe that we could have generated as much as 750 KJ of useful radiation. Experiments using the radiation pulse would be located in a position not affected by the PFS plasma, and the occluded radiation probably does not pose a significant problem.

Direct Drive Experiments

We conducted three Procyon experiments in which we switched current to a plasma implosion directly with the voltage produced by the EFF. Each of these tests produced useful radiation, and our best radiation results were obtained this way. On our highest fluence test, we dissipated ~2 MJ from the circuit[6], and measured 1.6 MJ radiation at ~60 eV. Currents from this test are shown in Fig. 4, and the x-ray pulse shape is shown in Fig. 5. With a full width at half maximum of ~200 ns we infer an average power for the radiation of ~ 8

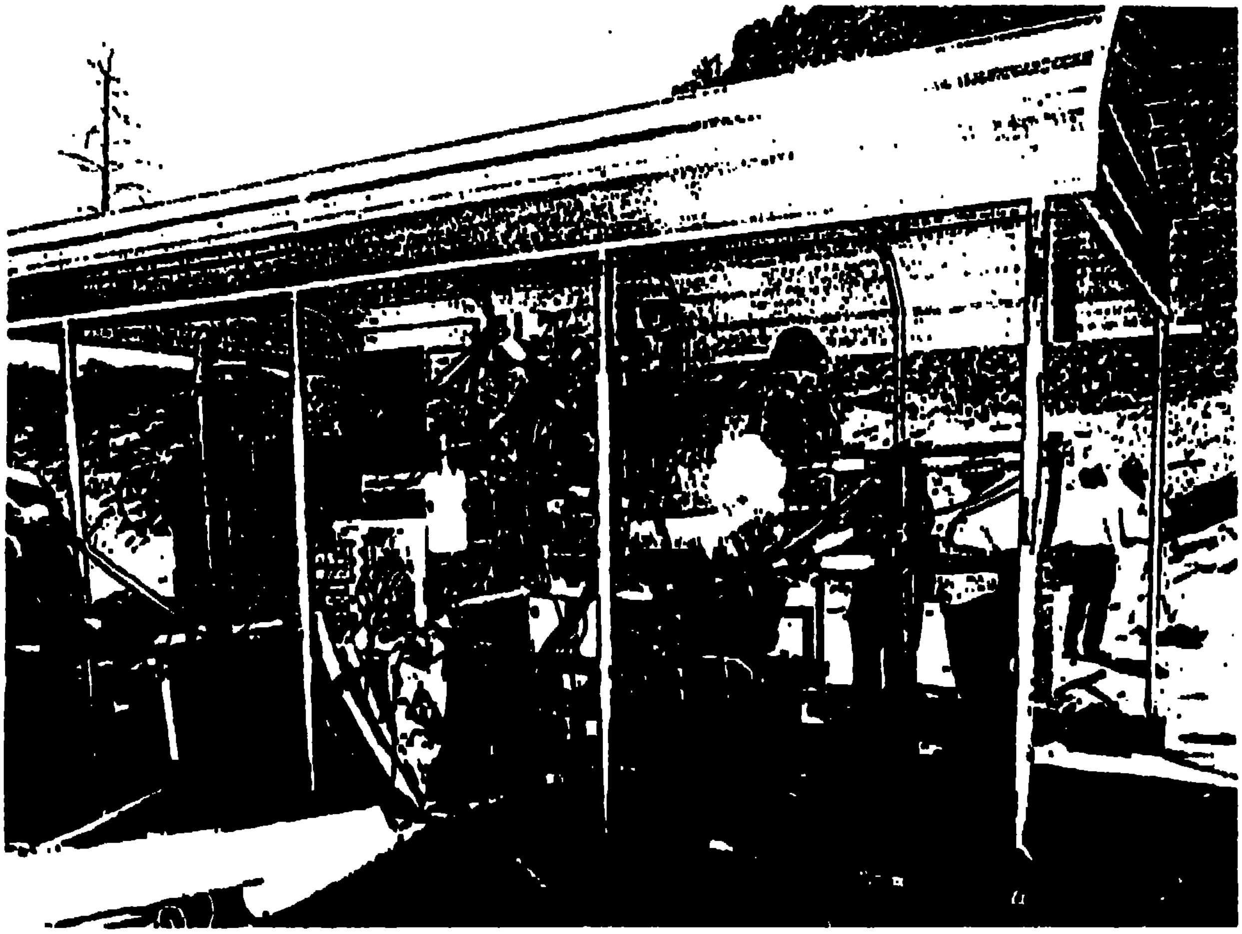

Figure 1 Procyon assembly ready to test on the firing pad. The MK IX generator is on the far left, the storage inductor and opening switch are in the central section, and the implosion and diagnostics chamber on the right.

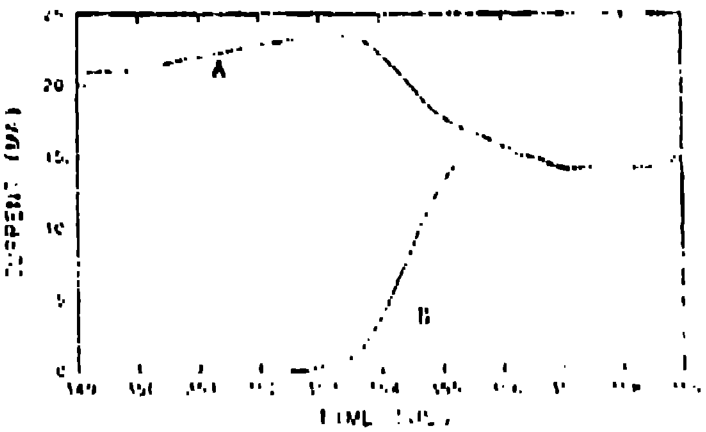

Figure 2. Storage inductor (A) and PFS (B) currents for test with implosion load. The first dip in the PFS current is due to the PFS switching and the second is due to the plasma z-pinch.

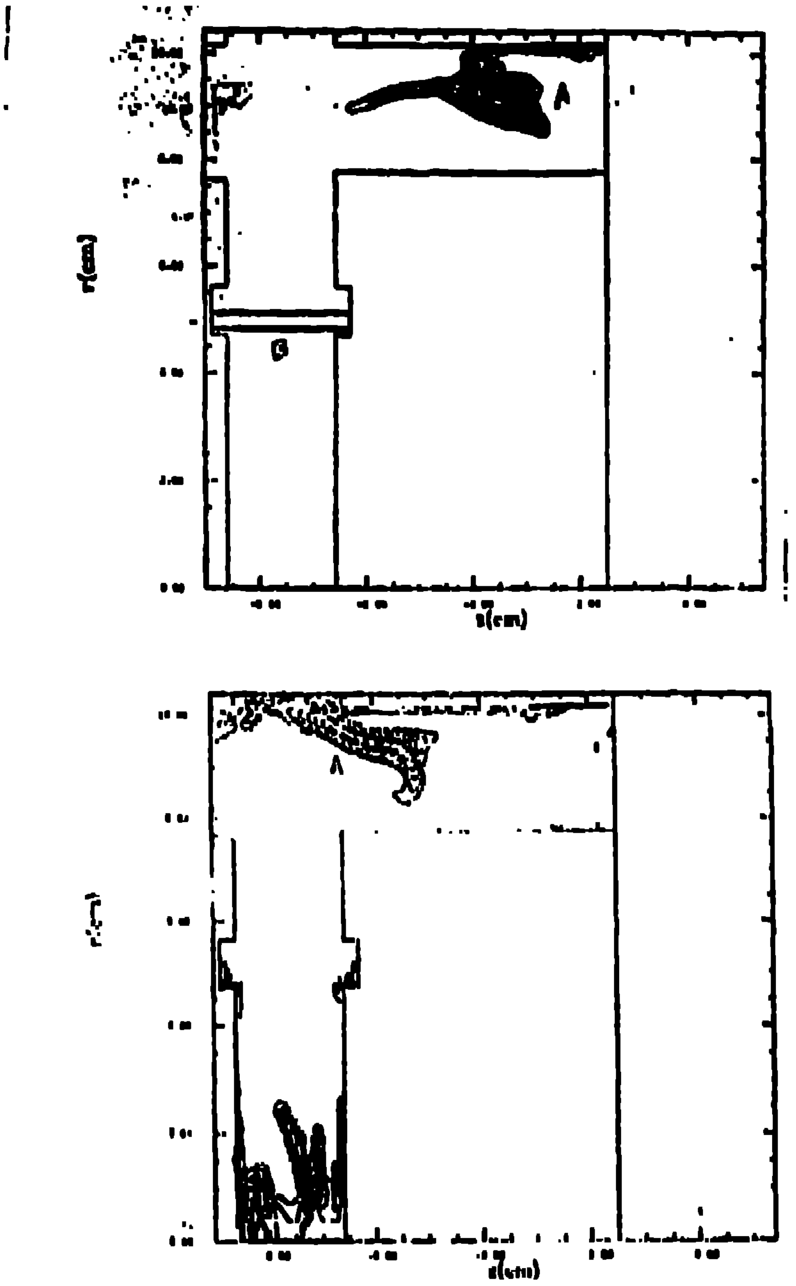

Figure 1. 2-D MHD calculation of a Procyon PFS test. a) At this time the PFS gun plasma (A) has separated from the inner wall, and current has switched to the implosion load (B). b) At this time, the calculation indicates that the implosion has occurred on axis and radiation is emitted. However, the gun plasma blocks the x-ray detector view ports.

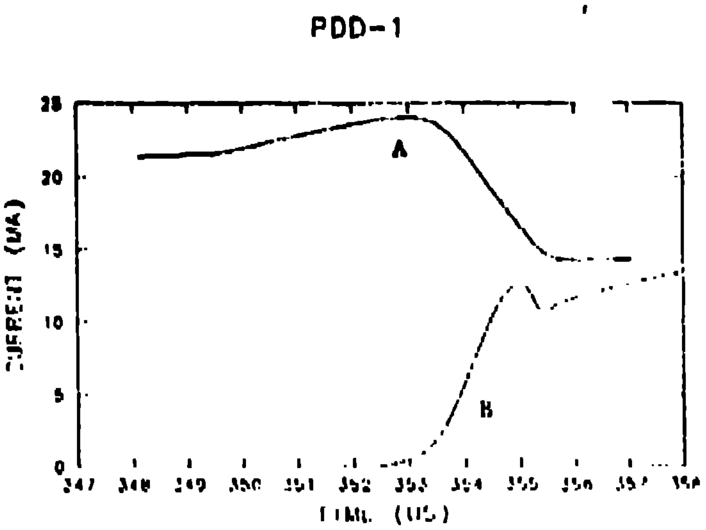

Figure 4. Storage inductor (A) and load (B) currents for test producing 1.5 MJ radiation. The dip at ~355 µs indicates pinch occurring.

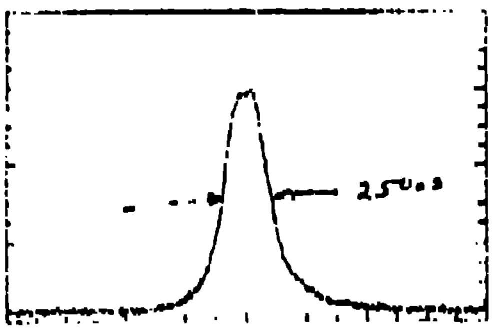

Figure 5. Kimfoil filtered x ray diode signal from 1.5 MJ radiation test. Full width at half maximum is ~250 ns indicating an average radiation power of ~6 TW.

TW. One of our three tests employed a contoured electrode by extending a conical protrusion approximately half way across the 2-cm gap, starting at approximately half the initial plasma radius. The primary purpose for the contour was to encourage a high-velocity jet to be emitted axially from the pinch region. The jet was impacted on a high-density target to produce radiation. A short-duration (~50ns), high-temperature (~60eV) radiation pulse was measured from the target region, and in addition, the contour seemed to reduce or eliminate axial instabilities. Figure 6 shows visible framing camera records from one test with parallel electrodes to compare with the shaped electrode test. Although the instabilities shown for the parallel electrode test are among the worst observed, the difference shown is dramatic. A more thorough discussion of these data are given in another paper in this conference[7]. We generally consider the instabilities harmful, and the radiation fluence from the parallel electrode shot shown was about one half of that on our best shot. However, recent analysis of the radiation produced by the highly unstable pinch indicates that this may have been the highest temperature, ~97 eV, of any we produced[7]. Although we have uncovered a rich ground for further exploration, changing programmatic goals preclude our pursuing them further, and we present those exploratory results for others who may have the opportunity.

Solid Liner Tests

The emphasis in our work has now turned to producing high pressure shock waves by impacting solid density liners onto targets of interest. The Procyon system also allows us to perform such experiments at high energy (and with high dI/dt), and we have performed one preliminary solid liner experiment. Because the solid liner experiments do not produce large quantities of radiation during their implosion phase, the radiation baffles needed to protect the vacuum dielectric interface on plasma implosion tests are not needed. This allows us to implement a lower inductance load, as illustrated in Fig. 7. With the reduced inductance of the load shown, we expect to be able to deliver almost 20 MA to solid liner loads[8]. Figure 8 shows the currents measured in our first experiment. A partial failure during the operation of the MK-IX generator resulted in a storage inductor current of only 19.1 MA (as opposed to the 21-22.5 MA that has been a very reliable value for this system). This, in turn, led to a load current of only 16 MA. The liner chosen for this test was 12 mg of aluminum, and the reduced current profile led to a slower implosion than expected. Since this was a preliminary experiment, we had no target for the liner to impact, and diagnostics were limited. However, as can be seen from the waveform, the liner achieved significant implosion velocity by ~360 μs, and the implosion profile is consistent with the imposed waveform. Apart from verifying that our low inductance load coupling was satisfactory, possibly the most significant result from the test was provided by the visible framing camera that viewed the outside of the liner. By itself, the record is confusing and difficult to explain. The outside of the liner appears to blow material off the surface. There is a striated effect along the axis of the cylinder, that could correlate with machining imperfections on the liner, although the spacing of the striations does not correlate in any way with machining tolerance. In addition, there are apparently random effects that do not correlate with any observed imperfections. We have recently performed an experiment on the Pegasus facility that allows us to have increased confidence in this interpretation. The same phenomena are observed on this test, although reduced in magnitude and with fewer random effects. Further study is required, but since dI/dt on the Procyon test is <10 MA/μs, while the dI/dt on Pegasus is >1.5 MA/μs, we may be observing a limit on liner surface quality that must be dealt with as we pursue higher currents and rate of delivery.

Future Tests

Stability of imploding liners plays a very important role in the future success of our efforts. In order to drive high-mass liners to high implosion velocities with reasonable efficiency, high convergence ratios must be achieved. We are currently conducting experiments on the Pegasus capacitor bank, which has a risetime of 6-8 μs to a current of 4-12 MA. We have also conducted a preliminary liner stability test with the Procyon system to demonstrate that our low inductance power feed will function adequately for the liner loads. After gathering stability data on Pegasus for a parameter of interest, our intention is to observe the same parameters using the Procyon system that can give us higher I and dI/dt. In this way, we can obtain very useful information about how various parameters vary as we approach levels that we will achieve on the Atlas capacitor bank. One of our earliest investigations will be to see if a thin layer of solid material will lend stability to an otherwise melted liner. This was the physics goal for our first Procyon liner test. Since the current achieved was less than anticipated, and because performed the test w/ [illegible] diagnostics, because of its preliminary nature, we did not [illegible].

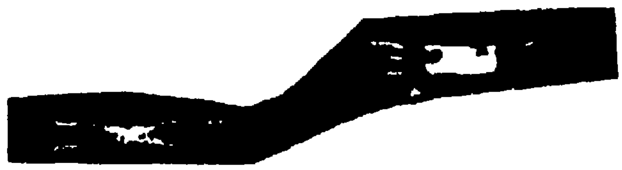

Figure 6. Framing camera records from (a) parallel electrode test and (b) contoured electrode test. A large instability is seen in (a) in the frame before pinch, while such an instability is not seen with the contoured electrode.

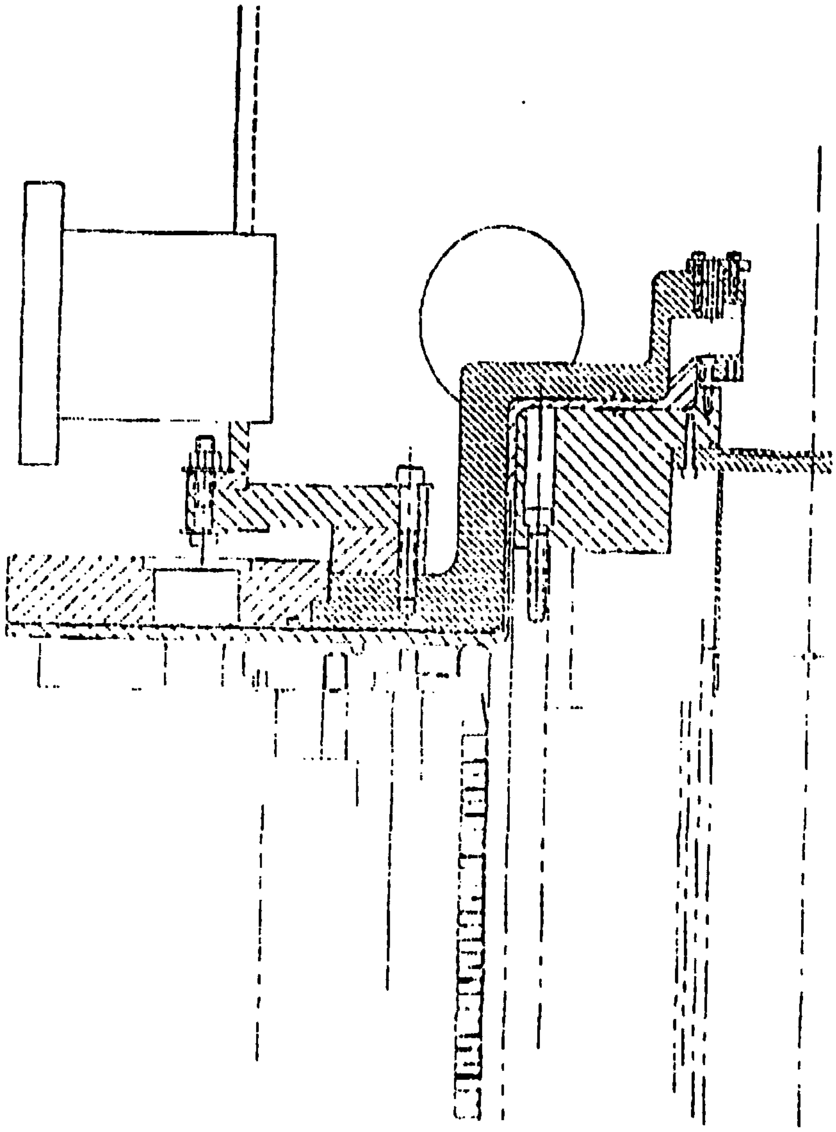

Figure 7. Reduced inductance load configuration for Procyon liner tests. Configuration allows complete radial access to the load, and axial access from one end. With this load, we should be able to deliver almost 20 MA to a liner load.

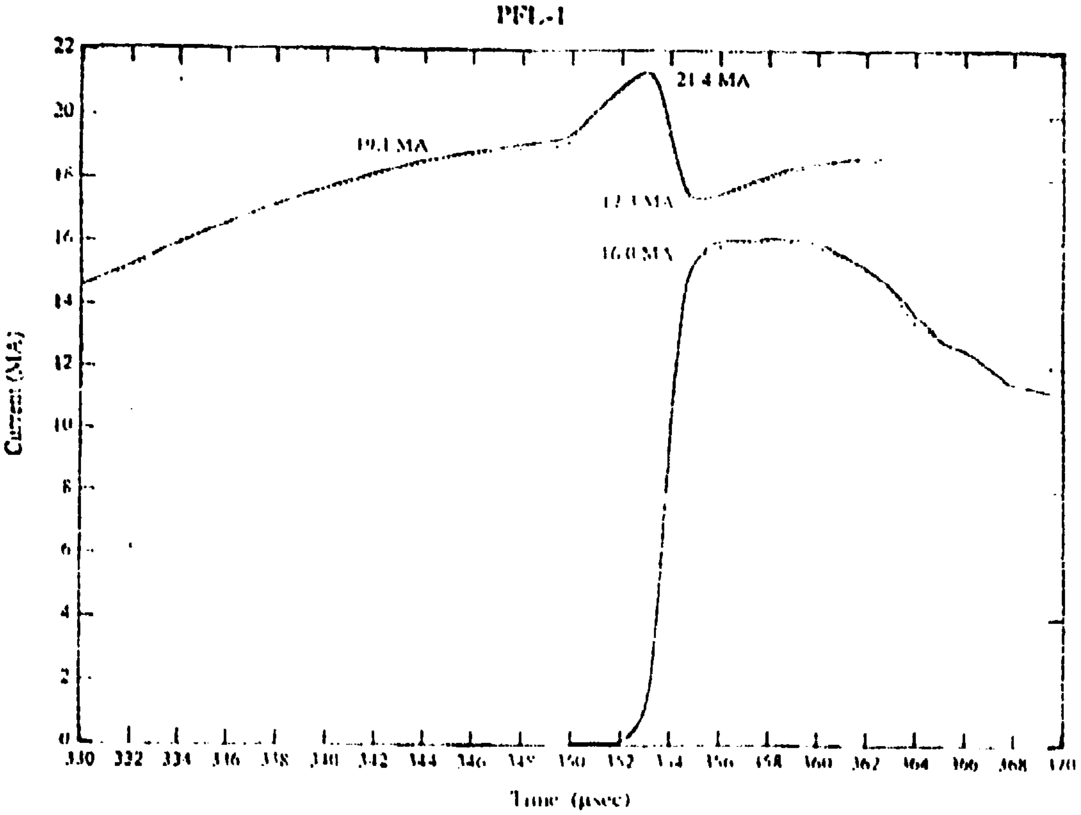

Figure 8. Storage (A) and load (B)) currents for our first Procyon Liner Experiment. Implosion begins to affect the waveform at ~ 360 μs.

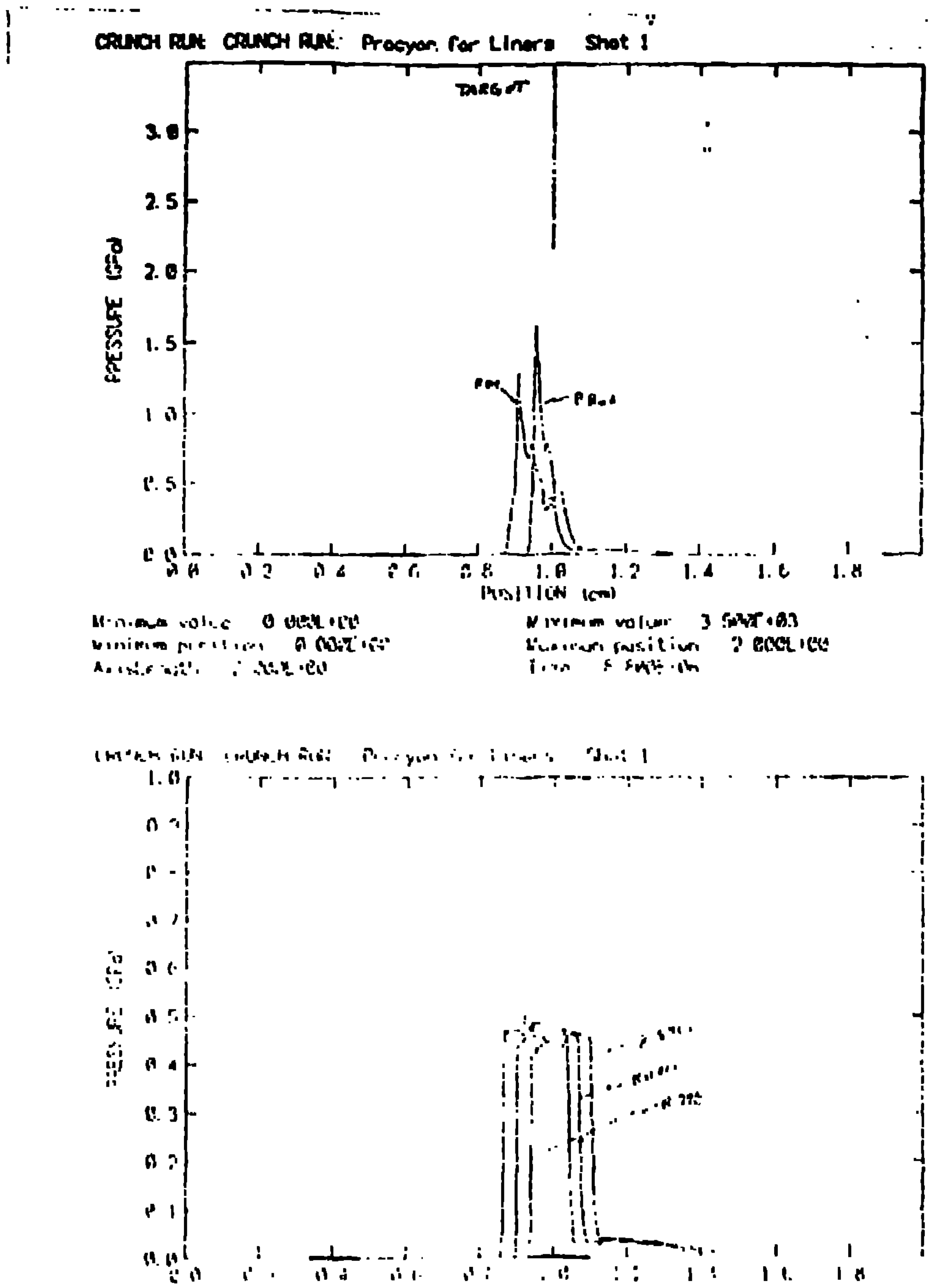

Figure 9. Pressure profiles calculated for Procyon liner tests. (a) Shows the high pressure spike generated by a thin platinum layer on an aluminum liner. (b) Shows the profile from an aluminum liner. The target material is platinum in both cases.

liner at the right time to observe its condition when it was mostly melted. However, with diagnostic improvements that we are making based on the experience of our first test, and with Pegasus tests in addition, we are confident that we will be able to achieve this goal on subsequent tests. Other tests will follow as we learn more of the parameters of interest. In addition, we can begin developing diagnostic capability on Procyon that will be important for Atlas experiments. We have made computer simulations of the kind of pressures that can be achieved by driving liners into targets of interest using the Procyon system. Figure 9 shows two plots of pressure profiles that can be achieved in a Procyon experiment. With a layer of Platinum on the inner surface of an aluminum liner, pressures of ~15 MB can be achieved for short times, or pressures of ~5 MB can be maintained for considerably longer times. Using such liners, we can develop the ability to diagnose the pressures produced in such a way, and further to perform experiments in this environment.

Conclusions

We have demonstrated that Procyon is a reliable system for PFS, plasma implosion or heavy liner experiments. Procyon develops 18 MJ magnetic energy, and performance parameters allow experiments to be conducted in the range where multiple megajoules are delivered to a load. We have recently been performing experiments in which a castable explosive is used with our axial detonation system, which can save considerable explosive expense on each shot. In preparation for higher energy tests, both with fixed machines and even larger explosive pulsed power devices, we hope to study liner physics issues in future test series, and perhaps commence preliminary high-pressure physics tests.

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