DEPARTMENT OF THE NAVY
NAVAL SURFACE WEAPONS CENTER
DAHLGREN, VIRGINIA 22448

Proj 35 - B

WHITE OAK LABORATORY
SILVER SPRING, MD. 20910
(202) 394-

DAHLGREN LABORATORY
DAHLGREN, VA. 22448
(703) 663-

IN REPLY REFER TO:
R16:OHD:sdm
3900

3 NOV 1982

From: Commander, Naval Surface Weapons Center
To: U. S. Department of the Interior Geological Survey
(John G. Gregory, EGS-Mail Stop 620)
Reston, Virginia 22092

Subj: Development of a Hydrogen Gas Generator for the EAVE Program

Encl: (1) Subject Report

1. Enclosure (1) summarizes the laboratory type tests of the hydrogen gas generator program and is submitted for your information.

2. Design and fabrication of a bread-board prototype lithium/water gas generator is now in progress.

G L MacKenzie
G. L. MACKENZIE
By direction

Development of a Hydrogen Gas Generator for the EAVE Program

Summary

Work on this program has progressed to the point where design and fabrication of a bread-board prototype for use in the EAVE vehicle can now be initiated. Both scale-up and full-scale feasibility testing have been successfully completed on the lithium/water reaction. Full scale demonstration runs at the operating pressure of 10,000 psi using a working cavitation erosion nozzle have been accomplished.

Background

Programs have been underway for the past several years at two U.S. sites to develop unmanned, free-swimming undersea inspection vehicles. Through the use of robotics, these vehicles may be programmed in advance to perform specific tasks such as inspecting off-shore drilling rigs for stress fractures or underwater pipes for leaks. The robot technology development program in progress at the University of New Hampshire, called the Experimental Autonomous Vehicle (EAVE) Program, has progressed to the point where the vehicle is now ready to undergo serious underwater inspection maneuvers.

One such maneuver involves the EAVE vehicle proceeding to a suspect joint on an off-shore drilling rig and visually inspecting this joint for any damage. However, in order for the EAVE vehicle to actually see the bare metal joint, it must first clean off the barnacles and other marine growth that has accumulated over the years. This cleaning process is to be accomplished by a small but powerful tool known as a cavitation erosion nozzle, which in turn is powered by a compact chemical gas generator. The cavitation erosion nozzle developed by Daedaleon Associates, Inc., of Woodbine, MD, is capable of cleaning one square foot of heavily encrusted metal plate to bare metal in one minute. This cleaning device requires a self-contained power source which must generate pressure in excess of 5000 psi to drive water through the controlled cavitation nozzle for bursts of approximately 30 to 60 seconds. The energy to accomplish this task could be supplied by a variety of means. But in order to meet the requirements for self-containment on the EAVE vehicle and to generate the tremendous pressures required, only a chemical gas generator can be practically considered. While many gas generator reactions are possible, the most efficient and most practical, considering the constant availability of ambient water, is the reaction:

$$2Li + 2H_2O \longrightarrow 2Li(OH) + H_2$$

Using this reaction, the water, which serves as an oxidizer, can be drawn from the ocean. Thus, only the fuel component, lithium, need be transported by the underwater vehicle.

During the previous year, development of the lithium/water gas generator has progressed from small-scale laboratory testing to full-scale prototype tests.

Experimental Results

A. Lithium Metal

From the previous report it can be determined that the reaction rate of lithium metal with water is fairly slow (a layer of $\sim$.0035 cm - Li reacts with water every second to produce H_2 at ambient pressure). (Special Note: In Table I of the previous report dated 7 June 1982 a factor of 10^{-1} was inadvertantly left out of the first draft. Thus values under column 8 - Regression Rate for Table I should actually be .55 x 10^{-1} mm Li/sec.) Since it was presumed that this reaction rate would not change dramatically with increasing pressure, the ingot size would have to present a fairly large surface area to the water in order to achieve a rapid pressure build-up in the reactor. The expense of casting or machining exotic shapes and sizes to achieve maximum surface area was prohibitive for this research program, and thus readily available ingots had to be utilized. The ingot size selected was the 1/4-pound cylinder, 2.25" D x 3.8" H. Machining experiments conducted by the supplier, Lithium Corporation of America (Lithcoa), determined that the thinnest slice that could be sectioned off these ingots was approximately 0.250" thick. Hence an order was placed with Lithcoa for ten pounds of these lithium wafers, each wafer 0.250" thick and 2.25" in diameter.

B. High Pressure Testing of Lithium/Water Reaction in Closed Bomb Facility

In order to accomplish the initial testing of the lithium/water reaction at high pressure, a 700cc Applied Combustion Technology closed bomb available at the Naval Ordnance Station, Indian Head, Maryland was utilized. This bomb was ideal for our purposes in that it could be instrumented for both temperature and pressure and all data could be stored in digital form on magnetic tape. A cross-sectional view of this bomb is shown in Figure 1.

This bomb is capable of withstanding internal pressures of 70,000 psi and has an additional attraction in that it can be rotated 180° on its trunion by means of a rope and pulley system. To load the bomb, it is first brought to a vertical position as shown in Figure 2, and half-filled with 350cc of water. The top closure, shown in Figure 3, contains a steel cage that is bolted to the closure and is used to hold the lithium wafers in place during the test. In order to fit inside this cage, the lithium wafers have to first be sliced in half. With the water and lithium in place, the closure is sealed and the test bay evacuated. The ropes are then pulled by hand to invert the bomb 180°, (Figure 4) allowing the water inside the bomb to cover the lithium and initiate the reaction. For a typical test the reaction rate at first is fairly slow, with as much as 30 seconds passing before an appreciable pressure build-up can be detected inside the bomb. But once the reaction starts, build-up to maximum pressure is rapid, with peak temperatures on the order of 1500 to 2000°F experienced. All of the lithium is converted to lithium hydroxide and hydrogen gas.

The tests were begun with amounts of lithium designed to keep the maximum pressure within 5000 psi. As more confidence was gained in the test techniques and the reaction itself, the mass of lithium was gradually increased. In the beginning, faulty transducers were a constant plague to the test effort. But by the end of this initial testing phase, all of the bugs had been worked out, and the ideal transducers located and fixed in place. The data for the closed bomb firings is presented in Table 1 and the firing traces for each test appear in Figures 5 through 12. Maximum pressures achieved from these tests ranged from 2000 to 12,000 psi. The most noteworthy discovery of these initial high pressure tests was the greatly enhanced reaction rate of the lithium metal with increasing pressure. While the reaction rate of lithium metal with water is only 0.0035 cm/sec at ambient pressure (1A), at pressures of 10000 psi this reaction rate increases to .0900 cm/sec, an increase in reaction rate by a factor of 25. This result alone will greatly simplify any future ingot design since large surface area is no longer a necessity for sufficient gas evolution. A plot of reaction rate vs pressure derived from the two most significant tests (#7 and #8) is presented in Figure 13.

C. High Pressure Testing of Lithium/Water Reaction in 8" Isostatic Press Facility

This program was very fortunate to have at its disposal the 8" isostatic press facility (Figure 14) located at the Naval Surface Weapons Center (NSWC), White Oak, Maryland. This facility is a converted 8" Naval gun with breeches at both ends. Its primary purpose is for the isostatic pressing of explosive charges. Our intended use of the facility was to have it serve as the pressure vessel for dynamic testing of the lithium/water reaction. As it turned out, the 8" press was ideally suited for this sort of testing and only minor modifications to the plumbing were necessary before testing could begin. The interior of the press, shown in Figure 15, contained a well 20.3 cm in diameter and 121.9 cm long. Since this volume (∿40 l) was really more than necessary for out test purposes, half of the usable volume was filled by means of four perforated metal spacers, bringing the working volume to 19.8 l. For each test, the interior of the vessel is first completely filled with water (∿20 l). The test sample, consisting of a known mass of lithium wafers weighted with iron ballast, is then dropped inside the vessel. The vessel is quickly closed (Figure 16), and the reaction allowed to proceed to completion. A cross-sectional view of the fully loaded 8" isostatic press is shown in Figure 17. To give the operators sufficient time to seal the vessel, each lithium wafer was coated with heavy motor oil. The first inhibitor used was silicone grease, but it took over 15 minutes for the water to remove this barrier, which was far too long for the test purpose. Thus after the first two tests, the silicone grease was abandoned completely in favor of the heavy motor oil.

It took the water approximately 30 seconds to remove the oil barrier and begin acting on the lithium metal. Since the press could easily be closed in less than five seconds, this inhibiting process allowed an ample safety factor. Pressure build-up inside the vessel can be monitored on both a strip-chart recorder and a dial gauge. Connected to the base of the 8" press is a 30' length of flexible high pressure tubing that leads to a Daedalean Associates, Inc. (DAI), cavitation erosion nozzle. When the pressure inside the vessel exceeds 10,000 psi, the operator at the nozzle is instructed to open the high pressure valve and commence operation of the cavitation erosion nozzle. The 5 gallons of water and LiOH inside the vessel are then expelled through the nozzle until only gas remains inside the vessel. This gas is also bled off until the vessel is empty. A series of five tests using the above procedure were conducted on the 8" press, with increasing amounts of lithium introduced for each test. The results from these tests are presented in Table II.

The first three tests were used primarily as ranging shots to establish what peak pressures might be expected from a given amount of lithium metal. The peak pressure was always somewhat of an unknown, since there was no way of predetermining the void space in the vessel when it was finally sealed for each test. A difference of only a few hundred cubic centimeters in the void space could make a substantial difference in peak pressure for the same mass of lithium reacted. Only for the final two tests in the series was the water bled through the cavitation erosion nozzle. These were the only two tests in which the peak pressure actually approached or surpassed 10,000 psi.

A typical strip chart record for these tests is presented in Figure 18. While few in number, these tests clearly demonstrated the practicality of using the lithium/water reaction for rapidly producing the power needed to drive water at pressures between 5000 and 10,000 psi through a cavitation erosion nozzle.

Discussion

On 4 August 1982, a meeting between John Gregory of the Minerals Management Service, Dick Bruce of DAI, Bill Barber of NSWC, White Oak and Bob Corell, Dick Blidberg, and Art Westneat of the University of New Hampshire, took place at the University of New Hampshire in Durham, NH. Following an impressive demonstration of the EAVE vehicle on Lake Winnipesaukee and a thorough explanation of the EAVE vehicle's capabilities, many of the problems that had appeared difficult from a distance, disappeared when the three working groups came to grips with them. First, there is little need to worry further about the backward thrust produced by the nozzle, since the EAVE vehicle can easily compensate for this thrust with its electrical thrusters. Second, the weight problem we had thought insurmountable for the only economically viable pressure vessel that was commercially available, can be easily handled on the EAVE vehicle by removing one of the battery cases (Figure 19), which weighs almost as much as the pressure vessel, and compensating for any extra weight by means of larger buoyancy tanks. Finally, the test designed for the combined EAVE, cavitation erosion nozzle, lithium/water power supply, is for demonstration purposes only. The primary purpose is to produce a short film showing the EAVE vehicle doing actual, useful work. Thus, while a continuous, high pressure power source would be the long term goal, it is not needed for this demonstration effort. With all of these various points factored in, the successful completion of this program becomes a matter of time and coordination. All major roadblocks appear to be removed. Hardware required to interface the DAI cavitation erosion nozzle and the lithium/water high pressure power supply with the EAVE vehicle, have already been ordered, and will be available by 1 December. This hardware will be assembled and tested by NSWC and DAI and should be ready for testing on Lake Winnipesaukee by early May.

Future Plans and Milestones

1. Design and fabricate bread-board power supply/cavitation erosion nozzle package for use on University of New Hampshire EAVE vehicle. (9 August - 3- November 1982)

2. Test bread-board unit in Baltimore-Washington area. (1 December - 30 April 1983)

3. Ship bread-board unit to University of New Hampshire and conduct integration of bread-board unit with EAVE vehicle and initial shake-down tests. (3 May - 7 May 1983)

4. Conduct final demonstration test of EAVE vehicle using cavitation erosion nozzle powered by lithium/water generator to clean underwater structure. Film these tests. (10 May - 14 May 1983)

Figure 1: Cross-Sectional View of 700cc Closed Bomb

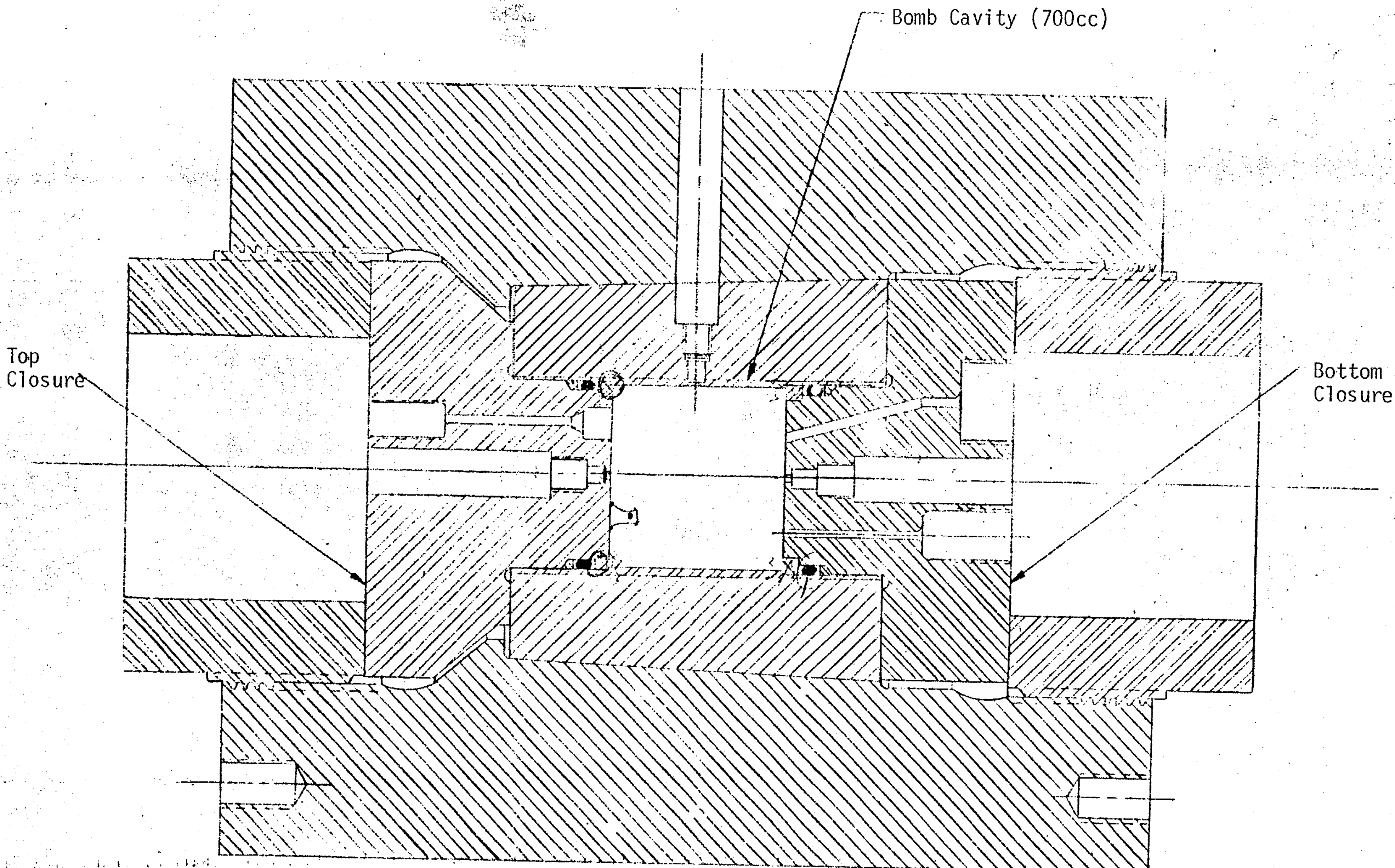


Figure 2: Applied Combustion Technology 700cc Closed Bomb Loaded and Ready for Inversion

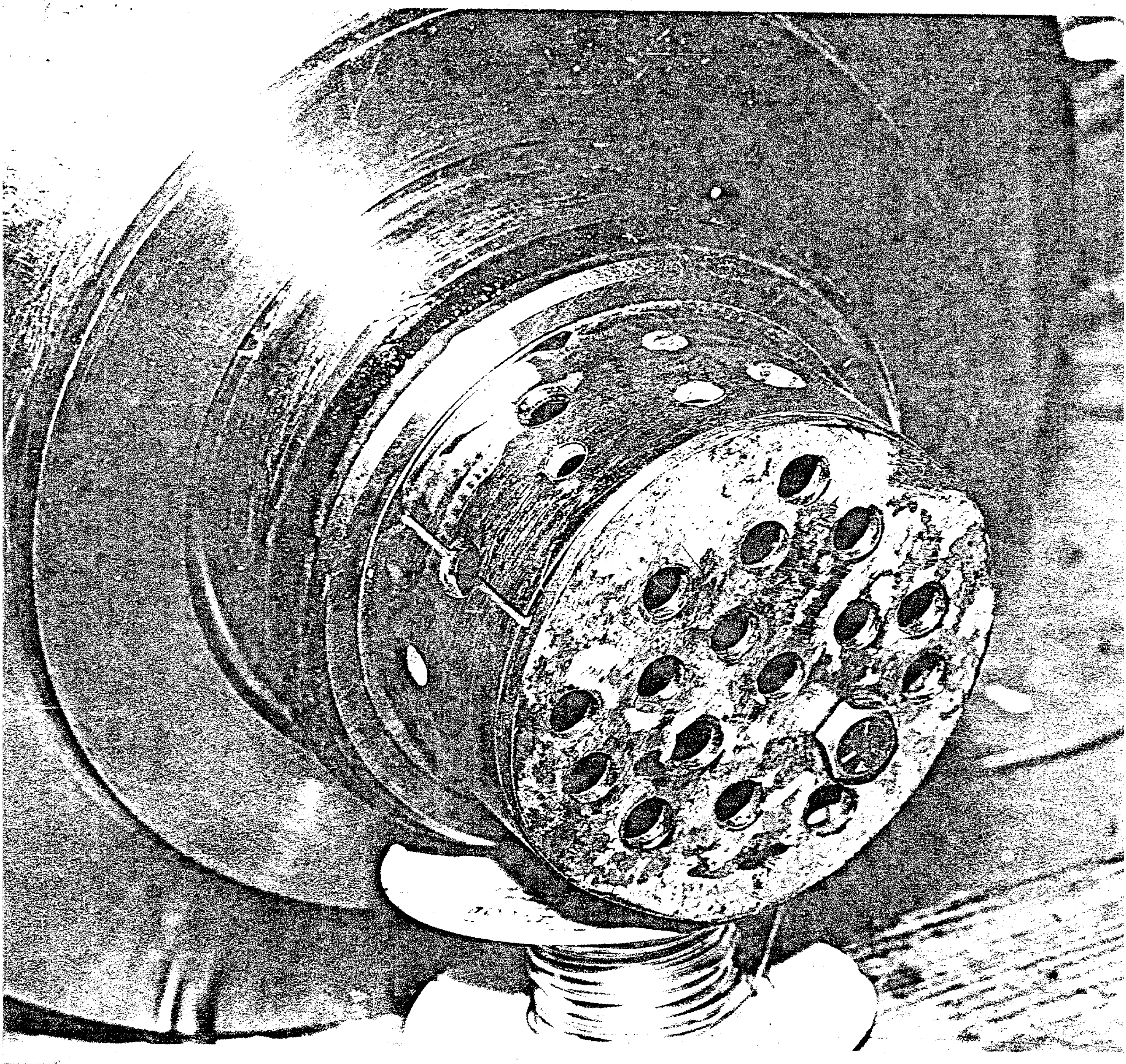


Figure 3: Top Closure of 700cc Bomb With Sample Cage in Place

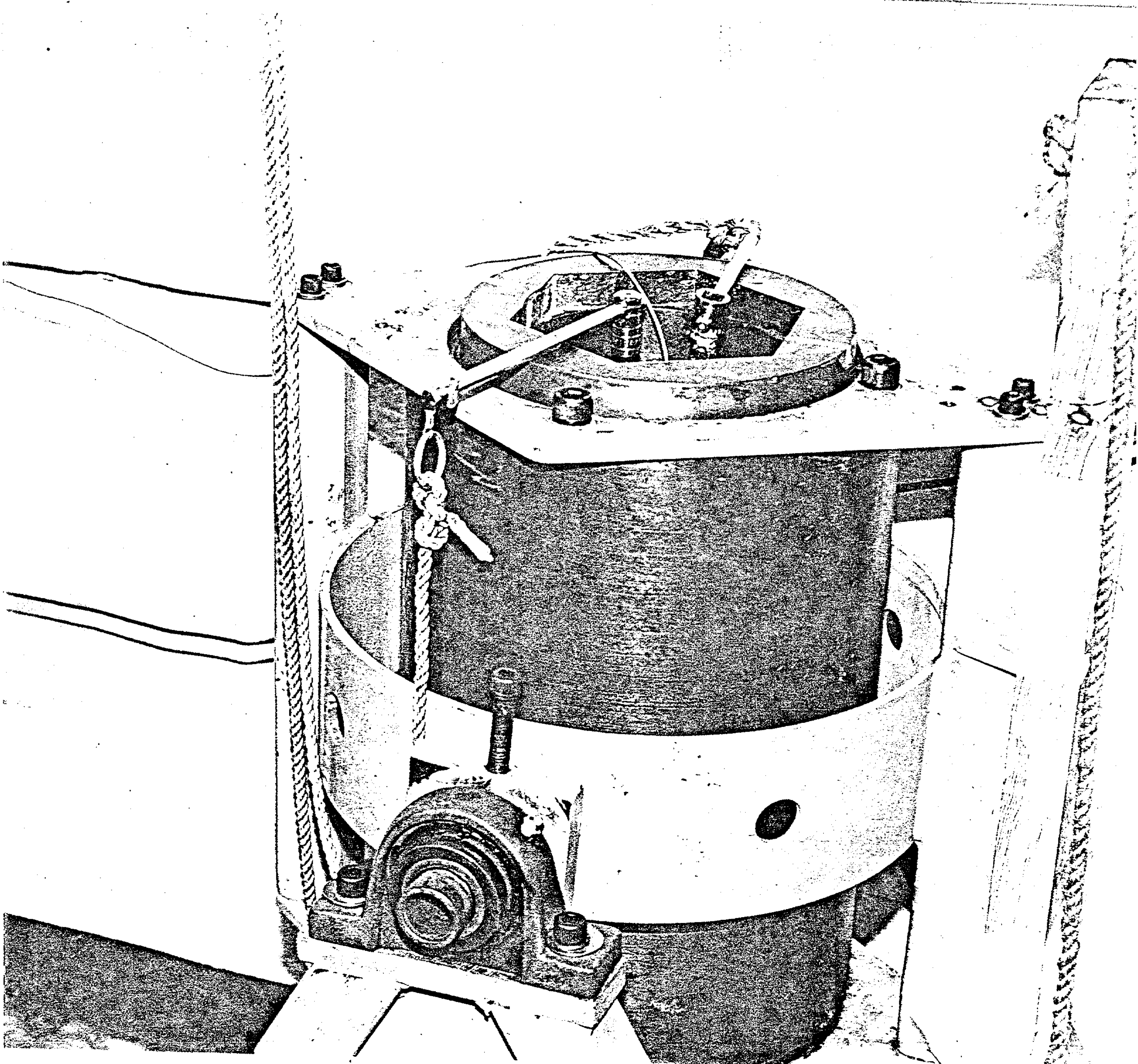


Figure 4: 700cc Closed Bomb Inverted with Test Underway

Figure 5: Temperature vs Time Record for Test #1

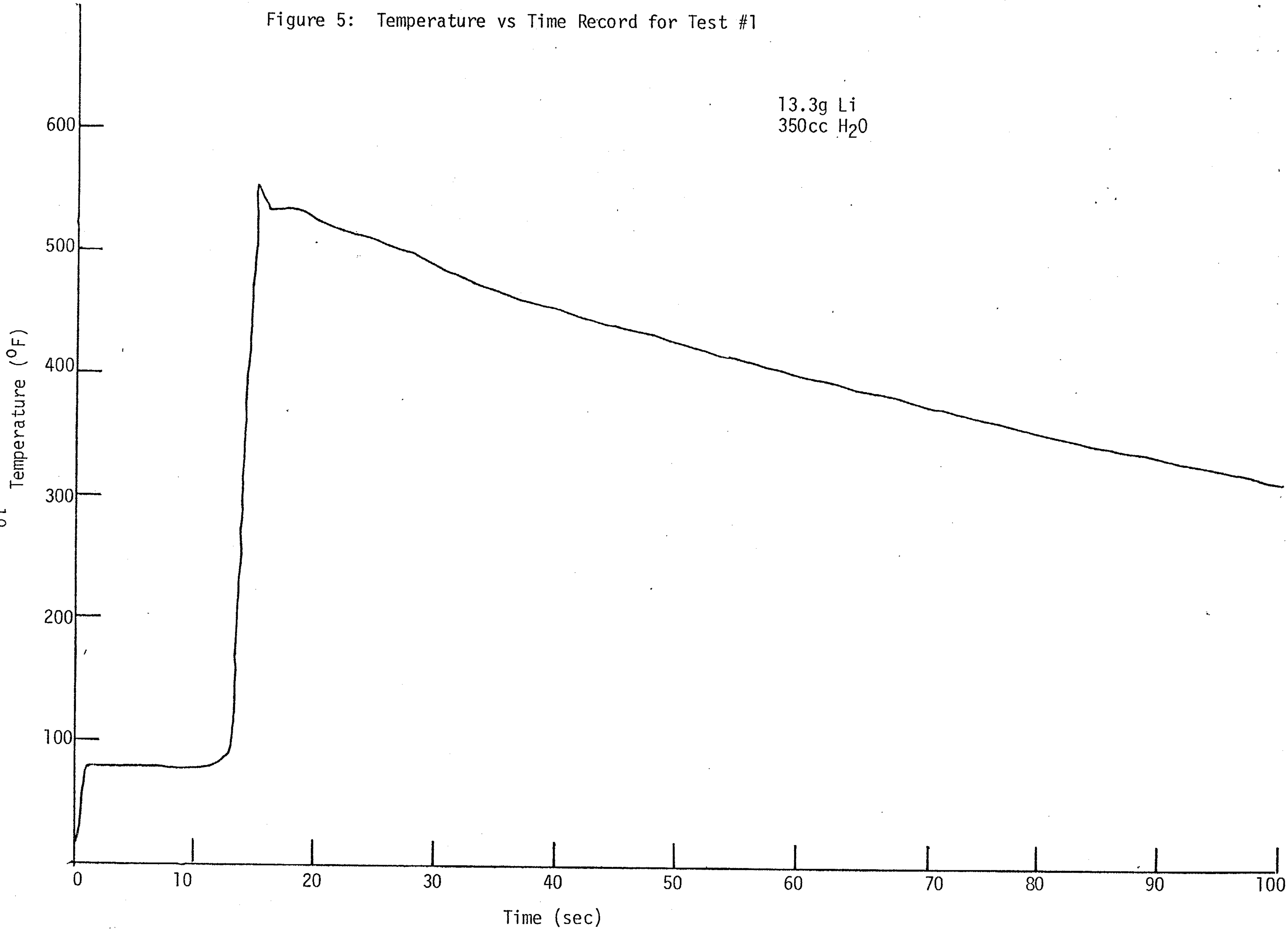


Figure 6: Pressure vs Time Record for Test #2

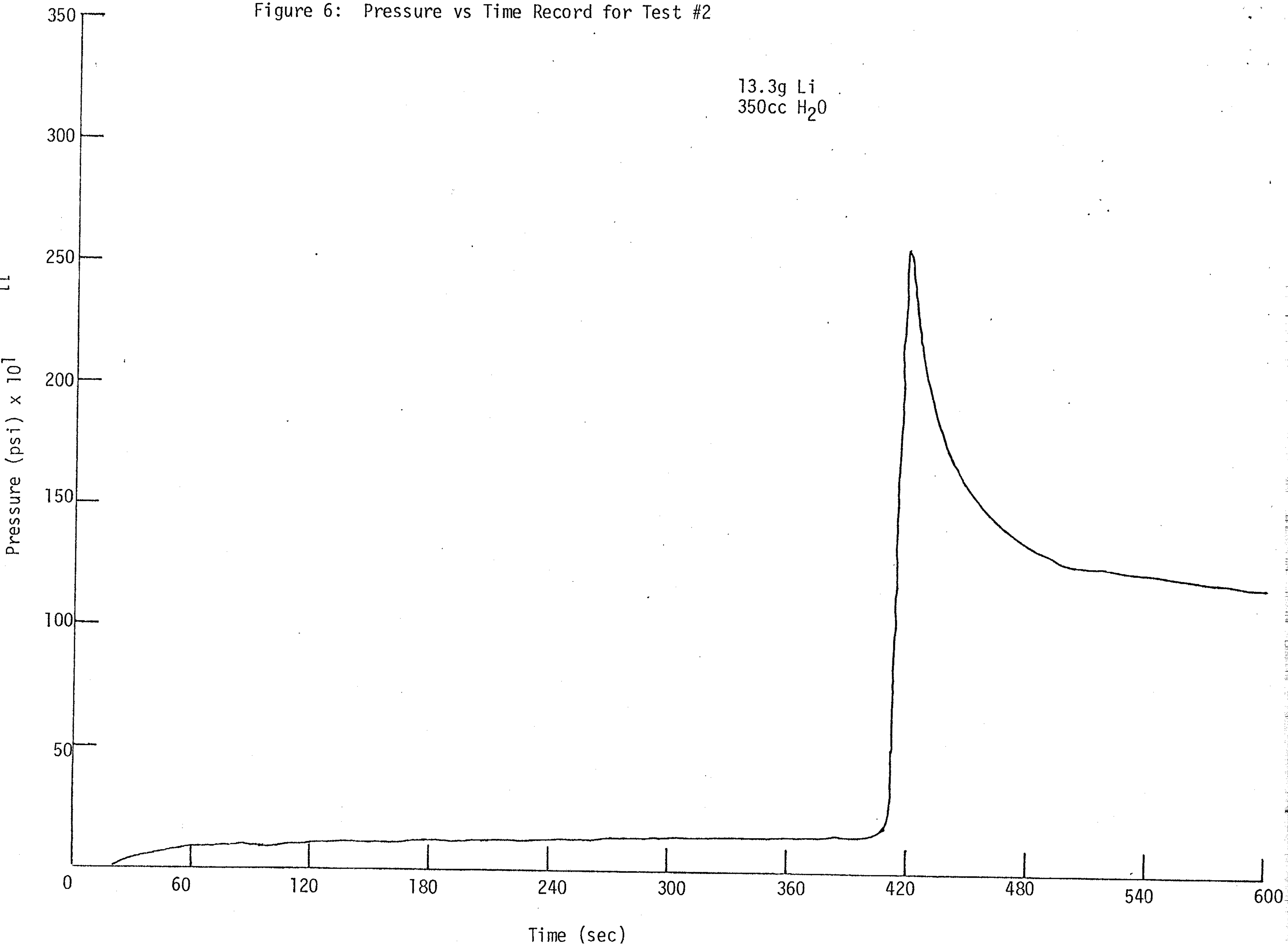


Figure 7: Pressure vs Time Record for Test #3

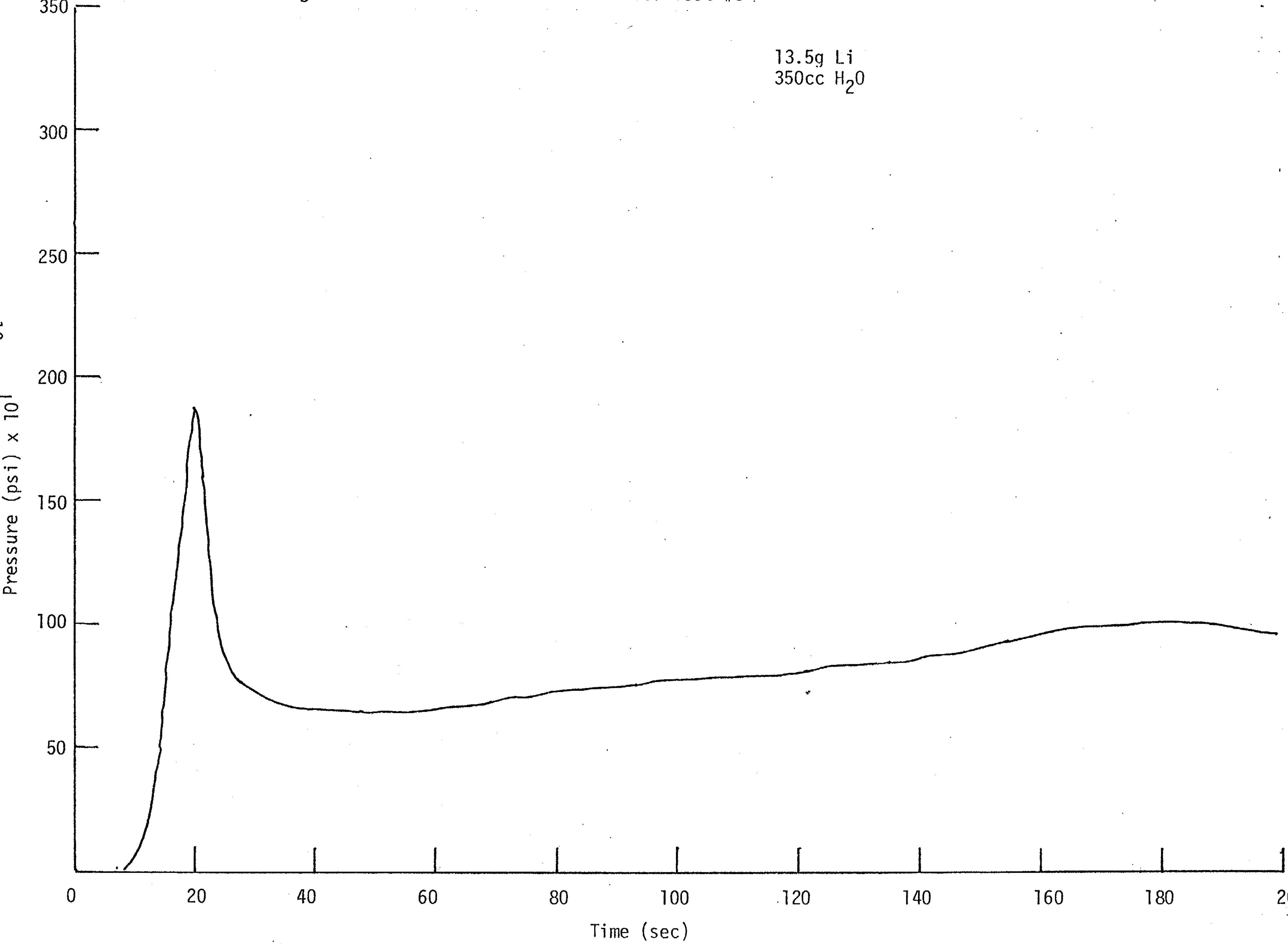


Figure 8: Pressure vs Time Record for Sample #4

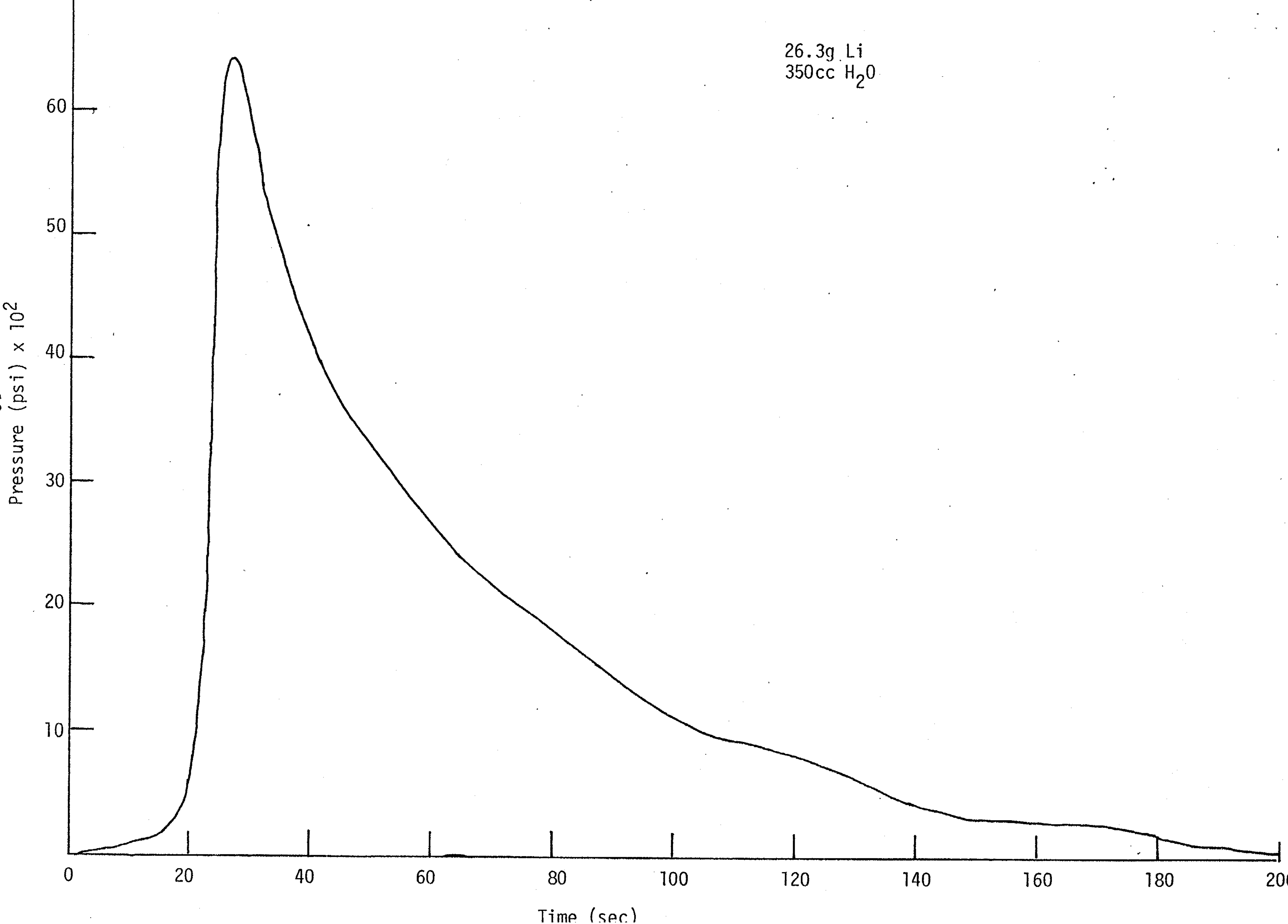


Figure 9: Pressure vs Time Record for Test #5

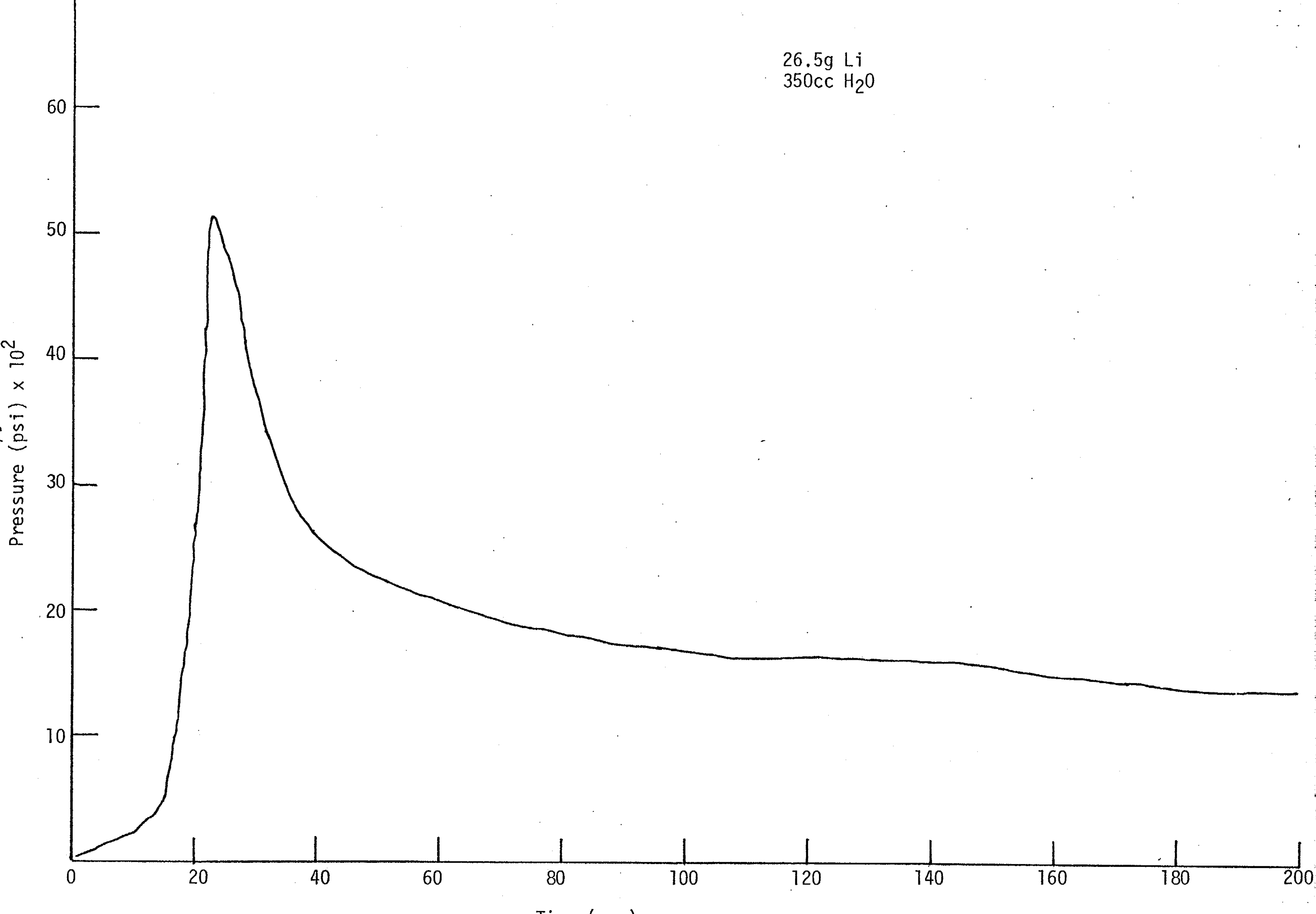


Figure 10: Pressure vs Time Record for Test #6

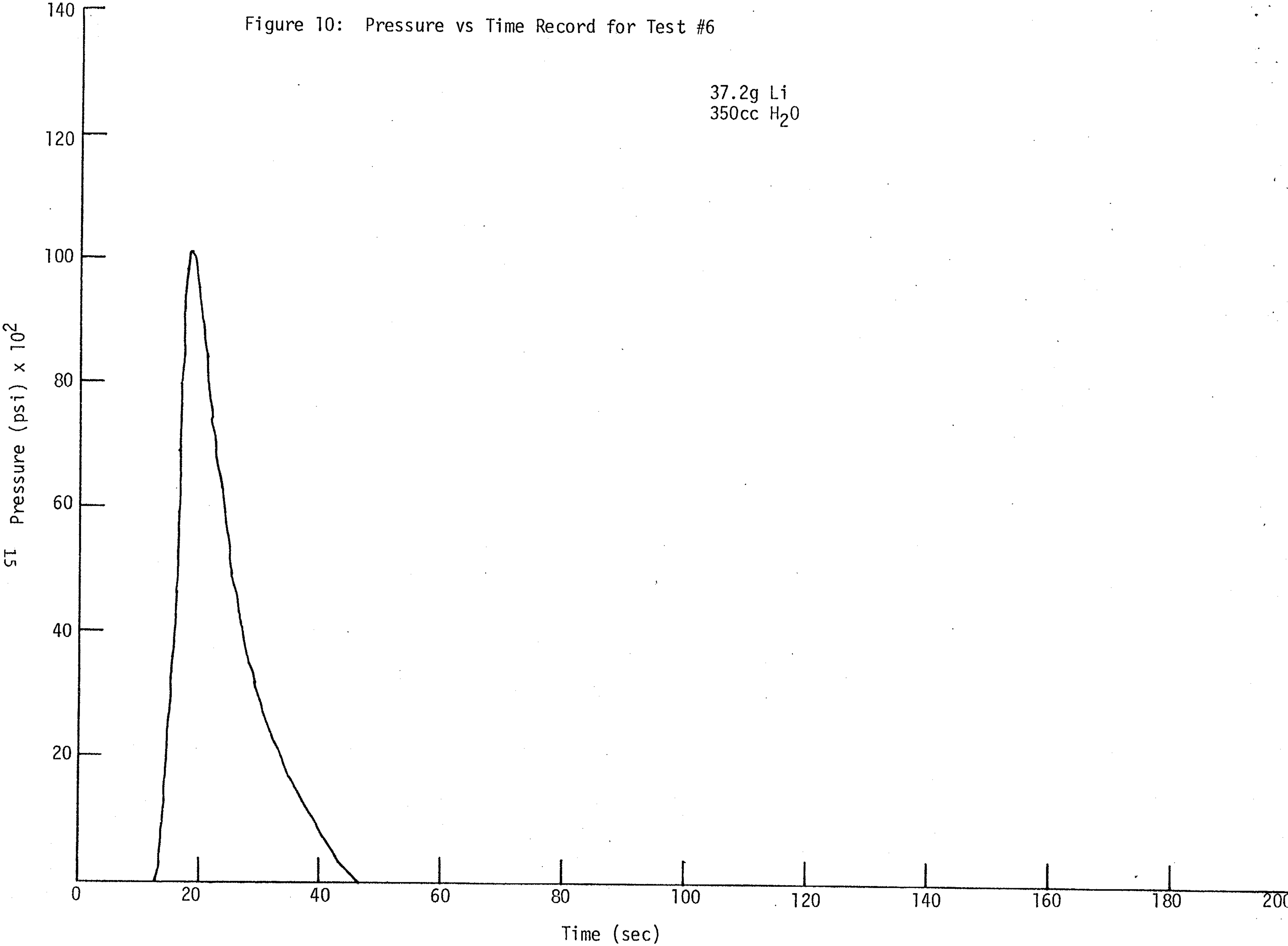


Figure 11: Pressure vs Time Record for Test #7

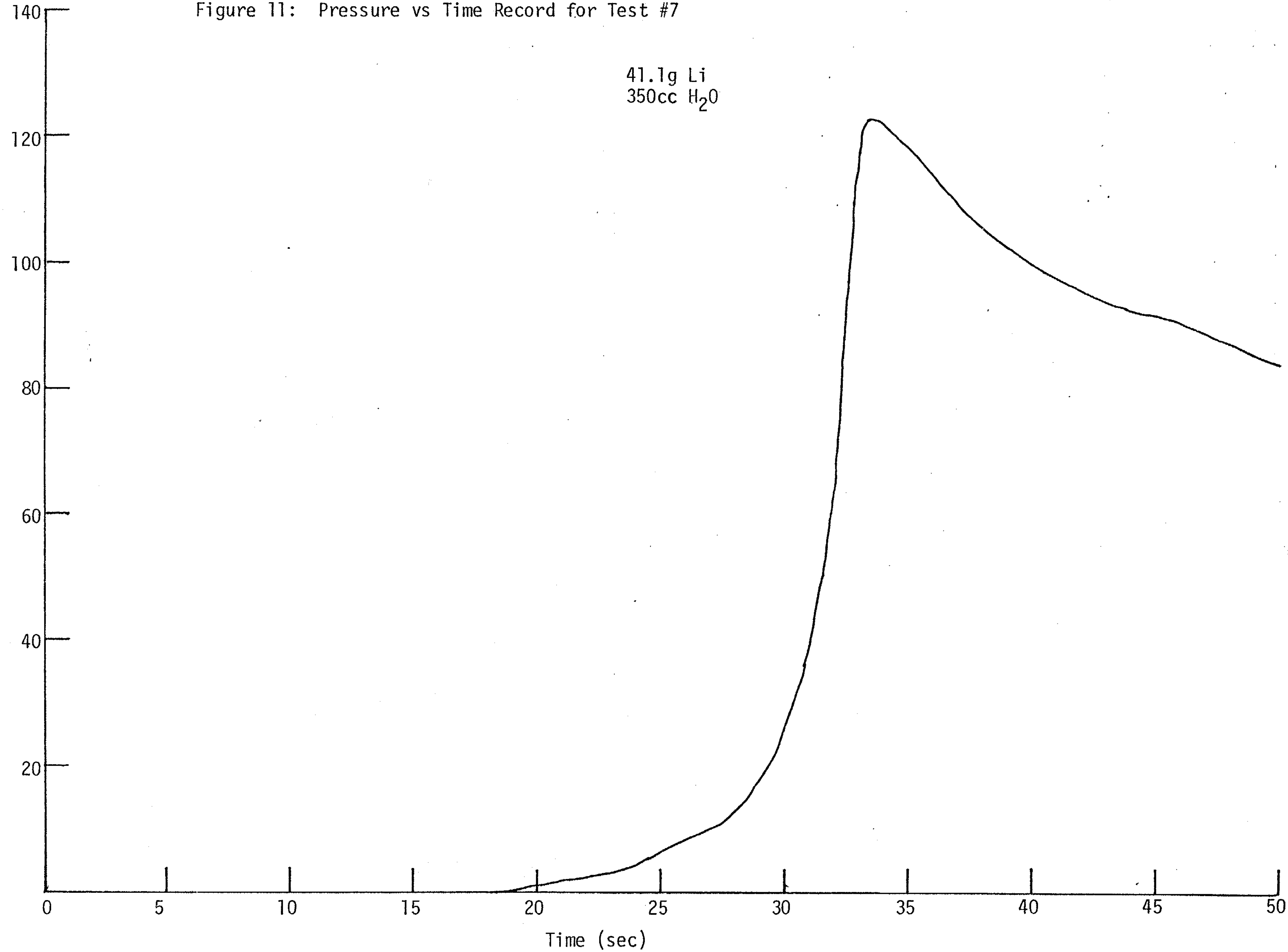


Figure 12: Pressure vs Time Record for Test #8

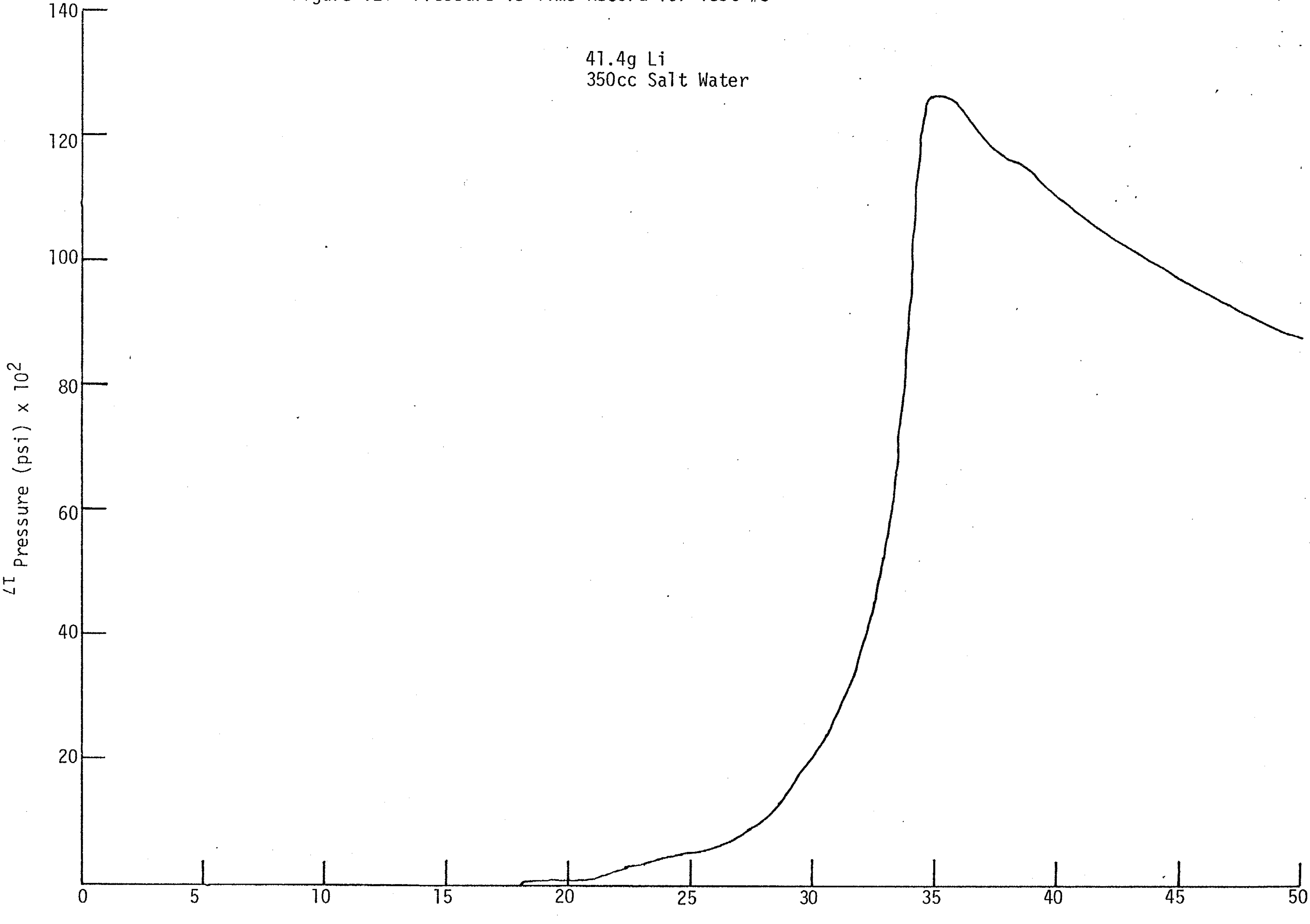
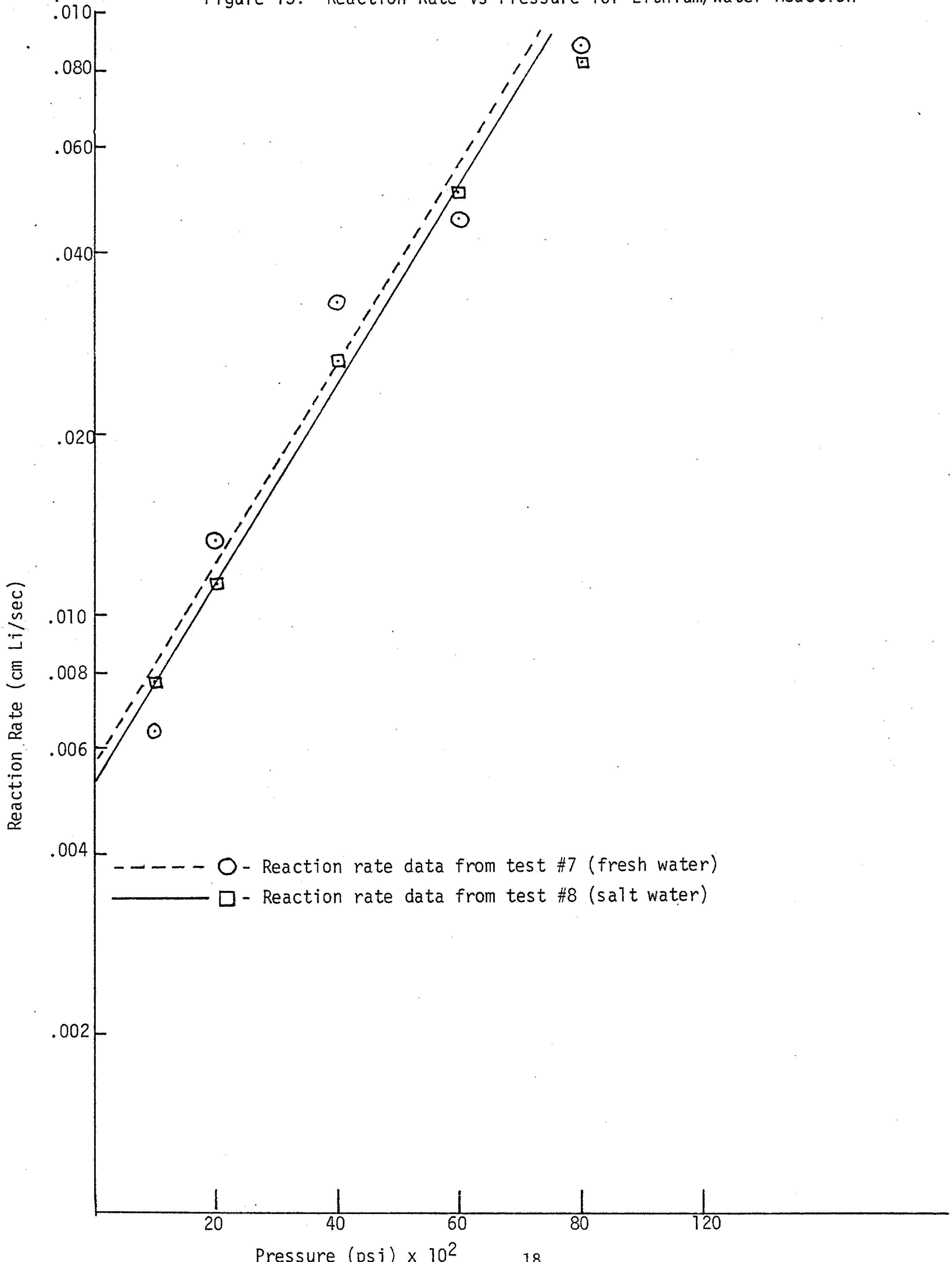


Figure 13: Reaction Rate vs Pressure for Lithium/Water Reaction



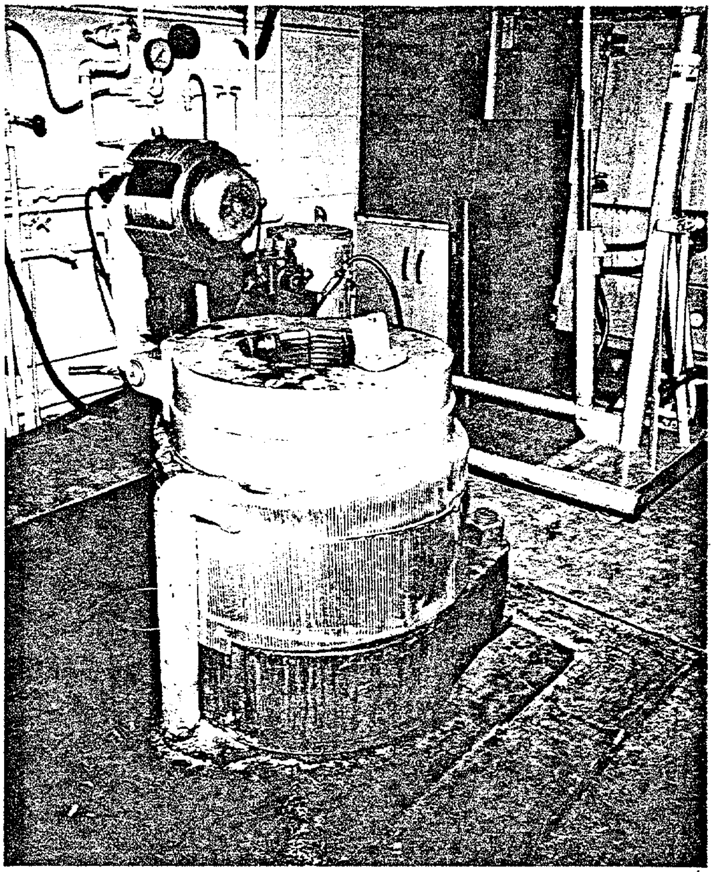


Figure 14: Exterior View of 8" Isostatic Press

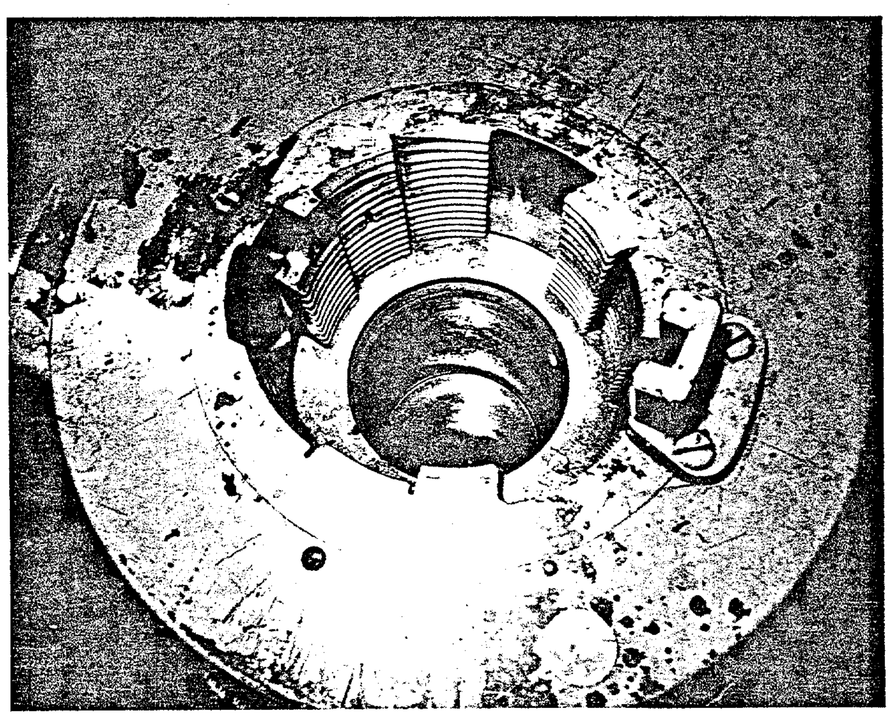


Figure 15: Interior View of 8" Isostatic Press

Figure 16: 8" Isostatic Press Ready for Test Operation

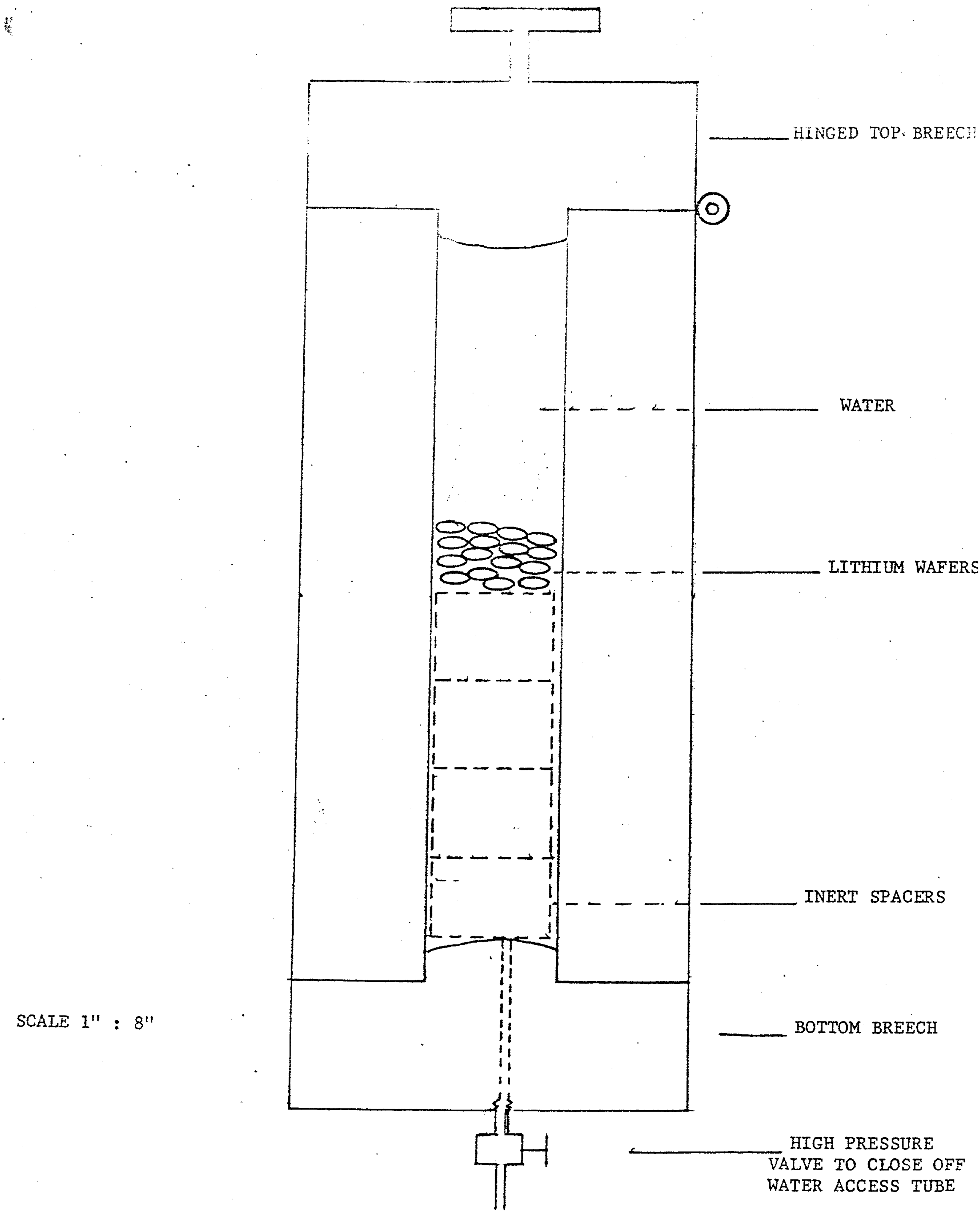
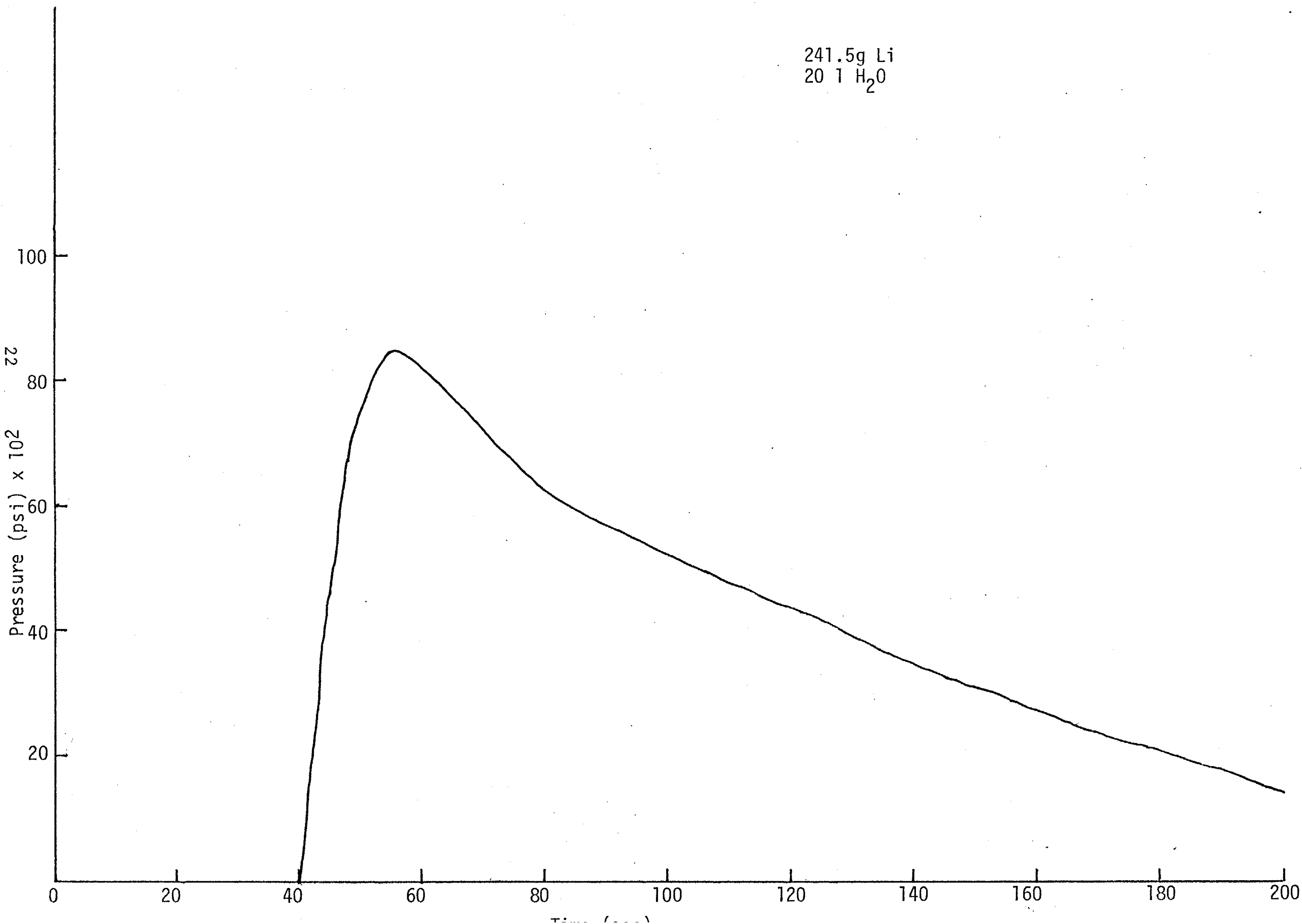


Figure 17: Cross-Sectional View of 8" Isostatic Press Facility at NSWC, White Oak

Figure 18: Pressure vs Time Record for Test #4 in 8" Isostatic Press



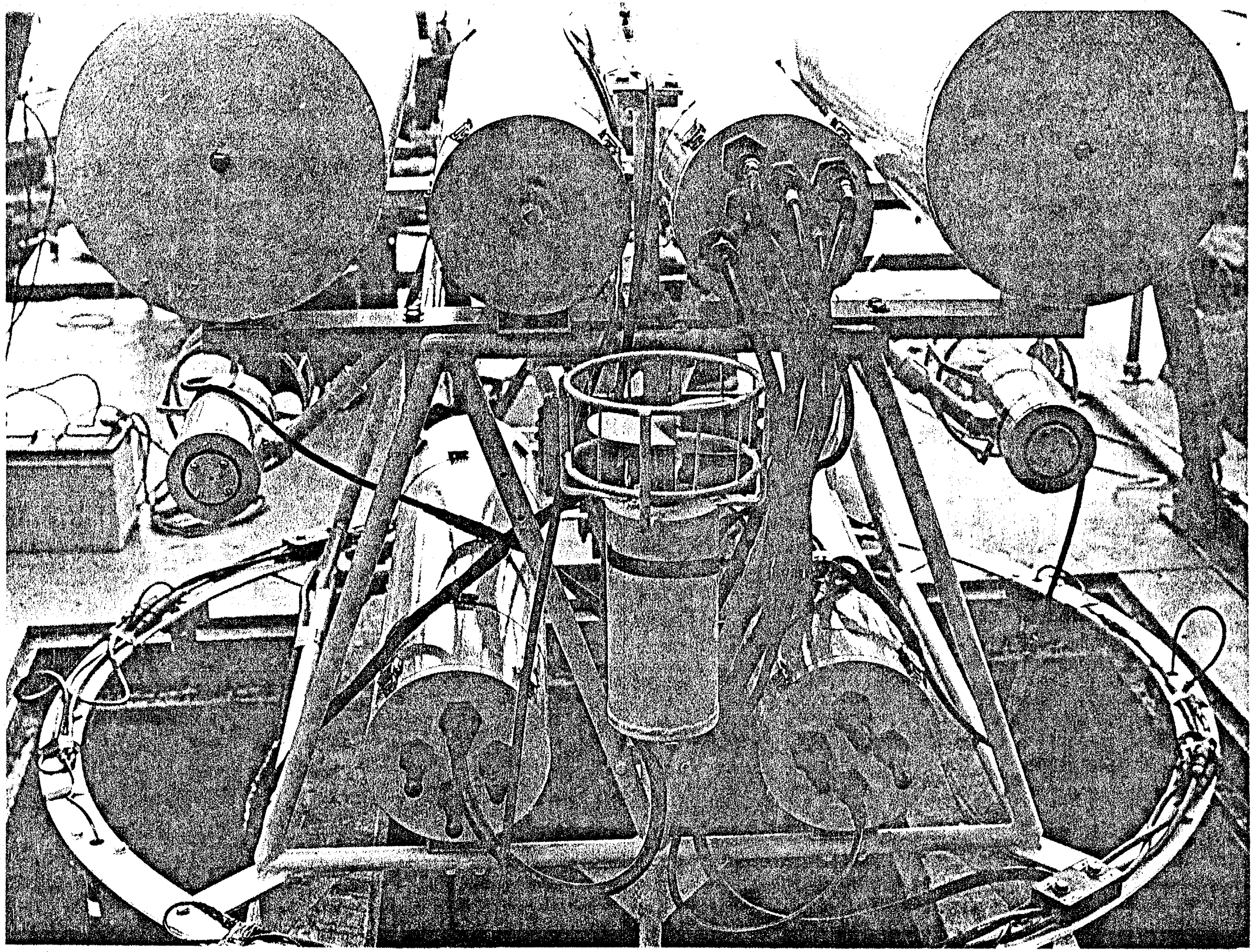


Figure 19: EAVE - East Underwater Vehicle Showing Location of Two Battery Cases at Base of Vehicle.

Table I

High Pressure Testing of Lithium/Water Reaction in 700 cc Closed Bomb

Test #	Weight of Li (g)	H_2O(CC)	P_{max} (psi)	Tmax (^oF)	Rise Time to Peak Pressure (sec)	Reaction Rate (cm Li/sec) at Selected Pressures (psi)						Remarks
						1000	2000	4000	6000	8000	10000	
1	13.3	350	--	545	--							A
2	13.3	350	2600	539	12							B
3	13.5	350	1900	1800*	10							C
4	26.3	350	6400	2100*	7							OK
5	26.5	350	5200	952**	8							D
6	37.2	350	10100	1912**	7							E
7	41.1	350	12300	--	9	.0064	.0134	.0329	.0456	.0889	.0902	F
8	41.4	350	12650	--	9	.0077	.0114	.0264	.0505	.0834	.0879	G

A - Pressure transducer failed to record.
B - Automatic bomb rotator failed, turning bomb only 90^o. Bomb had to be manually rotated final 90^o after a six minute delay. Then reaction peaked in 12 sec.
C - Pressure unreliable on this test as transducer failed to return to zero at conclusion of test.
D - Bomb leaked, hence peak pressure unreliable.
E - Unreliable pressure transducer, would not return to zero.
F - Used good BLH pressure transducer; should be very reliable. No thermocouple data from this test as thermocouple was deleted in order to prevent leaks. Fresh water (distilled) used in tests 1 through 7.
G - Same information as in F, except that salt water was used in this test. Tests 7 and 8 provide the most reliable data.

* - Milli-volt readings for these two tests were beyond capabilities of thermocouples used (Type J). Temperature values provided in this table are estimates for these two tests.
** - Temperature data for these two tests should be the most reliable, as thermocouple capable of recording beyond 1500^{o}F was used in these two tests.

SPECIAL NOTE: For tests 1 - 6, the lithium wafers were contained in a steel basket. For test 7 and 8, the wafers were simply wired in place to the closure, allowing the water free access to the samples once the bomb had been rotated. Thus tests 7 and 8 most simulate what would actually occur in the full-scale testing.

Table II

Full-Scale Testing of 8" Isostatic Press Facility

Test #	Weight Li (g)	H_2 Evolved (1 @ STP)	Time to Reach Peak Pressure (sec)	Peak Pressure (psi)
1	27	43.2	1800*	500
2	80	128	1800*	2100
3	162.5	260	30	7000
4	241.5	386	30	8500[X]
5	443.5	710	30	25000[Y]

*The long reaction time in these tests was due to the fact that the lithium was coated with silicone grease. For subsequent tests, only a heavy motor oil was used as an inhibitor.

[X]When pressure reached 5000 psi, water in vessel was valved off through a DAI cavitation erosion nozzle (0.025" throat diameter). It took approximately two minutes to reach zero pressure.

[Y]When pressure reached 10,000 psi, water in vessel was valved off through a DAI cavitation erosion nozzle (0.025" throat diameter). It took approximately four minutes to reach zero pressure.