LA-UR-96-3440 Revised 2/11/97

THE ATLAS PROJECT

W.M. Parsons, E.O. Ballard, R.R. Bartsch, J.F. Benage, G.A. Bennett, R.L. Bowers,
D. W. Bowman, J.H. Brownell, J.C. Cochrane, H.A. Davis, C.A. Ekdahl, R.F. Gribble,
J.R. Griego, P. D. Goldstone, M.E. Jones, W.B. Hinckley, K.W. Hosak, R.J. Kasik, H. Lee, E.A.
Lopez, I.R. Lindemuth, M.D. Monroe, R.W. Moses, S.A. Ney, D. Platts, W.A. Reass, H.R.
Salazar, G.M. Sandoval, D.W. Scudder, J.S. Shlachter, C.T. Thompson, R.J. Trainor, G.A.
Valdez, R.G. Watt, G.A. Wurden, and S.M. Younger

Los Alamos National Laboratory
Los Alamos, NM. 87545

Abstract

Atlas is a facility being designed at Los Alamos National Laboratory (LANL) to perform high energy-density experiments in support of weapon-physics and basic-research programs. It is designed to be an international user facility, providing experimental opportunities to researchers from national laboratories and academic institutions. For hydrodynamic experiments, it will be capable of achieving a pressure exceeding 30-Mbar in a several cm^3 volume. With the development of a suitable opening switch, it will be capable of producing more than 3-MJ of soft x-rays.

The capacitor bank design consists of a 36-MJ array of 240-kV Marx modules. The system is designed to deliver a peak current of 45- to 50-MA with a 4- to 5-µs risetime. The Marx modules are designed to be reconfigured to a 480-kV configuration for opening switch development. The capacitor bank is resistively damped to limit fault currents and capacitor voltage reversal. An experimental program for testing and certifying prototype components is currently underway.

The capacitor bank design contains 300 closing switches. These switches are a modified version of a railgap switch originally designed for the DNA-ACE machines. Because of the large number of switches in the system, individual switch prefire rates must be less than 10^{-4} to protect the expensive target assemblies. Experiments are underway to determine if the switch-prefire probability can be reduced with rapid capacitor charging.

Introduction

The Atlas project within the High Energy Density Physics (HEDP) Program at LANL is an element of a strategic response to the changing requirements being placed on Department of Energy (DOE) Defense Programs (DP). These requirements include the Presidential call[1] to ensure the safety and reliability of US nuclear weapons without underground testing. DOE and the national laboratories will continue their responsibility for maintenance, surety, and reliability of the nation's remaining stockpile.

High energy density physics experiments require three distinct environments to successfully support necessary weapons-related experiments. These three classes of capability include pulsed-power, high-energy lasers, and ultra-high-intensity lasers. Both the pulsed-power and laser capabilities are called out in the DOE/DP Stockpile Stewardship and Management Program[2]. Atlas will be the first of several new facilities constructed to support this Program. Atlas will also be used to perform basic research experiments[3] to support science and technology development.

Pulsed power machines are used to generate high energy density conditions by discharging multi-megampere currents into a centrally located, cylindrical liner. Near the liner, the current density and associated magnetic fields dramatically increase. The interaction of the current and magnetic field produces Lorentz forces which implode the cylindrical liner. A lightweight liner can collide with itself on axis, converting its kinetic energy into soft x-rays. A heavier liner can be used to either compress sample materials to high pressures, or when driven into a central target, produce extremely high shock pressures for hydrodynamic experiments.

Several pulsed power machines, including Saturn[4], PBFA-Z[5], Shiva Star[6], Pegasus II[7], and Procyon[8], are currently being used for high energy density physics experiments. Saturn, PBFA-Z, and Procyon are used almost exclusively with lightweight liners for radiation experiments. Shiva Star and Pegasus II are frequently used to drive heavy liners for hydrodynamic experiments. However, neither Pegasus II nor Shiva Star have sufficient energy to reach the conditions required to support the weapon-physics hydrodynamic experiments envisioned for the future. A comparison of these current facilities and the projected Atlas capabilities is shown in Table I.

Table I. Comparison of Existing Facilities With Atlas

Facility Name	Facility Location	Liner Type (direct drive)	Peak Stored Energy (MJ)	Typical Load Current (MA)	Effective Pulse Width (μs)
Saturn	SNL	light	5.4	7 - 10	0.05 - 0.1
PBFA-Z	SNL	light	14	15 - 20	0.1 - 0.5
Procyon	LANL	light	explosive	15 - 20	1 - 2
Shiva Star	PL	heavy	9.4	12 - 20	8 - 15
Pegasus II	LANL	heavy	4.3	6 - 12	8 - 12
Atlas	LANL	heavy	36	40 - 50	5 - 10

Atlas Requirements

The Atlas machine must be flexible in order to accommodate a wide variety of weapons physics and basic research experiments. Other requirements for the facility include: (1) maximizing the radial and axial diagnostic access around the target chamber, (2) a machine reliability of 95% or greater, (3) a repetition rate of 100 tests/year, and (4) a machine lifetime of 1000 tests at full voltage. Finally, the facility should include full support services for users including data analysis, film processing, and planning and coordination areas. An artist's conception of the Atlas capacitor bank and target chamber is shown in Fig. 1.

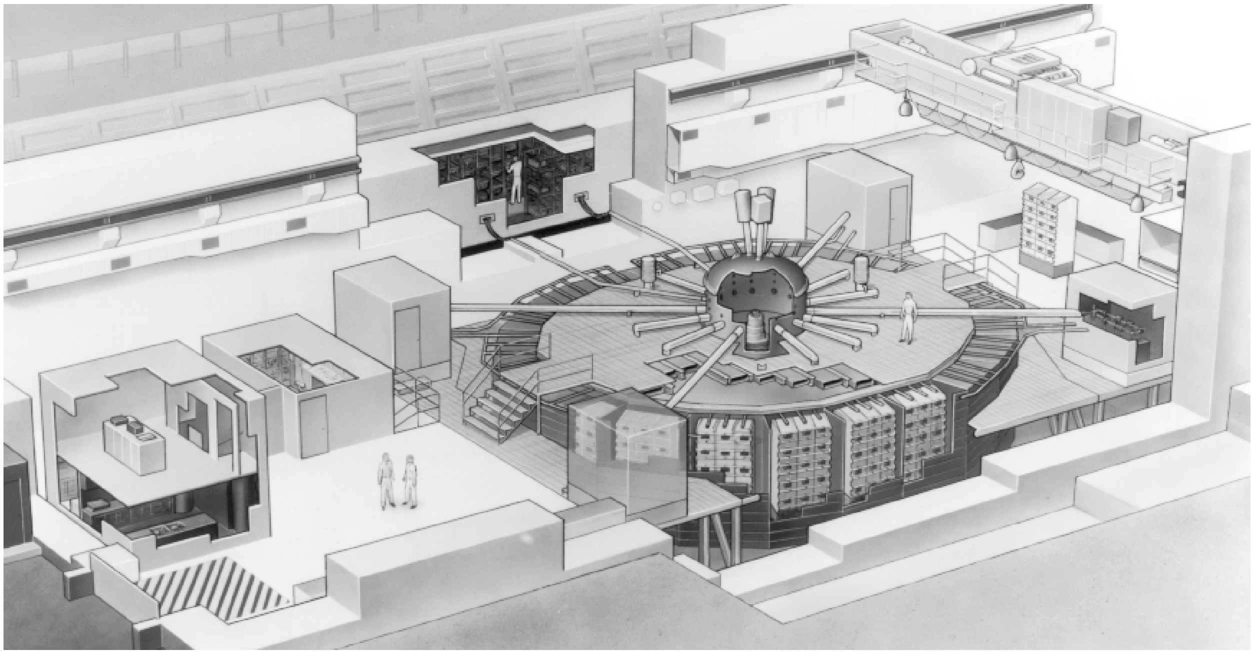


Fig. 1 Atlas capacitor bank and target chamber

Hydrodynamic Optimization

The primary mission for Atlas is to drive hydrodynamic experiments. Three figures of merit were chosen to optimize the 36-MJ Atlas machine for hydrodynamic performance. The most important quantity is the pressure achieved in the target. The two other figures of merit include the target volume and the time duration of the pressure pulse.

To simplify the optimization, we applied several constraints. First, we assumed an aluminum liner impacting an aluminum target. The magnitude of the pressure pulse is then proportional to the velocity of the liner's inner surface at impact. Second, we constrained the target to be a 1-cm-diam cylinder. This is large enough for relevant material samples and provides sufficient room for axial diagnostics. Third, we required that the unmelted portion of the liner be at least

0.25-cm-thick at impact. This insures that the pressure pulse lasts long enough to saturate the entire volume of the target. Fourth, we chose a Marx module "building block" of 120-kV. This matches the ratings of typically available closing switches and high energy-density capacitors. Finally, we added enough resistive damping to each Marx module to limit capacitor voltage reversal to 20%.

We began the study by using various forms of analytic scaling, parametric modeling, and 0-D computer codes. These allowed us to quickly pick a set of capacitor bank voltages and liner sizes that produced the highest liner velocities at impact. We then moved to more sophisticated 1-D computer codes, such as *Crunch*[9] and *Raven*[10], to optimize the solution. The results from the *Raven* calculations are shown in Fig. 2.

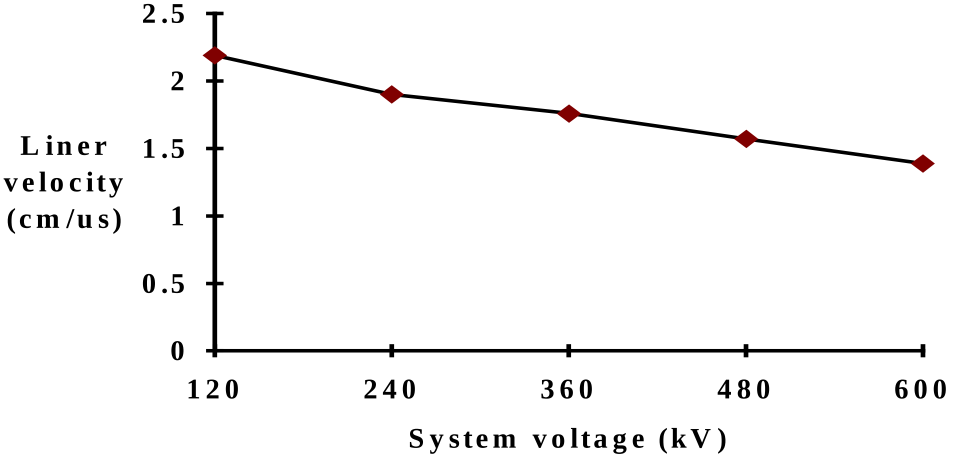


Fig. 2 Liner velocity vs system voltage

As shown in Fig. 2, the highest liner velocities under the given constraints were achieved at a system voltage of 120-kV. However, an inherent engineering problem exists with this configuration. The constraint of 20% voltage reversal of the capacitor bank is only met with a dynamic load. In the case of a fault condition or a static load, the voltage reversal of the bank exceeds 20%. When additional resistive damping is added to protect the bank under any condition, the 120-kV configuration outperforms the 240-kV configuration by less than 5%.

We chose 240-kV as the optimized solution for several reasons. First, since a 120-kV Marx module has only two capacitors, a 36-MJ Atlas would contain 300 modules. Each module requires separate cabling, diagnostics, data acquisition, etc. which would double the number of assembly parts required by a 240-kV system. The increase in cost and associated decrease in reliability due to these extra components is not justified by its marginal increase in predicted performance. Second, the 120-kV design has an extremely low impedance and its performance is based on ideal calculations of system inductance. If the system were constructed, an inductance increase of only a 1-nH would drastically reduce its peak current and hydrodynamic performance. The 240-kV configuration, because of its higher source impedance, is much less sensitive to actual variations from calculated inductances. Finally, the 120-kV configuration will not support plasma flow switch[7] (PFS) development. In the 240-kV configuration, two Marx modules could easily be connected in series to form a 480-kV module, a near-ideal configuration for PFS operation[11]. Calculations indicate that more than 3-MJ of soft x-rays would be produced if a 480-kV Atlas could successfully operate with a PFS and a light liner.

A diagram illustrating the optimized hydrodynamic capabilities of Atlas is shown in Fig. 3. Pressure is inversely proportional to target volume, and the highest absolute pressures are achieved using composite liners or multiple colliding shells.

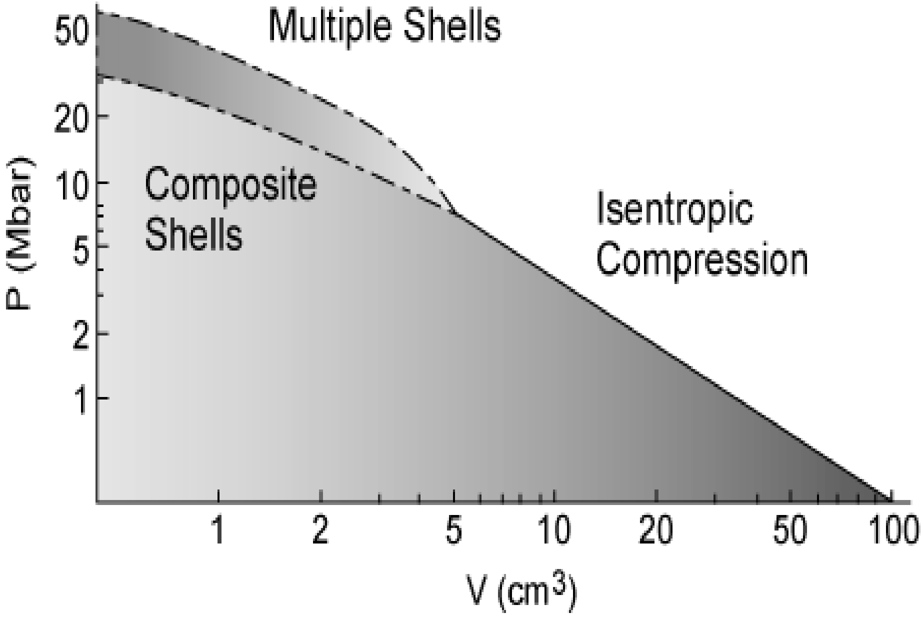


Fig. 3 Pressure vs target volume capabilities

Capacitor bank design

The 36-MJ Atlas capacitor bank will consist of 152 Marx modules, each containing four, 60-kV capacitors. Two closing switches will be used to “erect” each of the Marx modules into its 240-kV configuration. The capacitors in an individual module will be interconnected with a stainless steel resistor to provide damping. High-voltage coaxial cables will be used to transmit current from a pair of modules to an output isolation switch. The other side of the output isolation switch will be connected to a rigid, Mylar-insulated coaxial transmission line. A total of 76 of these lines will converge on to a central header which surrounds the target chamber. A schematic of a 240-kV Marx module is shown in Fig. 4.

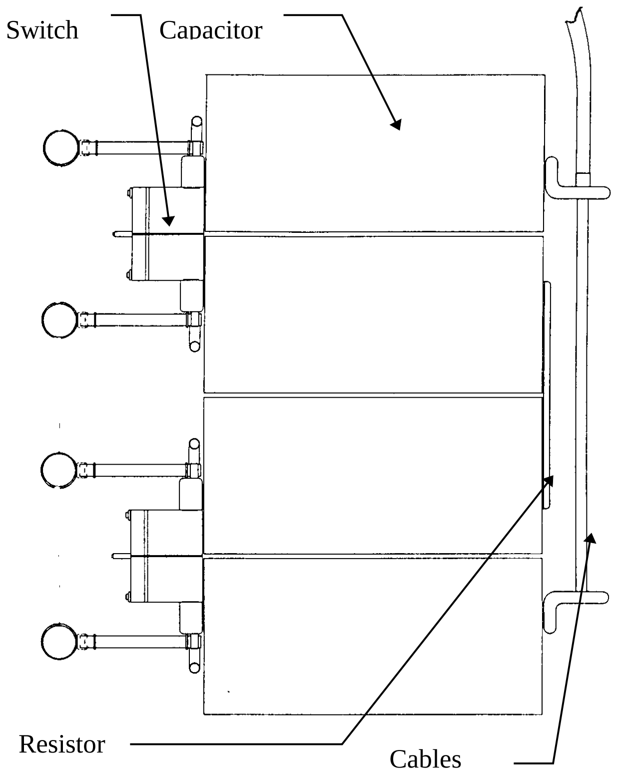
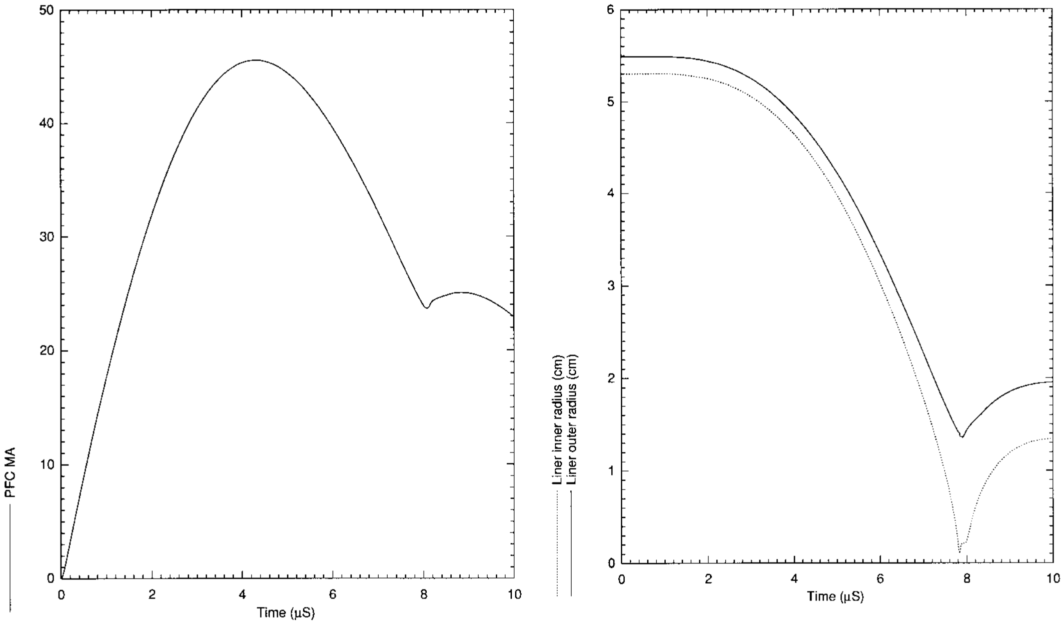


Fig. 4 240-kV Marx module

The 240-kV modules will be arranged in vertical stacks with two modules in each stack. For PFS development, the two modules can be connected in series to form a single 480-kV Marx module. This reduces the rise time of the system and therefore the time the switch is required to conduct current in a "closed" state.

Two stacks of two Marx modules will form a "maintenance unit". Each maintenance unit will be independently removable from the system and will contain its own control and data acquisition module and railgap trigger system. Railgap periodic maintenance requirements indicate that one maintenance unit will be removed from the system for refurbishing after each major test. The modularity of the maintenance units will help achieve the maximum anticipated repetition rate of 2 tests/week while still maintaining the overall system reliability requirements.

Figure 5a shows a simulation of the current waveform generated by the Atlas capacitor bank driving a 5.3-cm radius, 68-gm aluminum liner. As can be seen from the illustration, a peak liner current of 45.5-MA is reached in 4.3-µs. Figure 5b illustrates the inner and outer liner radii during this implosion. Zero-D modeling shows the peak liner velocity exceeding 2-cm/s before impacting an 1-cm diam target.



a **b**

Fig. 5 Projected performance for a 68-gm liner at 240-kV
(a) liner current (b) inner and outer liner radii

Capacitors. The Atlas capacitor design is based on the 20% voltage-reversal, 30-kJ capacitors used in the Pegasus II Facility. Each Atlas capacitor is rated at 60-kJ stored energy (two 30-kJ Pegasus II units in parallel), 60-kV charge voltage, 330-kA discharge current, and less than 20-nH inductance. The case style has been modified to a *Fastcap*[12,13] configuration which will greatly ease the construction of the Marx modules. These cases are fiberglass with electrical bushings mounted at the front and rear of each capacitor. Two vendors were selected to each manufacture 20 prototypes. Capacitors from both vendors are currently under evaluation to certify their performance capabilities under Atlas operating conditions.

Marx module switches. Each of the 300 switches in the Atlas system will be operated at a 120-kV holdoff voltage, a 330-kA conduction current, and a 3-coul charge transfer. We chose the railgap switch for this application because of its demonstrated low jitter, low inductance, and high coulomb-transfer capabilities in other pulsed power systems[6]. We tested several of these switches in the laboratory at current levels exceeding 800-kA and at a charge-transfer exceeding 5-coulombs. The switch performed well with the exception of deformation of the trigger rail under prefire conditions. We are presently working with the manufacturer to improve its mechanical integrity. Our tests indicate that after approximately 200- to 300-coul of accumulated charge transfer, the switch will prefire at 120-kV. For an individual switch to have a prefire probability of less than 10^{-4}, periodic maintenance will be required approximately every 120 coulombs.

Damping resistors. There will be two types of damping resistors in the Atlas system. The series resistors shown in Fig. 4 must conduct the full discharge current of each module. Reticulated vitreous carbon plates[14] were initially chosen for this application due to their inherently low inductance and excellent energy absorption capabilities (80-J/cm^3). However, when using them in oil, we had to derate them to 20- J/cm^3 to prevent oil vapor from forming within the resistor. We are now testing a folded stainless steel foil resistor for this application. The other type of damping resistor is a shunt resistor and is used to absorb high-frequency, parasitic oscillations between Marx modules and the header system. The shunt resistors will be located across the output of each module, but are only required to conduct modest currents.

Capacitor bank charging system. The prefire of a railgap switch is the most likely system failure mode. To reduce the number of prefires and their effect on the pulsed power system and target assembly, we are considering two prefire-prevention techniques. The first involves using large power supplies to rapidly charge the bank. This technique is based on the assumption that prefire probability increases with the time a switch has to withstand voltage. We have established a baseline prefire rate with a 12-s charging time and will investigate the effects of faster charging rates. If need be, a 1430-MVA generator[15], located next to the Atlas construction site, is capable of charging the capacitor bank in less than 1-second. We can also use this generator in a “regeneration” mode to augment the available grid power. The second technique involves isolating the Marx modules from the expensive target assembly with switches that remain open until the bank nears full charge. The switches would then close and the bank would be immediately triggered. These switches also allow the flexibility to test charge the modules, individual or collectively, to condition components and test for faults.

Target Chamber

Present estimates indicate more than 12-MJ of energy will be trapped and dissipated in the target chamber when the vacuum insulator breaks down from the Poynting vector changing direction. The current design of the target chamber has walls that are lined with energy absorbing material to prevent damage from the shrapnel and debris of the discharge. The chamber will be approximately 2-m in diameter to support the extensive suite of diagnostics that is anticipated.

Because of the variety of anticipated experiments, a high degree of flexible diagnostic access is necessary. Diagnostic access for end-on and radial views of the target will be available. Several in-line port pairs for diagnostics that involve active backlighting with visible light or x-rays will also be available. The large chamber dimensions necessitate re-entrant port capability for those diagnostics that require high flux. To facilitate alignment of these diagnostics, the target chamber and associated diagnostics will be preassembled in a staging area and then lowered on to the machine for final alignment.

Acknowledgments

The authors gratefully acknowledge the Department of Energy, Defense Programs, for their support of this project. We would particularly like to thank Dr. Vic Reis, Dr. Robin Staffin, and Dr. Robert DeWitt for their efforts.

References

1. Presidential Decision Directive and Act of Congress (P.L. 103-160).
2. "The Stockpile Stewardship and Management Program: Maintaining Confidence in the Safety and Reliability of the Enduring U.S. Nuclear Weapon Stockpile", U.S. Department of Energy, Office of Defense Programs, May 1995.
3. J.C. Solem, "Basic Science with Pulsed Power & Some Off-the-Wall Ideas", LA-UR-95-1110, presented at the Spring Workshop on Basic Science Using Pulsed Power, Santa Barbara, CA, April 5-7, 1995.
4. D.D. Bloomquist, *et. al*., “Saturn: A Large X-Ray Simulation Accelerator”, Proc. 6th IEEE Int’l. Pulsed Power Conf., pp 310, June, 1987.
5. R.B. Spielman, *et. al*., “PBFA-Z: A 20-MA Driver for Z-Pinch Experiments”, Proc. 10th IEEE Int’l. Pulsed Power Conf., pp 396, July, 1995.
6. R.E. Reinovsky, *et. al.*, "Shiva Star Inductive Pulse Compression System", Proc. 4th IEEE Int'l. Pulsed Power Conf., pp 196, June, 1983.
7. J.C. Cochrane, *et. al.*, "Plasma Flow Switch and Foil Implosion Experiments on Pegasus-II", Proc. 9th Int'l. IEEE Pulsed Power Conf., pp 805, June, 1993.
8. J.H. Goforth, *et. al.*, "Review of the Procyon Explosive Pulsed Power System", Proc. 9th Int'l. IEEE Pulsed Power Conf., pp 36, June, 1993.
9. *Crunch*: One-Dimensional finite-element Hydrodynamics System by Stan Humphries, Jr., Acceleration Associates, 13407 Sunset Canyon NE, Albuquerque, NM 87111.
10. *Raven* is a 1-D MHD code with equation of state, strength of materials, and radiation transport. It was developed at Los Alamos under a contract with the Department of Energy.
11. R.L. Bowers and N. F. Rodereck, “Effects of Bank Voltage on Single-Stage Switching Using a Plasma Flow Switch”, unpublished LANL technical report, February, 1996.
12. "Advanced Power Technology Program, Volume II: Inductive Energy Storage", report to the Defense Nuclear Agency by Maxwell Laboratories, sections 9 & 10, July 19, 1989.
13. W.A. Reass, *et. al.*, "Capacitor and Railgap Development for the Atlas Machine Marx Modules", Proc.10th IEEE Int’l. Pulsed Power Conf., pp 522, July, 1995.
14. C. Thompson, *et. al.*, "Series Fault-Limiting Resistors for Atlas Marx Modules", Proc.10th IEEE Int’l. Pulsed Power Conf., pp 1472, July, 1995.
15. H.J. Boenig, "The Los Alamos 600 MJ, 1500 MW Inertial Energy Storage and Pulsed Power Unit", Proc. 8th Int'l. IEEE Pulsed Power Conf., pp 719, June, 1991.