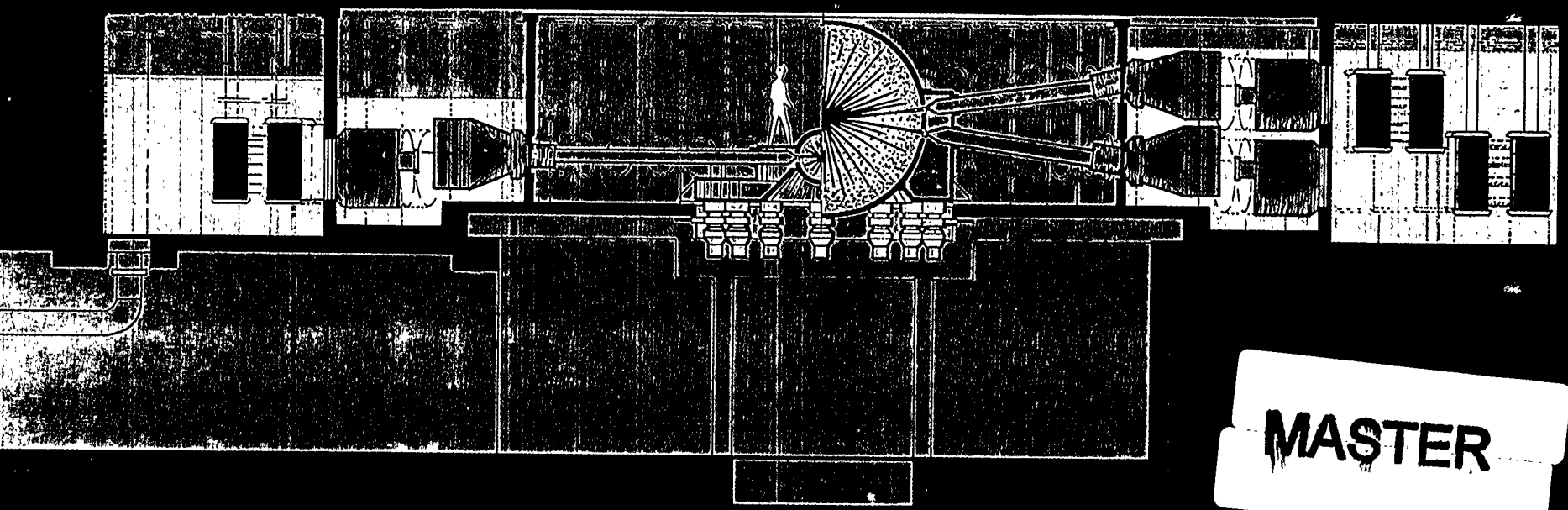
SAND--95-2992

Pref to
Lee Garner
Collection
7/80 ... OPN #126

Particle-Beam Fusion Research Facilities at Sandia National Laboratories



MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

Portions of this document may be illegible electronic image products. Images are produced from the best available original document.

THE COVER

Artist's concept of two phases in the design of Sandia's Particle-Beam Fusion Accelerator (PBFA). PBFA-I, the world's largest short-pulse facility, will be capable of irradiating a fuel pellet with a 40-nanosecond (40 x 10^{-9} s) pulse of 1 megajoule (1 x 10^{6} J) energy and 30 terawatts (30 x 10^{12} W) peak power. In its first operation in the early 1980s, PBFA-I is expected to obtain significant thermonuclear burn. The PBFA-II upgrade phase will subject pellets to 3.5 megajoules and 100 terawatts, approaching the regime of scientific breakeven and net energy gain during the mid-1980s.

Electrical Units for Power and Energy

For the inertial-confinement fusion (ICF) process, characteristic energies in the range of 1 to 15 megajoules (MJ), powers of 1 to 100 terawatts (TW), and times of 1 to 100 nanoseconds (ns) are routinely encountered. Parameters describing electrical components used in the research typically involve voltages of 500 kilovolts (kV) to 4 megavolts (MV) and currents of 500 kiloamperes (kA) to 30 megamperes (MA). Other units and helpful conversion factors are shown below.

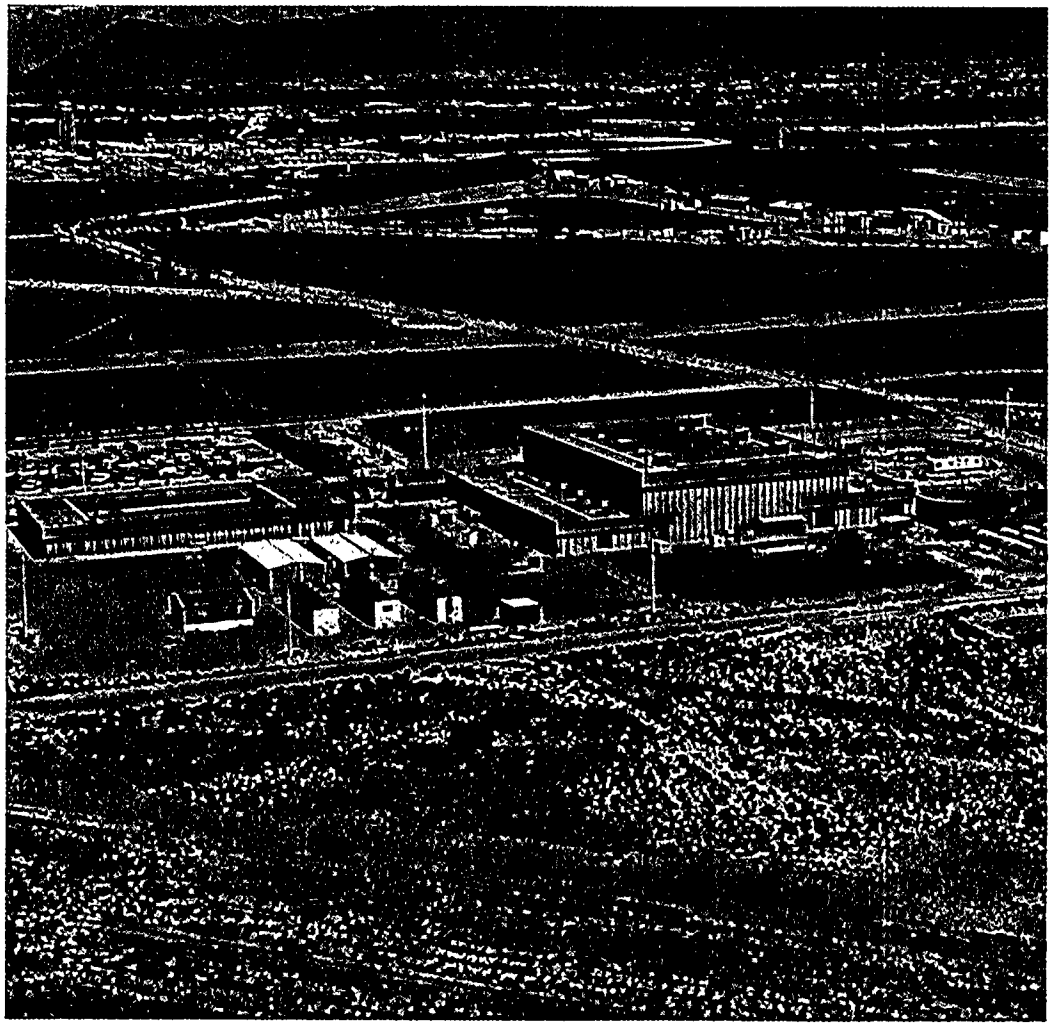
	Unit		*Conversion Factors*
energy	J (joule)	1 J	= 0.239 cal (calorie)
		1 kJ	= 0.948 Btu (British thermal unit)
		1 MJ	= 0.278 kWh (kilowatt-hour)
			= energy equivalent of 0.5 lb TNT
power	W (watt)	1 W	= 1 J/s (joule per second)
		1 kW	= 1.34 hp (horsepower)
		1 TW	= 1.34 billion hp
time	s (second)	1 ns	= 10^{-9} s

about Sandia

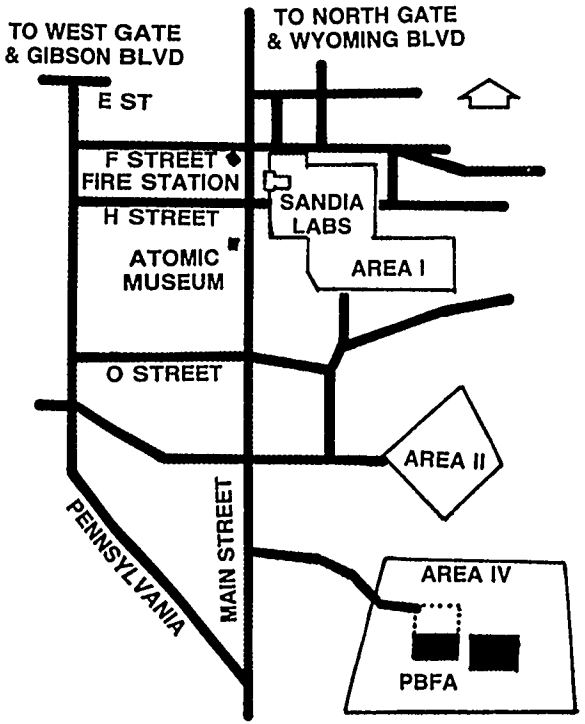
Sandia Corporation, a subsidiary of Western Electric, operates Sandia National Laboratories as a multiprogram organization for the US Department of Energy (DOE) on a nonprofit, no-fee basis. Its main facilities are at Albuquerque, NM and Livermore, CA. Although the primary responsibilities of the laboratory are research and development for nuclear weapons systems, nearly one-third of our effort today is devoted to energy programs.

Our research in inertial-confinement fusion (ICF) is based on pulse-power capabilities that grew out of earlier developments of intense relativistic electron-beam (e-beam) radiation sources for weapon effects studies. ICF involves irradiating a deuterium-tritium pellet with either laser light or particle beams until the center of the pellet is compressed and heated to the point of nuclear fusion.

This publication focuses on the use of particle beams to achieve fusion, and on our various facilities that are used in support of the particle-beam fusion (PBF) program.



aerial photo of Sandia's particle-beam fusion accelerator (PBFA) laboratory and office complex at Albuquerque, NM



Particle-Beam Fusion Research Facilities

Particle-Beam Research and Development: New Directions in Fusion Power 4

History of Sandia's Pulsed-Power Program for Particle-Beam Fusion Research 5

Particle-Beam Generation 6

Pulsed-Power Accelerator Operation 7

The Hydra-HydraMITE Facility 9

The Proto-I Facility 11

The Proto-II Facility 13

The PBFA-I Facility 15

The SuperMITE Facility and PBFA-II 17

Fusion Data-Acquisition Facilities 19

Appendix — Pulsed-Power Historical Milestones 20

A Glossary of Acronymns and Terms 23

Particle-Beam Research and Development: New Directions in Fusion Power

For 30 years scientists have searched for ways to harness fusion power—the energy source of the sun. As the world's energy problems grow more severe, the United States is increasing its commitment of scientific resources for research and development of this energy source.

Today, as DOE's lead laboratory for the pulsed-power approach to fusion, Sandia is engaged in major research and the construction of new facilities at its Albuquerque site. We also coordinate DOE-supported pulsed-power fusion work at other government-operated laboratories, at universities, and with industrial contractors.

Many complex technical problems remain to be solved, but there is reason for optimism about the future of fusion power. Ultimately this nation's past investment in nuclear weapons programs may lead to one of its greatest peacetime benefits.

Major goals of our fusion program include the following:

- Complete a particle accelerator to deliver sufficient beam energy for "igniting" fusion targets
- Obtain "net energy gain." This goal would provide fusion energy output in excess of energy stored in the accelerator
- Develop a technology base for the repetitive ignition of pellets in a power reactor

Once these goals are reached, the technology will be introduced to the nation's commercial sector.

History of Sandia's Pulsed-Power Program for Particle-Beam Fusion Research

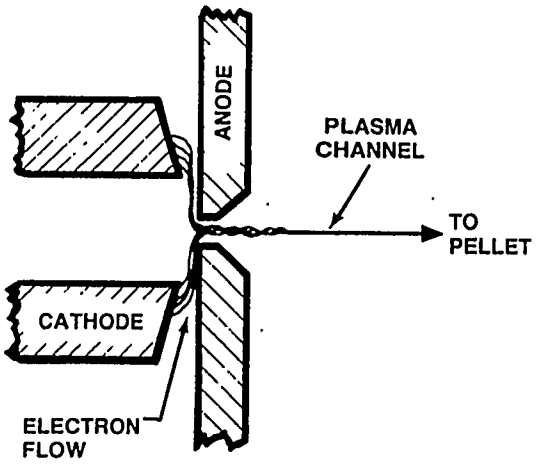
The technology employed in our pulsed-power accelerators began in 1964 at the Atomic Weapons Research Establishment (AWRE) in Aldermaston, England, under the direction of J. C. Martin. At that time a series of ideas were turned into successful hardware to form the basis of a prolific accelerator technology in the United States. Government agencies, primarily the Department of Energy (DOE) and the Defense Nuclear Agency (DNA), have funded this technology. DOE funding has been directed primarily toward research at Sandia, while DNA-funded work has been mostly at commercial firms.

Noteworthy historical milestones of our program are found in the Appendix.

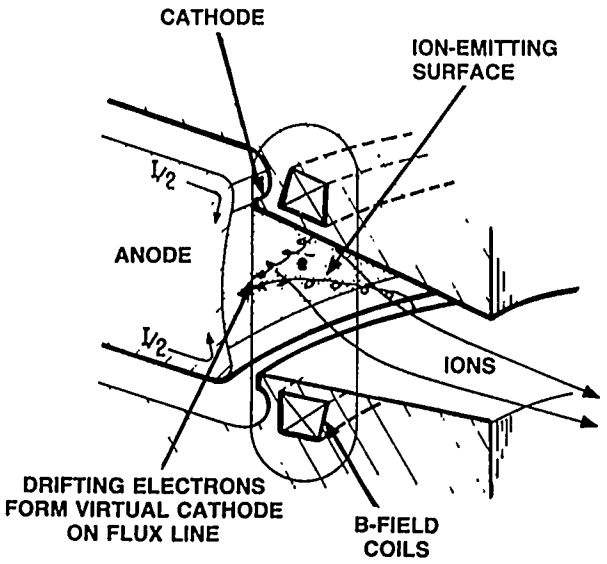
Particle-Beam Generation

Beams of energetic electrons and light ions are produced by forming a plasma (an ionized gas of free electrons and ions) between the two electrode surfaces in a vacuum diode and then accelerating these particles across the small interelectrode gap. Electrons are liberated on the negative metal electrode surface when small whiskers explode as the diode current increases. Ions are formed at the positive electrode surface either by causing a small discharge to flash over the surface or by generating ions externally and injecting them into the diode. Depending on the particle desired, the geometry, field configurations, and diode polarity are selected to produce electron flow or (by employing externally generated magnetic fields) to suppress electron flow and enhance ion flow—both with relatively high efficiency. Schematics of these two methods of producing ion and electron beams are shown below.

Electron Beam Diode



Ion Beam Diode



Pulsed-Power Accelerator Operation

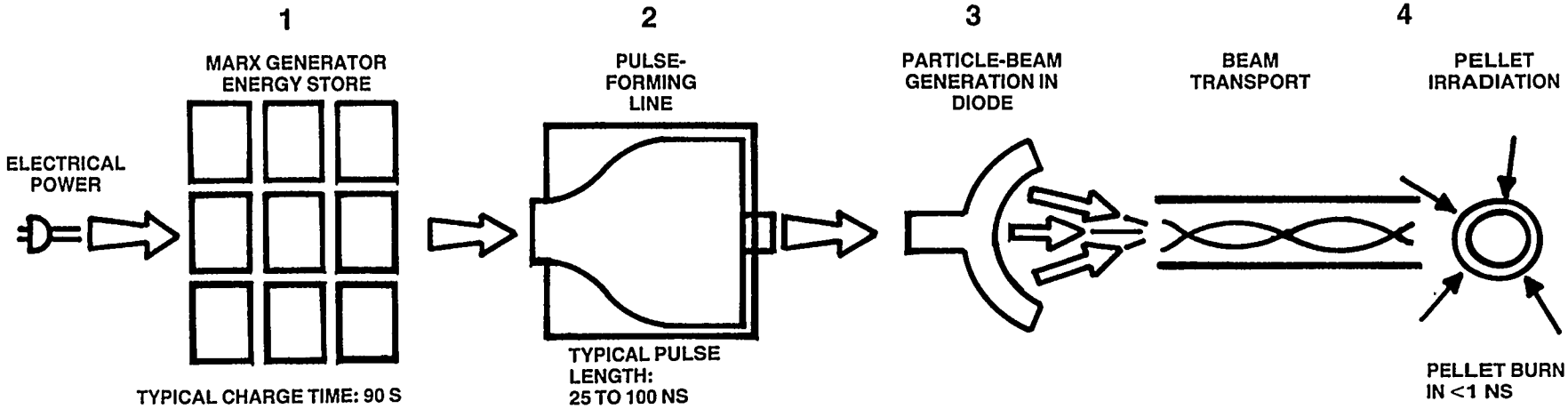
A pulsed-power particle-beam accelerator generates and focuses intense beams of energetic particles. Because the power requirements for fusion are many times greater than the world's present power production capability, energy in these accelerators must be taken slowly from local power grids and then compressed in time-bounded stages (temporally) through a network of electrical pulses. This temporal compression bridges the gap between accelerator power consumption at 40 kW and the production of power at a rate approaching 100 TW.

Four stages characterize the operation of accelerators in the fusion program:

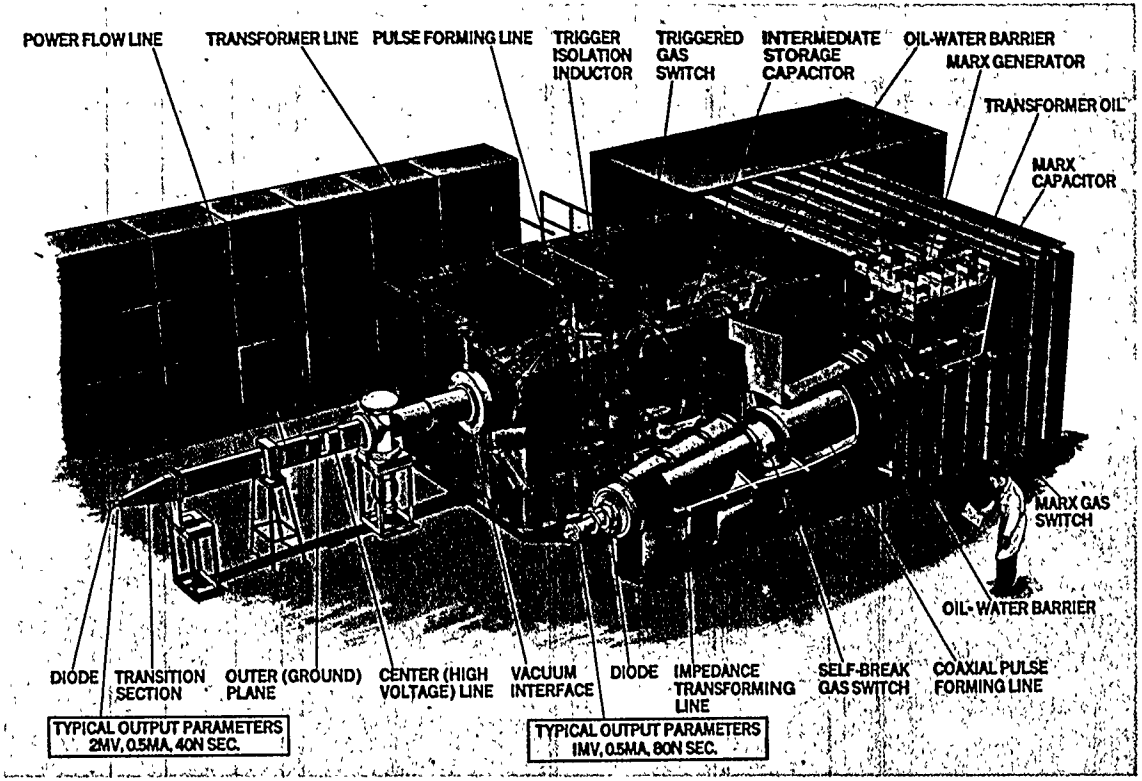
1. Electrical energy is slowly stored in a bank of high-voltage capacitors (often called a Marx generator).
2. Through the use of high-speed switches to multiply voltage, the energy is transferred rapidly into a pulse-forming line. This line then shapes the energy into a pulse of large amplitude and short duration.
3. The power pulse is delivered to a high-voltage diode in vacuum for conversion into a beam of energetic electrons or light ions.
4. Under forces produced by electric and magnetic fields within the diode, the beam acquires energy and can then be focused to almost 1/100 its original area.

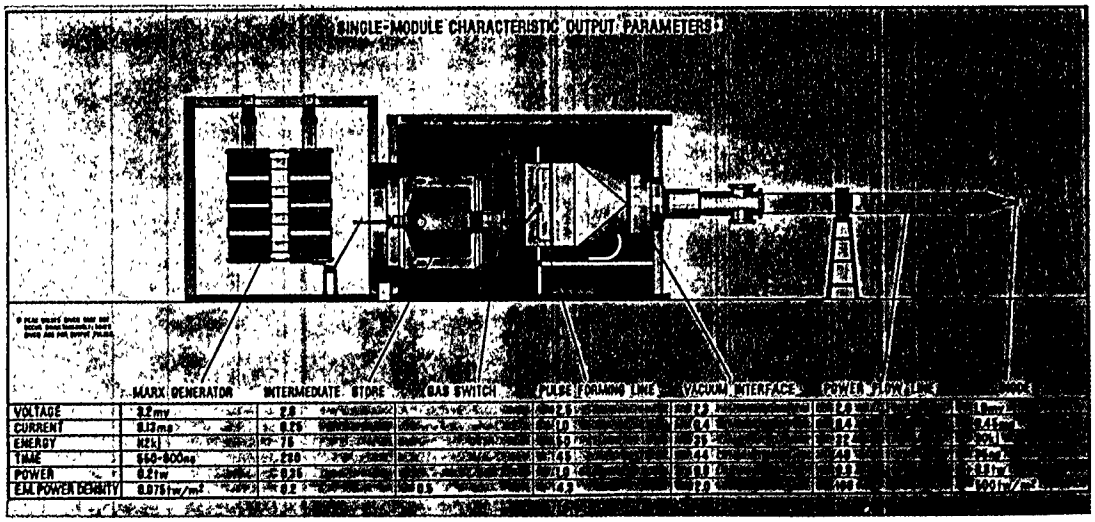
A single beam may irradiate a target within a diode—or several beams may be propagated outside the diode along a narrow preionized channel toward the fusion target.

Intense target irradiation is achieved, then, by compressing energy in time to get high power, and power in space to get high power density.



HYDRA-HYDRAMITE





C80-5030

The Hydra-HydraMITE Facility

The Hydra-HydraMITE Facility is a high-energy, pulsed, electron-beam, ion-beam, or bremsstrahlung X-ray source. In 1971 Sandia designed and assembled Hydra (lower right side of top drawing) in order to provide an energy source of short duration for studies of radiation effects. Hydra is presently used in generating tightly focused electron and light-ion beams for the Particle Beam Fusion (PBF) Program. HydraMITE (upper left side of top drawing), a prototype module of the 1-million-joule, 36-module PBFA-I, was constructed in 1979 for pulsed-power engineering evaluation. It is also used to generate high-power electron and ion beams.

The principal components of the Hydra leg are the

- Marx generator energy store
- Coaxial water dielectric pulse-forming line
- High-pressure self-break gas switch
- Coaxial impedance transforming line
- Vacuum diode

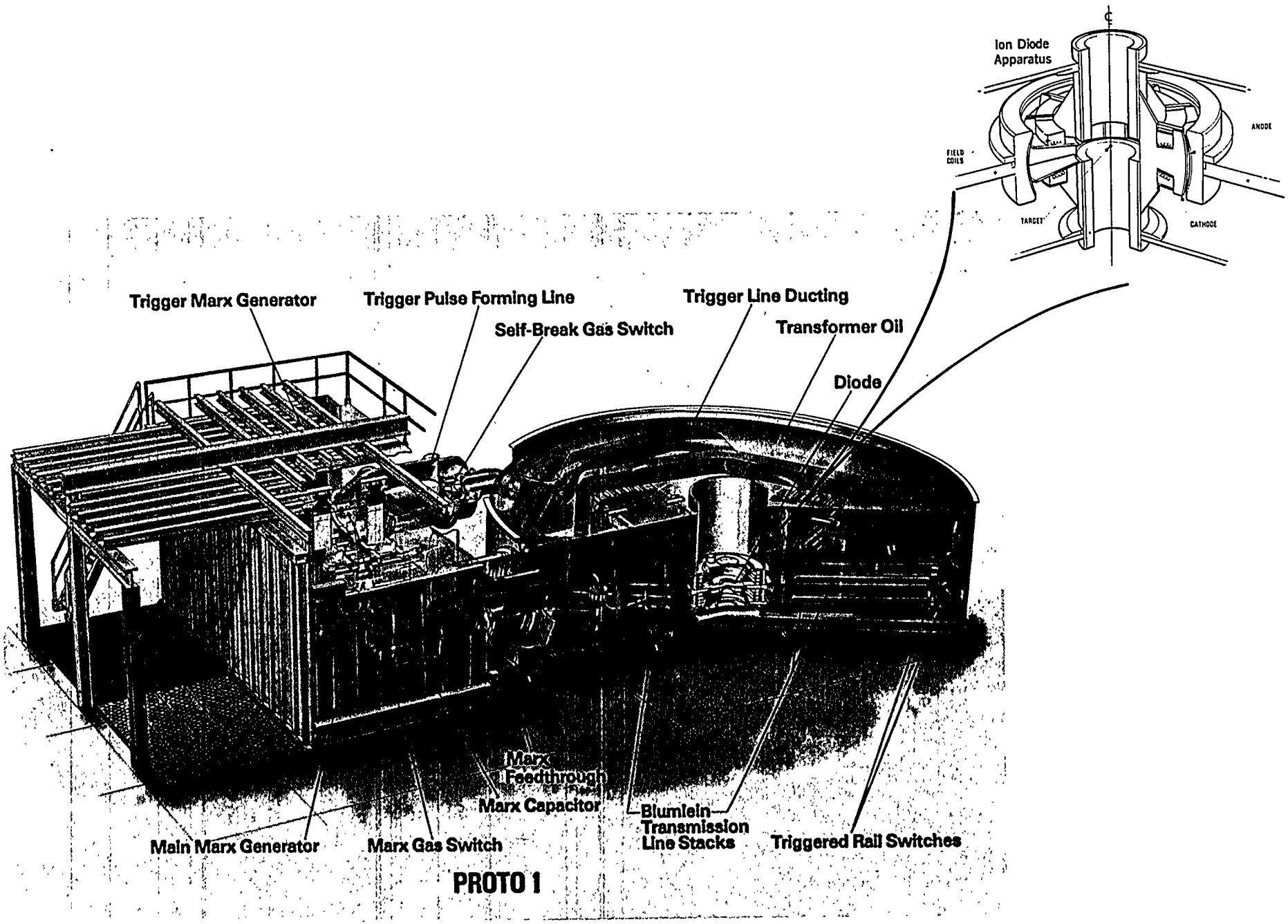
The HydraMITE leg uses the same Marx generator—but with more advanced components in the water section for higher power density storage, and a long magnetically insulated power flow line to deliver the fast-rising power pulse down to a small-diameter diode. Examples of some of the advanced components used in the water section include an intermediate storage capacitor, triggered switch, parallel pulse-forming lines, pulse-sharpening switches.

On HydraMITE and PBFA-I the problem of transporting electromagnetic energy at increasingly higher power densities (see bottom drawing) has been successfully addressed by (1) judicious design of pulse-forming components, (2) selection of dielectrics of sequentially higher breakdown strength, and (3) use of a self-magnetically insulated transmission line. These improvements have resulted in the highest-power density transport yet achieved.

A voltage pulse of either positive or negative polarity can be applied to the Hydra or HydraMITE sections, depending on the desired application. Thin anodes of light materials (e.g., aluminum or carbon) are used for electron-beam generation. For X-ray production, thick targets of heavy materials are used. And either surface flashover sources or externally driven plasma generators are used for ion-beam production. Both Hydra and HydraMITE diodes are horizontally mounted for easy diagnostic access.

Hydra-HydraMITE Performance Characteristics

	Nominal Operating Parameters	
	Hydra	*HydraMITE*
Marx Generator		
Charging Voltage	75 kV	95 kV
Typical Shot Rate	1 pulse/h	1 pulse/h
Energy Stored	70 kJ	112 kJ
Diode		
Peak Diode Voltage	1.0 MV	1.9 MV
Peak Diode Current	0.4 MA	0.5 MA
Total Beam Energy	35 kJ	35 kJ
Particle-Beam Environment		
Transported-Beam Energy	35 kJ	30 kJ
Peak Beam Power	0.4 TW	>0.8 TW
Pulse Width (Full width, half maximum—FWHM)	80 ns	40 ns


Ion Diode Apparatus
ANODE
FIELD COILS
TARGET
CATHODE
Trigger Marx Generator
Trigger Pulse Forming Line
Self-Break Gas Switch
Trigger Line Ducting
Transformer Oil
Diode
Marx Feedthrough
Marx Capacitor
Blumlein Transmission Line Stacks
Triggered Rail Switches
Main Marx Generator
Marx Gas Switch
PROTO 1

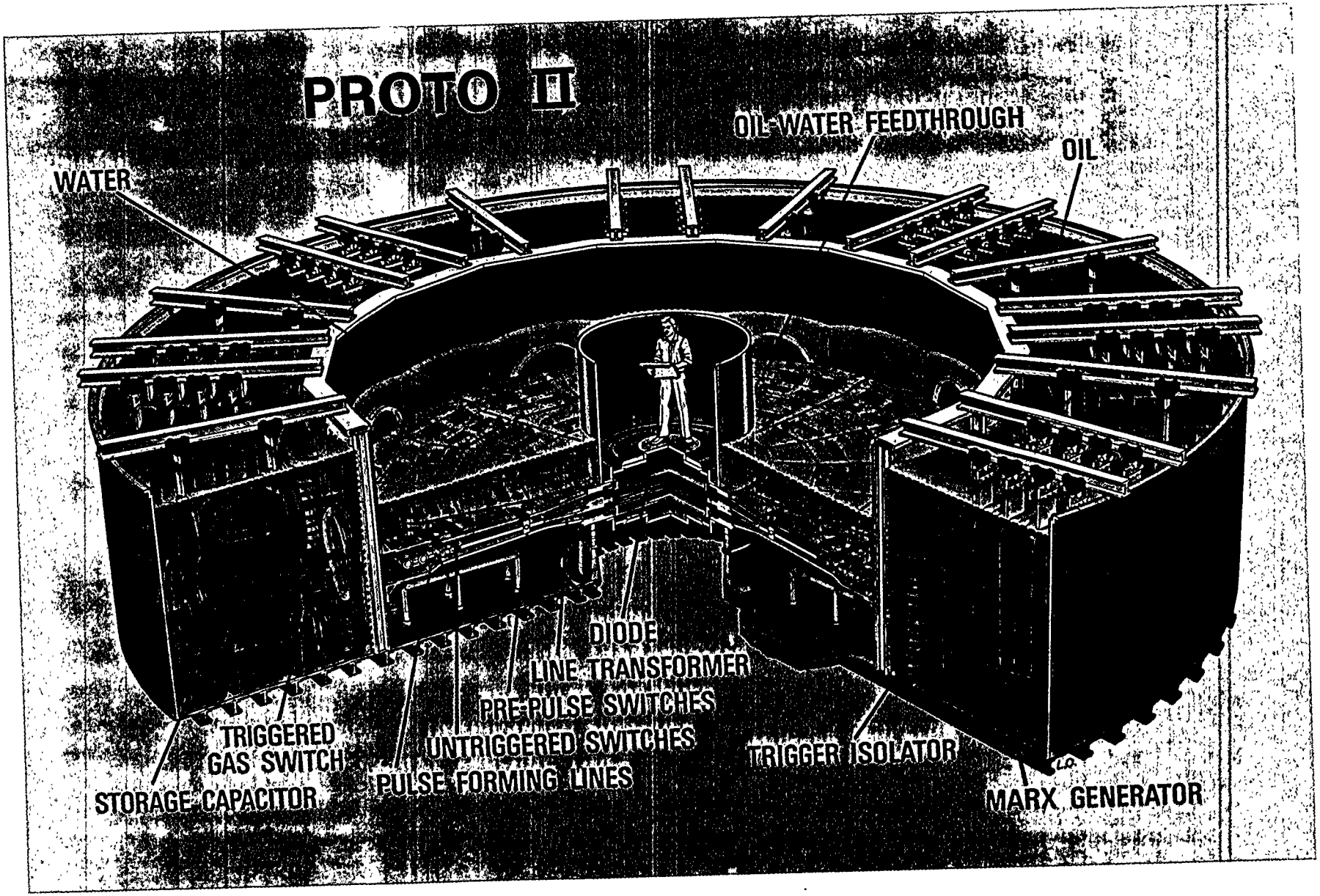
The Proto-I Facility

Proto-I is a high-power, short-pulse facility for the production of electron and ion beams and X rays. Sandia designed and assembled this facility in 1974 as a first prototype for driving inertially confined fusion targets. The main components are two Marx generators (one for charging transmission lines and one for triggering switches in the oil section), and a set of six rectangular Blumlein transmission-line stacks that form the power pulse delivered to the diode. A large-diameter vacuum diode in the center of the accelerator can generate a single upward-directed electron beam, a pair of electron beams irradiating a common target from both sides, or a radially directed light-ion beam.

In operation, one Marx energy store charges the intermediate lines in each parallel Blumlein stack to a high negative voltage while the trigger Marx is charging a short water-dielectric pulse-forming line. When the gas switch at the end of this line fires, voltage is applied to a set of 12 rail switches at the end of each Blumlein. A fast-rising high positive-voltage pulse is launched down the center line and converges radially into the diode. In the electron-beam mode, a power convolute section in the oil just outside the diode determines whether one or two electron beams are generated. For light-ion-beam generation, external field coils in the diode provide the magnetic field required to suppress electron flow. The diode has vertical axial diagnostic access from both above and below the accelerator.

Proto-I Performance Characteristics

	Nominal Operating Parameters	
Marx Generator		
Charging Voltage	45 kV	
Typical Shot Rate	1 pulse/2 h	
Energy Stored	60 kJ	
Diode	*One Beam*	*Two Beams*
Peak Diode Voltage	2-2.5 MV	2-2.5 MV
Peak Diode Current	0.5 MA	0.25 MA/beam
Total Beam Energy	20 kJ	10 kJ/beam
Particle-Beam Environment		
Transported-Beam Energy	20 kJ	10 kJ/beam
Peak Beam Power	1 TW	0.5 TW/beam
Pulse Width (FWHM)	25 ns	25 ns


PROTO II
OIL-WATER FEEDTHROUGH
OIL
WATER
DIODE
LINE TRANSFORMER
PRE-PULSE SWITCHES
UNTRIGGERED SWITCHES
PULSE FORMING LINES
TRIGGERED GAS SWITCH
STORAGE CAPACITOR
TRIGGER ISOLATOR
MARX GENERATOR

The Proto-II Facility

In 1976 Sandia designed and assembled Proto-II as a second prototype for driving inertial fusion targets. A high-power, short-pulse facility for electron- and ion-beam production and X-ray bremsstrahlung generation, Proto-II has also been used for propagating particle beams along plasma channels and for driving cylindrical magnetically imploded liners. The main components are 8 Marx generators, 16 intermediate storage capacitors (2 per Marx), 8 triggered-gas switches, 16 water-insulated triplate transmission lines, impedance matching transformer sections, and a large-diameter, low-inductance vacuum diode.

Marx energy is fed into the intermediate storage capacitors within the oil section. When the triggered-gas switches are fired, this energy passes into the water section to charge 16 pulse-forming lines. Depending on the positioning of two sets of self-break water-peaking switches, a power pulse lasting 20, 45, 60, or 80 ns converges radially into the diode. The transformer section just outside the diode provides for impedance matching to a variety of diode loads. At the end of the transformer a set of polarity reversal rods can be adjusted to pulse the diode with either positive or negative polarity.

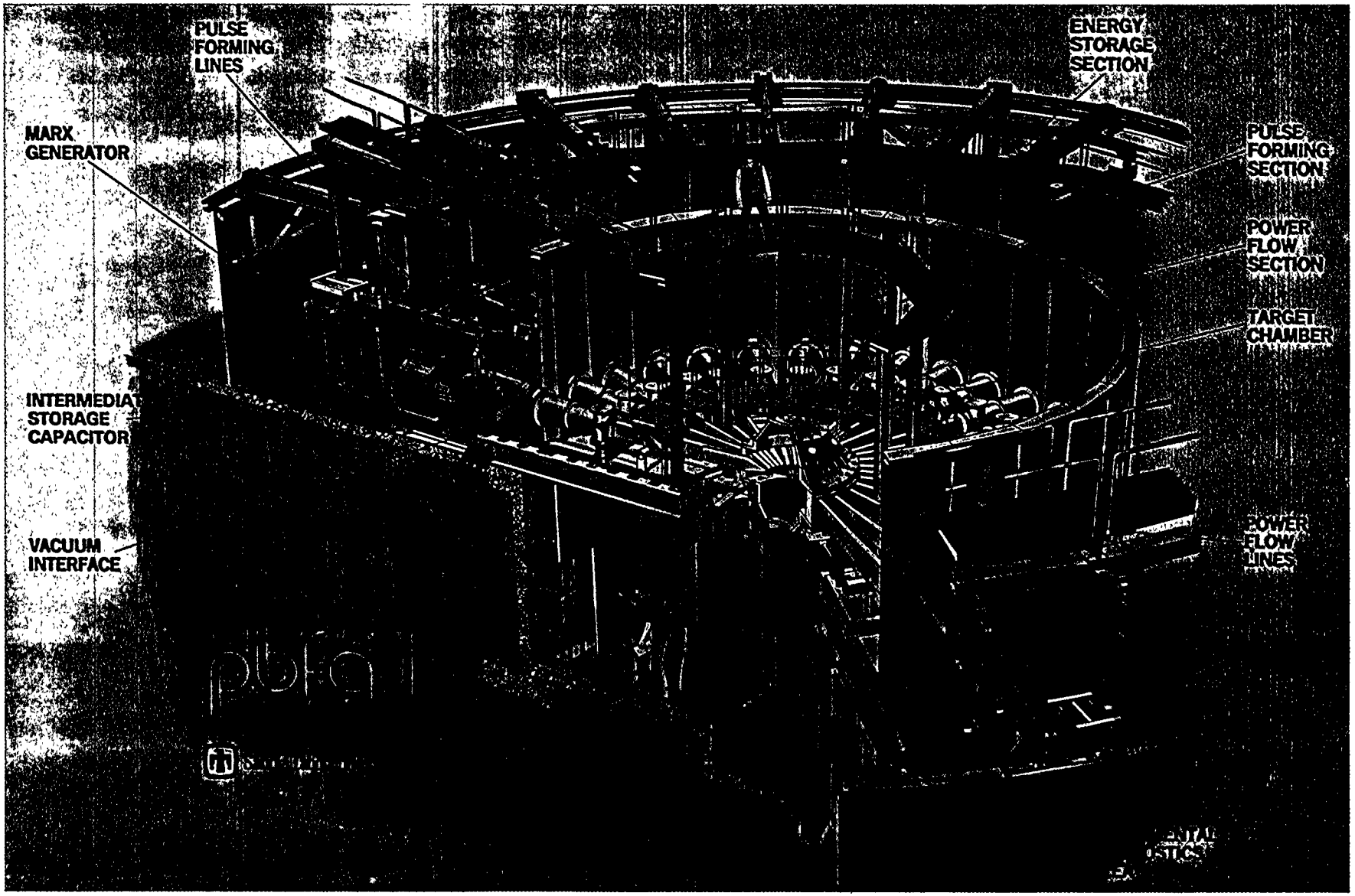
Diode hardware has been designed to provide for several functions, e.g.:

- For generating
  - A single electron beam
  - A pair of beams irradiating a common target from opposing sides
  - Multiple (up to 12) electron beams converging radially onto a common target
  - A radially converging ion beam
- For magnetically imploding axially mounted loads such as thin cylindrical foils

The diode has vertical axial diagnostic access from both above and below the accelerator.

Proto-II Performance Characteristics

	Nominal Operating Parameters
Marx Generator	
Charging Voltage	80-95 kV
Typical Shot Rate	1 pulse/5 h (electron mode)
Energy Stored	900 kJ
Diode	
Peak Diode Voltage	1.5 MV
Peak Diode Current (both sides)	8 MA
Total Beam Energy	~300 kJ (45-ns mode)
Particle-Beam Environment	
Transported-Beam Energy	>200 kJ (45 ns)
Peak Beam Power	8-10 TW (45 ns)
Pulse Width (FWHM)	20, 45, 60 or 80 ns


PULSE FORMING LINES
ENERGY STORAGE SECTION
MARX GENERATOR
PULSE FORMING SECTION
POWER FLOW SECTION
TARGET CHAMBER
INTERMEDIATE STORAGE CAPACITOR
VACUUM INTERFACE
POWER FLOW LINES

The PBFA-I Facility

PBFA-I is a high-energy, high-power, short-pulse facility for generating electron and light-ion beams, X-ray bremsstrahlung, and short, high-flux neutron bursts from fusion reactions. It was designed and assembled in 1978-80 by Sandia as the first modular multiterawatt super-power generator for research on thermonuclear fusion physics. This first-generation PBFA (PBFA-I) is made up of 36 pulsed-power modules, all identical in configuration and output parameters to HydraMITE. Each module consists of

- A Marx generator in the oil-energy storage section (outermost annulus of the tank)
- Intermediate storage capacitor
- Triggered gas switch
- Water-peaking switches and transmission lines in the water pulse-forming section
- Vacuum interface and magnetically insulated transmission line in the power-flow section
- Final in-diode anode-cathode gap in the front-end assembly (center section of tank)

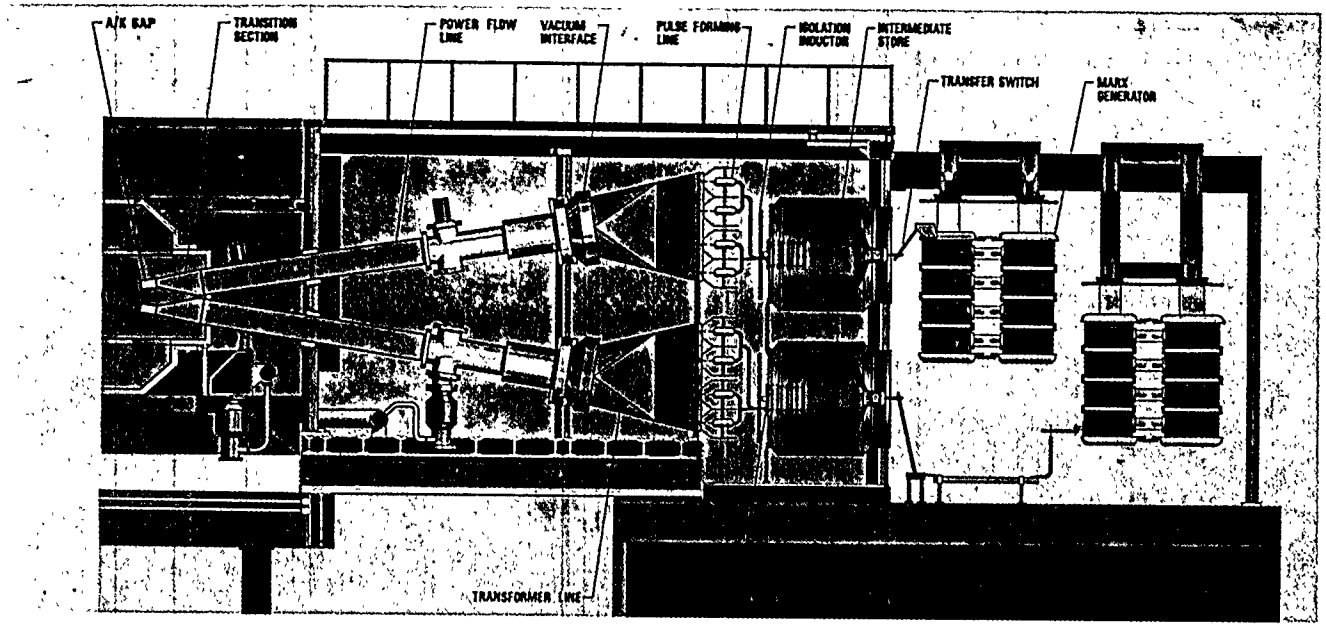
A second-generation accelerator (PBFA-II) is planned for future assembly within the same tank structure as PBFA-I. The new facility will be a 72-module device with more than three times the output power of PBFA-I.

In operation, a fast-rise power pulse delivered to the end of the power-flow lines is converted (depending upon the application) into electron or light-ion beams in the vacuum diode region. For the electron mode, the beams emerge into an atmosphere contained by a spherical chamber (one of several front ends designed for the accelerator) and propagate along preionized plasma channels to symmetrically irradiate a target on the chamber axis.

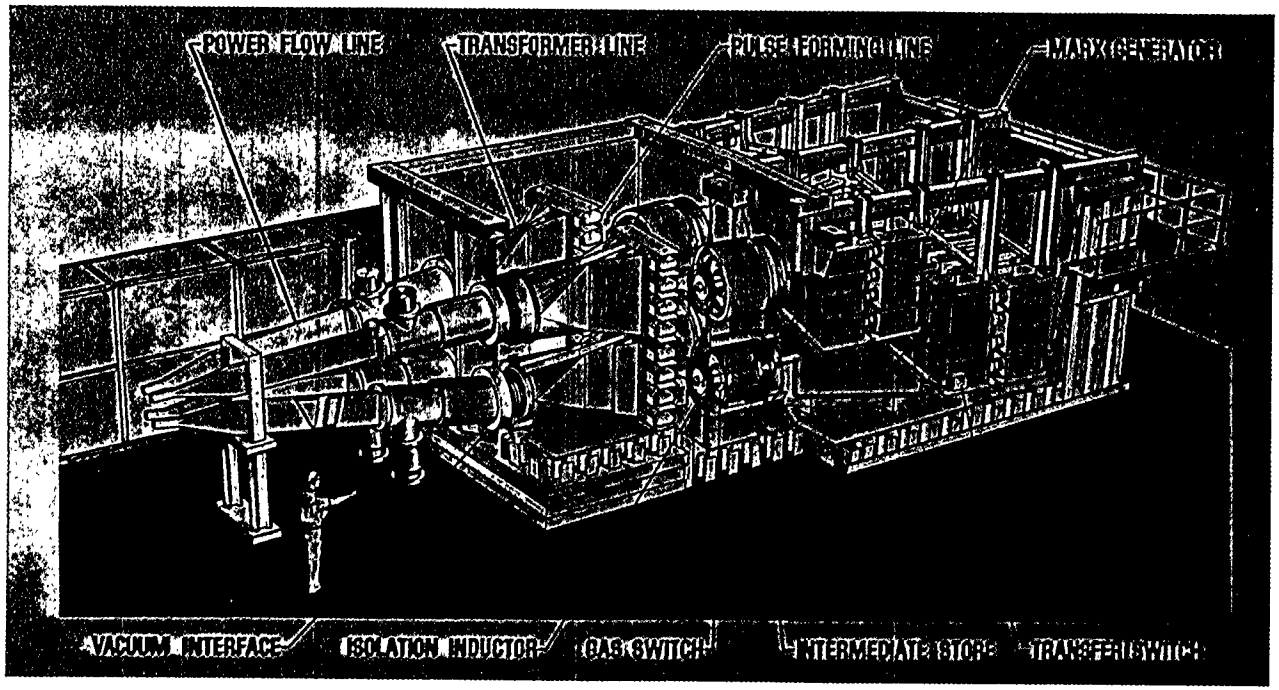
PBFA-I is our first accelerator to use a fully computerized control system. A distributed microprocessor system will be employed for accelerator support-system monitoring, timing and firing sequence control, and data acquisition.

PBFA-I Performance Characteristics

	Nominal Operating Parameters	
	One Module	*36 Modules*
Marx Generator		
Charging Voltage	95 kV	95 kV
Energy Stored	112 kJ	4 MJ
Diode		
Peak Diode Voltage	1.9 MV	1.9 MV
Peak Diode Current	0.45 MA	15 MA
Total Beam Energy	35 kJ	1.2 MJ
Particle-Beam Environment		
Transported-Beam Energy	30 kJ	1 MJ
Peak Beam Power	>0.8 TW	30 TW
Pulse Width (FWHM)	40 ns	40 ns



PBFA II POWER FLOW LINE (PRELIMINARY CONCEPT)



SUPERMITE

The SuperMITE Facility and PBFA-II

SuperMITE is a high-power, short-pulse accelerator designed and assembled in 1979-80 for research in fusion physics and pulsed-power technology. Initially this accelerator will perform the pulsed-power engineering and evaluation necessary to perfect a 4-MV, 1.4-TW module for PBFA-II. (The SuperMITE tank is designed as equivalent to a 20° sector of the main PBFA tank so that the final module will be directly transferable to PBFA-II.) Pulsed-power testing is being conducted in

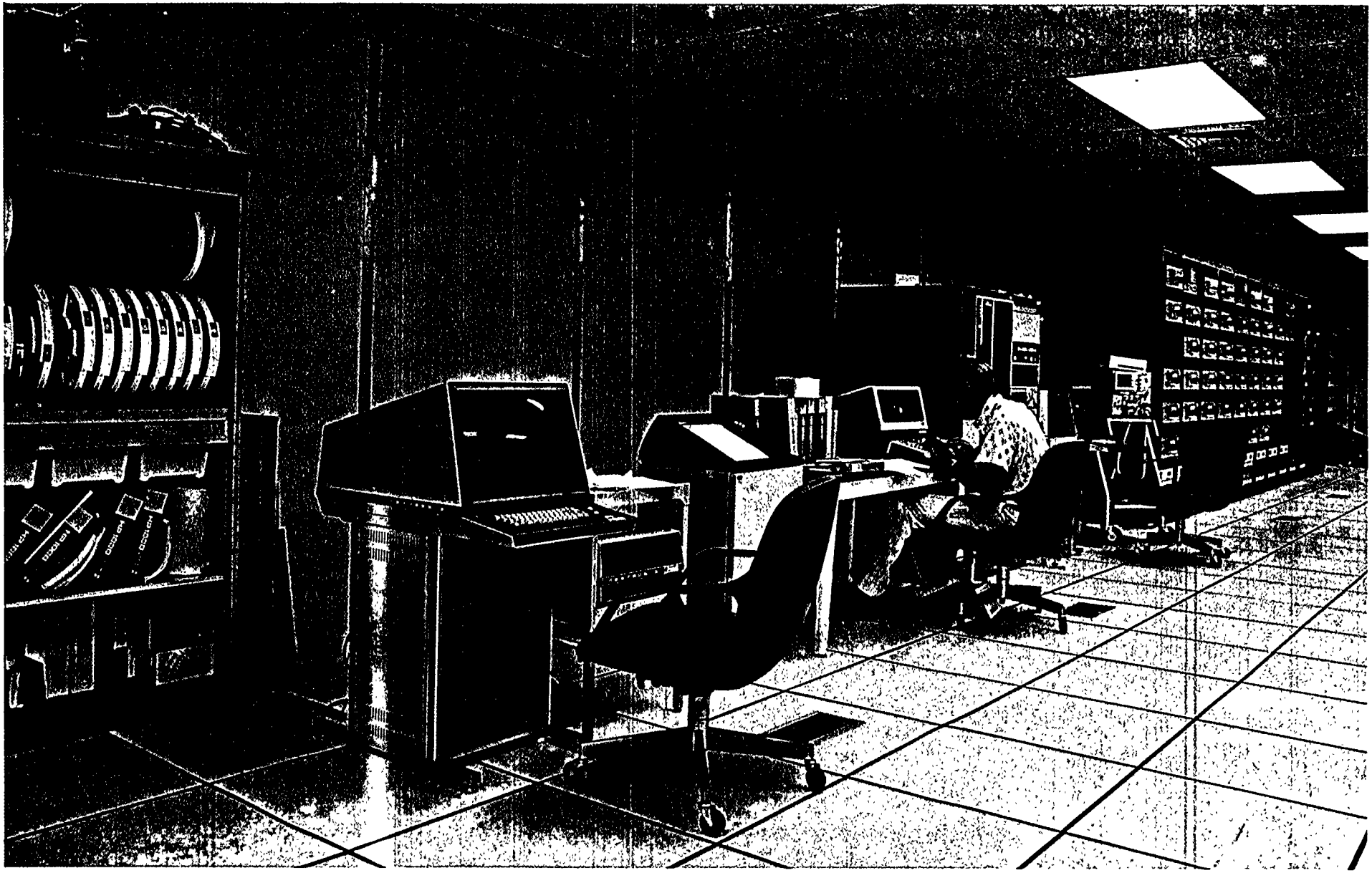
- Increased Marx energy storage
- 4-MV pulse-forming networks
- High-voltage gas switching
- Improved vacuum interface and electron injector designs
- High-power magnetically insulated transmission lines
- Advanced ion-diode designs

Four PBFA-II prototype modules will be installed and optimized in the second phase of SuperMITE. The objective is to produce a demonstration facility for studying design problems related to PBFA-II geometry in order to convert from PBFA-I to PBFA-II with optimum efficiency.

A third phase is to convert from PBFA-II prooftesting to an operational facility for experiments on electron- and ion-beam diode optimization, multiterawatt particle-beam focusing, beam propagation and overlap, and pellet irradiation.

SuperMITE/PBFA-II Performance Characteristics

	Nominal Operating Parameters		
	One Module	*Four Modules*	*72 Modules (PBFA-II)*
Marx Generator			
Charging Voltage	100 kV	100 kV	100 kV
Energy Stored	208 kJ	832 kJ	15 MJ
Diode			
Peak Diode Voltage	4 MV	4 MV	4 MV
Peak Diode Current	0.4 MA	1.6 MA	25 MA
Total Beam Energy	60 kJ	240 kJ	4 MJ
Particle-Beam Environment			
Transported-Beam Energy	50 kJ	200 kJ	~3.6 MJ
Peak Beam Power	1.4 TW	5.6 TW	100 TW
Pulse Width (FWHM)	35 ns	35 ns	35 ns



Fusion Data-Acquisition Facilities

The fusion data-acquisition facilities record electrical signals that diagnose pulsed-power aspects of the accelerators, voltage and current performance of the diode loads, and a wide variety of experimental diagnostic signals. The systems are made up of several parts: a computer with disk and tape drives for program storage and permanent data logging, CRT terminals for communication, and a series of high-speed transient digitizers and standard fast-sweep oscilloscopes.

Monitor signals from each accelerator are transmitted to a patch panel within a shielded screen room via semirigid coaxial cables. The signals are attenuated and connected through a computer-controlled switching matrix to the digitizers and oscilloscopes. After converting the high-frequency analog signals to digital form, the digitizers store them in a local memory. The computer then reads the digital data and performs the following manipulations: correction for vertical and horizontal nonlinearity, baseline subtraction, calibration for vertical sensitivity and horizontal sweep speed, signal cable frequency response and relative cable length, attenuation and monitor sensitivity factors.

Programs are available for extensive data analysis and comparison to theoretical predictions and previous experimental results. The entire acquisition and analysis activity can be routinely completed within 5 to 10 minutes after a shot.

Hydra-HydraMITE, Proto-I, and Proto-II activities are supported by a 32-data-channel facility. The photo shows the 44-channel system that supports PBFA and SuperMITE.

Appendix
PULSED-POWER HISTORICAL MILESTONES

Date	*Description*	*Facility/Devices*	*Specific Results*	*Significance*
1964	Atomic Weapons Research Establishment accelerator inception	SMOG (AWRE)	Initial operation of first pulsed-power accelerator at AWRE, ~3 MV, 50 kA	Start of pulsed-power technology transfer to Sandia.
1965	Accelerator operation	SPASTIC	First US pulsed-power accelerator operation, 3 MV, 50 kA	Collaboration with AWRE; Sandia commitment to pulse power.
1965	Formation of Sandia pulsed-power group	Area V	Pulsed-power division established to build simulation facility	Sandia commitment to large pulsed-power apparatus and research for simulation.
1966	Accelerator operation	Hermes-I	Oil-filled Blumlein accelerator operation at 3 MV, ~50 kA	Extendable technology for high-voltage accelerator and simulation facility.
1968	Accelerator operation	Hermes-II	Operation at 1.3 TW - 100 kJ output at 13 MV, 100 kA	Largest simulator accelerator available in the US.
1970	Accelerator operation	Nereus	350-kV, 100-kA, 2Ω output accelerator	Our first low-impedance, water-insulated line, solid dielectric-switched unit.
1972	Accelerator operation	Hydra	Modular - 1Ω, 1-MV, 1-MA, 50-kJ output	Pinching and fusion experiments started.
1972	Accelerator operation	Slim	400-kV, 0.7-MA, 70-ns output	Our first mylar-insulated, low-impedance accelerator with multiple beams. The beam pinch experiment led to the present fusion program.

Appendix

Date	*Description*	*Facility/Devices*	*Specific Results*	*Significance*
1974	Accelerator operation	Proto-I	2 MV, 500 kA, 1 TW, 20 ns	First double-sided multichannel switched accelerator specifically designed for fusion experiments. Also large-scale test of triggered and untriggered multichannel oil switch.
1976	Water switching test bed	Ripple	Researched present water pulse line technology	Provided untriggered multichannel water switching, staged switching for short-pulse, high-power output. Later the MFI and water convolutes were developed.
1977	Accelerator operation	Proto-II	8 TW, 1.5 MV, 6 MA, 20 ns, 100 kJ	Provided first multimodule water-insulated accelerator for fusion experiments.
1977	Start accelerator construction	PBFA-I	Place contracts for facility construction and initial procurement.	Initiate PBFA project.
1978	Test bed operation	RTF-I	First rep rate pulsed-power experiments	Provided 350-kV, 300-J/pulse to 100 pps (or 30 kW). First studies of entire rep rate system were done. 10^6 shot switch, 10^5 shot diode operation at 100 kA/cm^2.
1978	Test bed operation	MITE/MITL	Test of PBFA-I technology utilizing *M*agnetically *I*nsulated *T*ransmission *L*ine	Developed prepulse shields, convoluted lines, magnetic insulation, 208 kJ Marx, pulse inversion, dual polarity, power flow, and 90% efficient magnetically insulated power flow for 7 m at 10^{11} W/cm^2.
1979	First multiple-stage ion acceleration demonstration with pulsed-power drive	Pulselac	Magnetic insulation of multiple gaps and space charge-neutralized transport demonstrated	First experimental verification of new low cost means that may be extendable to generate intense ion beams at 100 MeV or more.

Cont.

Appendix

Date	*Description*	*Facility/Devices*	*Specific Results*	*Significance*
1979	Test bed - cavity design and beam stability studies	Radlac	9-MV, 25 kA, 12-ns operation	First modular multistage high-current accelerator with cavities employing radial transmission lines.
1979	Test bed - accelerator operation	HydraMITE	Full power test of PBFA-I module	Provided 0.8-TW, 2-MV, 400-kA, 35-ns pulse for PBFA-type experiments. Permitted the final design to be released for PBFA-I fabrication.
1979	Adoption of ion baseline approach for PBFA-I and II	MITE, HydraMITE	Pulse inversion and stacking demonstrated	Allow higher voltage modules with either polarity to be used in PBFA.
1979	Start construction PBFA-II module	SuperMITE	200-kJ Marx generator installed; tank completed	Will allow full-scale module testing of PBFA-II concepts. Will provide test bed for ion-beam experiment.

PROJECTIONS

Date	
1980	PBFA-I operation, SuperMITE operation
1984	PBFA-II operation
1986	ETF (Engineering Test Facility) conceptual design
1988-89	Initiate ETF construction
1991-92	Operate ETF
2000	Operate EPR (Experimental Power Reactor)

A Glossary of Acronymns and Terms

anode The electron-collecting electrode of an electron tube

atom the smallest particle of an element that still retains the characteristics of that element

AWRE Atomic Weapons Research Establishment

cathode the electron-emitting electrode of an electron tube

CRT cathode-ray tube

deuterium an isotope of hydrogen, represented by the symbol D. The deuterium atom consists of a central nucleus, which contains one proton and one neutron, plus an external (or orbital) electron

dielectric a nonconductor of direct electric current

diode a two-electrode electron tube with a cathode and an anode (an ion source)

DNA Defense Nuclear Agency

DOE US Department of Energy

electrode an electric conductor through which an electric current enters or leaves a medium; e.g., solid, plasma, or vacuum

electron a fundamental particle carrying a single negative electric charge

EPR Experimental Power Reactor

ETF Engineering Test Facility

fusion the union (or combination) of two nuclei of the lightest elements to form at least one heavier nucleus; the process is accompanied by the release of large amounts of energy

hydrogen the lightest element. The atoms of hydrogen consist of a nucleus and a single orbital electron. Three isotopes of hydrogen are known; their nuclei contain, respectively, one proton (hydrogen), one proton and one neutron (deuterium), and one proton and two neutrons (tritium)

ICF inertial-confinement fusion

ion an atom or group of atoms that carries an electric charge. Since a hydrogen atom, regardless of the isotope, contains a single electron, the loss of this electron leaves a positive ion that is also the nucleus

ionization the removal of an electron from a neutral atom, thereby creating a positive ion

isotopes forms of the same element in which the atomic nuclei contain the same number of protons but different numbers of neutrons

MFI magnetic flashover inhibition

neutron an uncharged elementary particle. All atomic nuclei, except the lightest isotope of hydrogen, contain one or more neutrons

nucleus the central region of an atom; it carries a positive charge equal to the number of protons present

PBF particle-beam fusion

Cont.

A Glossary of Acronymns and Terms

PBFA — particle-beam fusion accelerator

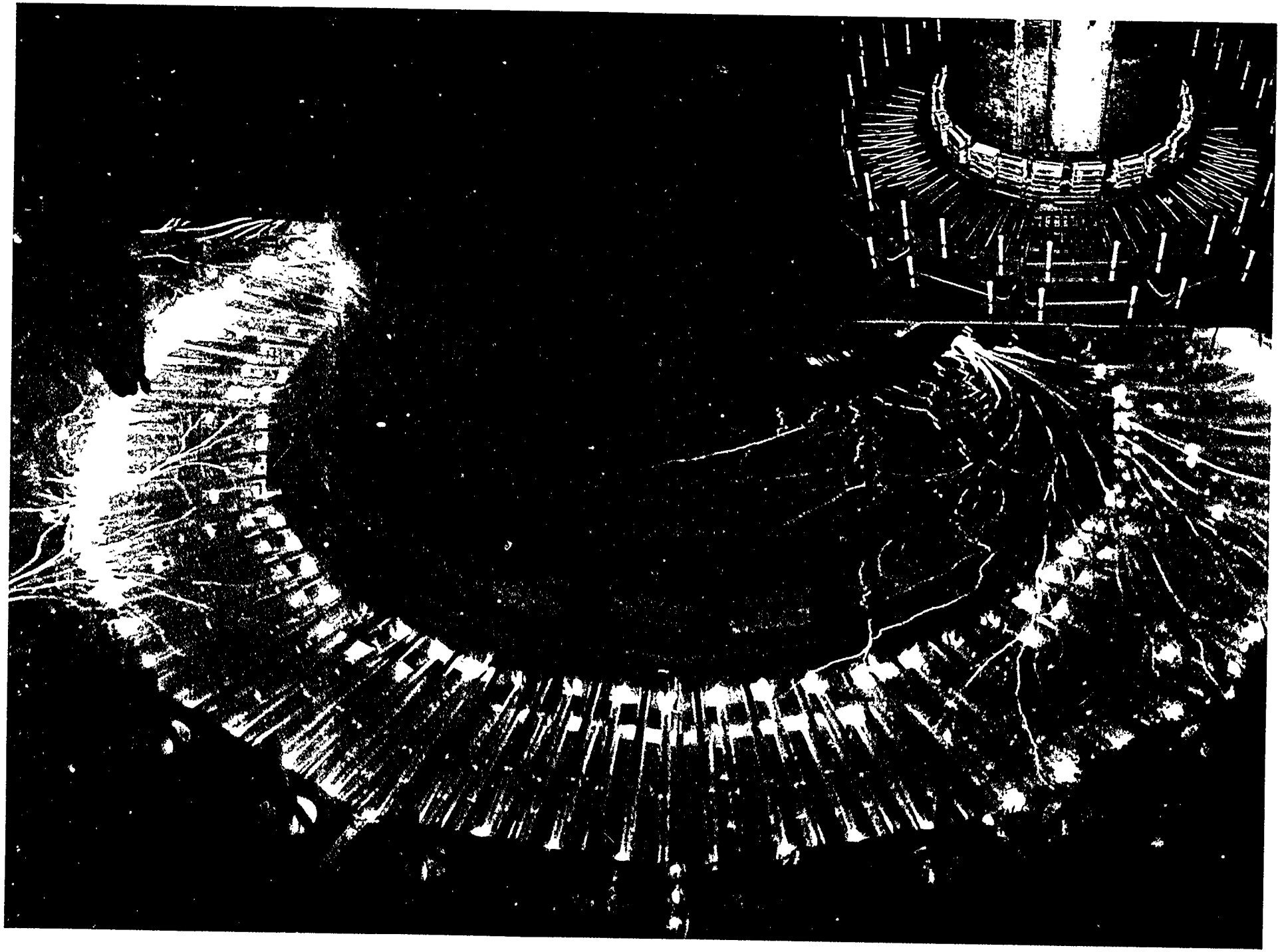
plasma — an ionized gas containing electrically equivalent numbers of positively charged ions and free negatively charged electrons

proton — a fundamental, positively charged particle. All atomic nuclei contain one or more protons

tritium — an isotope of hydrogen, represented by the symbol T. The tritium atom consists of a central nucleus, which contains one proton and two neutrons, plus an external orbital electron. Tritium differs from the other two isotopes of hydrogen in that it is radioactive.

BACK COVER

An experiment on Proto-II to test the operation of polarity-reversing hardware mounted in the water dielectric just outside the diode region. Arcs below the water form just after the power pulse (10-TW peak, 45-ns duration) and trap the energy inside the diode. The discharges on the surface of the water that look like lightning bolts are a consequence of high electric fields induced by the rapid power flow. (Inset shows actual hardware)



7/80 . 3000