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PBFA CONTROL AND MONITOR SYSTEM

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ABSTRACT

The Control/Monitor system, built by the Kirtland Operation of EG&G's Energy Measurements Group for Sandia Laboratories' Particle Beam Fusion Accelerator, will use a distributed-microprocessor system interfaced to a minicomputer. The major purpose for the microprocessors and minicomputers is to organize the operation of the accelerator into systematic, preplanned sequences that will maximize the scientific output of the facility.

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GLOSSARY

A/D	Analog to Digital
D/A	Digital to Analog
DMA	Direct Memory Access
EMP	Electromagnetic Pulse
IEEE	Institute of Electrical and Electronic Engineers
LED	Light Emitting Diodes
RAM	Random Access Memory
RFI	Radio Frequency Interference
ROM	Read Only Memory

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INTRODUCTION

What happens if you zap a tiny deuterium-tritium pellet with a 30 terawatt (30,000,000,000,000 watts), 35 nanosecond (35 billionths of a second) ion beam ? Sandia Laboratories, Albuquerque, thinks you'll get nuclear fusion, and they are building the Particle Beam Fusion Accelerator (PBFA) to prove it (Figure 1). The Kirtland Operations of EG&G's Energy Measurements Group has the responsibility for the design, development, and fabrication of the distributed-microprocessor system that controls and monitors the major PBFA subsystems.

PBFA will employ the Inertial Confinement Fusion (ICF) process. If the process can compress the deuterium-tritium pellet to one or two thousand times liquid density, heat it to about one hundred million degrees and hold it all together for a few nanoseconds, the deuterium-tritium should fuse together, producing helium, neutrons, and lots of energy. If we can figure out how to zap 1-10 pellets/second and harness the energy, we may be able to build a power plant and help solve the world's energy problems.

PBFA is one of several approaches to Inertial Confinement Fusion (ICF) that is being studied today. Laser fusion is another inertial confinement approach. Particle beams have a much higher efficiency than the existing laser beam systems: ≈30% efficiency for PBFA vs. ≈0.1% for glass laser systems. The higher efficiency will allow smaller, less expensive power plants.

PBFA was originally designed to produce a 2.0 megavolt, 15 megamp pulse of electrons, but current pellet research favors light ions. PBFA will have the capability to produce either electron or ion beams. PBFA will be upgraded in a second phase to produce a 100 terawatt beam.

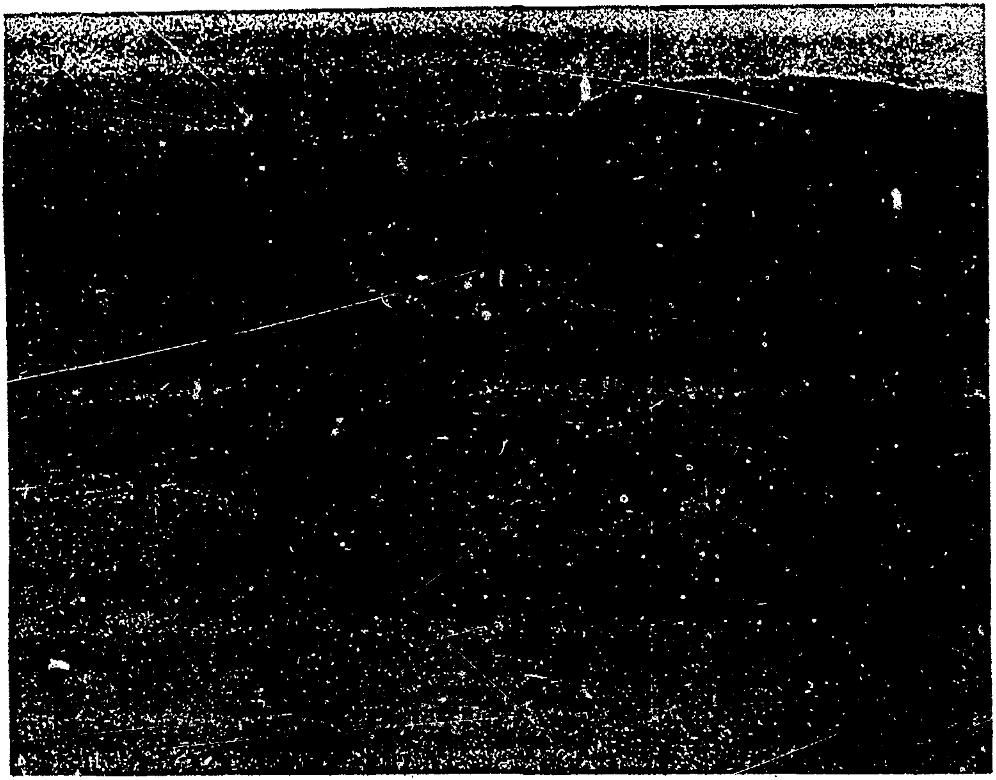

Figure 1. Aerial view of PBFA Facility.

Gerald Yonas, manager of fusion research at Sandia, has published an article* in Scientific American that describes Sandia's fusion programs in more detail.

Before describing EG&G's distributed-microprocessor, Control/Monitor system in detail, a functional description of PBFA is in order.

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*"Fusion Power with Particle Beams", Gerald Yonas, Scientific American November 1978.

PBFA OVERVIEW

The accelerator consists of 36 identical sections arranged in a radial geometry with the pellet in the center. Figure 2 shows a cutaway view of the accelerator, which will be contained in a circular tank structure consisting of three concentric tanks. The large octagonal pit under the tank will house some of the trigger systems and experimental equipment.

Each of the 36 accelerator sections consists of a Marx generator, an intermediate storage capacitor, a triggered gas switch, a pulse-forming section, a vacuum insulator, and a self magnetically insulated transmission line. A diagram of one accelerator is shown in Figure 3. The Marx generators (Figure 4) are simply high voltage pulse generators. Each Marx generator has 32 capacitors that are charged in parallel to 100 kilovolts and discharged in series to produce a 3.2 megavolt pulse. The 36 Marx generators are triggered by 9 Marx Pulser Units (MPU) which are triggered in turn by a smaller pulse generator.

The Marx generators have considerable inductance, making them relatively slow (700 nanosecond discharge). The intermediate storage capacitors (Figure 5) are used to shorten this time. The intermediate storage capacitors are dumped through the triggered gas switches into the pulse-forming lines (Figure 5), where multi-point, self-breaking, water switches shorten the pulse to about 35 nanoseconds. The output of each pulse-forming section is transmitted through the vacuum insulator to the center of the accelerator by a vacuum transmission line (Figure 6), also called a magnetically-insulated transmission line.

The outer portion of the PBFA tank (Figure 7) will hold about 300,000 gallons of transformer oil for the Marx generators. The middle portion of the tank will hold about 150,000 gallons of deionized water for the pulse-forming lines. The central portion of the tank will hold the experimental equipment, which is presently being designed.

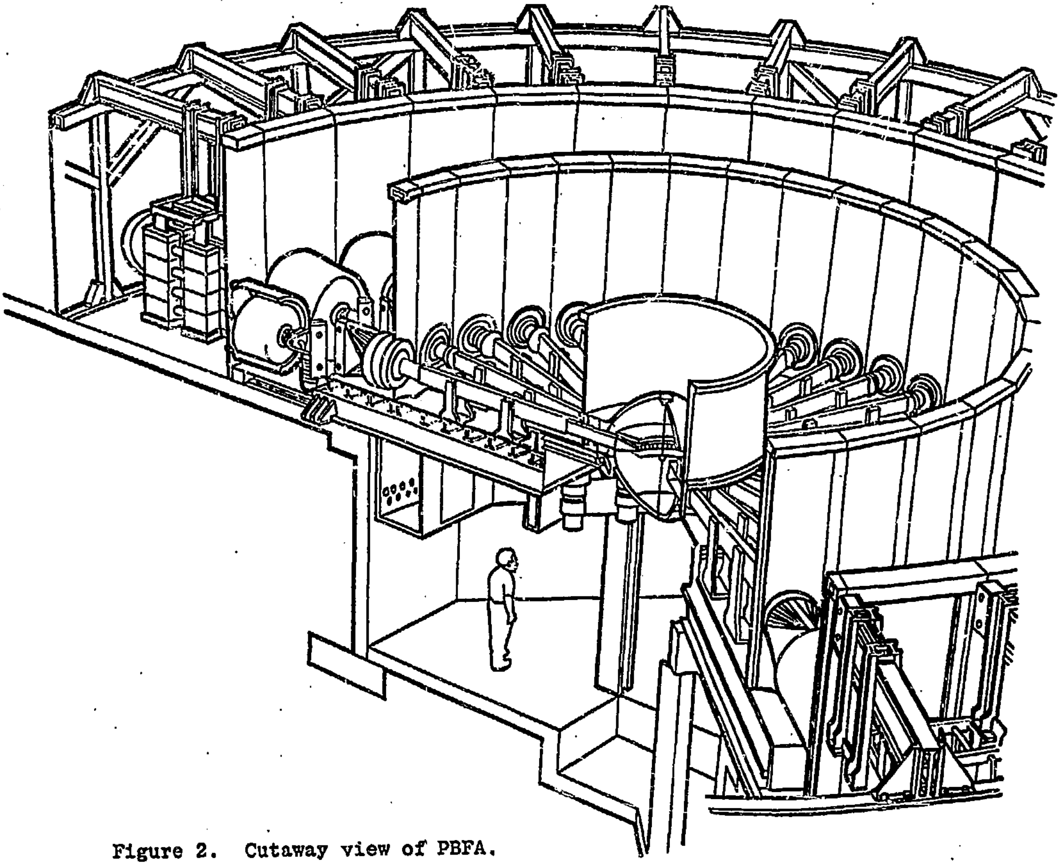

Figure 2. Cutaway view of PBFA.

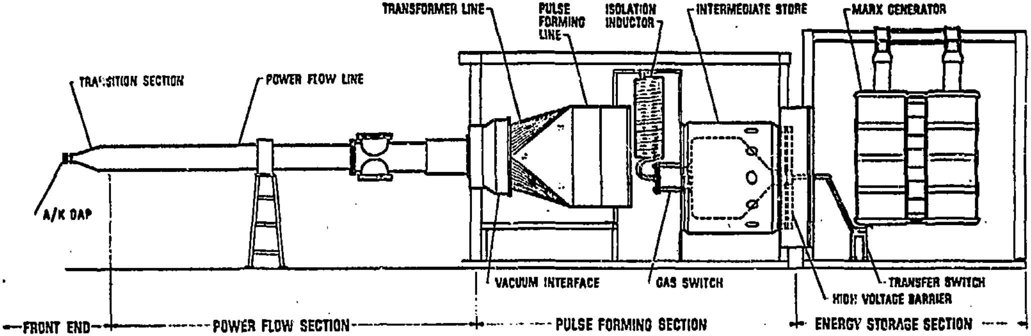

Figure 3. Cutaway view of one accelerator.

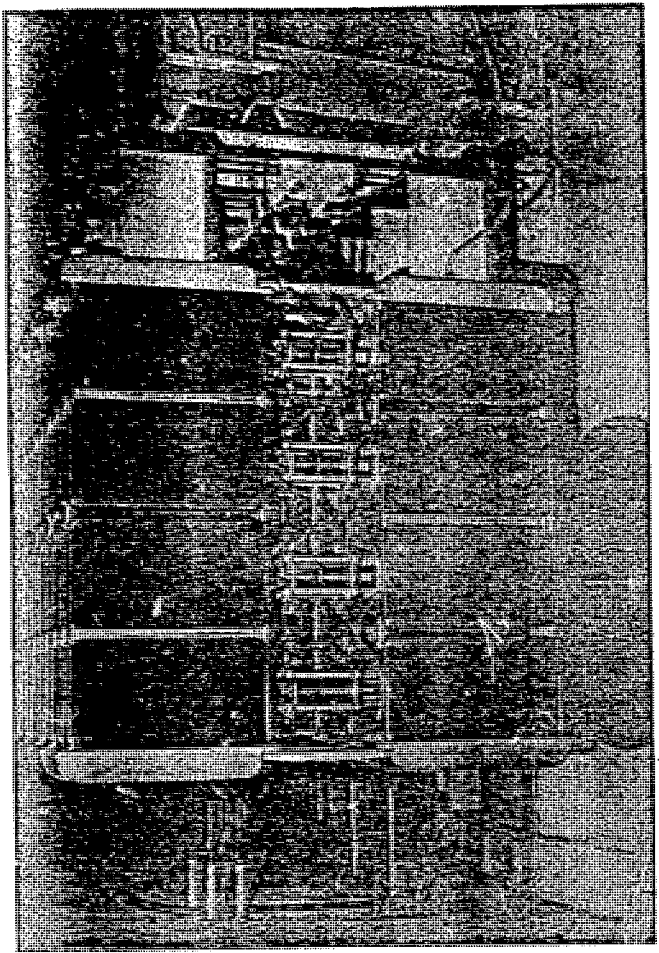

Figure 4. Marx Generator.

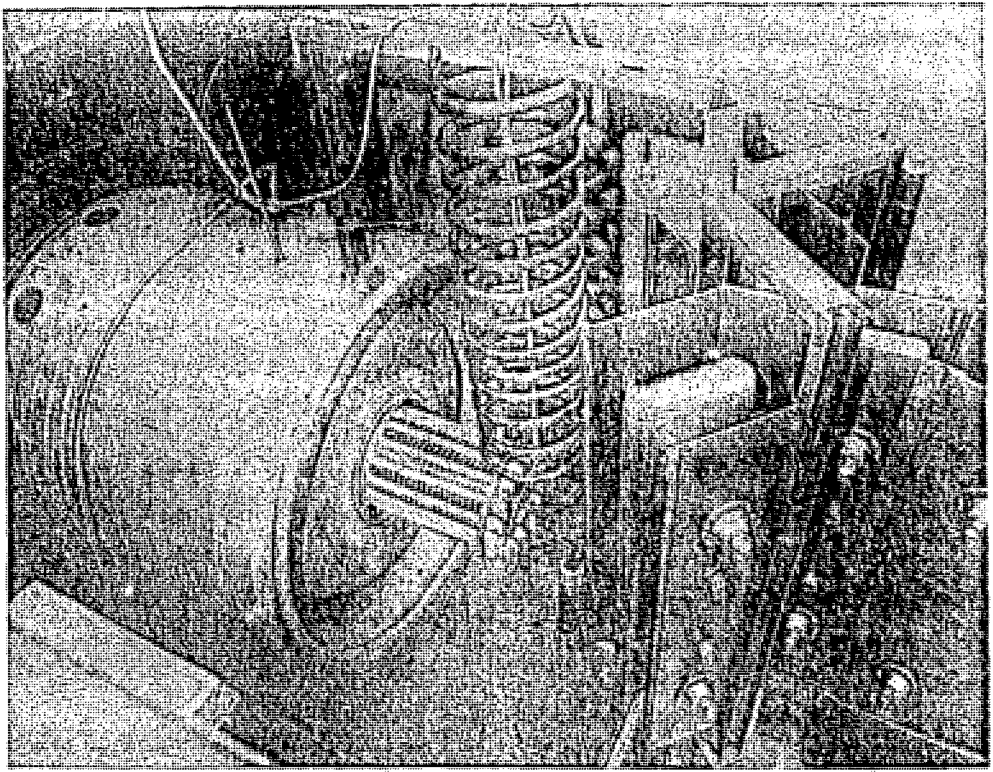

Figure 5. Storage capacitor, Trigatron switch, and pulse-forming line.

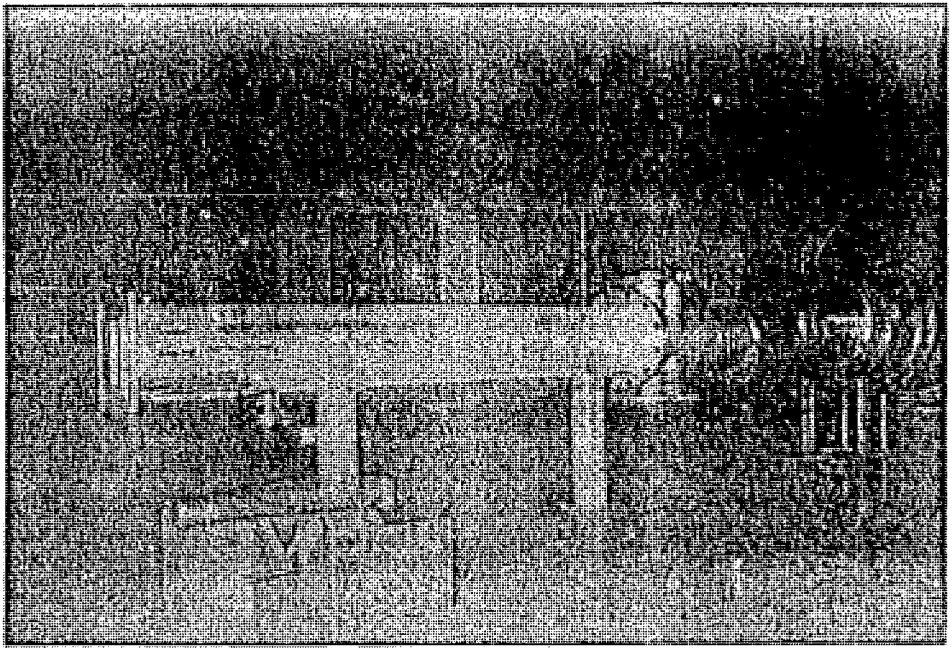

Figure 6. Vacuum transmission line.

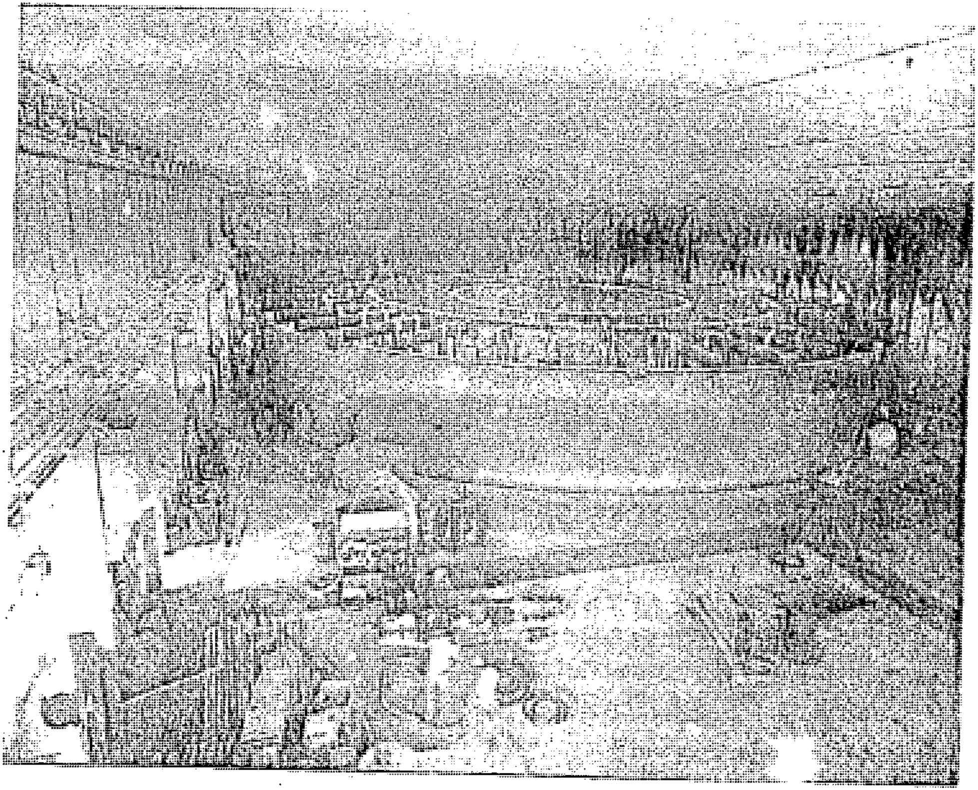

Figure 7. PBFA tank.

CONTROL/MONITOR SYSTEM

The PBFA Control/Monitor system (Figure 8) will utilize a distributed-microprocessor system interfaced to a minicomputer. The primary function of the distributed-microprossor system will be to guide the accelerator operator through the pre-shot preparations and the charging and firing sequence, giving him checklists and error messages at each step to ensure the accelerator is properly configured for the intended experiment.

The distributed-microprocessor system will also record operating data during the charging and firing sequence. The control system will be capable of charging and firing the accelerator remotely. This may be necessary if gamma ray and neutron radiation in the Control/Monitor room exceeds safe levels.

Control of the accelerator is quite simple, consisting mainly of energizing solenoids and relays, and monitoring switch closures and slowly varying analog signals. PROTO II, the prototype of PBFA, is operated completely manually. PBFA is more complex than PROTO II, but it could also be operated with simple manual controls. However, because of the high cost of construction and operation of the accelerator, it is important to obtain good data from each shot. It is expensive and frustrating to prepare a complex experiment and then lose the data because some detail of the charging and firing sequence was overlooked.

An extensive system of diagnostic cables has been installed under the accelerators to the data acquisition screen room where fast data will be recorded for experiment and accelerator diagnostics. The data acquisition cable system has about 900 individual, half-inch, foam-flex cables with the electrical lengths trimmed to within less than one-tenth of a nanosecond.

Each major PBFA subsystem will have a control panel in the Control/Monitor room. The Control/Monitor room is a screen room to protect the operator and electronic components from EMP, which the accelerator is expected to generate. All penetrations through the screen room wall will have transient suppression diodes and RFI filters.

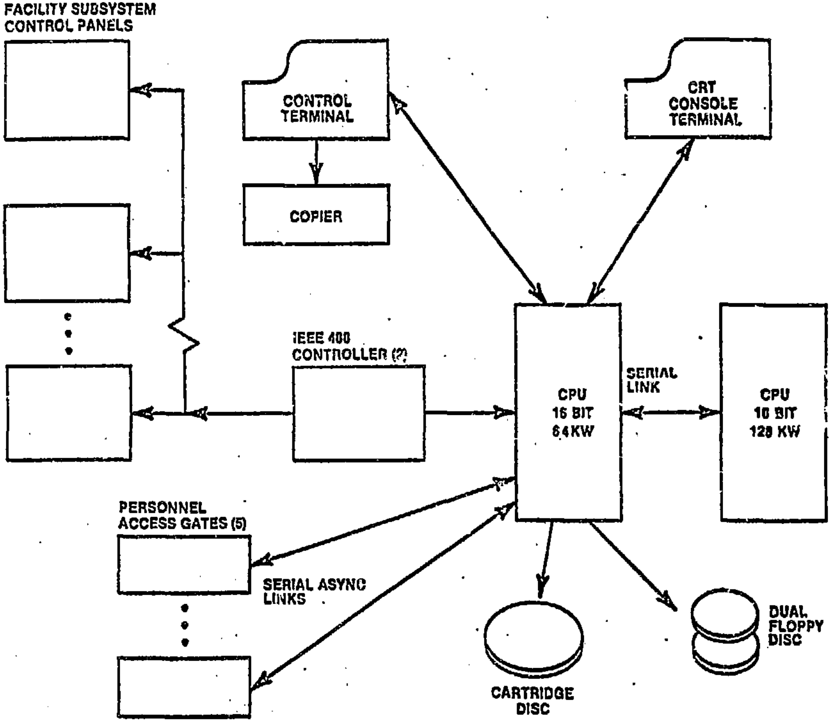

Figure 8. Control/Monitor System block diagram.

Sandia requested that the Control/Monitor system have manual control capability for all of the subsystems. The manual controls ensure that the accelerator can be restored to a safe condition in the event a minicomputer or microprocessors are damaged by EMP.

Sandia also requested that the Control/Monitor system be automated to provide the operators with status information and check-lists to guide them through the many detailed steps necessary to carry out a successful experiment. Finally, Sandia wanted the capability to complete the final steps of the charging and firing sequence from a remote location, if necessary, to provide additional personnel protection from radiation.

A distributed microprocessor system with a minicomputer for overall control was selected to meet these objectives. Figure 9 is a simplified block diagram of the Control/Monitor system. Each major subsystem will have manual control capability independent of the distributed microprocessor system. In some cases, such as the SF_6 system, there will not be manual control capability in the screen room but manual controls will be provided elsewhere in the facility.

The Control/Monitor system minicomputer shown in Figure 10 is an HP-1000 system with 64,000 words of memory, two hard-disc drives, and two floppy-disc drives. The hard-disc drives will be used for software management. The dual floppy disc will be used to record accelerator data for malfunction diagnosis and archival shot records.

The data acquisition system also has an HP-1000 computer which has more memory and more hard-disc storage. The data acquisition computer will be used to acquire and analyze shot data from 44 Tektronix 7912 transient digitizers. The two computers were procured on a bid basis from one computer manufacturer in order to have common software systems and a single maintenance contract.

The Control/Monitor system software will all be programmed in FORTRAN, the programming language most familiar to the accelerator users.

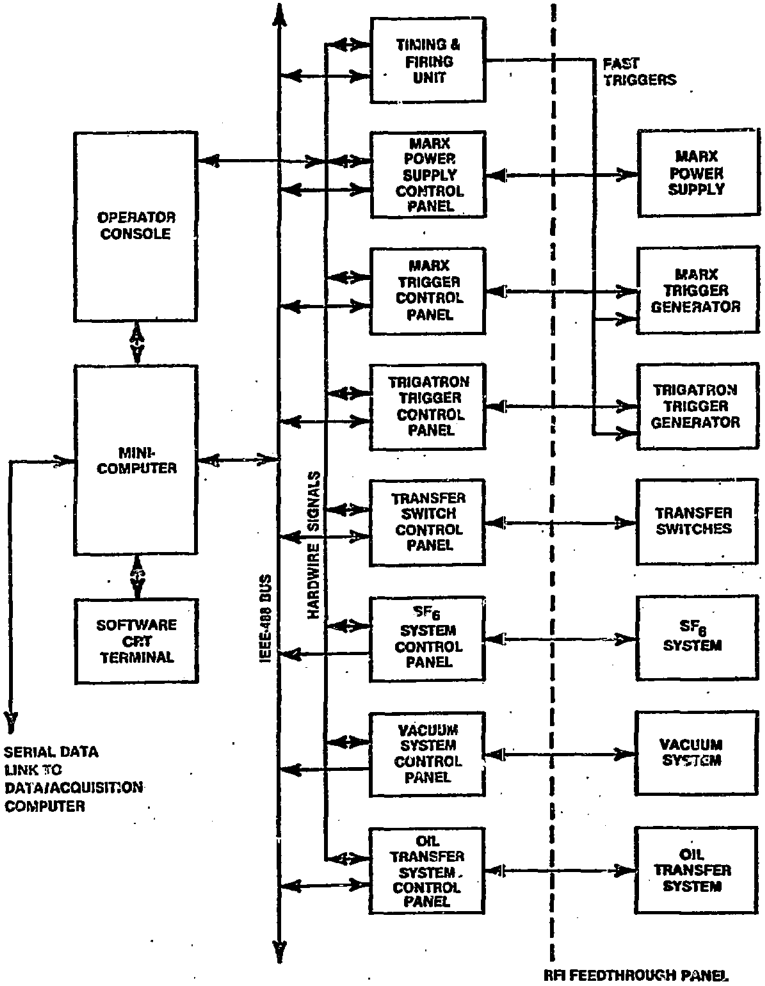

Figure 9. PBFA subsystem block diagram.

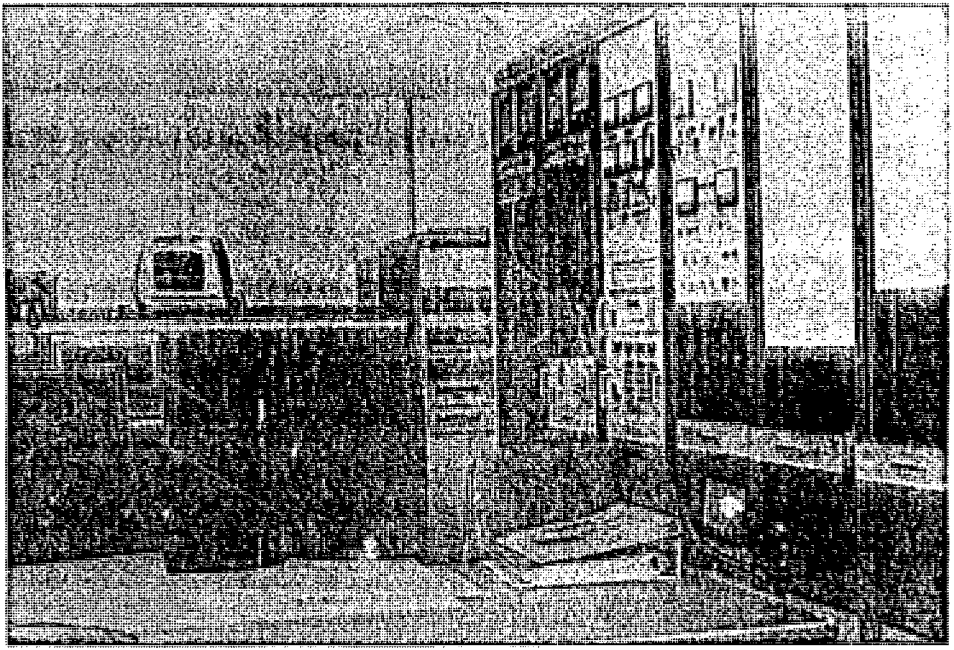

Figure 10. Control/Monitor room.

Each major subsystem will contain a microprocessor with an IEEE-488 interface to the minicomputer. The microprocessor will perform the control and monitor functions for the subsystems and transmit subsystem status to the minicomputer over the IEEE-488 bus when the minicomputer requests subsystem status. Each subsystem microprocessor will accept control commands from the minicomputer if the subsystem has been manually switched to the computer mode.

The Intel SBC 80 microprocessor card family was selected for the subsystems. This card family is supported by several second sources. A broad selection of RAM, ROM and I/O cards are available for it. Several manufacturers supply compatible A/D, D/A and IEEE-488 cards. The SBC 80 microprocessor bus has been designed to facilitate upgrading as new microprocessors are introduced. PBFA will use an 8-bit microprocessor, but the SBC 80 mother board has a 16-bit data bus so that the microprocessor can be upgraded to a 16-bit microprocessor simply by replacing the cards.

One special purpose card was designed for PBFA. This card has the IEEE-488 interface and a 256-byte RAM that can be transferred over the IEEE-488 bus by DMA with a data rate of about 100 kilobytes per second. Most of the PBFA subsystems can be operated with the Intel SBC 80-10 CPU card which has 1k of RAM and 4k of ROM. This card does not support DMA with its onboard RAM. Without DMA capability, the data rate on the IEEE-488 bus would be too slow for PBFA, and a special-purpose card was designed to overcome this limitation.

The IEEE-488 bus was selected for the PBFA Control/Monitor system because it is reasonably fast and well standardized. A large number of manufacturers supply test equipment and other devices for the bus. The data acquisition system also uses the IEEE-488 bus to interface with the Tektronix 7912 digitizers.

Most of the subsystems' control panels will have hardware connections to the timing and firing unit, which will control the final 10 seconds of the firing sequence. The timing and firing unit will be started when all subsystems are ready to fire and the Marx generators and trigger systems are charged. The timing and firing unit will automatically arm the transfer switches, close the vacuum valves, apply EMP protection to the ion gages, disconnect the trigger system power supplies, etc.

Most of the major subsystems will also have hardware connections to the operator console. A master control panel at the operator console will have switches to select the accelerator mode, an abort button, an emergency fire button, and various safety override switches. All safety interlocks and protective circuits will be hardwired through the master control panel.

Each PEFA subsystem is unique, but the SF_6 system is fairly typical. A detailed description of it will illustrate the application of the microprocessor systems. The major components of the SF_6 system are shown in Figure 11.

SF_6 (Sulfur Hexafluoride) is a high-voltage insulating gas that is used in the Marx generator swithces and in the trigatron switches. The Marx switches use SF_6 at ≈30 psi; trigatron switches use SF_6 at ≈150 psi. These pressures will vary with the Marx-charging voltage and must be regulated and stabilized to the correct pressure before each shot. When the accelerator is idle, the SF_6 pressure is reduced to a standby pressure which is set high enough to prevent oil or water from leaking into the switches.

The SF_6 gas must be kept pure and free of dust that could cause prefires. After each shot, the Marx switches and the trigatron switches must be purged with fresh gas to remove SF_6 decomposition products and switch debris. The gas is quite expensive, so it is recycled through a reclaimer during the purge sequence and returned to a gas reservoir. The reclaimer does not have sufficient capacity to purge the Marx and trigatron switches simultaneously.

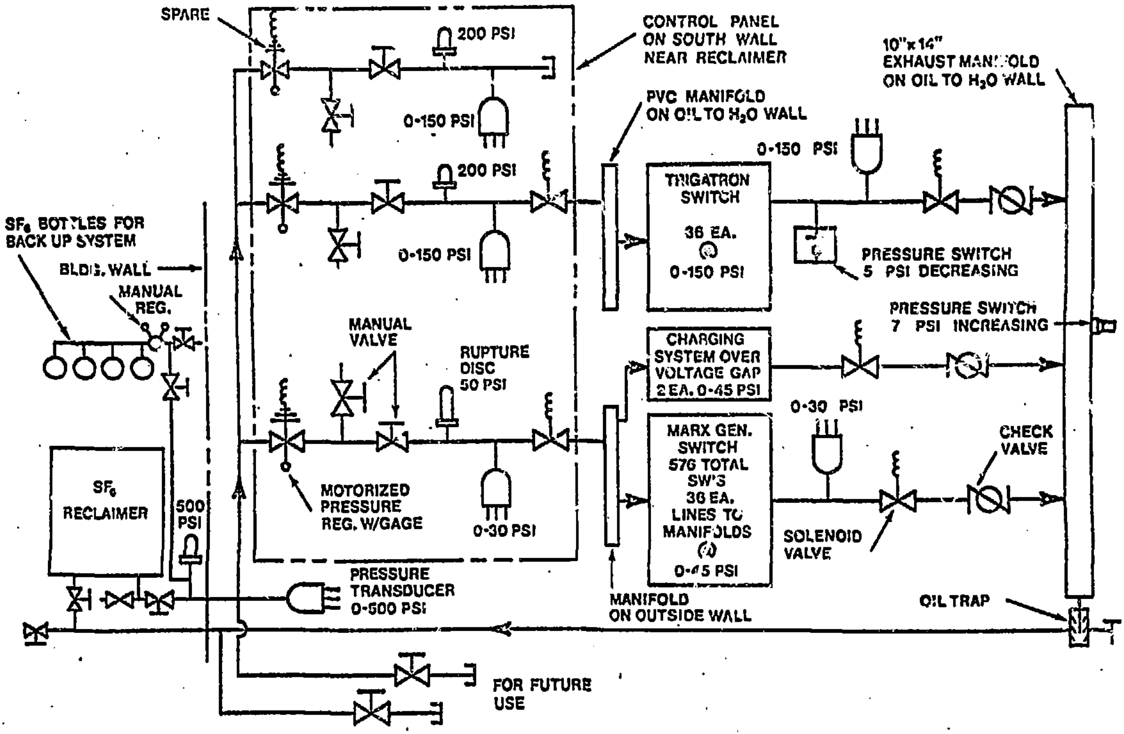

Figure 11. SF_6 system major components.

The Marx switches are purged by opening solenoid valves to the reclaimer, thereby allowing fresh gas to flow through the switches. Marx switches will be purged for about one minute.

The trigatron switches have a single gas inlet/outlet port and are purged by first closing solenoid valves to the supply and then opening solenoid valves to the reclaimer. The gas in the switches is allowed to flow to the reclaimer until the gas pressure has dropped to about 7 psi. The trigatron can then be repressureized for the next shot, or repressurized to the holding pressure. The trigatron purge sequence will take about a minute.

Manual controls will be provided for purging the SF_6 swithces. The manual system will also be interfaced with the microprocessor, which will be programmed to perform the pressurizing and purging sequences automatically.

The microprocessor will also transmit the status of the SF_6 system to the minicomputer. The operator will be able to check the status of the SF_6 system from a computer CRT terminal at the operator's console. At shot time, the mocroprocessor will record all pertinent SF_6 data for transmission to the minicomputer, which will enter the data into the floppy-disc shot record. The SF_6 control panel will be interconnected with the operator console and timing and firing unit. If the accelerator is already charged when an SF_6 malfunction occurs, the shot will be inhibited and the operator will be advised of the cause of the malfunction at the control console CRT terminal. The the must then decide what to do. Some of his options would be to override the inhibiting signal and proceed to shoot, shoot the Marx into dummy loads, discharge the Marx through grounding relays, force the Marx to self-break by reducing the SF_6 pressure, etc.

The only critical fast-timing signals generated by the Control/Monitor system are the two trigger signals that trigger the Marx generators and the trigatron switches. The first trigger fires the Marx generator. The second, which occurs about 700 nanoseconds later, fires the trigatron switches when the intermediate storage capacitors Marx generators have reached full voltage.

Four general-purpose trigger pulses will be provided for experiments. They will be adjustable in 10-nanosecond increments to occur ±5 milliseconds from shot time.

SUMMARY

A lot more can happen in 35 nanoseconds than first imagined. A 30 terawatt beam focused on a deuterium-tritium pellet will produce significant research information on fusion, particularly in the area of fusion-produced commercial energy.

PBFA's Control/Monitor system, designed, developed, and fabricated by the Kirtland Operation of EG&G's Energy Measurements Group, will use a distributed-microprocessor system interfaced to a minicomputer. The functions of the microprocessors are to transmit subsystem status to the minicomputer, receive commands from the minicomputer, and to automate subsystem functions, thus relieving the operator of time-consuming and tedious chores.

The function of the minicomputer is to monitor the status of all subsystems, and determine if each subsystem status is correct. If not, it will send commands to the subsystems to correct the condition or transmit alarms and error messages to the operator. The minicomputer will also generate archival shot records.

Eventually for safety reasons, it may become necessary to fire the PBFA remotely; the Control/Monitor system will have the capability for remote charging and firing of the accelerator.

The Control/Monitor system and all PBFA subsystems will be completed and ready to fire in the summer of 1980.