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SAFETY ASSESSMENT DOCUMENT (SAD) FOR THE PRINCETON BETA EXPERIMENT MODIFICATION (PBX-M)

By

J.R. Stencel
R.F. Parsells
(Editors)

APRIL 1988

PLASMA PHYSICS LABORATORY

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Safety Assessment Document (SAD) for the Princeton Beta Experiment Modification (PBX-M)

Princeton Plasma Physics Laboratory
Princeton, NJ 08544

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(Editors)

SAFETY ASSESSMENT DOCUMENT

PRINCETON BETA EXPERIMENT MODIFICATION

PBX-M

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ISSUE DATE: NOVEMBER 1987 Revision 0

PBX-M SAFETY ASSESSMENT DOCUMENT

13.0 APPENDIX D

Review Committee Assessment and Project Response

1.0 INTRODUCTION AND GENERAL DESCRIPTION (K.Bol)

1.1 Introduction

The Princeton Beta Experiment-Modification (PBX-M) is an experimental device of the tokamak type. A tokamak is characterized by a strong toroidal magnetic field composed of an externally driven component parallel to the torus centerline modified by the field produced by a transformer-driven current (OH) in the confined plasma. A second magnetic field parallel to the major toroidal axis is added to provide radial equilibrium for the plasma. As an advanced tokamak, PBX-M will have additional magnetic fields to reshape the plasma cross section from a circle into a kidney bean shape; it will also be equipped with 6MW or more of auxiliary heating power provided by four neutral beam injectors, with RF systems, and with an extensive set of diagnostics. Potential hazards associated with PBX-M, which are analyzed in this report, result from energy stored in the magnetic fields, high voltages necessary for the operation of some of the equipment and diagnostics, neutron radiation when the neutral beams are run with deuterium and x-rays, especially those emitted as a result of plasma-wall interaction. This report satisfies the requirements set forth in the PPPL Health and Safety Directives, specifically HSD-5003, and in DOE Order 5481.1B and its Chicago operations supplement (DOE86, DOE82).

1.2 Scope of Modification

PBX-M is a modification of PBX, which in turn was a modification of the Poloidal Divertor Experiment (PDX). A Safety Assessment Document for PBX was issued February 9, 1984. The PDX to PBX modification, in terms of device operation, involved minimal changes. Controls, interlocks, power supplies, radiation and electrical hazards all remained the same.

The current modification is much more extensive. It entails a totally new control system, the addition of six new power supplies, a new polarity-reversing panel, five new coils inside the vacuum vessel, extensive new bus work both inside and outside the vacuum vessel, and considerable revision of the personnel-protective interlock system. However, much remains the same. The basic machine and the Toroidal Field (TF) and Ohmic Heating (OH) coil systems are unchanged. For the Equilibrium Field (EF) only a minor relocation of a coil pair was made plus the addition of a set of existing coils (CF-10). The TF and EF power sources are untouched; but the operating mode of the Ohmic Heating Supply (OHS) will be somewhat changed. These three are the highest power system; the biggest new supply, the Indentation Field Supply (IFS), has about 20% the MVA rating of the smallest of the old, the EF.

Two other machine changes have a major impact on the physics but virtually none on the safety aspect. These are (1) an increase in plasma major radius from 145 to 165 cm, and (2) the addition of a set of aluminum plates shaped to form a conducting shell that hugs the plasma over most of its surface. Inspection of Figure 1-1 indicates the changes from PBX to PBX-M.

1.3 Goals and Objectives

The ultimate goal of the PBX/PBX-M program is to achieve by the use of highly shaped plasmas much higher values of beta, the ratio of plasma to magnetic field pressure, than are achievable in standard tokamaks. The PBX-M design is a refinement of PBX; it will rely on the conducting shell to stabilize the mode which was found to be most limiting of beta in PBX. The larger major radius of PBX-M allows for a more deeply indented plasma and provides room for divertor chambers near the bean lobes. The additional power supplies and highly articulated coil system will allow the degree of control over the plasma shape that the close fitting conducting shell necessitates. The initial objectives of the PBX-M program will be the verification of these design goals.

1.4 Participants in PBX-M Design, Construction, and Operation

The primary participants in the design, development, construction, installation, and operation of PBX-M are the U.S. Department of Energy (DOE) and the Plasma Physics Laboratory of Princeton University (PPPL).

a. DOE within its Office of Fusion Energy has the responsibility for the development of the fusion power program.

b. PPPL has the responsibility for overall planning, scoping, and monitoring within the guidelines provided by DOE Directives. Ultimate responsibility for the operation rests with PPPL. This includes the operational and environmental health and safety of the operating personnel and the general public. The relationship of PPPL (Princeton University) and DOE is governed by U.S. DOE Contract DE-AC02-76-CHO-3073.

1.5 Summary of Significant Items

Design, development, manufacture, fabrication, construction, installation, tests, operation, maintenance, and subsequent modifications are and will be accomplished in accordance with safety provisions of the DOE Environmental Safety and Health (ES&H) Orders and the generally applicable environmental guidelines of the Environmental Protection Agency (EPA). In particular, the applicable criteria for routine and accidental occupational exposure to radiation are in accord with DOE 5480.1A, Chapter XI (DOE81) requirements. Applicable sections of the DOE orders have been interpreted and established as design requirements on detailed site-related characteristics. Buildings, facilities, and systems have been designed and built to assure safe operation.

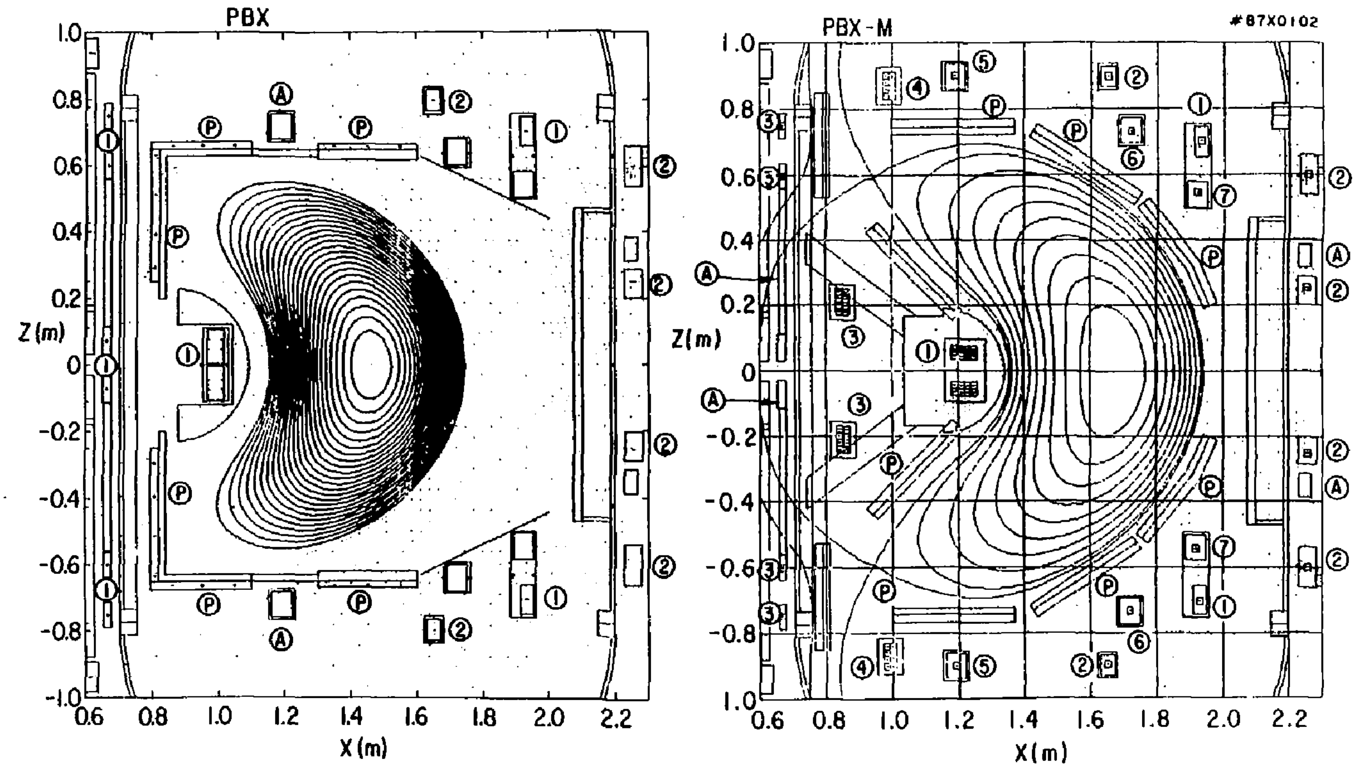

PBX
PBX-M
#87X0102
Z (m)
X (m)
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2

Figure 1-1

A summary tabulation of the principal hazards evaluated and the safety provisions incorporated is presented in Table 1-1.

Table 1-1

HAZARD EVALUATION AND DESIGN PROVISIONS

Consideration	Provision
Hydrogen	Installation per established safety codes. Air/H_2 mixture concentrations safe for all failure modes.
High Voltage	Interlocks, locks, fences, ground provisions, insulation, marking, controls. All interlocks identified in operations procedure and verified prior to facility operation, tested periodically.
Radiation	X-rays and neutrons are potential radiation problems; safety office issues authorization for safe operation. Health Physics monitors, surveys, and issues radiation work permits as needed. Continued monitoring as experiment progresses.
Coils and Mechanical Equipment	Design margins adequate for stress and deflections. Detailed calculations performed.
Fire Enclosure	Device is within a building protected by automatic halon system. Building materials and construction are in accordance with fire codes.
Power Supplies	Installed per fire protection codes and N.E.C.

2.0 SUMMARY SAFETY ANALYSIS (J.R. Stencel)

2.1 Hazards

The operation of this experiment will not generate effluents of any kind which might contribute to the pollution of air or water. Any hazards that accidents may cause are localized, contained, and controlled within the confines of the protective envelope that surrounds the PBX-M device and its electrical connections to external power sources.

Specific hazards analyzed were:

A. Materials

1. Toxic or carcinogenic materials are not, in general, employed in this operation. PCBs are still present in some capacitors and transformers.

2. Fire and explosion hazards

   Hydrogen/deuterium is used to fuel the tokamak, a palladium leak serves to purify the gas. The flow into the machine is limited to about 200 torr-liter/second by piezo electric valves which is about 1/4 liter per second at S.T.P. In practice this rate is never maintained for more than a second.

   Everything evacuated from the vacuum vessel by pump is exhausted outside the building. The gas itself is commercial grade and is delivered in 5000 liter S.T.P. bottles at 1750 psi pressure. Since the test cell volume is over 350,000 cu. ft., release of a full bottle would result in an average volume concentration of 0.05%, far below the lower explosive mixture limit of 4% (assuming full mixing).

B. Electrical Hazards

Large power supplies dominate the operation of the device. Their installation and interlock protection meets all PPPL requirements of HSD 5008, section 2 (HSD2a, HSD2b).

C. Mechanical Hazards

Full use of a finite element code to analyze the PBX-M vacuum vessel for mechanical stress and to support the design of new coil supports guarantees safe operation under even the worst case electromechanical and gravitational loads.

Rotating equipment and heavy objects are potential sources of mechanical hazards to personnel.

1. Vacuum pumps - Conventional mechanical vacuum pumps and turbomolecular vacuum pumps are used.

2. Heavy Objects - The risks associated with handling heavy objects will be minimized by following the procedures outlined in the PPPL HSD 5008, Health and Safety Manual (Section 9.8). The Laboratory has a Lift Committee to review other than ordinary lifts.

3. Pressurized Systems - Pressurized systems which present hazards due to the possible creation of projectiles are the following: air receivers, the gas delivery system, and the fire protection systems (Halon 1301).

These systems have been installed as standard acceptable risk systems. The probability of failure is considered to be low and acceptable.

4. Miscellaneous - Portable and non-portable power-driven tools such as electric drills and band saws, will be sources of hazard to personnel because of the possibility of improper use of defective equipment.

D. Radiation Hazards

1. Ionizing

Radiation from PBX-M is expected to be limited to X-radiation (bremsstrahlung) and neutrons, with minimal activation. Monitoring for radiation levels will take a conservative approach as is customary at the start-up of all new devices at PPPL. Thermoluminescent dosimeters (TLD) will be placed on the vessel and the surrounding area to indicate potential exposure dose levels and patterns. Real time high sensitivity monitors are in place in areas requiring occupancy during initial operations. When new operating parameters are introduced, appropriate surrounding occupied areas will be evacuated until adequate radiation data are collected.

Authorization for operation of new operating parameters of PBX-M will not be granted until Health Physics certifies that there is no radiation hazard.

2. Non-Ionizing

The PBX-M will use some lasers for diagnostics. These devices are regulated by HSD 5008, Section 3 (HSD3). Personnel operating these lasers come under the medical surveillance articles of HSD 5008, which follows ANSI Z136.1-1986 (ANSI 86). Because these lasers are interlocked during operations, the potential hazards are related to individuals involved in standard alignment and calibration procedures. These individuals according to Laboratory policy must be knowledgeable in the use of lasers, and, where deemed appropriate, they will take part in laser training programs.

2.2 Fire Safety

A. Combustible Materials

The Hazards Analysis of the PBX-M Project identified the following combustible materials.

1. Hydrogen

This gas, needed to fuel the discharge, is only used in leak-tight, metal systems.

2. Plastic conduits

Plastic conduit is used in limited amounts where electrical noise reduction is required. Plastic conduit is installed in open areas to increase the probability that any fire would be detected quickly by the fire detection system.

3. Insulating oil

There are no oil-filled capacitors in the machine area, but capacitor banks are used in connection with the OH system, some RF systems which will be attached to PBX-M, and with both the diagnostic neutral beam and the heating beams. These have all been in existence for at least seven years (some for much longer) and were constructed in accordance with the best practice of the time. It is laboratory policy in accordance with EPA policy to replace obsolete banks with PCB-free material but to allow continued use of existing PCB type capacitors. There is a total of five gallons of oil in the MG filter capacitors which are located in an enclosure in the MG area. A metal strip was installed around the perimeter of the enclosure to contain any oil that spills, and a smoke detector that is tied into the PPPL fire alarm system was also installed.

4. Wood

Fire retardant treated wood covered with a fire retardant paint and fire retardant treated masonite is the principal construction material of the platform. There is adequate fire protection in this area.

5. Other Materials

The most significant quantities of combustible materials are the insulation on cables and bus bars.

6. Contributory Causes

The Accident Analysis identified the contributory causes for starting fire to be primarily electrical faults. Historically the most dangerous fault is failure of a high current bus joint, with consequent formation of an arc and ignition of fires by blobs of molten metal as well as by the arc itself of nearby insulation. Regular checking of all high current joints, especially where aluminum is used, is the only preventive.

B. Fire Detection Systems

The control room and experimental areas both have ionization smoke detection. In additior, the experimental area has flame detection.

C. Fire Suppression Systems

Both the control room and the experimental area are protected by a Halon 1301 total flooding system.

2.3 Property Damage

Fire damage is the principal property damage risk. Fire alarm boxes and annunciator alarms are connected through the fire alarm system to the fire and security offices, which are manned at all times. A trained Emergency Services Unit (ESU) will respond to alarms with backup support provided by Plainsboro Township.

2.4 Explosion and High Pressure Safety

A. Capacitor Explosion - Indoor capacitor banks are surrounded by expanded metal mesh or by solid walls to help contain any explosion. Circuit protection is installed to prevent excessive energy dissipation inside a capacitor thereby reducing the probability of a violent event.

B. High Pressure Airline. - A compressed airline enters the area. Pipes are conservatively designed and installation recessed to minimize damaging effects. A protective device cuts off the air on sudden drop in pressure.

C. High Pressure Waterline. - Cooling water is part of the area facilities. Conservative design and sudden pressure drop protection minimizes the damage.

D. Pressurized Gas Bottles. - Working gases for PBX-M experiments are contained in standard pressurized gas cylinders. Explosion hazard is minimized by the conservative design of the bottles, by secure anchoring of the bottles, and by keeping the absolute minimum of bottles in the area.

2.5 Natural Phenomena

2.5.1 Earthquakes

The area is in a low probability earthquake region. All equipment is designed to "most probable" earthquake standards.

2.5.2 Tornados, Extreme Wind

The building was built over 20 years ago. No adverse effect was evident during the most violent winds during this period.

2.5.3 Floods

The area is not in a floodplain and there have not been any floods in its 20 years existence.

2.6 Noise

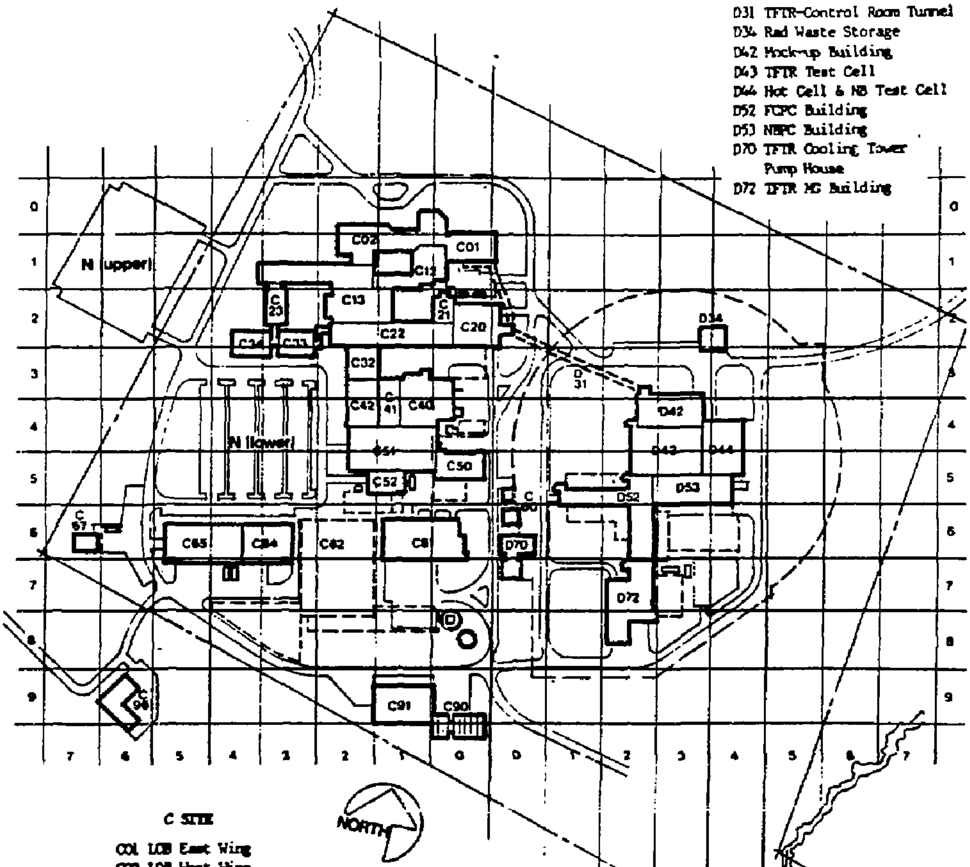
There are no significant noise sources associated with the PBX-M device or its equipment.

3.0 SITE

3. Location

The experimental area for the PBX-M is the high bay area in the CS Building (Fig. 3-1), C-Site James Forrestal Campus, of the Princeton University Plasma Physics Laboratory.

C & D SITES



D SITE

- D31 TFTR-Control Room Tunnel
- D34 Rad Waste Storage
- D42 Mock-up Building
- D43 TFTR Test Cell
- D44 Hot Cell & NB Test Cell
- D52 FCPC Building
- D53 NBPC Building
- D70 TFTR Cooling Tower Pump House
- D72 TFTR MG Building

C SITE

- C01 LOB East Wing
- C02 LOB West Wing
- C12 Cafeteria/Admin Wing
- C13 Administration Building - GPCC/Library
- C20 Tech Shop
- C21 L Wing Addition
- C22 Laboratory Building
- C23 Theory Wing
- C32 Shop Building
- C33 Module I
- C34 Module II
- C40 RF Building
- C41 CS Building
- C42 COB Building
- C50 Systems Test Building (Exper. Pwr./ESAT)
- C51 MG Building
- C52 FLT Power Building
- C60 Cooling Tower Pump House
- C61 Maintenance Building
- C62 Switchyard
- C64 Receiving #3
- C65 Receiving #4
- C67 EV Building (Firehouse)
- C90 Mobile Trailers
- C91 CAS Building
- C96 Annex

Parking lots referred to as lettered

Figure 3-1

4.0 FACILITY AND PROCESS DESCRIPTION

4.1 Experimental Area (S. Hand)

PBX-M experimental area is located in the northwest corner of the C-Stellarator (CS) building (Figures 4.1-1 and 4.1-2). It consists of three adjacent but separate areas: the machine area, two control rooms, and two general purpose rooms.

The machine area is defined by a 32" thick radiation shielding wall extending approximately 75' from columns 2K to 3K and from this column line, for approximately 52' toward the south. The wall extends from the first floor (elevation 98'-6") to elevation 121'-0" (Figures 4.1-3 and 4.1-4). Access to the machine is at two levels: the first floor and the platform (elevation 104"-6"). The machine supports are at the first floor level as well as the 16" deionized cooling water mains, power buses, T.F. coil hydraulic system, safety breaks and various ancillary components. The main access to the machine is at the platform level, where most of the diagnostics are located. A third level, the balcony, is at elevation 117'-4 3/4" and extends from the north, west, and south radiation walls approximately 5'. More diagnostic components are located on this level. The mac..ine area at the platform level is accessible to the 5 ton and 30 ton rail cranes. In addition to the high current DC power, there is 110/220/480 VAC power available in the machine area.

The main operation-control room is located adjacent to the west radiation wall and extends westward 30 feet. It extends approximately 40 feet in the north, south direction. The floor is at elevation 111'-2". The neutral beam control room is located adjacent to the north radiation wall and extends northward 12 feet. It extends approximately 71 feet in the east, west direction. The floor is at elevation 112'-4". Both control rooms have 110V electrical service.

The two general purpose rooms are located under the operations control room at the first floor level. One room (C103) is used as a light assembly and technician ready-room, and the other (C104) is used for a diagnostic laser.

The experimental area is fire protected by a central Halon system. Nozzles are located at various levels starting at the first floor and extending to the high bay. In addition, hand-held fire extinguishers are strategically placed throughout the area.

All machine area access doors are interlocked and have kick-out panels. During machine operation the area is monitored by closed circuit TV.

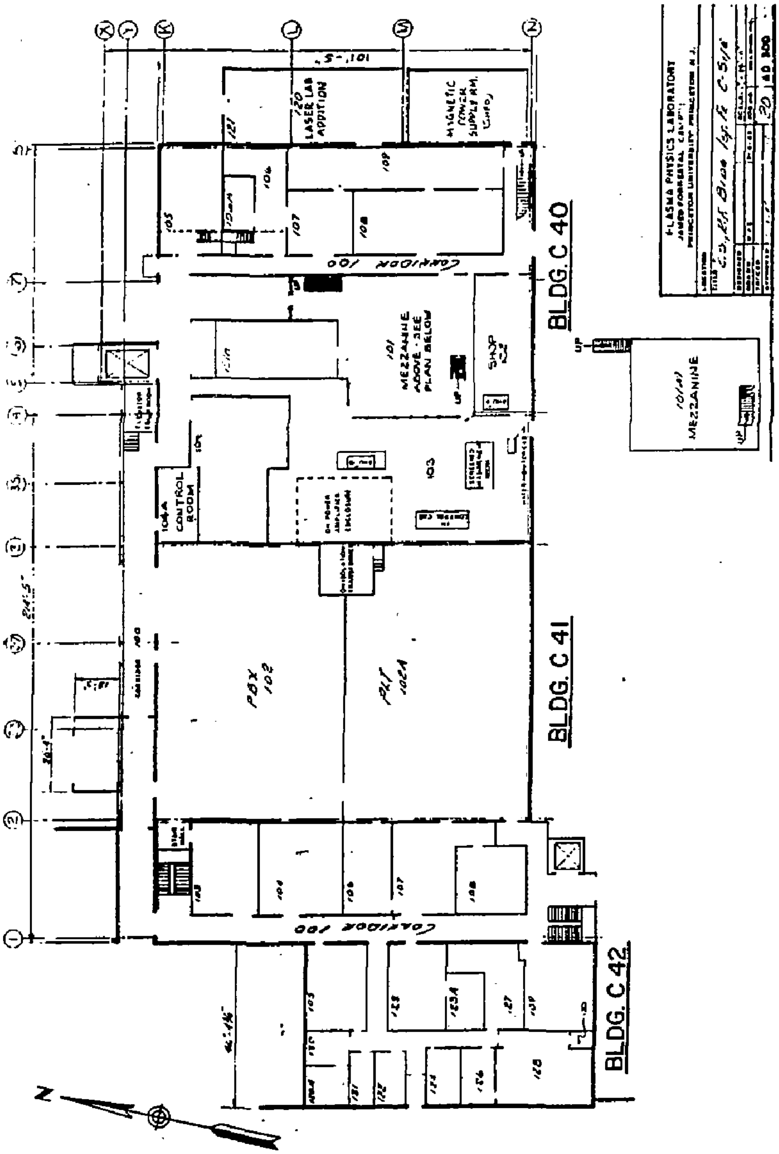


Figure 4.1-1

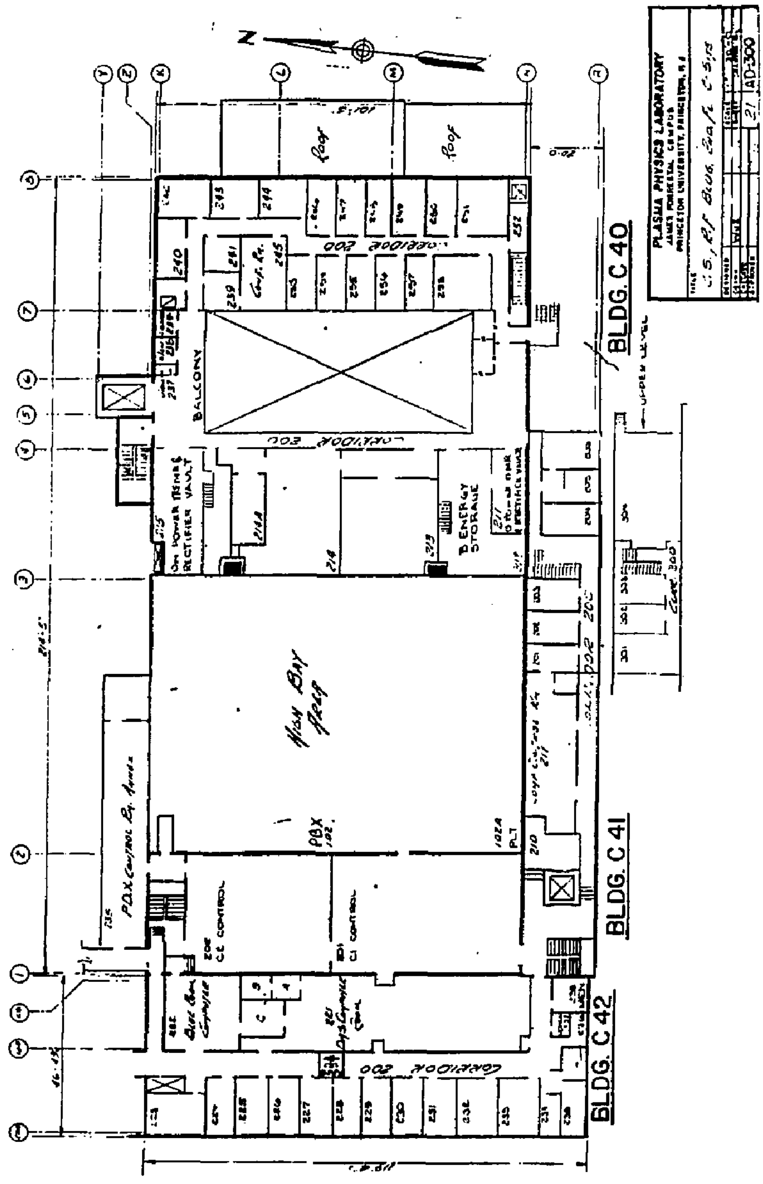
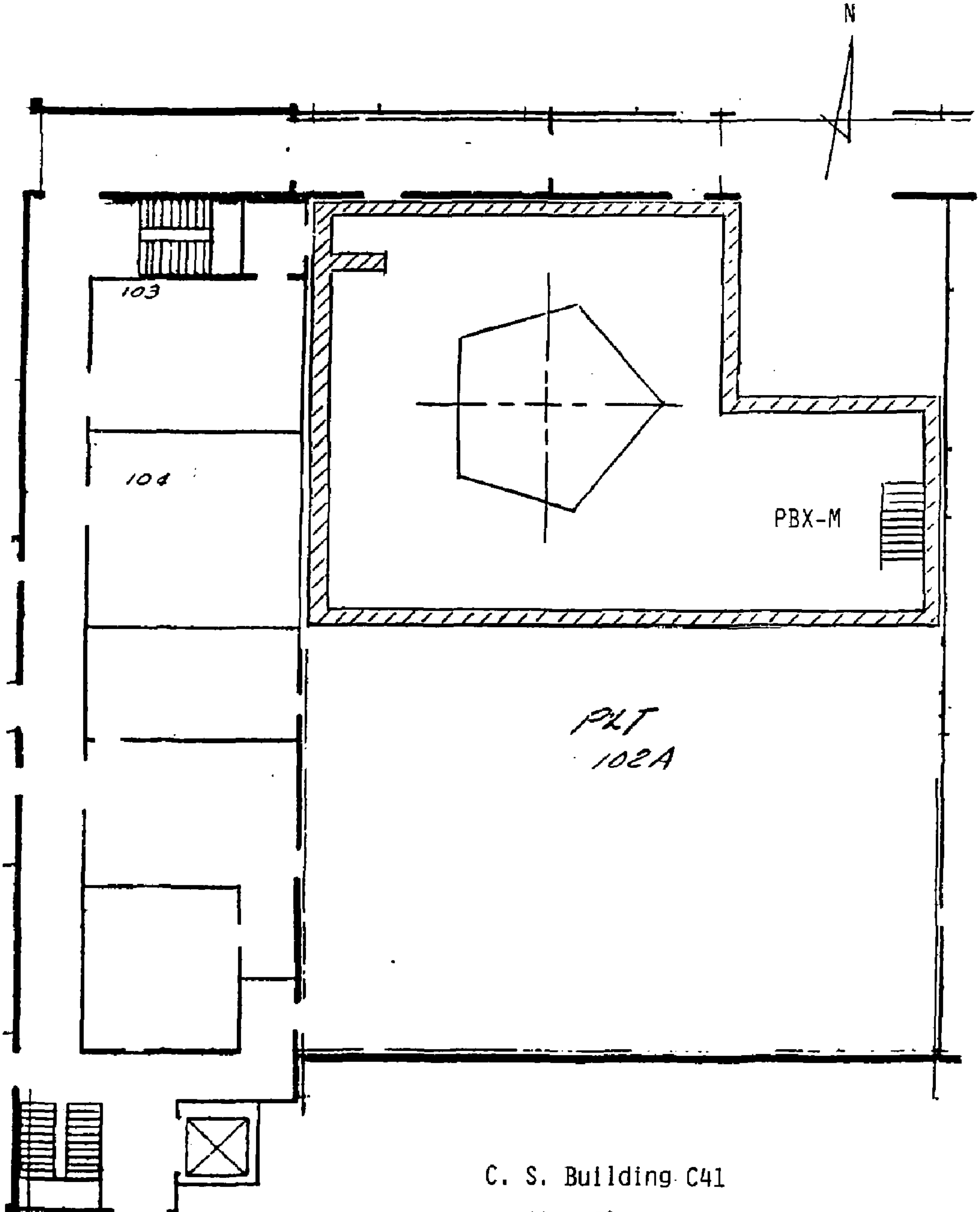
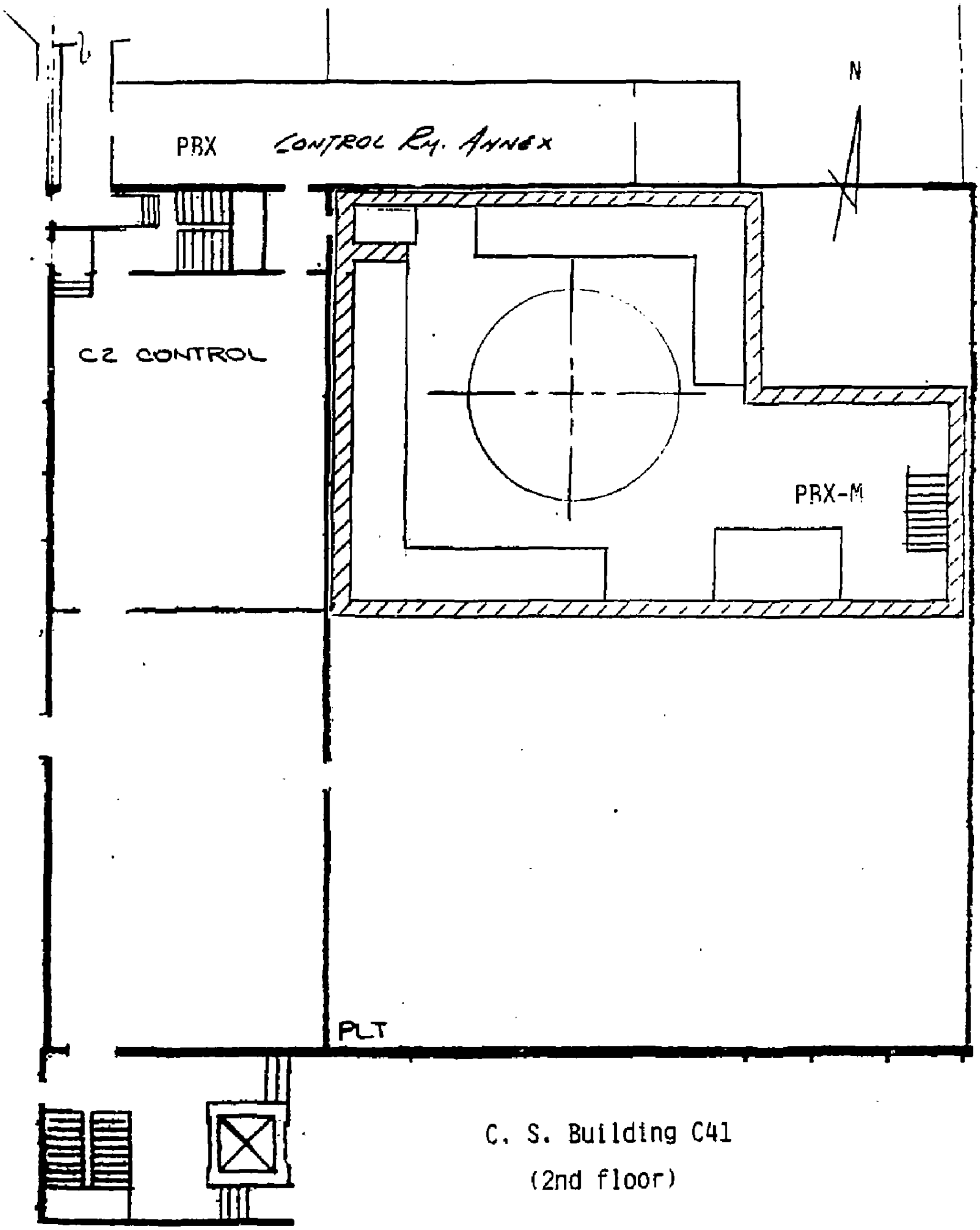

PLASMA PHYSICS LABORATORY
BLDG. C 40
BLDG. C 41
BLDG. C 42
BALCONY
HIGH BAY AREA
PBX
ENERGY STORAGE
CORRIDOR 200
AD-300

Figure 4.1-2



C. S. Building C41
(1st floor)

Figure 4.1-3



C. S. Building C41
(2nd floor)

Figure 4.1-4

4.2 Power Supplies (D. Ashcroft)

4.2.1 PBX-M Electrical Power Systems

This section presents a safety assessment of the electrical power systems to be used on the PBX-M machine. The equipment covered herein includes the OH Coil Power Supply, the EF Coil Power Supply, the TF Coil Power Supply, the Radial Field Coil Power Supply, the shaping Field Coil(s) Power Supplies, and the AC Power Distribution System.

4.2.1.1 OH Coil Power Supply

The power supply that will be used to power the PBX-M OH coil is the same power supply that has been in operation for the past 10 years, initially to supply power to the PLT OH coils and subsequently to the PDX and PBX OH coils. The performance of this equipment with respect to both equipment safety and personnel safety has been demonstrated during many years of successful operation.

The design of the equipment and the associated safety features are commensurate with that expected in a research facility and at the power levels used. The equipment meets the requirements of PPPL Health and Safety Directives (HSD 2a, HSD 2b).

Safety features associated with this equipment include the following:

A. All high power equipment is completely guarded by sturdy wire mesh fencing to a height of eight feet. This fencing is well separated from all operating equipment and all gates are locked with serialized Kirk key locks.

B. All local control and monitoring equipment is located outside the perimeter of the safety fencing. All controls and monitoring equipment which interface with high energy or high voltage sources are isolated by either two independent insulating gaps or optically isolated electronics.

C. All equipment located outside the perimeter of the safety fencing containing 480 VAC or higher has its conductors shielded by protective barriers which must be mechanically unfastened using tools in order to be accessed, or the cabinet is fitted with a Kirk key lock. Such shielded compartments are labelled with high voltage warning signs.

D. Capacitor banks are provided with Kirk key interlocked shorting and grounding switches, mechanically operated from a safe location isolated from the capacitor banks. These capacitor banks are located outside the rectifier building and are completely surrounded by safety fencing. This fenced-in area cannot be entered without a key released at the switch when in the safe grounded position. In addition, this capacitor area may not be entered without a second key (a padlock key) obtainable only from cognizant operations personnel and released only to listed personnel who are qualified by training to have access to the area.

E. All equipment enclosures (high and low voltage) are solidly grounded to building ground.

F. The safe control areas are limited access areas, meaning that card keys having authorized magnetic code are required for entry.

G. Fire extinguishers suitable for electrical type fires are strategically located throughout the area. The rectifier room is protected by an automatic sprinkler system which is connected to operate the emergency stop in the event of water flow. The room also has a smoke detection system.

H. Whenever a high voltage area is entered, even though it is safe, there must be at least two qualified persons present so as to have a safety watch in sight at all times in the event of an emergency. (See also K below.)

I. An electromechanical fast acting heavy duty crowbar assembly is located at the output of the power supply. Upon sensing a power supply or system fault, the crowbar is activated. Additionally, power supply firing pulses are blocked, commutating bank energy is discharged, and the power supply output is shorted, thereby dissipating energy in the load. The power supply AC breaker will be tripped if current remains higher than the predetermined trip set point.

J. Lower voltage (less than 208 VAC, 125 VDC) control and monitor wiring are not intermixed with high voltage wiring.

K. In the event that high voltage areas must be entered for inspection, service or maintenance, a safety procedure must be followed. This procedure includes the following sequential steps:

(1) Notification of on-duty cognizant operating personnel that the area is going to be entered.

(2) Orderly and safe shutdown of equipment.

(3) Orderly and safe shutdown of incoming power.

(4) Obtaining of Kirk keys and padlock keys from operating consoles and personnel required to unlock the appropriate area.

(5) Initiate the use of "yellow tags" by personnel entering the high voltage area. These tags will be securely attached to protective devices (e.g., a racked out circuit breaker) and removed only by these same people after they have left the high voltage area. (This procedure complies with Section 2 of HSD-5008.)

(6) Upon entering the high voltage area all energy storage devices (e.g., capacitors) are shorted and grounded using appropriate grounding sticks, and personnel protective equipment (insulating gloves, goggles) following a rehearsed (written) procedure.

(7) Visual "hands off" inspection of the area is made to establish the safe status of equipment prior to any work being done.

(8) Only authorized trained personnel are permitted within high voltage areas.

The modification made to the OH power supply for PBX-M consists almost entirely of changes in power circuit electrical configuration. None of the foregoing statements is changed by this reconfiguration. The modification has been subject to Conceptual, Preliminary, and Final Design Reviews, in which the Project and Operational Safety Office specifically, and other reviewers in general, have assured that the requirements of codes, standards, and regulations have been met. The equipment will be operated in PBX-M within electrical ratings and other operating constraints established by years of experience in using the same components in PLT, PDX, and PBX.

4.2.1.2 EF Coil Power Supply

The power supply that will be used to power the PBX-M EF coils is the same power supply that has been in operation for PLT/PDX/PBX. The performance of this equipment with respect to both equipment safety and personnel safety has been demonstrated during many years of successful operation.

This equipment was purchased, installed, and tested at the same time as the OH Coil Power Supply and is located in the same general area. Because of its location and functional similarity to the OH equipment, the same safety assessment comments apply as made above for the OH equipment.

Several years ago, during the operation of PDX, the EF supply was upgraded to provide a higher intrinsic current capability (15kA). It is this upgrade EF rectifier that will be used to supply the PBX-M EF. Since the supply will not be required to operate beyond 10kA for PBX-M, and since it has demonstrated this capability in PBX use, one may conclude that it comprises equipment which has an established safety record.

4.2.1.3 TF Coil Power Supply

The power supply that will be used to power the PBX-M TF coils is the same power supply that has been in operation for the past 23 years for all machines at C-Site, initially for the C Stellarator and more recently for PBX. The safety features of this equipment have been demonstrated over this time.

This power supply comprises eight large dc generators plus associated rotating generator field exciters, drive motors, liquid rheostats for motor control, power buswork, disconnect switches, circuit breakers, control transfer switches, control circuits, and control and monitoring consoles.

Safety features associated with this equipment include the following:

A. The generators, exiters, drive motors, rheostats, circuit breakers, and control transfer switches are all totally enclosed such that covers must be unbolted or doors unlocked to gain access to hazardous circuits.

B. Buswork and disconnect switches are completely guarded by sturdy wire mesh fencing to a height of eight feet. All gates to this fenced-in area are locked with serialized Kirk key locks. Furthermore, the disconnect switches located within this fenced-in area are enclosed by plexiglass covers and the disconnect switches themselves are keyed with Kirk key locks.

C. Control and monitoring circuits are located in separate cabinets whose doors are locked with keys obtainable only from cognizant personnel.

D. All equipment enclosures (high and low voltage) are solidly grounded to building ground.

E. Emergency shutdown pushbuttons are prominently located throughout the area, providing for the rapid and safe shutdown of all equipment in the event of an emergency. Periodic testing of this system is performed routinely.

F. Fire extinguishers suitable for electrical type fires are strategically located throughout the area. The motor generator sets are protected by a CO_2 fire protection system. The MG control room and the dc board enclosures have halon systems. Critical areas of the MG building are provided with thermal and smoke detection systems.

G. Fast acting heavy duty circuit breakers are located at the output of the generators arranged to open and ground the outputs and dissipate energy stored in the load inductance. Upon the detection of a fault, in addition to the opening of the circuit breakers, the electrical power to the generator fields is interrupted, thus interrupting the electrical output of the generators and maintaining the stored energy in the flywheel as purely mechanical kinetic energy.

H. The generators and power control devices are fully instrumented to monitor performance, providing continuous displays of system status as well as audible annunciation of fault conditions.

I. Low voltage control and monitor wiring are run separately from high voltage wiring.

J. All monitoring devices located within hazardous areas are insulated by two independent insulating gaps.

K. In the event that a high voltage area must be entered for inspection, service, or maintenance, safety procedures very similar to those described above for the OH power supply are followed. Entry to the unsafe experimental machine areas can be gained only after a Safety Isolation Switch (a Kirk key multiple contact switch) has been removed to the SAFE position, disabling all power supplies. This securely opens all MG disconnect switches, and grounds and shorts the respective loads.

L. The entire area in which the generators and associated control devices are located is a limited access area requiring controlled identification card entry.

For PBX-M there are no equipment modifications required for the TF Coil Power Supply.

4.2.1.4 Radial Field Coil Power Supply

The power supply that will be used to power the PBX-M radial field is the same power supply that has been used for years on PDX and PBX. As with other power supplies used on PDX, the safety features have been demonstrated to be effective over the years of use. This power supply comprises a self-contained transistorized power amplifier controlled from the PBX-M Control Room.

Safety features of this equipment include the following:

A. The power amplifier is completely guarded by sturdy wire mesh fencing to a height of eight feet. This fencing is well separated from all power connections and its single gate is locked with a serialized Kirk key lock.

B. All control and monitoring lines are isolated via optically isolated links and electronics. 480 VAC power is isolated by 30kV isolation transformers.

C. The power amplifier enclosure is solidly grounded to building ground.

D. A fast acting overcurrent trip circuit as well as a ground fault detector circuit are used to protect the equipment and provide for an emergency shutdown.

E. In order to enter the power amplifier area, the Kirk key for the gate must be obtained from the control room which automatically shuts down the power system.

The supply will be operated exactly as it has been operated for PBX, hence its established safety record can be inferred to apply to PBX-M operation.

4.2.1.5 Shaping Field Coil(s) Power Supplies

A major feature of the PBX-M, as compared to PBX, is the provision of considerably greater flexibility in shaping the plasma cross section. This provision, in part, comprises the utilization of six power supplies for reconfigured poloidal field coils. These supplies (coils) have been designated IF, DF, T1, T2, T3, and T4. Except that the IF furnishes 20kA at 500 VDC, the DF 10kA at 200 VDC, and T1-4 5kA at 300 VDC, they are built in exactly the same configuration. Thus all have the same safety features. In general, each of the Shaping Field Supplies was designed and manufactured to provide the same time-proven safety measures provided in the EF and OH coil power supplies.

Safety features of the Shaping Field Coil Power Supplies include:

A. All high power equipment is completely guarded by sturdy wire mesh fencing to a height of eight feet. This fencing is well separated from all operating equipment.

B. All controls and monitoring equipment which interface with high energy or high voltage sources are isolated by either two independent insulating gaps or optically isolated electronics.

C. All equipment enclosures (high and low voltage) are solidly grounded to building ground.

D. The safe control areas are limited access areas, meaning that card keys having authorized magnetic code are required for entry.

E. Fire extinguishers suitable for electrical type fires are strategically located throughout the area. The rectifier room is protected by an automatic sprinkler system which is connected to operate the emergency stop in the event of water flow. The room also has a smoke detection system.

F. Whenever a high voltage area is entered, even though it is safe, there must be at least two qualified persons present so as to have a safety watch in sight at all times in the event of an emergency (ref. HSD 2a).

G. The design of these supplies has been subject to Conceptual, Preliminary, and Final Design Reviews, in which the Project and Operational Safety Office specifically, and other reviewers in general, have assured that the requirements of PPPL Health and Safety Directives have been met.

4.2.2 AC Power Distribution

The AC power distribution that will be used to provide AC power to the various PBX-M power supplies is substantially the same distribution system used to power equipment for PBX. The safety of this equipment has been demonstrated during years of successful operation.

This equipment comprises 138kV/4.16kV three-phase power transformers, circuit breakers, series reactors and/or capacitors, shunt reactors and/or capacitors where required, and distribution transformers for lower voltage levels for various equipment. All of this equipment is monitored and protected by current transformers, potential transformers, spark gaps, lightning arrestors, appropriate grounding and remote controls, monitors, and annunciators. The level of monitoring and protection is commensurate with that required by industry standards for a distribution system of this type.

In addition to the above ancillary protective equipment are the following safety features:

A. All high power equipment is located in a outside fenced area, with gates padlocked for extra security. The keys to these locks may be obtained only from the cognizant power dispatcher, who has the authority and responsibility to limit the distribution of these keys until satisfied that only authorized and knowledgeable personnel will enter the hazardous area under safe conditions. In addition to the padlock key, a controlled identification card key is required to gain entry to this area.

B. All controls and monitoring equipment which interface with high energy or high voltage sources are isolated by at least two independent insulating gaps.

C. All equipment enclosures are solidly grounded to earth ground.

To provide power for the PBX-M Shaping Field Coil power supplies, additional 5kV class cabling, metal-clad switchgear, current-limiting reactors, and ancillary protective equipment have been installed. These additions were made to be in all ways similar and compatible with the established PBX distribution system. That is, the system as augmented remains at a level of monitoring and protection commensurate with that required by industry standards for a distribution system of this type.

4.2.3 DC Power Distribution

The DC power distribution scheme that will be used to provide DC power to the various machine coils is the same as used for PBX, in the case of the TF, OH, EF, and Radial Field Coils. This distribution system has demonstrated years of safe operation. The shaping field coils, IF, DF and T1-T4, added for PBX-M, are supplied through a network of cable and buswork that is designed to be electrically similar to the remainder of the system. It may be inferred, then, that the additional portions of the distribution system are as conservatively (safety) designed as those portions which have served well.

A. The shaping fields are supplied by DC cables made up of multiple 2kV class, 750kCM single conductor cables in parallel. These cables are run, in numbers as required by the National Electrical Code, in ladder-type cable tray, between the power-supply planking and the DC disconnect/ grounding switches.

B. Planking interconnections interlocked by links of various physical dimensions are provided to control dispatch of the DC power from the power supply ends of the transmission lines.

C. Fully rated DC disconnect/grounding switches, interlocked in the same manner as OH, EF, etc., are provided to assure positively safe machine access.

D. Transmission lines are terminated with semiconductor voltage transient limiters.

E. Power passes from DC disconnect switches to planting interconnections interlocked by physical dimensions and thence to coil feed buswork. These latter features are described further under "Coil System," below.

4.3 PBX-M DEVICE (J. Alton/D. Knutson)

4.3.1 Coil System

4.3.1.1 Poloidal Field Coils (PF)

The primary functions of the Poloidal Field system are to stabilize, heat, and shape the plasma.

The upgrade PBX-M poloidal coil system includes five (5) new internal (in-vessel) coils and the establishment of nine (9) separately powered coil groups (see Fig. 4.3.1-1).

A) Divertor Field (DF)

B) Indentation Field (IF)

C) Equilibrium Field (EF)

D) Active-Feedback (AF)

E) Trim Systems 1 thru 4 (T-1 thru 4)

F) Ohmic Heating (OH)

All of the PF coils are water-cooled copper conductor wound coils of conventional design. The coils located inside the vacuum vessel are encased in stainless steel to eliminate outgassing from their insulating materials and to reinforce them mechanically.

All of the coils use a primary insulation of half-lapped layers of mylar insulating tape (6.5 kV per mil-dielectric strength). The internal canned coils then use a combination of dry glass insulation, epoxy impregnated to complete their dielectric/mechanical bundle. The external coils use a B-stage epoxy-glass insulation scheme to complete their electrical/mechanical bundle.

The poloidal coil parameters are listed in Table 4.3.1-1.

4.3.1.2 Passive Coils

The Passive Coil system was installed to carry currents induced by vertical motion of the plasma, which helps in slowing or damping these vertical motions.

POLOIDAL COIL SYSTEM FOR PBX-M

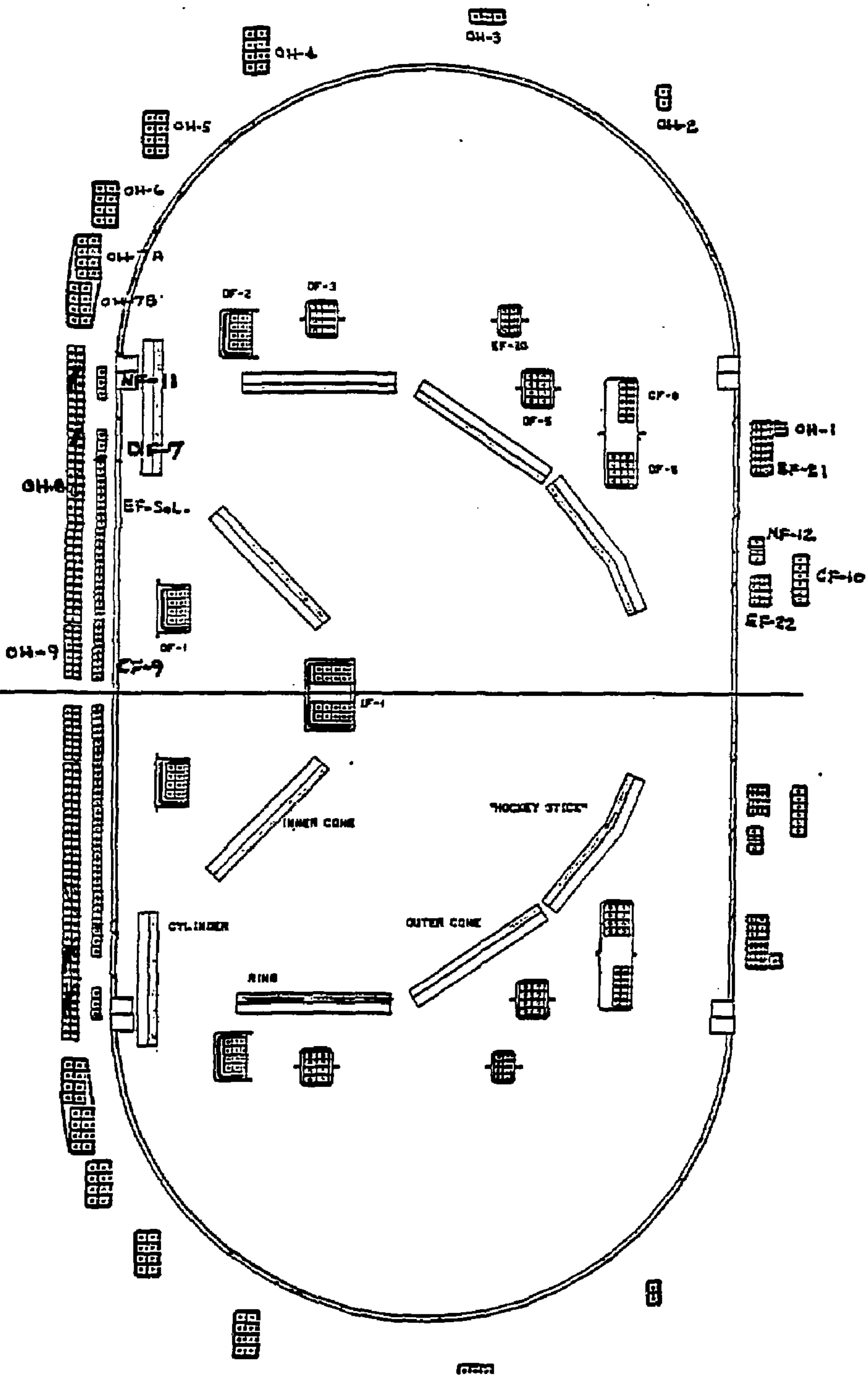


FIGURE 4.3.1-1

PBX-M COIL DATA SHEET

POLOIDAL COILS

SYSTEM ID	COIL ID	MEAN COIL RAD. (in.)	NO. TURNS	CONDUCTOR WIDTH (in.)	CONDUCTOR HEIGHT (in.)	CONDUCTOR HOLE DIA. (in.)	COPPER AREA (in^2)	COPPER LENGTH per coil (ft.)	COIL WEIGHT (lbs)	COIL RESISTANCE (ohms)
Equilibrium Field	CF-10	92.638	6	1.110	0.625	0.313	0.609	291.0	687.2	0.0039
	EF-20	64.961	7	0.734	0.500	0.250	0.310	283.1	286.4	0.0062
	EF-21	88.767	13	0.734	0.500	0.250	0.310	604.2	726.8	0.0158
	EF-22	88.767	8	0.734	0.500	0.250	0.310	371.8	447.2	0.0097
Shaping Field	CF-8	75.076	6	0.625	1.110	0.313	0.609	239.0	560.8	0.0032
	IF-1	48.110	16	0.775	0.775	0.250	0.552	402.2	848.0	0.006
Divertor Field	DF-1	33.460	8	0.775	0.775	0.250	0.552	134.9	285.0	0.002
	DF-7	26.260	3	0.724	0.847	0.250	0.557	41.2	89.0	0.0006
	NF-11	26.260	3	0.724	0.847	0.250	0.557	41.2	89.0	0.0006
Trim No. 1	DF-2	39.020	8	0.775	0.775	0.250	0.552	163.4	345.0	0.0024
Trim No. 2	DF-3	46.850	8	1.110	0.625	0.313	0.609	196.2	463.4	0.0026
Trim No. 3	DF-5	67.717	8	1.110	0.625	0.313	0.609	283.7	669.8	0.0038
Trim No. 4	DF-6	75.591	8	1.110	0.625	0.313	0.609	316.6	747.7	0.0042
Active - Feedback	NF-12	88.498	3	1.110	0.625	0.313	0.609	139.0	328.3	0.0019
	EF-SOL-	26.260	28	0.734	0.500	0.250	0.310	385.0	463.1	0.0101
Ohmic Heating	OH-1	90.553	1	0.875	0.875	0.250	0.709	47.4	130.3	0.0005
	OH-2	79.370	2	0.875	0.875	0.250	0.709	83.1	228.4	0.0010
	OH-3	62.630	3	0.875	0.875	0.250	0.709	98.4	270.4	0.0011
	OH-4	40.433	8	0.875	0.875	0.250	0.709	169.4	465.4	0.0019
	OH-5	31.102	8	0.875	0.875	0.250	0.709	130.3	358.0	0.0015
	OH-6	24.173	8	0.875	0.875	0.250	0.709	111.2	305.6	0.00128
	OH-7A	24.942	8	0.875	0.875	0.250	0.709	104.5	287.2	0.0012
	OH-7B	24.217	8	0.875	0.875	0.250	0.709	101.4	278.7	0.00116
	OH-8	23.909	36	0.625	1.320	0.313	0.740	100.15	1295	0.004602
	OH-9	23.909	8	0.625	1.050	0.313	0.572	450.673	222	0.001296

Table 4.3.1-1

PBX-M COIL COOLING DATA SHEET

POLOIDAL COILS

SYSTEM ID	COIL ID	FLOW/PATH (GPM) *	NO. OF PATHS	VELOCITY (FPS)	PULSED CURRENT (kA)	ESW (sec)	REP. RATE (sec)	MAX CU TEMP °C	MAX WATER TEMP °C	COPPER LENGTH PER FLOW PATH (ft)
Equilibrium Field	CF-10	3.609	1	15.06	10	1.5	300	17.0	16.3	291.0
	EF-20	1.994	1	13.04	10	1.5	300	30.8	28.0	283.1
	EF-21	1.295	1	8.47	10	1.5	300	50.0	42.4	604.2
	EF-22	1.707	1	11.17	10	1.5	300	34.6	29.8	371.8
Shaping Field	CF-8	4.035	1	16.84	20	1.5	300	31.5	28.9	239.0
	IF-1	2.420	2	15.83	20	1.5	300	36.0	33.9	201.1
Divertor Field	DF-1	3.032	1	19.84	10	1.5	300	17.6	17.2	134.9
	DF-7	5.882	1	38.48	10	1.5	300	17.3	16.4	41.2
	NF-11	5.882	1	38.48	10	1.5	300	17.3	16.4	41.2
Trim No. 1	DF-2	2.721	1	17.80	5	1.5	300	13.4	13.3	163.4
Trim No. 2	DF-3	4.512	1	18.83	5	1.5	300	13.1	13.0	196.2
Trim No. 3	DF-5	3.659	1	15.27	5	1.5	300	13.2	13.0	283.7
Trim No. 4	DF-6	3.440	1	14.36	5	1.5	300	13.2	13.0	316.6
Active - Feedback	EF-SOL-	1.674	1	10.95	2	1.5	300	12.7	12.6	139.0
	NF-12	5.480	1	22.87	2	1.5	300	12.2	12.2	385.0
Ohmic Heating	OH-1	5.445	1	35.62	20	1.5	300	25.6	24.3	47.4
	OH-2	3.984	1	26.06	20	1.5	300	25.6	24.8	83.1
	OH-3	3.624	1	23.71	20	1.5	300	25.8	25.0	98.4
	OH-4	2.667	1	17.45	20	1.5	300	26.3	25.3	169.4
	OH-5	3.094	1	20.24	20	1.5	300	25.8	25.1	130.3
	OH-6	3.383	1	22.13	20	1.5	300	25.8	25.1	111.2
	OH-7A	3.503	1	22.92	20	1.5	300	25.8	25.0	104.5
	OH-7B	3.563	1	23.31	20	1.5	300	25.7	25.0	101.4
	OH-8&9 Inner	3.767	1	15.72	20	1.5	300	34.8	28.8	268.8
	OH-8&9 Outer	3.665	1	15.30	20	1.5	300	34.9	28.0	282.1

*Based on 400 psi ΔP, Inlet Temp = 12 °C

Table 4.3.1-1 (cont'd.)

There are a total of five pairs of passive coils in the vacuum vessel surrounding the plasma.

These coils are fabricated from a composite of aluminum and stainless steel. A layer of nominal 1/8" thick stainless steel is explosion-bonded to the plasma side of the aluminum to protect it from the plasma.

Each coil is manufactured as either 5 or 10 segments, which are fastened together with hardware, after they are brought inside the vacuum vessel.

The upper and lower matching coils are then bussed together to form a complete circuit. The "hockey-stick" coil differs from the other coils in that it has upper-lower bus connections at eleven places around the vacuum vessel. The coil parameters are indicated in Table 4.3.1-2.

A. Bus Runs

Most of the bus runs are water cooled and fabricated in sections which are mechanically fastened together with stainless steel hardware.

Each bus connection has been inspected using "PBX-M Pre-Power Test Joint Inspection Procedure" number CS-PBX-07. (See Appendix C.)

The outlet water temperature of each bus run is monitored for thermal protection and feed back to the main controls.

B. Polarity Reversal Panel

The "Polarity Reversal Panel" (Fig. 4.3.1-2) is located in the basement planking room which is secured with a Kirk key interlock. It is on the machine side of the disconnect switches and links the bus runs from both the coils and the switches. Using removal copper planks, it allows each P.F. system to be operated in either the positive or negative modes.

A failsafe system has been installed which indicates to the control room, that the proper planks are in position on the panel.

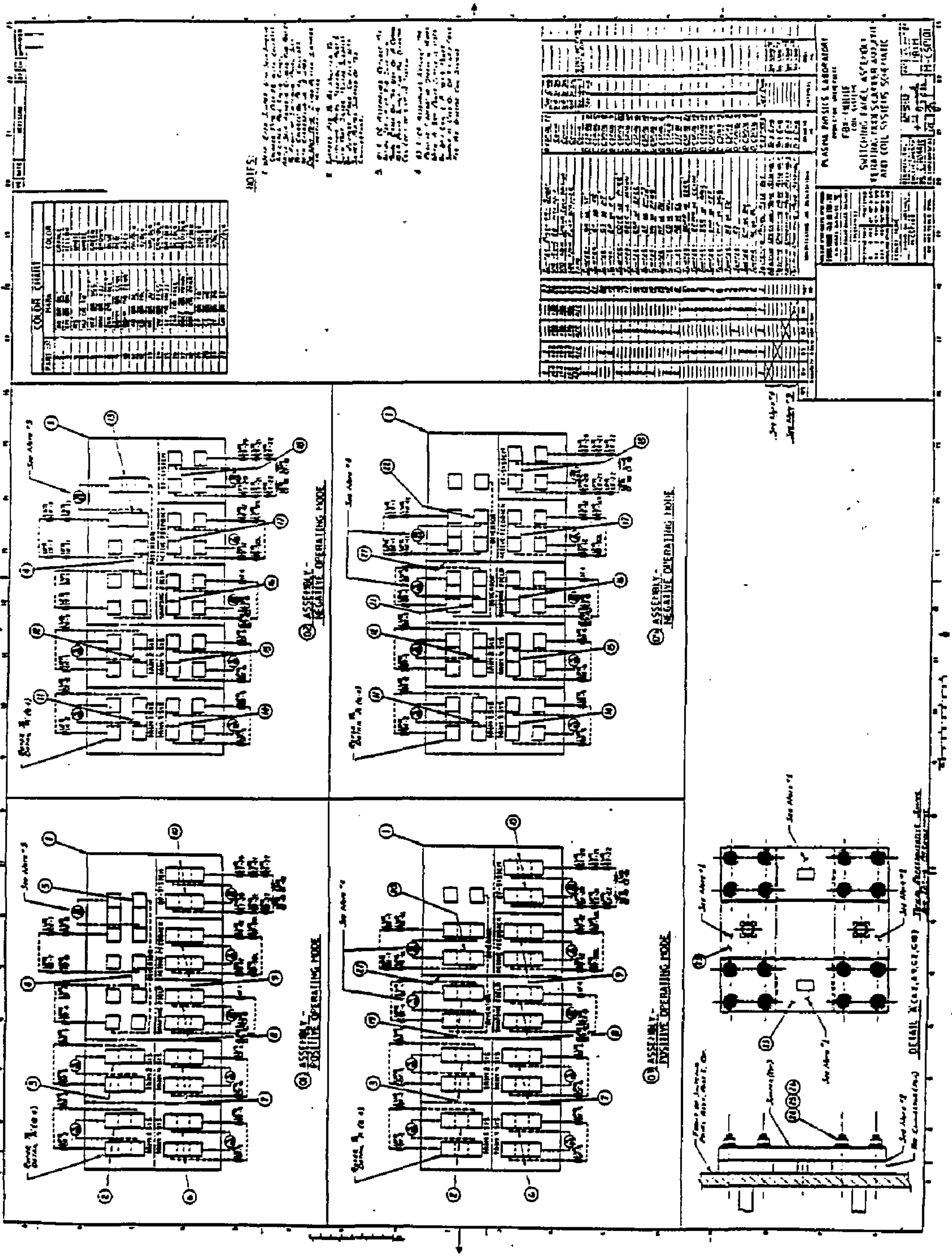


FIGURE 4.3.1-2

Grounding terminals have been installed on the panel which allows a coil system to be grounded before removing the copper planks.

Additional precautions such as color-coded silhouettes have been added to ensure that all planks are in their proper position.

TABLE 4.3.1-2

PASSIVE COIL PARAMETERS

Passive Coil	Max Design Induced Current (KA)	Segments per Coil
Inner Cone	138.0	5
Cylinder	24.0	5
Ring	123.0	5
Outer Cone	60.0	10
Hockey-Stick	10.0	10

4.3.1.3 Poloidal Field Coil Bus System

There are a total of nine individual poloidal field coil bus systems on the PBX-M device. They connect the P.F. coils at the machine with the polarity reversed panel and power disconnect switches located in the basement areas.

For purposes of safety and ease of identification, eight of the new systems have been color and letter coded as noted in Table 4.3.1-3.

TABLE 4.3.1-3

System	Coils	Letter Code	Color Code
E.F.	EF-20,21,22,CF-10	A	Gray
I.F.	CF-8, IF	B	Blue
D.F. (A)	DF-7, NF-11	C	White
D.F. (B)	DF-1	D	White
Trim 1	DF-2	E	Orange
Trim 2	DF-3	F	Yellow
Trim 3	DF-5	G	Green
Trim 4	DF-6	H	Brown
A.F.	EF-Sol., NF-12	J	Red

4.3.2 Vacuum System

The vacuum vessel is formed from two concentric vertical axis cylinders 60" in axial length with radii of approximately 28" and 88", respectively; the volume between them is enclosed top and bottom by a pair of hemi toroidal spinnings of 30" minor radius and 58" major radius each. The wall of this vessel is formed from 1/2" 304 stainless steel. The toroidal vessel geometry thus formed is broken electrically in two locations on a major diameter at the torus; forming two hemitori. The resulting vacuum vessel is thus composed of 8 flanged segments bolted together with elastomer "O" rings forming the vacuum seals. Twenty toroidal field coils located every 18^{o} surround the vacuum vessel. At every other toroidal field location a structural "I" beam is mounted inside the toroidal spinnings top and bottom. These supports carry both active and passive coils. The reinforced inner-cylinder also supports active and passive coils. A number of vacuum diagnostic ports have been provided in the gaps between the toroidal and poloidal field coils. Man access to the vacuum vessel interior is possible through certain ports on the equatorial plane and certain dome flanges. The vessel interior is defined as a "confined space" so that work inside the vessel must be conducted according to the safety rules and regulations for "confined spaces," per HSD 5008, section 8 (HSD8). Breathable atmosphere is maintainable by continuous ventilation of the vessel.

4.3.3 Vacuum Pumping System

The vacuum vessel is pumped by four 1500 l/sec turbo pumps backed by a 50 cfm mechanical pump. The system is roughed down from atmospheric pressure by means of a 500 cfm mechanical pump. Several Ti Ball sublimation getters provide active metal surface pumping during plasma operations. The vacuum system "mimic" control panel is in the room below the PBX control room. Only trained, qualified personnel are permitted to operate the system.

4.4 PBX-M Operating Controls (P.Mathe, R.Mica)

4.4.1 Control System Architecture

4.4.1 Introduction

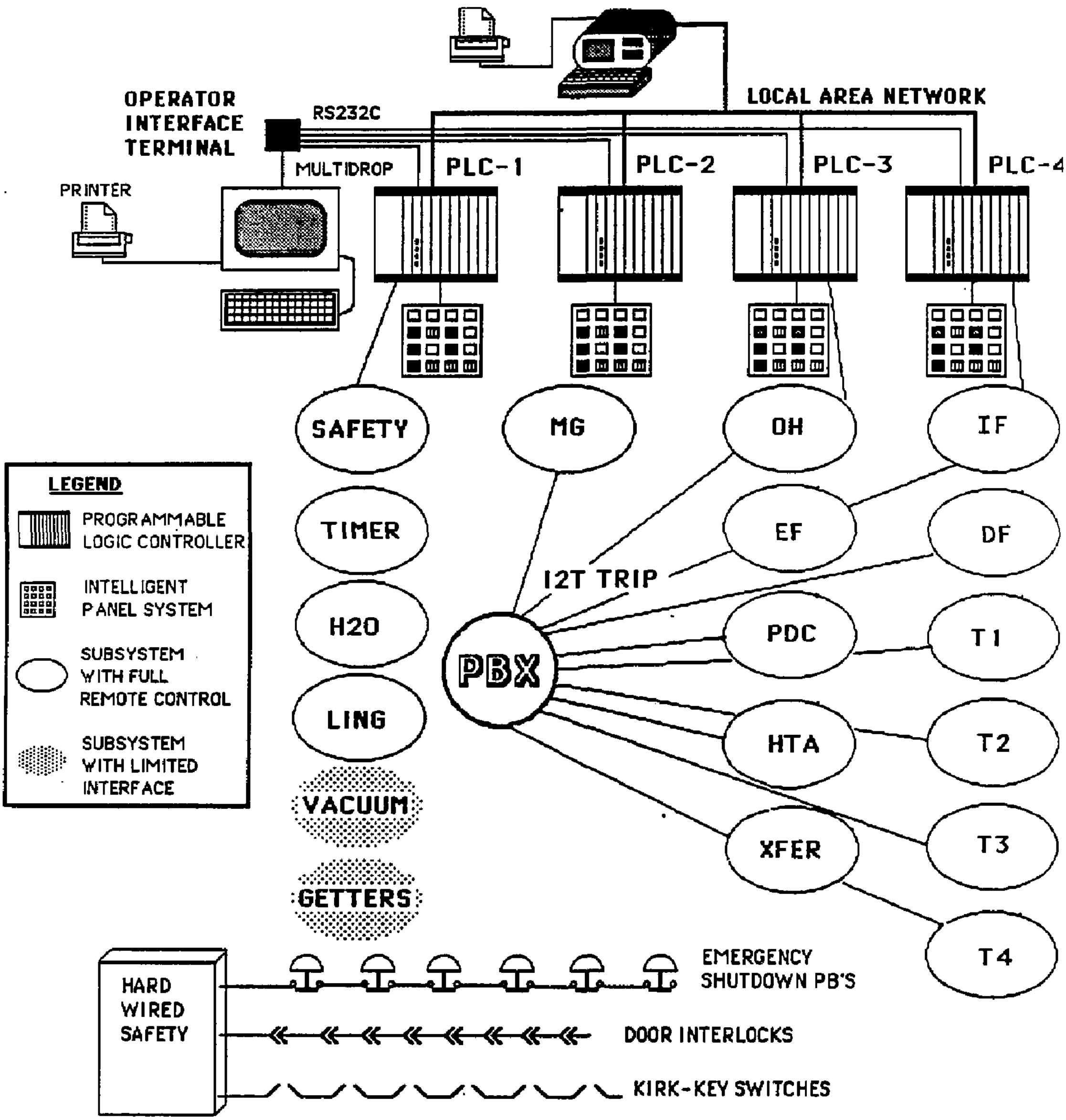
The supervisory and control functions on the previous machine (PBX) were provided by an IBM-1800 process controller. This computer became obsolete and was replaced by a modern distributed control system (Fig. 4.4-1). The system consists of four PROGRAMMABLE LOGIC CONTROLLERS (PLC's) connected via an industrial local area network, a CRT CONSOLE which accesses the PLC's memory through its own data acquisition links, OPERATOR CONTROL PANELS which utilize serial communication to the PLC's, and a PROGRAM LOADER/MONITOR which permits on-line monitoring of the PLC logic and status.

4.4.1.2. Programmable Logic Controllers (PLC's)

PLC's are reliable control equipment, since they are made to operate in industrial environments and use solid state components. They offer flexibility both in the area of software and hardware, because of their modular architecture. Software development is simplified by powerful program development tools that also permit quick debugging and troubleshooting of the system. The distributed I/O architecture reduces the cost of wiring by placing remote I/O racks at the controlled equipment and communicating back to the CPU via high-speed serial links with CRC error detection and correction for error-free communication. PLC's are not new to the laboratory, they have been used on all major projects- TFTR, PBX, PLT, S-1- and the experience has been very favorable.

4.4.1.3. Distributed Architecture

One of the benefits of distributed architecture is that each PLC is responsible for controlling a fewer number of subsystems resulting in simplified software management effort. Each PLC is independent, allowing different individuals to work in parallel on several subsystems. Logic execution speed is increased since several processors operate simultaneously. A new requirement, however, is a communication path that allows sharing information among the PLC's. This requirement is met by industrial local area networks. Several interlocks are shared on a periodic basis, and the reliability of this communication is expected to be similar to requirements imposed on remote I/O communication. The network also provides expansion for future subsystems on PBX-M, a few of which are



REF DWGS

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C4CC-A-HED401-DL MAIN DRAWING INDEX
C4CC-A-HED402-DL MAIN DRAWING INDEX
C4CC-A-HP1-100-DL PLC-1 DRAWING INDEX
C4CC-A-HP2-100-DL PLC-2 DRAWING INDEX
C4CC-A-HP3-100-DL PLC-3 DRAWING INDEX
C4CC-A-HP4-100-DL PLC-4 DRAWING INDEX

ENG: P. Méthé
DATE:
CHKD:
APPD:

PRINCETON UNIVERSITY
PLASMA PHYSICS LABORATORY

TITLE: PBX M
CONTROL SYSTEM BLOCK DIA

DWG. NO. C4CC-A-HED405-BL
REV.

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Figure 4.4-1

already under consideration, such as pellet injection, RF heating, and current drive. This expansion can be accommodated in a way that will have minimum impact on existing systems, since new software will reside in new PLC's.

4.4.1.4. Operator Interface

Intelligent Panel System

The operator control panels are based on CTC's Intelligent Panel System (IPS) which utilizes serial communication to the PLC's (Fig.4.4-2). The system contains illuminated push-button panels, key-pads, vacuum fluorescent and plasma displays. The control board which supports up to four of these modules provides the translation of parallel signals to serial format.

Pushbutton Panels

The lighted pushbutton panels contain 32 illuminated buttons and were chosen to provide a similar control environment to the previous hardwired console. The PUSH-TO philosophy is maintained, that is, the lights behind the command buttons are used as prompts for operator actions. When the buttons are not lit and pushed, the associated display modules provide messages that explain the reason why the system cannot accept the command.

Plasma Displays

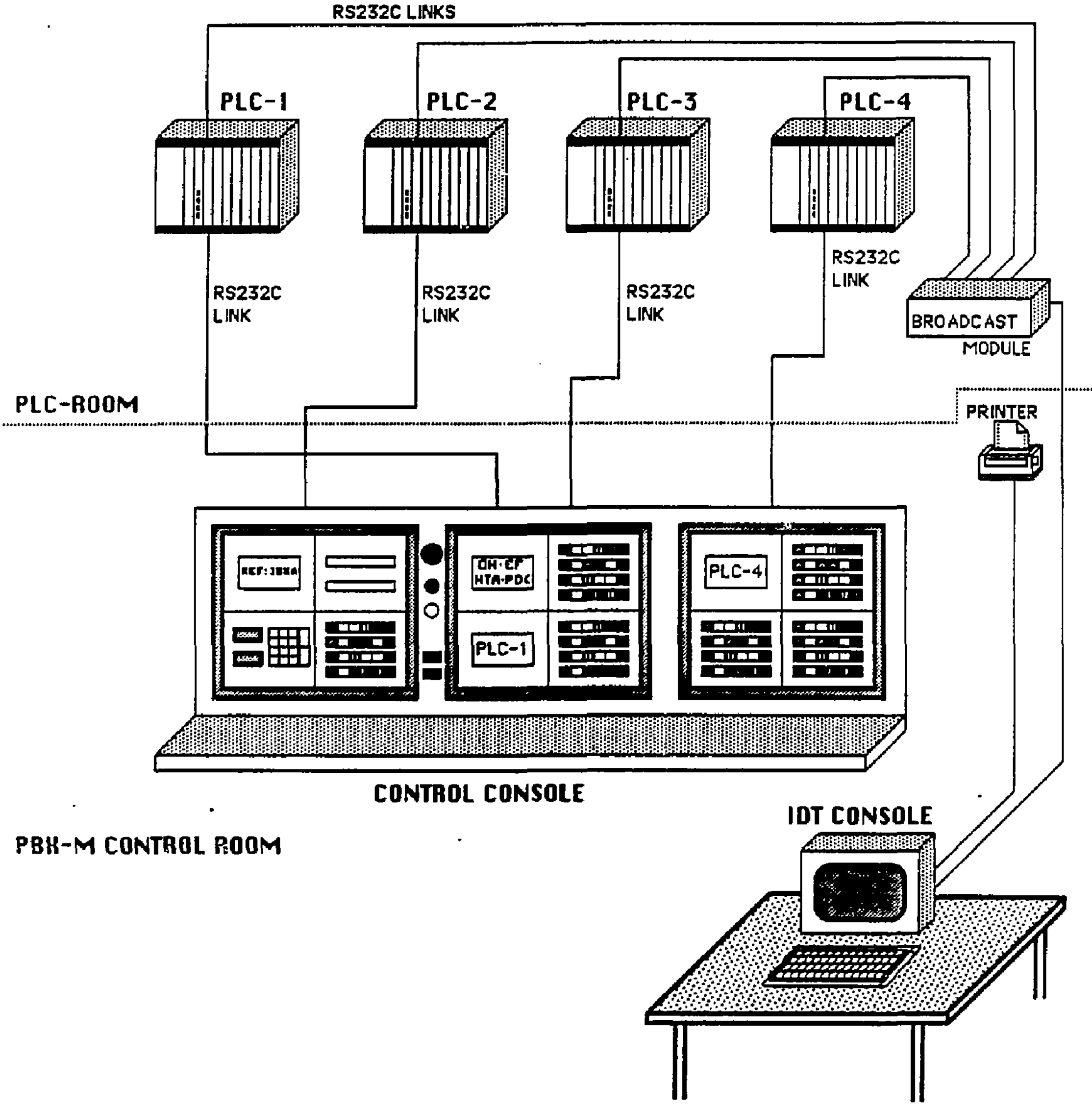
The plasma display features 4 lines of 16 characters for primitive operator prompts, error messages, or display of parameters. The main annunciator system implemented with the CRT Console provides detailed alarm display and logging capabilities.

Vacuum Fluorescent Display, Real-time Clock

The vacuum fluorescent display module features two lines of 24 character alphanumeric displays. It also contains a real-time clock, settable and readable by the PLC. The clock information will be used with the Annunciator System for logging the date and time information with the alarm messages.

Numeric Keypad

The numeric keypad module contains two rows of 8-digit display, and a telephone style keypad for entry of numerical values to the PLC's.



REF DWGS

C4CC-A-HED400-DL MAIN DRAWING INDEX C4CC-A-HED401-DL MAIN DRAWING INDEX C4CC-A-HED402-DL MAIN DRAWING INDEX C4CC-A-HP1-100-DL PLC-1 DRAWING INDEX C4CC-A-HP2-100-DL PLC-2 DRAWING INDEX C4CC-A-HP3-100-DL PLC-3 DRAWING INDEX C4CC-A-HP4-100-DL PLC-4 DRAWING INDEX	ENG: P. Mâthé CHKD: APPD:	DATE	PRINCETON UNIVERSITY PLASMA PHYSICS LABORATORY TITLE: PBX-M OPERATOR INTERFACE DWG. NO. C4CC-A-HED412-L0 REV

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Figure 4.4-2

4.4.1.5 Mimic Panels

The mimic panels will be mostly the ones inherited from PBX with an additional mimic for the new shaping field power supplies that will occupy the space freed up by the NF/CF mimic panel.

4.4.1.6 CRT Console

The CRT console is used primarily as a system annunciator to annunciate approximately 500 messages on various alarm conditions,but also provides several status pages on flow and area interlock conditions, and a system summary page . The terminal has its own data acquisition link via a serial multidrop connection to read the data from the PLC's and has a printer port for hard copy generation. The CRT console permits the creation of these displays and the message system without programming.

4.4.2. Hardwired Personnel Safety System

4.4.2.1. Introduction

The most significant change with the new PLC-based control system is the Hardwired Personnel Safety System (Fig. 4.4-1.). As opposed with the IBM-1800-based control system all Area access interlocks, such as Kirk interlock switches, door interlocks, and the Emergency Shutdown switches are summed up by a relay system. The resulting commands such as disable or shutdown are sent directly to the power supplies, or breakers bypassing the PLC system. Annunciation for all of the personnel safety devices is provided by the PLC system.

4.4.2.2 Area Access Interlocks

Exclusion Areas

In addition to the test cell there are other interlocked areas, i.e., bus and water tunnels, disconnect switch enclosures, planking room for polarity switching panel, which are located in the CS basement and together with the test cell constitute exclusion areas for PBX-M. The access to these areas and the interlocks used are according to the PPPL Safety Manual, and their operation is described below.

Safety Lock-out Switch (SLS)

The Safety Lock-out Switch prevents application of control power to the motor drives of coil disconnect switches until the area lock-up is completed. The hard-wired limit switches of the same disconnects are summed up into a key release solenoid which allows operation of the SLS to free access.

KIRK Interlocks

Under the normal operating conditions the experimental area is evacuated and locked. The KIRK interlock system of uniquely registered keys is implemented preventing operation of power sources if the area is not secured (Fig 4.4-3). If an emergency entry into the exclusion area is required, a secondary key under glass enclosure is available for each door. Usage of the secondary key causes emergency shutdown.

Door Interlocks

Each door leading to the exclusion area is equipped with a microswitch which is summed into the hardwired master disable circuit.

Kick-out panels

Each door leading to the experimental area is equipped with a kick out panel allowing quick exit from the area under the emergency condition.

4.4.2.3. Machine Safety Disconnect Switches

The primary safety devices for assuring personnel safety in the test cell are the coil disconnect switches. Their control is interlocked with Safety Lock-out Switch . The disconnect switches can only be operated when the SLS is put into RUN mode. When a disconnect switch is in the disabled position it grounds one side of the coil. Only when all the disconnect switches are grounded will access be allowed into the test cell. A maintenance mode is provided for all disconnects to perform maintenance work. This mode requires keys from all power supplies rendering them safe. This is an important safety improvement over the old system which required jumpering of the SLS contacts.

4.4.2.4. Emergency Shutdown System

At strategic locations manually operated emergency shutdown stations are provided. Activation of pushbuttons at these stations trips main breakers for each power subsystem, and closes the water valves to the machine. Each station is equipped, in addition to the pushbutton, with a light and reset button, and is hardwired into the Safety system.

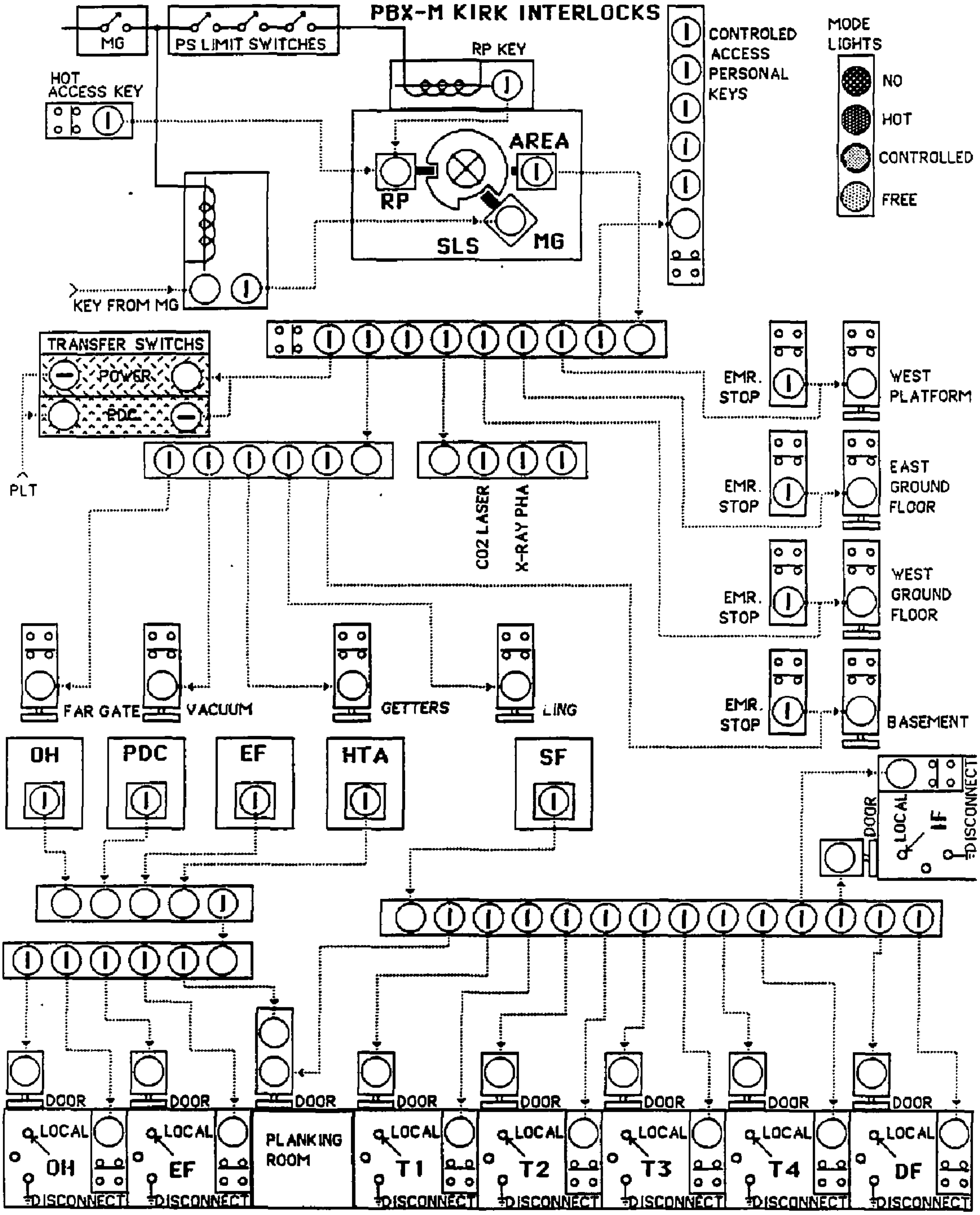

PBX-M KIRK INTERLOCKS
MG
PS LIMIT SWITCHES
RP KEY
HOT ACCESS KEY
AREA
RP
SLS
MG
KEY FROM MG
CONTROLED ACCESS PERSONAL KEYS
MODE LIGHTS
NO
HOT
CONTROLLED
FREE
TRANSFER SWITCHES
POWER
PDC
PLT
CO2 LASER
X-RAY PHA
EMR. STOP
WEST PLATFORM
EAST GROUND FLOOR
WEST GROUND FLOOR
BASEMENT
FAR GATE
VACUUM
GETTERS
LING
OH
PDC
EF
HTA
SF
DOOR
LOCAL
IF
DISCONNECT
PLANKING ROOM
T1
T2
T3
T4
DF

Figure 4.4-3

4.4.2.5. Master Disable

The hardwired Master Disable is used to disable the output circuits of each PLC until the test cell is secured. It is also used as a disable interlock when Kirk switches or door interlocks open while the SLS is in the RUN mode. Another use of this function is when communication between the control console and PLC is lost: the operator can activate the master disable pushbutton located on the control console.

4.4.3 Remote Control and Monitoring of Power Systems

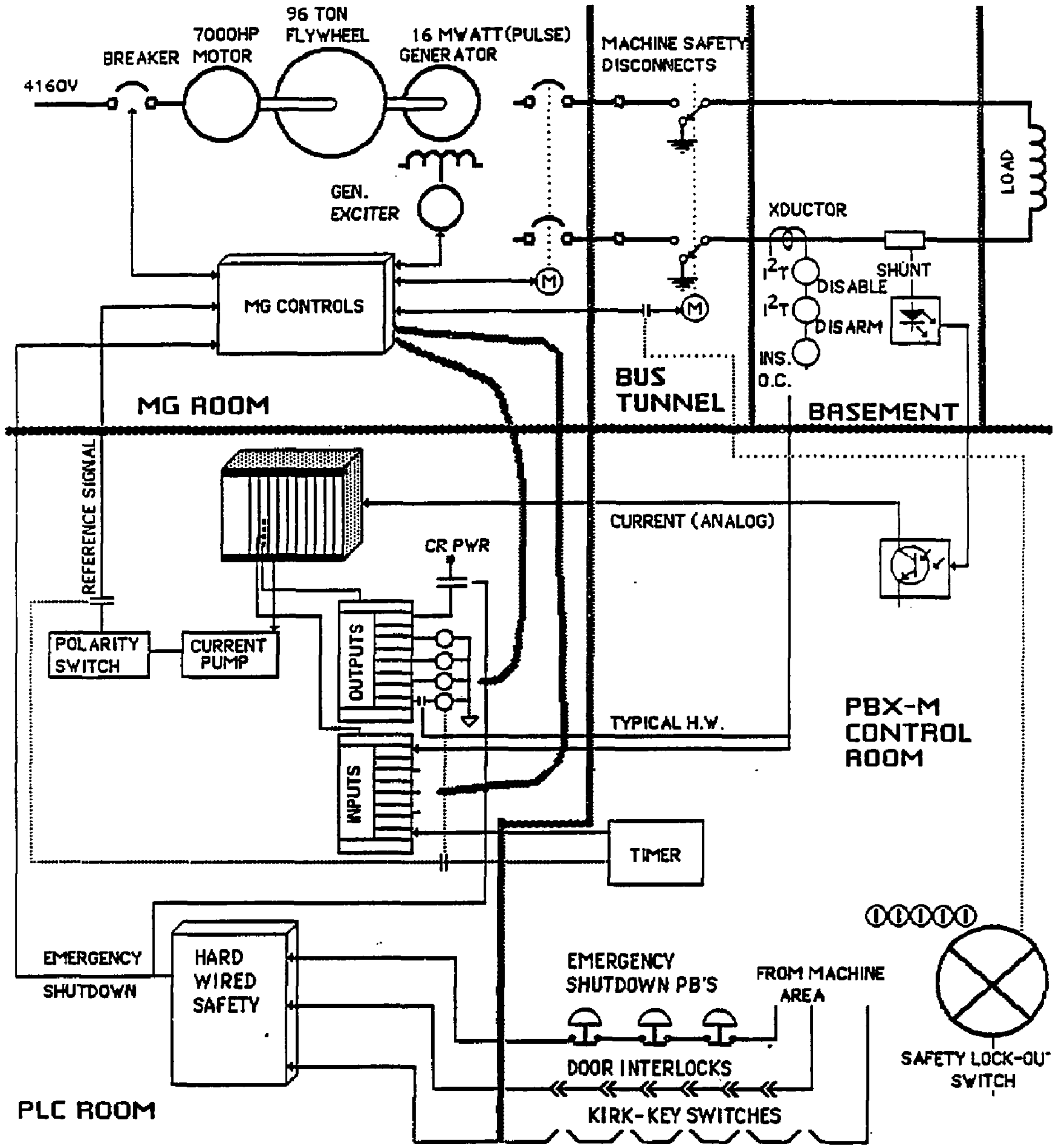
4.4.3.1. General

A. Block Diagram

A typical block diagram depicts the one line schematic of the given power subsystem; the physical arrangement; and the control interface to the power supply, the central controls, and any hardwired interlocks which are separate from the PLC controls. For illustration purposes the TF and OH subsystem block diagrams are included (Fig.'s 4.4-4 and 4.4-5). The remaining poloidal field subsystems closely resemble the OH subsystem.

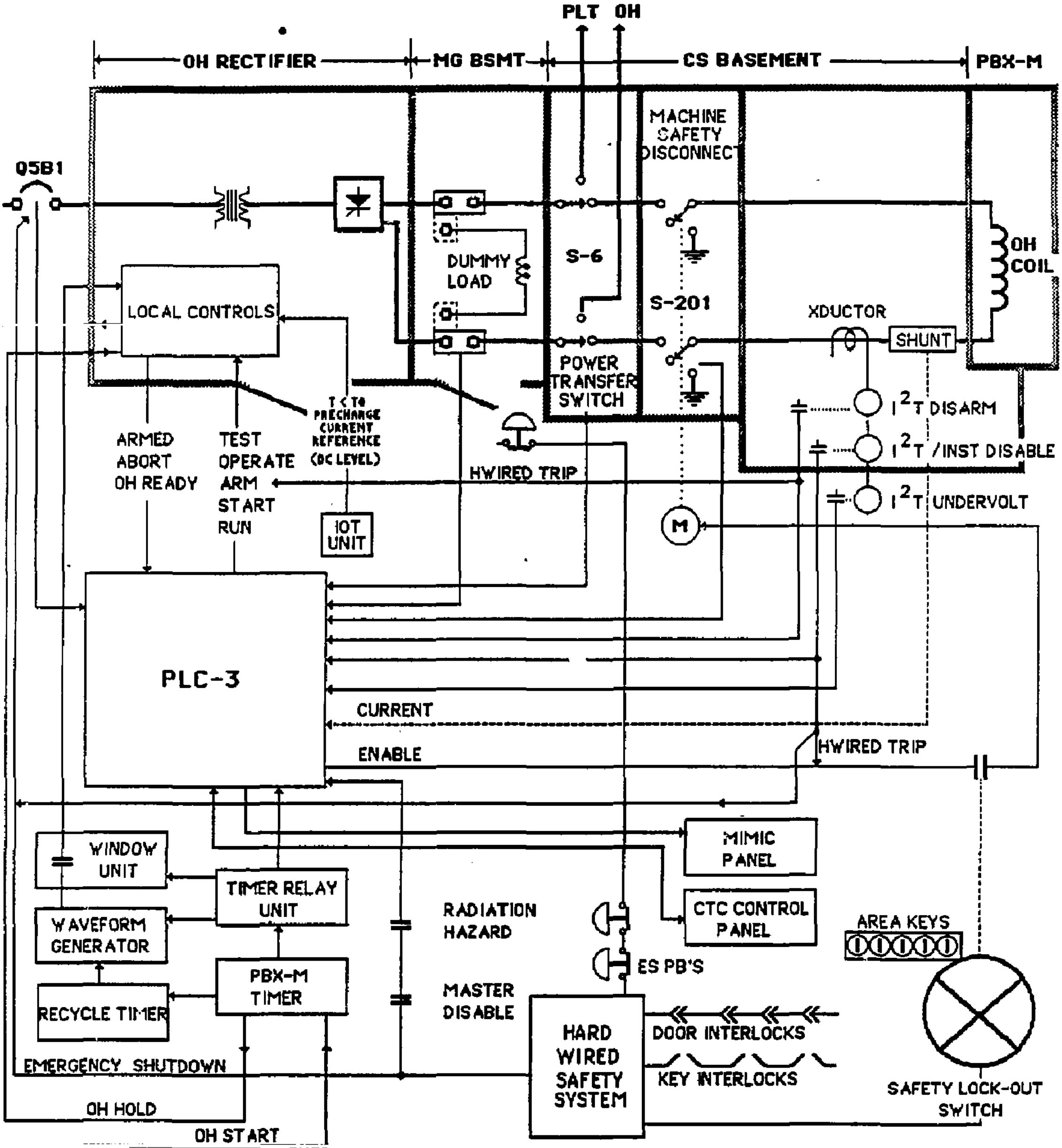
B. State Transition Diagram

The control of each of the subsystems follows a structured sequence of events. Some of these events are operator commands which will perform state transitions. The operator can exercise both upward and downward transitions. The upward transitions, which put the subsystem in a progressively more unsafe state (or closer to current pulsing) require that all the permissive conditions be satisfied. The operator and the control system can perform downward transitions, which bring the subsystem down into a safer level. The major states and the corresponding transitions for the TF and OH subsystems are shown on state transition diagrams, Fig's. 4.4-6 and 4.4-7.



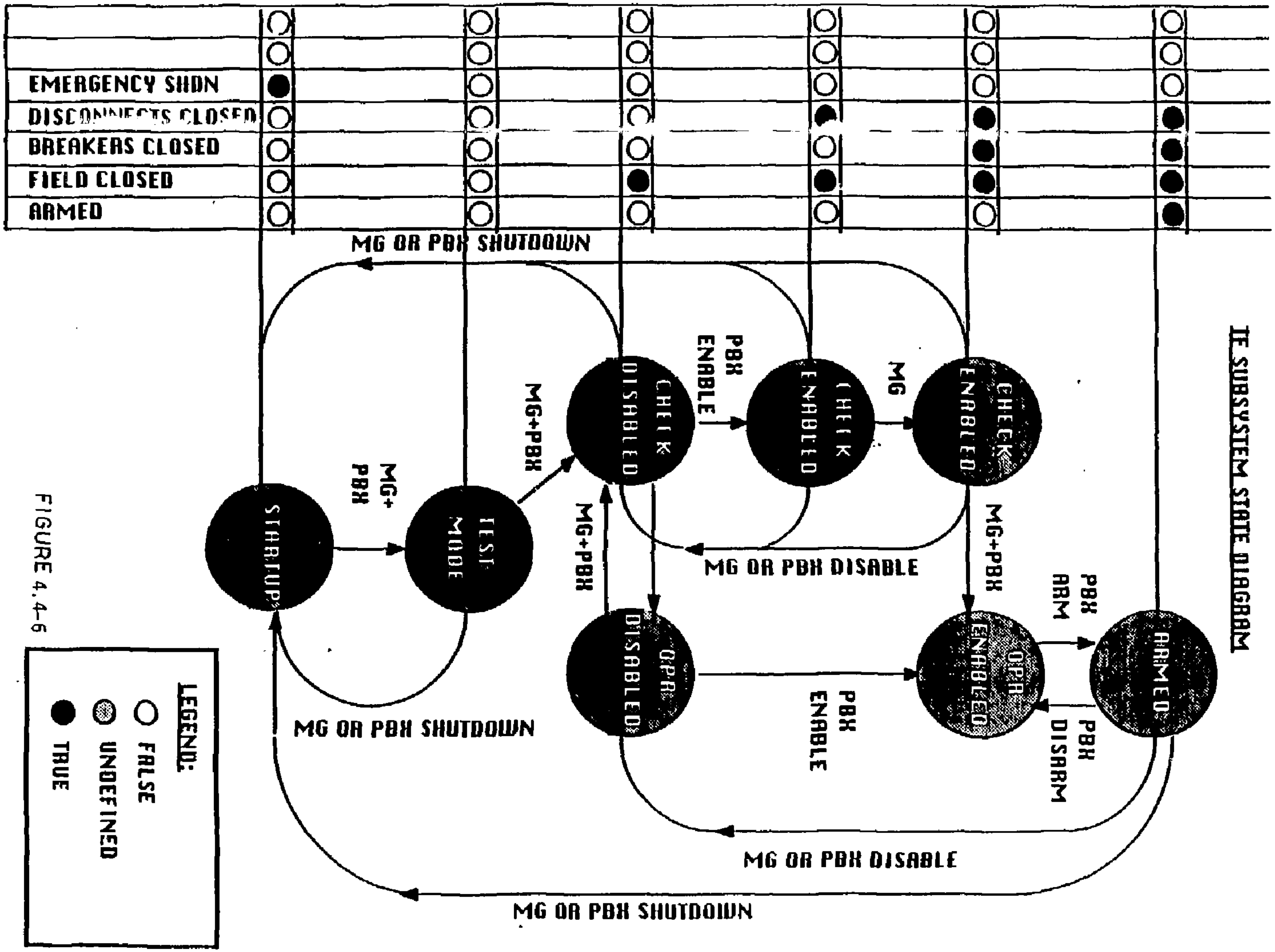
- TF CONTROLS BLOCK DIAGRAM

Figure 4.4-4



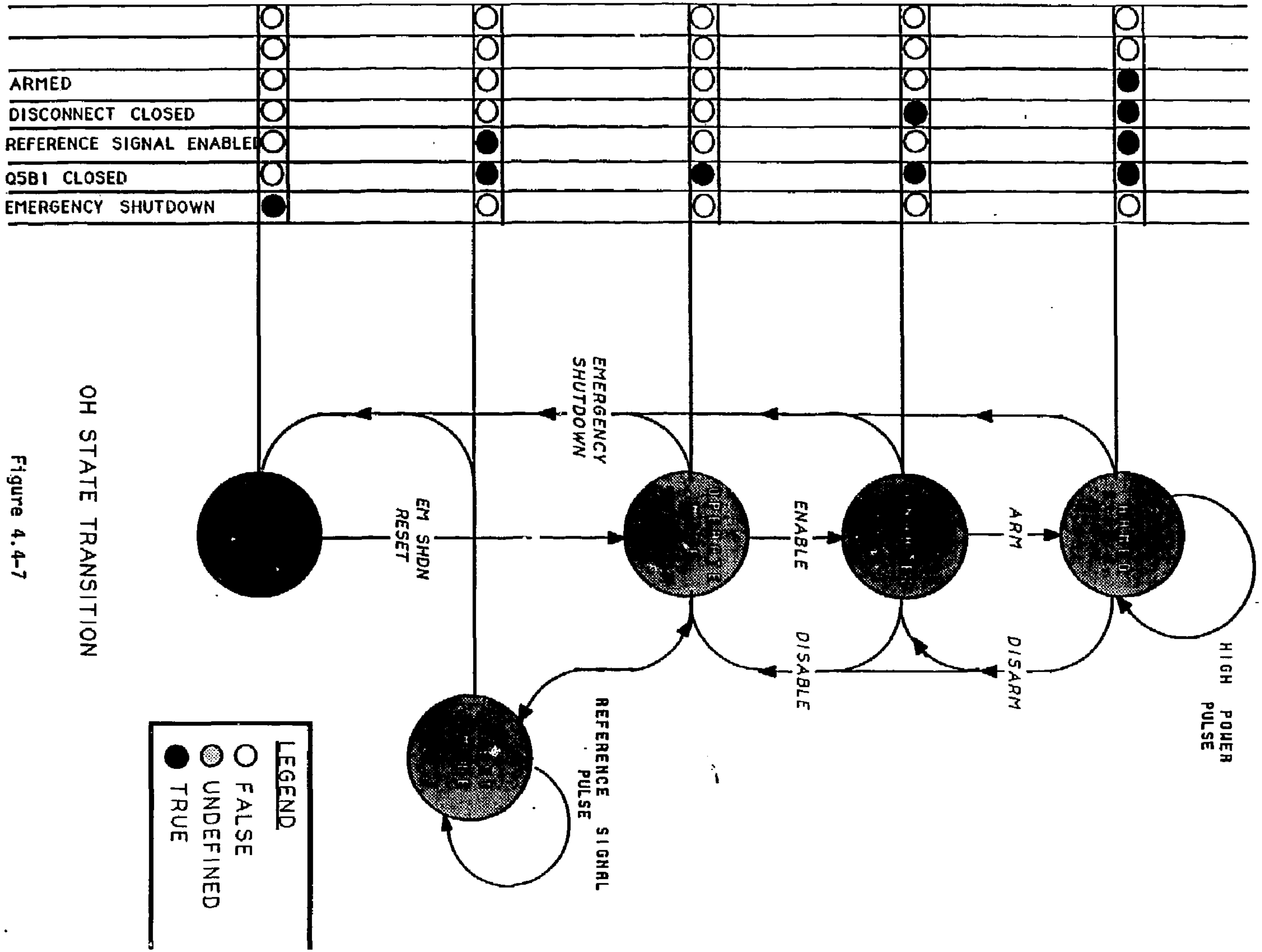
ENG: R. MIKA	DATE	PRINCETON UNIVERSITY PLASMA PHYSICS LABORATORY	
CHKD:		TITLE: OH POWER SUPPLY BLOCK DIAGRAM	
APPD:		DWG. NO.	REV

Figure 4.4-5



IF SUBSYSTEM STATE DIAGRAM

FIGURE 4.4-6



OH STATE TRANSITION

Figure 4.4-7

4.4.3.2 Toroidal Field Subsystem (MG)

A. Definition of functions (state transitions)

ENABLE IN OPERATE MODE

This function closes the disconnect switches, then the resistor breakers, and finally the high speed breakers.

ENABLE IN CHECK MODE

This function closes the disconnect switches only, permitting manual closing of the generator breakers by the MG operator.

ARM

This function connects the reference signal path to the generator field controls.

DISARM

This function disconnects and shorts the reference signal path to the generator field controls.

DISABLE

This function disarms the TF subsystem and trips the generator high-speed breakers, resistor breakers, and after a time delay opens the disconnect switches.

EMERGENCY SHUTDOWN

This function disables the TF subsystem and trips the generator field circuits. It will also force the TEST mode in the C4 controls.

4.4.3.3. Poloidal Field Subsystems

B. Definition of functions (state transitions)

ENABLE

The primary function of enable is to close the disconnect switch. For the SF subsystems this function also closes the AC contactor.

ARM

This function applies a control signal to the control rail of the reference signal relay allowing it to be operated by the PBX-M timer.

RUN

The run signal is timer generated; and if the subsystem is armed, it connects firing pulses to the SCR's allowing them to generate current.

DISARM

This function disconnects and shorts the reference signal path to the power supply.

DISABLE

This function disarms the subsystem and after a time delay opens the disconnect switches. For SF power supplies it also opens the AC contactors.

EMERGENCY SHUTDOWN

This function disables the subsystem and trips the main AC breakers. It will also force the TEST mode in the controls.

4.4.4. Machine Protection Functions

4.4.4.1 PLC System Protection

Since the PLC system is based on complicated computerized control equipment, there is potential for failure. The manufacturer (Reliance Electric) incorporated a number of safeguards which will detect any single point failure and shut down the process in a safe manner. In addition, at PPL we have designed both hardware and software features that will further enhance the integrity of the control system. Among them are watchdog timers that monitor the communication, through the I/O interface, the serial link to the control console, and the R-Net local area network. Upon detecting loss of communication, the system will selectively shut down.

4.4.4.2 Reference Signal Protection

The protective features for the reference circuit were designed to minimize the chance of producing excessive current due to failures in the reference signal amplitude or pulse length. Problems with amplitude are reported to the operator. Since PBX-M is operated in a pulse mode, the reference signal is only allowed in a window of time around T(O). At other times the reference circuit is disconnected from the power sources and grounded.

4.4.4.3 Overcurrent Protection

Each of the TF, OH, EF, IF, DF, T1, T2, T3, and T4 coils are equipped with a transductor that drives two integrating type overcurrent relays used for I^2t protection. The two units are set for selective tripping, the lower set unit disarms, the other disables the respective power subsystem. The instantaneous overcurrent trip also causes disable. The new implementation of these protective functions incorporates direct hardwired trips for both the disarm and disable signals. In the case of the OH and EF power supplies the hardwired disable opens the 4160V breaker, since these power supplies are not equipped with vacuum contactors.

4.4.4.4 Coil Cooling System

Each of the coils are cooled by deionized chilled water. There are approximately 100 inputs to the PBX-M controls system monitoring the status of over 500 flow and temperature switches. Any of these switches can disarm all operating systems by a global interlock. Some coils experience a larger temperature excursion after each pulse than others. In order to prevent temperature ratcheting, additional temperature switches (set to trip after each pulse) were installed on the OH, EF, and IF coils and are interlocked with the PBX-M Timer. The Timer is placed on hold until all these switches are reset.

4.4.4.5 *Hydraulic Clamp*

The unique demountable construction of the TF coils resulted in two joints in each coil. These joints are equipped with floating hydraulic clamps to impose a 2000 psi contact pressure on the joint and to allow relative motion of one coil with respect to another. The hydraulic system is operated at 8000 psi pressure and 40 pressure switches are used to monitor the pressure of each line. A pressure drop in the system would cause an increase in the electrical resistance at the joint which could result in thermal damage. The control system does not allow machine operation unless the pressure is normal.

4.4.5. Failure Mode and Effect Analysis

Critical failures for PBX-M operations, their effects, and both primary and secondary protection against those failures are shown in Table 5.14.

4.5 Radiation (J.R. Stencel)

4.5.1 Ionizing Radiation

The exposure history of the occupied areas having the greatest potential for personnel exposure is as follows:

In 1981 and again in 1982, the accumulative exposure doses to the PDX Control Room relative to PLT and PDX operation, did not exceed 200 mrem (St82, St83). In the first six months of 1983, these levels reached approximately 600 mrem (St84a, St84b) as PDX operations went into a period of extensive D-D runs before the PDX was shut down to become the PBX. In 1984, the levels were at 100 mrem (St85a, St85b) and in 1985, the levels were 365 mrem (Gi86). Because no individual spends his entire time in these areas, actual personnel exposures are much lower.

Occupational exposures are presently governed by Ch. XI of DOE Order 5480.1A (DOE81) and PPPL HSD-5008, Ch. 10. (HSD10). Draft Order 5480.11 is expected to be implemented by DOE within the next year.

Exposure control follows the as-low-as-reasonably-achievable (ALARA) philosophy. It is Laboratory Policy, that if an exposure is expected to exceed 1000 mrem/year, the Project Manager must petition the Executive Safety Board (ESB). If it appears that this level will be exceeded, the Project Manager will have to convince the Executive Safety Board that all reasonable measures have been taken to remain below this level. In no case will the dose be permitted to exceed the legal whole body exposure dose limits of 3 rem/quarter and 5 rem/year.

Radiation fluxes from the PBX-M are expected to be similar to the PBX, and at most, a factor of 2 higher (Ok86). The radiations involved are primarily neutrons (during D-D runs) and hard X-rays (Bremsstrahlung). Activation of vessel parts, as on PBX, are expected to be insignificant. Calculation of activation levels were done for PBX in 1980 (Sc80). This report postulated a 400 mrem/hour exposure rate at 1 minute after 500 pulses. Actual operations were such that measured levels were never measured to be over a few mrem/hour at the earliest occupancy after a run period. In any case, standard health physics procedures of radiation survey checks and wipe tests, when appropriate, have been, and will continue to be made before any maintenance or modification procedures begin.

Personnel will be monitored with radiation dosimeters supplied by an outside vendor. Personnel Dosimetry requirements for PBX-M will be established by the P&OS Health Physics Branch in accordance with the established criteria of HSD-5008 Supplement 10-1. *Records on exposure are kept by the PPPL Safety Office.* Health Physics will continue, as in the past, to do area monitoring which will consist of passive devices (film, track etch, Thermoluminescent Dosimeters (TLD)) supplied by an outside vendor and in-house TLD for radiation profile studies. Real time monitors our exposure rate at 1 minute after 500 pulses. Actual operations were such that measured levels were never measured to be over a few mrem/hour at the earliest occupancy after a run period. In any case, standard health physics procedures of radiation survey checks and wipe tests, when appropriate, have been, and will continue to be made before any maintenance or modification procedures begin.

The PBX-M will retain the same thick shield wall (32 inches of high density concrete) as was used for the PBX. There is no overhead shield on this facility so skyshine radiation will continue to contribute its share of the total exposure dose to occupied areas. Consideration was given to an overhead shield in 1979 (Gr79). However, because of the cost involved versus the small reduction in potential exposure, along with the knowledge of the operational history of this device, it was decided not to proceed with this task.

The PBX-M will also retain the Kirk interlock system, which prevents access to machine areas, that is, areas of greatest hazards which may include radiation during operation.

With the in-place shielding, interlocks, monitoring, and prior history of the PDX and PBX, no unusual or unique radiation problems are anticipated for the PBX-M.

4.5.2 Non-Ionizing Radiation

4.5.2.1 Lasers

The PBX-M, like its predecessors PDX and PBX, will use some lasers for diagnostics. These devices are regulated by HSD-5008 (HSD3) which follows ANSI Z136.1-1986 (ANSI86). Because these laser areas are interlocked during operations, the potential hazards are related to individuals involved in standard alignment and calibration procedures. These individuals by Laboratory Policy must be knowledgeable in the use of lasers, and where supervisors request, they will take part in laser training programs. Also all high powered class IV and most class IIIb lasers require written safe operating procedures.

4.5.2.2 RF/Microwave

RF/microwave heating is being considered for the PBX-M. The PPPL has had extensive experience with rf/microwave applications on the Princeton Large Torus (PLT) and are installing similar applications on TFTR.

Any such systems will have rigorous design reviews before implementation and all applications must meet with the requirements of the PPPL Health and Safety Directive on this topic (HSD4) and ANSI C95.1 (ANSI82). Surveys will be conducted in accordance with ANSI C95.5 (ANSI81) to ensure compliance with the present regulations. Interlocks would be used where appropriate and real time monitors (sniffers) would be installed for some specific frequency applications.

4.6 Fire Protection and Emergency Services

4.6.1 Fire Protection System

Fire damage is the principal property damage risk. The facility occupies parts of two floors of a multistory building. Both stories are protected by preaction, dry pipe automatic sprinkler systems with the second floor region designed for ordinary hazard occupancy. Fire alarm boxes and sprinkler annunciator alarms are connected through the fire alarm system to the fire and security headquarters which are manned at all times.

All fire alarms are also monitored by the plant monitoring system that provides information in a matter of seconds on the exact location of an alarm and on planned procedures. The system is computerized and includes the fire alarm boxes and sprinkler annunciator alarms for all PPPL occupied buildings. A Halon fire protection system is installed in the energy storage vault adjacent to the machine area. Smoke detectors that are located in the energy storage enclosure initiate the Halon release sequence, close the vents in the energy storage area, and shut off the ventilation fan.

The control room is protected by a Halon system. When the control room smoke detectors are triggered, dampers in the air conditioning ducts are automatically closed.

4.6.2 Fire Fighting Personnel and Equipment

The PPPL Emergency Squad, responds to all alarms with a pumper, a fully equipped emergency truck, and an ambulance, according to need. At least five full time fire fighters are available for each shift, 24 hours per day, seven days per week. (Another pumper truck serves as backup.) Under mutual aid agreements additional personnel and equipment from other plants and Plainsboro Township will respond and provide backup in the event of larger emergencies.

Any new power supplies that present an additional fire hazard will be installed in conformance with existing strict fire protection codes governing the building in which this experiment is housed. The capacitor-ignitron enclosure as well as the control room have Halon protection.

5.0 HAZARD ANALYSIS (Kees Bol/WBS Coordinators)

Accidents of sufficient severity to endanger continuation of program funding and their mitigation or risk acceptance are indicated in section 5.1 below. Other failure modes are listed in section 5.2.

5.1 High Consequence Accidents To Equipment

5.1.1 Machine Accidents

5.1.1.1 Mechanical Failures

A. Vacuum vessel buckling under combined electromechanical, gravitational, and atmospheric loading.

Analysis: The vacuum vessel, reinforced as per design, can withstand worst case loading under realistic dynamic conditions without stress limits being exceeded in either the vacuum vessel or its supports. The analysis is documented in Engineering Report (EAD R37 Rev. 1).

B. Failure of TF coils, especially the joints, under electromechanical stress (overturning moment).

Analysis: The TF coil points were a critical item in the original PDX design and are even more so in PBX-M. In the absence of a complete stress analysis, an operating limit has been established for the product of toroidal and poloidal field strength such that the TF joint stresses in PBX-M do not exceed those obtaining in PDX when it was operated at design conditions. By that criterion all PF supplies can be run at rated current for any TF current to 30kA; however, the margin of safety in the PDX design does not appear to have been documented.

Excessive coil currents would constitute a fault condition. Redundant overcurrent protection is provided for all power supplies as shown in Table 5-1. Except for the IF and TF it is a plausible assumption that the intrinsic current limits give adequate stress protection when the TF is held to 30kA.

Operation of the TF at full rating (43.7kA) is not covered by this document and will require further analysis as well as detailed operating procedures.

Table 5-1

System	$I^{(1)}_{op}$	$I^{(2)}_{max}$	$I^{(4)}_{1}$	$I^{(5)}_{2}$
IF	20	38	22	22
DF	10	15	11	11
T1	5	16	6	6
T2	5	17	6	6
T3	5	15	6	6
T4	5	14	6	6
EF	10	10	?	11
OH	20	25	22	22
TF	30	41(3)	?	33

Table 5-2

Coil	Max Fault T (°C)	Normal Max T (°C)	High Setting (°C)	Low Setting (°C)
OH 8/9, T&B	35	22	48-52	19-21
OH 7T	24	15	40-44	19-21
EF 21, T&B	20	12.3	40-44	19-21
IF 1	39	16	40-44	19-21
All other coils	-	-	40-44	-

(1) Design ratings
(2) Maximum currents power supplies can produce, given the primary reactance and the load resistance. (FR 1)
(3) Under-speed trip (2 shafts,4 x 2 generators)
(4) Instantaneous trip relay, power supplies
(5) Instantaneous trip relay, machine side

C. Failure of inaccessible buswork

Analysis: Buswork supports are presumed designed for operation at full parameters, but a comparison of design with "as built" status is not possible for the critical buswork to inner stack coils, nor were the original design criteria documented. The "as built" completely unsupported bus pair to OH8-9L was braced in 1983 through windows cut in the inner wall of the vacuum vessel and the matching upper pair does have some support. Fortunately, the PBX-M design currents in the remaining inner stack coils are reduced to half or less EF solenoid of the original values, so that even at full TF operation there will be a margin for those coils. Furthermore, the changed mode of operation of the OH, by allowing a much better balance of the +/-current swing, will reduce the maximum stress in those busleads for equivalent volt-second applications. The administrative application of signal level clamps will enforce the operating procedures to ensure this result.

D. Stressing EF coils by increasing rating from original design value of 7.2 to 10kA.

Analysis: A previous analysis showed operation at 10kA to be acceptable. Operation at 15kA, also contemplated at one time, would have required additional bracing of the coils themselves.

5.1.1.2 Electrical Failures

A. High resistance joint, leading to pitting, arcing and ultimate destruction, also to ignition of insulation by molten metal or the arc itself. Widespread soot can hamper machine operation though probably not force a permanent stop.

Analysis: Joints in TF buswork are monitored regularly. However, many bus joints in other systems are accessible only with difficulty, and the benefit of preventing an accident has to be balanced against the increased risk of causing one when reinsulation of the joint is carried out under very cramped and difficult conditions. In those cases the defense will be ex post facto, and will consist of much better fire and smoke detection for the Halon system than existed for PDX-PBX.

5.1.1.3 Overtemperature Failures

A. Deterioration or destruction of coil insulation and subsequent turn-to-turn shorts.

Analysis: To protect against insulation damage from overheated coils ($T > 0^{\circ}C$, CH87) PBX-M uses the following system: the shot timer is inhibited from beginning a new cycle until the water temperature in certain critical coils has dropped to a preset low temperature; I^2t relays limit the temperature rise from a credible fault current; and all systems are disarmed if any coil system exceeds a preset high temperature. The first two protect against damage from excessively high currents, from which the temperature rise of the copper far outruns the thermal measurement, and the third is protection against a steady current that exceeds the permitted level but which may fall in the "dead" zone of the I^2t relay.

Table 5-2 shows the coils that have been selected for special protection. All other coil systems have a fault temperature so low ($< 7^{\circ}C$) that an initial temperature just below the high temperature trip point will not result in damage from a subsequent fault. For the selected coils the opposite is true. Hence, it is necessary to ensure against insulation damage by starting a shot at a low enough coil temperature so a subsequent fault will not cause damage.

B. Fatigue failure of coils under repeated and excessive thermo-mechanical stress.

Analysis: Fatigue due to thermal cycling has not been found to be a problem where it has been examined.

5.1.2 Accident Sources External to Machine

5.1.2.1 Seismic

A. Collapse of shield wall.

<u>Analysis</u>: Unlike the remainder of the PBX-M shield wall, the older segment dividing PLT from PBX-M consists of stacked smooth rectangular blocks having no keying feature. An analysis undertaken in 1981 by the PPPL Mechanical Engineering Division to investigate raising the height of the divider, concluded that this should not be done without reinforcing the structure. A calculation by E. Kaminsky and E. Nelson carried out in 1980 showed the block wall separating PLT and (then) PDX to be unstable in case of an mpe event (i.e., a once-in-a hundred year earthquake). A job has now been initiated to brace at least that section of the shield wall.

5.1.2.2 Fire

<u>Analysis</u>: The machine area is protected by a Halon system. The smoke detection system is in process of being upgraded.

5.2 Failure Mode And Effects Analysis

The following tables are the Failure Mode and Effects Analysis for the reconfigured PBX-M Experimental Device.

TABLE 5-3

VACUUM VESSEL ASSEMBLY

FAILURE MODES AND EFFECTS ANALYSIS

Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
1. Vacuum Vessel Plate Sections	Maintain vacuum condition	A) Non-catastrophic air leaking external attachments	Torus interface values close; audible vacuum alarm warns operators. Stop operation, locate leak and repair.
		B) Catastrophic vacuum failure, as by implosion of a window	Vacuum alarm as above. Damage to pumps probable. Preventive measures: minimize window size; cover windows with plexiglass where compatible with diagnostic requirement; do careful checks for loose magnetic materials (tools, etc.) before each run.
		C) Leak in elastomer seal joining vacuum vessel components	Same as (A); however, many of the joints are inaccessible. Construction of the seal allows it to be pumped, providing some tolerance in seal quality.

Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
2. Vacuum Vessel insulating gap	Avoid short-circuiting OH voltage	Low resistance	Low voltage observed on internal flux loops and consequent inability to initiate discharge. Prevention: shield gap from plasma, debris. Corrective action: short defective gap and remove *shorting bars from* second gap, 180° away.
3. Vacuum vessel cooling/heating tubes on walls	Cool vessel during multigetter operation; heat during pumpdown	Leaks in cooling tubes	Loss of vacuum (see 1A). Cooling is not used; hot water heating only used during pumpdown. Corrective action: keep defective tubes under vacuum until next opening and then repair.
4. Internal active	Shape plasma	A) Leak in vacuum housing through defective weld	See 1A. Pump defective coil. If leak can be located, repair.
		B) Leak due to particle impact	See above. Preventive measures: exposed coils are shielded from neutral beams and plasma with graphite armor and with additional stainless steel shields.

TABLE 5-4

NEUTRAL BEAM INJECTION SYSTEM

FAILURE MODES AND EFFECTS ANALYSIS

Component	Function	Failure Mode	Failure Effect/Corrective Action
1. Neutral Beam-Torus Duct	Connects Neutral Beam to torus vacuum vessel; provides adequate clearance for beam	Missteering of ion beam	Potential impingement of beamline onto duct walls or components. Possible damage is prevented by duct scrapers which are positioned at the smallest section of duct to "scrape off" any beams diverging outside the defining aperture; and by water-cooled protective plates which prevent power deposition onto critical components of the main valve. Optical sensors at the duct scraper detect beam drift to provide for its correction.
2. Main Valve	Provides a seal between the torus and neutral beam vacuum enclosures when either vessel is pressurized while the other is under vacuum	A) Failure to fully open on command	A) Beam pathway to torus is partially or totally blocked preventing neutral beam injection. Beamline calorimeter remains in position blocking the neutral beam until the main valve is fully open.
		B) Failure to fully close on command	B) Inability to seal NB vacuum vessel from torus vacuum vessel when one vessel is pressurized, as required, until repairs are made.
		C) Leakage through valve seals	C) Failure effect and corrective action as in item 2, failue mode B). Removal of undesirable gas flow into evacuated vessel can be accomplished by the vacuum pumping systems or the NB cryopanels (if cold).

Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
3. Ion Source	Generates a low-volgage, high-current discharge to produce a plasma from which deuterium ions are extracted and accelerated	Filament or electrode (arc) short circuit	Greatly reduced generation of quiescent uniform plasma and deuterium ions in affected NBI's. Affected power supply (arc or filament) is automatically shut down and energy is safely dissipated without damage to affected NBI's or Neutral Beam Power Supply. NB operation can continue with the affected source shut down until repairs are made.
4. Ion Deflection Magnet	Deflect ions from the mixed beam leaving the neutralizer, onto the ion dump	A) Failure of magnet power supply	A) Ions are not deflected onto the ion dump but are sprayed onto the NB-torus duct. Duct scrapers and protective plates prevent damage to duct and duct components, as per item 1. Ion source is shut down by NB Power Supply. NB operation can continue in degraded mode until repairs are made.
		B) Break in electrical supply line to magnet, or break in magnet winding	B) See item 5, failure mode A).
5. Cryopumping System	Maintain proper vacuum conditions in the NBL from the deflection magnet to the torus end of the NB torus duct during normal operations	A) Cryogenic. line rupture	A) Release of cryogenic fluid(s), boil-off of of condensed gases on NB cryopanels, and pressure increase in Cryogenic Supply System (CSS). NB operation will cease and gate valve will close. Burst discs in the CSS will relieve any high pressure surge in the cryoplanels and CSS. Gases boiled off from the cryopanels can be removed by the Neutral Beam Vacuumm System. Absence of personnel in Test Cell during operations, as well as use of special procedures during maintenance will prevent hazards to personnel from released cryogens.

Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
		B) Loss or degradation of cryogenic supply to cryopanels	B) Effective pumping by cryopanels is degraded resulting in eventual shutdown of affected NBL. If fast warmup of cryopanels is involved, burst discs in CSS will prevent damage to cryopanels. Boiled off gases can be removed by NBVS.
6. Neutral Beam Vacuum Vessel	Provide main vacuum envelope for NBL	Major leakage or rupture	Pressure rise in the vessel will automatically shut down the NBL and close the absolute valves. Fast warmup of the cryopanels will cause burst discs in the CSS to relieve excess pressure and prevent damage to cryopanels.
7. Neutral Beam Line Cooling Water System (NBLCWS)	Provides cooling water to remove heat generated in ion sources, ion dumps, calorimeters, beam scrapers neutralizers, deflection magnets, and NB duct protective plates	A) Loss or degradation of cooling water supply to NBL components	A) Low water rate flow to and/or high water exit temperature from water-cooled components will cause interlocks in the NB Control System to shutdown the affected NB Power Supply(s) thus inhibiting NB operation. At least 10% of design water flow must be maintained in NBLCWS to prevent water freezing in components and piping subject to LN_2 temperatures, until temperature in the affected NBL components reach above-freezing levels.
		B) Leakage or rupture of cooling water line inside NB Vacuum Vessel	B) Loss of coolant would cause shutdown of of affected NBIS, as in item 8, failure A); cause pressure rise in NB vessel (detected by vacuum gauge readout in Main Control Room); and would result in vaporization of leaking water and subsequent (initial) condensation on cryopanels. Cryogenic supply to cryopanels will be shut down, and pressure rise in panels and CSS could cause burst discs in CSS to vent and relieve pressure. Gate valve will close and NBVS will be (remain) isolated from affected NBL. Water supply flow will be shut off as soon as possible, consistent with prevention of line freezing, and heatup of cryopanels. With increase in temperature of the cryopanels, condensed

	Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
				water will melt from cryopanels and collect at the bottom of the NB Vessel.
8.	Neutral Beam Injection System	Injection of Neutralized ions into the plasma providing auxilary heating	Loss of electrical power	All ion sources are automatically shut down, and gate valve closes. Cryogen flow to NB cryopanels is stopped and any pressure surges in the CSS or cryopanels are relieved by CSS burst discs and relief valves. Gases boiled off from cryopanels are released to NB vessel.

TABLE 5-5

VACUUM PUMPING SYSTEMS FAILURE MODES AND EFFECTS ANALYSIS

	Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
1.	Duct, Torus to High Vacuum Pump	Torus gas transmission, vacuum access to torus	Leakage	Pressure rise in torus and vacuum system detected by pressure instrumentation. Machine (PBX) operation and experiment interrupted-potential deuterium or hydrogen release to test cell area. Repair as soon as possible.
2.	Flange, Torus to High Vacuum Duct	Facilitate installation and structural joining, two flanges.	Leakage	Same as Item 1.
3.	Bellows, Joint Assembly; Torus to High Vacuum Duct	Torus motion isolation from high vacuum pumnp for each duct, two bellows.	Leakage	Same as Item 1.
4.	Ceramic Joint	Electrical Insulation	Leakage	Same as Item 1.
5.	Duct Bellows, Joint Assembly, High Vacuum Duct to TMP (41cm)	Motion isolation for each TMP in the TVPS	Leakage	Same as Item 1.
6.	Valve, Assembly TMP Inlet - High Vacuum Isolation TVPS	Isolation of TMP from torus vacuum vessel	A) Failure to close on command	A) Detected by valve position switch. If "Close" command is due to failed TMP, machine operation and experiment will be interrupted Bring torus up to atmosphere with N_2 gas. Repair as soon as possible.
			B) Failure to close on command	B) Detected by valve position switch. Machine operation continues in degraded mode. Repair at next scheduled maintenance period.
			C) Internal	C) Detected by pressure instrumentation.

Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
		leakage (across valve seat)	PBX-M operation will be interrupted. Bring torus up to atmosphere and repair as soon as possible.
		D) External leakage	D) Same as Item 1.
6a. Valve Assembly, TMP Inlet - High Vacuum Isolation	Isolation of TMP from NBL	A) Failure to close on command	A) Detected by valve position switch. Failure of valve to close will preclude NB operation due to excessive TMP pressure during Regeneration or oil back-migration if TMP failed. Vent NB with dry N_2 and repair as soon as possible.
		B) Failure to open on command	B) Detected by valve position switch. Machine (PBX-M) operation continues in degraded mode whereby the main roughing pumps regenerate NB cryopanels. Repair at next scheduled maintenance period.
7. TMP Assembly/TVPS (8)	High vacuum pumping of torus	A) Failure to start on command or stops running	A) Detected by pressure instrumentation. Isolation valve automatically closes. Machine operation continues in degraded mode. Repair at next scheduled maintenance period.
		B) External leakage	B) Same as Item 1.
8. TMP Assembly-NBVS(4)	Regeneration of Neutral Beam and initial pump-down from 10^{-1} torr	A) Failure to start on command or stops running	A) Detected by pressure instrumentation. Isolation valve automatically closes. Machine continues in degraded mode. Repair at next scheduled maintenance period. Can regenerate using roughing system.
		B) External leakage	B) Same as 1.
9. Duct, TVPS-TMP Discharge Vacuum	Access for gases from TMP to backing valve	Leakage	Same as Item 1. Isolate TMP assembly.

Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
10. Duct, NBVS-TMP Discharge Vacumn	Evacuate gases from NB	Leakage	Same as Item 1; unable to regenerate NB. Isolate TMP assembly.
11. Valve, TMP Backing TMP(TVPS)	Isolate TMP discharge from backing manifold	A) Failure to close on command	A) Detected by valve position switch. Shut down all TMP's and stop PBX-M operation. Repair or replace as soon as possible.
		B) Failure to open on command	B) Detected by valve position switch. Affected TMP is automatically shut down. Machine operation continues in degraded mode. Repair at the next scheduled maintenance period.
		C) External leakage	C. Same as Item 1.
12. Valve, TMP Backing (NBVS)	Isolate TMP discharge	Failure to close on command	Detected by valve position switch.
13. Pressure Gages for (8) TVPS-TMP's (3) NBVS-TMP's	Measurement of inlet pressure (vacuum status)	Erroneous indication	Redundancy provided by additional instruments. Machine operation may safely continue.
14. Valve, Torus Roughing Duct	Isolate torus from mechanical roughing/backing pumps. The duct in which this valve is located is also used to take suction on the torus (by the tritium cleanup system) when a leak occurs in the torus or vacuum system.	A) Failure to open on command	A) Detected by valve position switch. Rough pumping of torus is precluded.
		B) Failure to close on command	B) Detected by valve position switch. Torus is exposed to roughing manifold pressure and PBX-M operation is impossible (cannot achieve high vacuum). Repair as soon as possible.

Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
15. Valve, Foreline Trap Vacuum Inlet (TVPS)	Isolate foreline trap/backing pump from remainder of system	A) Failure to open on command	A) Detected by valve position switch. Can use redundant pump for TMP backing (will take longer for pumpdown). Repair at next scheduled maintenance.
		B) Failure to close on command	B) Detected by valve position switch. If "close" command is due to backing pump failure, vacuum system(s), PBX-M and/or neutral beam operations are shut down. Repair as soon as possible.
16. Roots/MP Pump Assembly Roughing (2)	Provide for rough pumping of the torus and neutral beams	Pumping ceases	Detected by pressure instrumentation. Rough pumping can proceed over a longer time interval using redundant pump. Isolate affected pump and repair at next scheduled maintenance.
17. Roots/MP Pump Assembly Backing (2 for TVPS) (2 for NBVS)	Provide backing for TMP's	Pumping ceases	Detected by pressure instrumentation. Redundant pump is capable of providing backing for all TMP's with full gas load. Isolate and repair at next scheduled maintenance.
18. Oil Demisters	Capture exhaust oil contamination from mechanical pumps	Oversaturation	Some oil contamination of exhaust line occurs, however, maintenance schedule will preclude this failure mode.
19. Backing/Roughing Pumps Exhaust Line	Transfer gas to atmosphere or tritium cleanup unit	Leakage	Detected by pressure instrumentation. Potential leakage of trace amounts of tritium. Area monitors will detect the low levels released and exhausted via the HVAC system. Shut down system (and PBX-M) and repair as soon as possible.
20. Solenoid Valve, TMP water inlet	Isolate coolant	A) Failure to open	A) Detected by cooling water flow switches. Coolant unavailable to TMP. TMP will automatically stop or be prevented from starting. Repair or replace at next scheduled maintenance period. Can continue to operate in degraded mode.
		B) Failure to close	B) Detected by cooling water flow switches. Close hand isolation valve and shut down TMP. Repair or replace at next scheduled maintenance period.

Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
		C) Leakage	C) Loss of cooling water detected by flow and/or temperature switches. Potential impact on electrical equipment. Close hand isolation valve and shut down TMP. Can continue operating in degraded mode. Repair at next scheduled maintenance period.
21. Valve, TMP Nitrogen Supply	Isolate vent gas	Failure to open	Detected by nitrogen supply pressure switch. Potential oil backstreaming upon TMP shutdown. Rebake of TMP plus valve repair or replacement required at next scheduled maintenance period.
		Failure to close	Detected by nitrogen supply pressure switch. Nitrogen delivery continues to TMP. Close TMP inlet and discharge isolation valves. Repair or replace at next scheduled maintenance period. Continue machine operation with remaining active TMP's.
22. Valve, TMP Oil Drain	Facilitate Oil Change	Leakage	Detected by oil level switch. Low oil level will result in automatic shutdown of TMP and closure of inlet and discharge valves. Continue operation with remaining active TMP's. Repair at next scheduled maintenance period.

TABLE 5-6

NITROGEN SUPPLY SYSTEM FAILURE MODES AND EFFECTS ANALYSIS

	Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
1.	Liquid Nitrogen Storage Tank	Stores the LN_2 supply on-site	A) Leakage	A) Loss of LN_2 detected by tank pressure indicator or level indicator (local). Isolate tank from supply system, and temporarily provide LN_2 from tank truck. Repair as soon as possible.
			B) Overpressurization	B) Detected by tank pressure instrumentation Excessive pressure precludes nominal service to loads. Pressure is relieved hand-operated valve relief valve (75 psig) or burst disc (90 psig). Repair as soon as possible.
			C) Underpressurization	C) Detected by valve position indicator. LN_2 cannot be transferred from tank to service loads. Shut down system and loads and repair as soon as possible.
2.	LN_2 Storage Tank Outlet Valve	Isolate storage tank from supply system and loads	A) Fails to close on command or fails closed	A) Detected by valve position indicator. LN_2 cannot be supplied to loads and will result in eventual shutdown of NBL's. Repair as soon as possible.
			B) Fails to close on command	B) Detected by valve position indicator. LN_2 storage tank can be isolated via closing of individaul service load supply valves (and later by hand operated valve). Repair as soon as possible.
3.	Vacuum Jacketed Supply Lines	Transmission of LN_2 supply to service loads	Thermal/leakage	Contamination of the LN_2 in the system with oxygen due to inleakage could cause a potential explosion hazard (if the leak is not repaired). Shut down Nitrogen System and affected load(s) until repairs are made.

	Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
4.	LN_2 Supply Valves to Loads	Isolate LN_2 supply to individual service loads	A) Fails to open on command or fails closed	A) Detected by valve position indicator(s). Supply of LN_2 to affected service load is prevented or interrupted. Shut down affected load until repairs are made.
			B) Fails to close on command	B) Detected by valve position indicator(s). When required, LN_2 supply can be isolated by closure of storage tank outlet valve which interrupts LN_2 supply to all service loads. Shut down system (and loads) and repair as soon as possible.
5.	Pressure Relief Valves Without Redundant Paths	Overpressure protection	A) Premature relief	A) Uncontrolled relief of LN_2 or GN_2 causes reduced system pressure and results in precluded supply service detected by pressure instrumentation. LN_2 supply is isolated by closure of storage tank outlet valve and system is shutdown until repairs are made.
			B) No relief	B) Detected by pressure instrumentation. Attempt to depressurize faulty leg. Effect repair as soon as possible.

TABLE 5-7

POLOIDAL FIELD COIL AND NEUTRAL BEAM POWER DISTRIBUTION SYSTEM FAILURE MODES & EFFECT ANALYSIS

Component	Function	Failure Mode	Failure Effect/Corrective Action
1. Power Main Leads	Transfer energy feeding power convertors buses	A) Failure to start on command (Breaker fails to close)	A) Failure will prohibit transfer of power No PBX-M operation. Facilitate repair as soon as possible.
		B) Breaker fails to open	B) Power flow continues to distribution system. Stored energy in the coils will be dissipated by intrinsic resistance with-in the coils and Pulsed Energy Con version System circuit. 4.5 kV distribution breakers will be tripped, and system and PBX-M will be shutdown. Facilitate repair as soon as possible.
		C) Overvoltage operation	C) Will result in 5 kV overvoltage for 60 milliseconds. System is designed for this operation mode. Breaker(s) open.
		D) Overcurrent operation	D) Thermal stress (I^2T) on system occurs during pulsing operation. System is designed not to exceed predicted (I^2T) thermal stress. Relays detect situation and open breaker(s).
		E) Short to ground	E) Protective relaying will cause breaker to trip removing power. PBX-M operation ceases. Facilitate repairs as soon as possible.
		F) Loss of control power	F) Breakers have stored energy mechanism which will enable manual operation to isolate the distribution system. PBX-M operation ceases. Facilitate repair as soon as possible.

Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
2. 5 kV Switchgear and Current Limiting Reactors	Distribute power to individual energy conversion systems	A) Failure to start on command (Switchgear breaker fails to close)	A) Failure will prohibit transfer of power to affected energy conversion system, and related sub-system operation cannot take place. Facilitate repair as soon as possible.
		B) Failure to stop on command (Switchgear breaker fails to open)	B) Power flow continues to subsystem. Upstream breaker can be manually operated as a backup trip. PBX-M shutdown; facilitate repairs as soon as possible.
		C) Overvoltage operation	C) See item 1, failure mode C).
		D) Overcurrent operation	D) See item 1, failure mode D).
		E) Short to ground	E) Feeder reactors sized to limit fault to effective breaker rating.
		F) Loss of control	F) See item 1, failure mode F). Individual feeder breakers can be manually operated.
		G) Inadvertent switching under load	G) Loss of power to feeder circuit. No power transferred to affected systems. These systems are shut down until power is restored.
3. 5 kV Cable	Facilitate power transmission from switchgear to Field Coil and Neutral Beam power supplies.	A) Overvoltage operation	A) Feeder cables designed to 133% insulation level to permit 60 millisecond, 8 kV operation. System operation can continue after overvoltage is cleared.
		B) Short to ground	B) Feeder breaker ground fault relaying will trip breaker. Affected Field Coil or Neutral Beam is prevented from operating. Facilitate repair as soon as possible.

Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
4. Field Coil and Neutral Beam Distribution System	See Section 7.2.3.1	Fire	System will be shut down by protective devices. Fire detection in the MG Building, East Building, or Experimental Area will preclude the existence of an undetected fire of destructive magnitude. Automatic sprinkler and Halon systems in these areas will suppress and control any fires .

TABLE 5-8

AUXILIARY SYSTEMS POWER DISTRIBUTION
FAILURE MODES AND EFFECTS ANALYSIS

	Component	Function	Failure Mode	Failure Effect/Corrective Action
1.	480V Feeder Circuit Breakers	Connects 4.16 kV Feeder to 480V switchgear bus.	A) Failure to close	A) No power to Feeder. Supply auxiliary power with an alternative feeder and circuit breaker. Check and repair breaker or control circuit.
			B) Overheating poor contacts	B) No power to Feeder. Supply auxiliary power with alternate feeder and circuit breaker. Check load on circuit. Preventive maintenance will minimize occurrence.
			C) Explosion	C) No power to Feeder, damage to switchgear, and potential fire. Extinguish fire. Check overcurrent relays and load on circuit. Preventive maintenance will minimize occurrence.
2.	4.16 kV Feeder Cable	Connects 4.16 kV subsystem to feeder circuit breakers	Short circuit; grounded	Trips circuit breaker. Supply power with alternate feeder. Prevent through periodic inspection.
3.	4.16 kV/480V Transformers	Energizes 480V bus	Internal short circuit	Primary fuse blows; no power supplied to 480V bus by affected transformer. Supply loads through alternate transformer.
4.	480V Substation Circuit Breakers	Connects transformer to 480V bus	Failure to close, overheating, or poor contacts	No power to load through affected substation breaker. Supply loads through alternate transformer and its substation breaker.
5.	4.16 kV Motor Control Center	Starts and stops motors for chillers; provides motor running protection	Contacts will not close, or MCC trips off	No power to chiller motors; loss of HVAC system chilled water. Shutdown PBX-M. Repair as soon as possible.
6.	480 V Feeder Cable	Connects 480 V subsystem to feeder circuit breakers	Short circuit; grounded	See item 2

Component	Function	Failure Mode	Failure Effect/Corrective Action
7. 4160V/480V Transformers	Energizes 480 V switchboards	Internal short circuit	Primary fuse blows; no power supplied to 480 V bus by affected transformer. Supply loads through alternate transformers by closing their disconnect switches and interconnecting bus manual circuit breakers.
8. 480 V Automatic Transformers Circuit Breakers	Connects transformers to 480 V bus	Failure to close, overheating, or poor contacts	No power supplied to bus through affected substation protector. Supply loads through alternate transformer and substation protectors by closing their disconnect switches and interconnecting bus manual circuit breakers.
9. 480 V Motor Control Centers	Starts and stops motors for various auxiliary system equipment; provides motor running protection.	Contacts will not close or trips off	No power to affected auxiliary system motor(s). Cessation of PBX-M operation may be necessary. Repair as soon as possible.
10. 4.16 kV/480 V Standby Power Transformer and Network Protector	Energizes 480 V switchboards by connection to diesel generator during loss of off-site power.	Internal short circuit (transformer); failure to close, overheating or poor contacts (network protectors)	No power to 480 V loads during loss of off-site power. Shut down PBX-M. Repair as soon as possible.
11. Diesel Generator "Substation" Circuit Breaker	Connects diesel generator to 4.16 kV bus during loss of off-site power.	Failure to close, overheating, or poor contacts	No power to all auxiliary loads during loss of of offsite power. Shut down PBX-M. Repair as soon as possible.

TABLE 5-9

TOROIDAL FIELD PULSED ENERGY CONVERSION SYSTEM (MG SETS)
FAILURE MODES AND EFFECTS ANALYSIS

Component	Function	Failure Mode	Failure Effect/Corrective Action
1. Transformer	Supplies AC power to drive MG sets	A) Turn to Turn Short	A) The ac breaker trips in 5 cycles (60 Hz) and the dc output voltage is reduced by 41 kV. Detected by oil pressure detection and winding temperature sensing; generates fault signal. The experiment is terminated. Shut down PBX-M.
		B) Overheated	B) See item 1, Failure Mode A)
		C) Loss of Cooling Oil	C) Detected by oil level gauge, oil flow indicator, and oil temperature detection. Failure effect and corrective action are the same as for item 1, Failure Mode A)
		D) Ground Fault	D) Detected by AC ground fault detection, and equipment. Failure effect and corrective action are the same as for item 1, Failure Mode A)
		E) Fire	E) Detected by oil pressure and oil temperature detection. Effect is limited by outdoor installation, and provision of crushed stone and drainage to prevent oil accumulation outside of transformer. Fire would be extinguished manually by use of outdoor apparatus. PBX-M is shut down.
2. MG	Converts AC to DC; supplies and controls the DC current in the coils.	A) DC terminals of a generator section shorted.	A) No output voltage across generator output. Detected by relaying. Shut down PBX-M.
		B) Fire	B) Detected by MG housing heat detectors. Fire is suppressed by CO_2 discharge within the housing. PBX-M is shut down.

Component	Function	Failure Mode	Fault Detection & Effect/Corrective Action
3. Metal Enclosed DC Equipment	Coil overvoltage protection and personnel safety.	A) Disconnected ground cable.	A) Ground protection exists in ground protection system which shut down PBX-M.
		B) Fire	B) Smoke emitted would be detected by MG Building smoke detectors. Damage to equipment could cause loss of function and consequent shutdown of PBX-M. Fire spread would be limited by metal enclosure, with extinguishment by CO_2, Halon, or by manual means.
4. AC and DC Cables	Connect converter transformer to the power supplies and coils to the power supplies, respectively.	A) Loose connection	A) Can result in overheating and damage to insulation, and possible loss of one or more cables. Experiment is terminated. Periodic inspection of high current terminations corrects loose connections.
		B) Ground Fault	B) Detected by ground fault relay trip. May cause large fault currents and unbalance ground potentials. Experiment is terminated.
		C) Fire	C) Detected by ground fault relay or by building smoke detector. Fires inside MG Building would be extinguished by CO_2 and Halon systems; fires outside the building would be extinguished by manual means.
		D) Excessive Cable Movement	D) Power testing has shown that movement of high current pulsed cables and bus during normal and postulated fault conditions is prevented by the restraints that have been installed.

TABLE 5-10

OHMIC HEATING PULSED ENERGY CONVERSION SYSTEM
FAILURE MODES AND EFFECTS ANALYSIS

Component	Function	Failure Mode	Failure Effect/Corrective Action
1. Transformer(s)		See 7.3.1-1	Item 1
2. Power Supply	Converts ac to dc; supplies and controls the dc current in the coils.	A) DC terminals of a power supply section shorted.	A) No output voltage. Detected by power supply internal (hard-wired) Power supply trips off. Shuts down PBX-M until bypassed or repaired.
		B) Loss of one module	B) See Table 5.2-7, item 2, Failure Mode B).
		C) Commutation failure	C) Experiment tails. Power supply trips off. Check for operator misadjustment, if not repair.
		D) Loss of cool ing water	D Power supply trips off. Investigate cause, repair or adjust as necessary.
3. Ignitron Reversing Switch.	Reverses the direction of the OH Coil current.	A) Switch stays closed in re-response to an open command.	A) Shorts out supply causing overcurrent trip. Investigate cause, repair or adjust as necessary.
		B) Switch closes.	B) See 5.2-8, 3.A.
4. The Energy Dissipation System	Generates high voltage for plasma initiation.	Dissipation resistance opens.	High voltage across the OH power supply and coil. Overvoltage protection system will prevent equipment damage. The experiment is terminated.
5. Metal Enclosed DC Equipment (Disconnects)	See Table 5.9 item 4		
6. AC and DC Cables	See Table 5.9 item 5		

TABLE 5-11

EQUILIBRIUM FIELD PULSED ENERGY CONVERSION SYSTEM FAILURE MODES AND EFFECTS ANALYSIS

	Component	Function	Failure Mode	Failure Effect/Corrective Action
1.	Transformer	See Table 5.10 item 1.		
2.	Power Supply	See Table 5.10 item 2.		
3.	Metal Enclosed DC Equipment	See Table 5.10 item 5.		
4.	AC and DC Cables	See Table 5.10 item 6.		

TABLE 5-12

NBPSS FAILURE MODES AND EFFECTS ANALYSIS

Component	Function	Failure Mode	Failure Effect/Corrective Action
1. PPS HV Transformer	Converts 3 phase AC power to DC power	A) Grounded or transformer winding.	A) Breaker trips on closing. Affected power supply cannot be operated but NB operation can continue in degraded mode. Replace and/or repair transformer. Check condition of rectifier stacks.
		B) Open transformer winding.	B) Reduced power available from Primary Power Subsystem. Affected NBIS operation is degraded. Replace and/or repair transformer.
2. PPS HV Rectifier		A) Open rectifier stack	A Reduced DC current output or no power. Affected ion source is degraded or inoperable. Replace and/or repair rectifier stack.
		B) Shorted rectifier stack	B) If one or more series rectifiers are shorted, each of the remaining rectifiers will be subjected to a higher voltage and may eventually fail into a line to line short. Affected ion source may become inoperable (breaker will trip on closing). NB operation can continue in degraded mode. Replace shorted rectifiers.
		C) Combustible gases in transformer	C) Possible internal explosion and damage to transformer with resultant inoperability of affected ion source. Potential damage to adjacent equipment is mitigated by the physical separation of adjacent equipment in the switchyard and by the enclosure of the transformers in steel jackets which would prevent equipment damage from any small missiles which may result from an internal explosion in a transformer. This failure mode and effect will be prevented

Component	Function	Failure Mode	Failure Effect/Corrective Action
			by running a dissolved gas analysis on a continuing basis, using built-in gas detection equipment; if arcing is indicated, preventative maintenance procedures will be followed.
3. PPS capacitor bank (filter)	Provides local energy storage for Modulator Regulator, as well as transient compensation.	A) Shorted or ruptured capacitor	A) Higher stress level on the remaining units. Affected ion source operation can continue. Determine the location of the shorted capacitor and replace at next scheduled maintenance period.
		B) Open capacitor	B) Increased ripple to Modulator/Regulator. Affected ion source operation can continue. Determine the location of the open capacitor or blown fuse and replace at next scheduled maintenance period.
4. Modulator/ Regulator	Provides control and regulation of accel voltage pulses.	A) Fails to turn on	A) The power pulse is not delivered and delivered and affected ion source cannot be operated. NB operation can continue in degraded mode. Determine the location of the failed component and repair and/or replace.
		B) Fails to turn off	B) Power to Ion Source could be extended with possible damage to Ion Source and/or Modulator/Regulator. Time-out of arc and filament will prevent such damage. Affected NBIS cannot be operated but degraded NB operation can continue. Determine the location of the failed component and repair and/or replace.
		C) Loss of cooling water	C) Power pulse to affected M/R is prevented or terminated automatically. Operation of affected ion source is precluded but NB operation can continue in degraded mode. Repair and/or replace affected equipment.
5. Auxiliary Subsystem Power Supplies	Provides arc, filament and decel power to the Neutral Beam Ion Source.	A) Failure to turn on	A) Affected auxiliary power pulse for one ion source is not delivered. Operation of affected NBIS is degraded or precluded; NB

Component	Function	Failure Mode	Failure Effect/Corrective Action
			operation can continue in degraded mode. Determine the location of the failed component and repair and/or replace.
		B) Failure to turn off	B) Extended power pulse to element(s) of the Neutral Beam Ion Source with possible damage to the Ion Source. Protection against catastrophe afforded by AC breakers and rectifier fuses. Affected ion source cannot be operated but NB operation can continue in degraded mode. Determine the location of the failed component and repair and/or replace.
		C) Decel voltage goes off while the accel supply is on	C) Current on all grids goes up with resulting overheating and possible damage: Interlock removes accel voltage. Other corrective action as in item 5, Failure Mode B.
		E) Loss of cooling water	E) Operation of affected power supply(s) is automatically prevented or terminated and affected ion source is shut down. Operation of affected ion source is precluded but NB operation can continue in degraded mode. Repair and/ or replace affected equipment.
6. NB Control Subsystem	Provides control and monitoring of the NBPS.	A) Loss of control power	A) Ion Source power pulse will be terminated and the affected ion source will be safely shut down. NB operation can continue in degraded mode, if a partial failure. Determine failed component and repair and/or replace.
		B) Instrumentation malfunction: missing or erroneous data	B) Incomplete or faulty process information detected by operator. Shutdown affected beam line. Locate source of error and make the necessary adjustments or repairs.

TABLE 5-13

DIESEL GENERATOR SYSTEM FAILURE MODES AND EFFECTS ANALYSIS

Component	Function	Failure Mode	Failure Effect/Corrective Action
1. Diesel Generator Support Systems (Fuel Oil, Lube Oil, Cooling Water, and Starting Systems)	To start the diesel engine and maintain the engine temperature, lubrication and fuel oil at optimum operating levels	Failure to carry out required function	Detected by affected support system parameter monitors, and/or by generator speed monitor. Diesel engine fails to start or is shutdown automatically (see note (a) below).
2. Diesel Generator Breaker	Connects diesel generator with 4.16 kV bus	Failure to close on command, overheating, or poor contacts	Absence of current in 4.16 kV and 480 V subsystems detected by 4.16 kV load feeder ammeters, and 480 V switchboard bus feeder wattmeters, voltmeters and/or ammeters. Diesel generator cannot supply power (see note (a) below).
3. 5 kV Cable Intertie	Connects diesel generator breaker with 4.16 kV bus	Short or open circuit	Failure causes trip of generator breaker. Diesel generator cannot supply power (see note (a) below).

(a) In the event that PBX-M's primary power distribution fails and the Diesel Generator fails to start, operate or deliver power, the facility will go into a safe shutdown status. This means that by way of the hardwired interlocks required of each system the power supplies will shut down, energy will be dissipated safely, valves to vacuum systems will close.

TABLE 5-14

PBX-M CONTROL SYSTEM PROTECTIVE FUNCTIONS

Component	Function	Failure Mode	Failure Effect/Corrective Action
PLC Memory	PLC System Hardware	Random output pattern	Internal diagnostics - Disable/ External watchdog timer - Disable
PLC Processor		Random output pattern	Internal watchdog timer - Disable External watchdog timer - Disable/
I/O Communication		I/O not being updated	External watchdog timer - Disable/ Internal diagnostics - Disable
I/O Rail		Random I/O pattern	Internal diagnostics - Disable/ External watchdog timer - Disable
Output point stuck		Loss of control	H.W. Master disable (OPERATOR) Emergency shutdown (OPERATOR)
Input module fails		Loss of status	Software check
R-NET Communication		Loss interlocks	Internal diagnostics - Disable/ R-NET watchdog timer - Disable
Control PNL comm.		Loss of control	PLC - Disable/panel shut down--None
Scan stops	PLC system Software	Loss of control	Internal diagnostics - Disable/ External watchdog timer - Disable
Ref. hits amplitute limit	Reference signal	Coil damage	Warning message Overcurrent RLYS - H.W. Disable
REF. Signal too long		Coil overheating	Window unit time-out/ PLC - Disarm
REF. at wrong time		Unwanted pulse	Window unit blocks it / None
High current fault	Coil overcurrent	Thermal damage	Overcurrent RLYS - H.W. disarm Overcurrent RLYS - H.W. Disable
Low current exceeds steady state rating		Mechanical stress	Overcurrent RLYS - H.W. Disarm
Inst. overcurrent			Temperature switches - Disarm Overcurrent RLYS - H.W. Disable
Flow problem	Coil cooling system	Loss of cooling	PLC disarm on flow PLC disarm on temp. sw.

TABLE 5-14

PBX-M CONTROL SYSTEM PROTECTIVE FUNCTIONS

Component	Function	Failure Mode	Failure Effect/Corrective Action
Temperature trip		Coil overheating	PLC disarm - none
Recycle too fast		Temp ratcheting	Timer recycle inhibit PLC disarm on temp sw.
	Hydraulic clamps		
Low pressure		TF joint overheating	PLC2 disable - PLC1 global intlk - disable

6.0 QUALITY ASSURANCE (R.F. Parsells)

PBX-M has operated under the guidance of a specifically tailored version of NQA-1 titled PBX Modification Plan of Conformance, PPPL Technical Operations Manual of Procedures, No. EP-PBX-M-001, February 11, 1986 (see Appendix A). This document has been supplemented with the PBX-M Design Review Procedure, No. PPPL-EP-001, (see Appendix B).

6.1 The Project was audited against the Design Review Procedure in May of 1986.

6.2 The Project was assigned a Work Package Coordinator (WPC) for Quality Assurance by PPPL QA/R Department head. The QA WPC reports to the Project Manager and works with each of the other WPC's to plan and schedule QA/QC activities.

6.3 Table 6-1 shows the assurance controls currently legislated for the safety aspects of the operational phase of PBX-M.

7.0 CONDUCT OF OPERATIONS (K. Bol)

7.1 Organization

The Laboratory has compiled a set of Health and Safety Directives (HSD's) which describe safety organization and responsibilities. Safety at PPPL is considered to be a line responsibility extending throughout the line organization to all Laboratory employees. The Project and Operational Safety Office maintains a close liaison with the PBX-M staff to provide input to PBX-M on safety related issues. A project safety coordinator has been assigned to provide a single point of contact between the P&OS and PBX-M organizations. Additionally, the PPPL Safety Office provides an independent audit function of safety processes. Also area safety coordinators are assigned to all areas of the Laboratory in accordance with HSD-5002 (HSD5).

7.2 Training

Training is addressed in HSD-5028 (HSD6). The Laboratory has an active safety training program.

All devices at PPPL including PBX-M require skilled and well-trained employees. Specifically, in the area of safety training, sessions have been held on fire protection systems, including Halon. All training will meet the requirements and standards of the Laboratory. The PBX-M project managers will be responsible for identifying employee deficiencies and ensuring their enrollment in required courses.

TABLE 6-1

CONFIGURATION CONTROL

TOPIC	CONCEPT DESIGN REVIEW	PRELIMINARY DESIGN REVIEW	FINAL DESIGN REVIEW
Functional Requirements	Baseline, Approved	Changes	Changes
Specifications	List	Modification, Status	Approved Specification
Design Approach	Sketchs & Family Tree	Layouts, Family Tree	Drawings, Complete
Reliability	Preliminary Assessment	Update	Update
Fabrication Methods	Anticipated	Update	Update, Special Tools
Procurements	List, preliminary	List	Final List
Schedule	Preliminary	Update	Update
Cost	Preliminary Estimate	Status	Status
Verification			
Inspection		List critical	Special Instruction, Procedures, Tooling etc.
Test	Preliminary Test Plan	Test Plan, Draft	Test Plan/Test Procedures/ Test Equipment
Qualification	Proposed	Update	Quality Test Results
Risk	Preliminary	Critical Areas	Final Assessment
Integration & Assembly		Preliminary Plan	Plan & Procedures
Safety	Preliminary	Update	Update

* The above partial listing of topics and documentation to be evaluated at each Design Review is for guidance only, subject to appropriate modification, expansion, or revision by the Design Review Working Group Chairperson.

7.3 Testing Program

Preoperation and operational testing is conducted on all new equipment, components, or structures. Written procedures are used for new tests and are signed off by P&OS. New operating parameters which have a potential for radiation production are monitored by P&OS and subsequently released for routine operation by written memo or radiation work permit (RWP).

7.4 Configuration Control

Formal configuration control was set up for the design phase of PBX-M and is described in PBX Modification Plan of Conformance, PPPL Technical Operations Manual of Procedures, No. EP-PBX-M-001, February 11, 1986, (See Appendix A). This document has been supplemented with the PBX-M Design Review Procedure, No. PPPL EP-001, (See Appendix B).

7.5 Procedures

HSD-5015 (HSD7) encourages written procedures for most operations and requires them for unusual hazards. The PBX-M project uses written procedures in accordance with this HSD.

7.6 Safety Review System

An independent safety review is provided by HSD-5014 (HSD8). New systems procedures will have safety review and signoff. In addition, the area safety coordinator will note deficiencies on a daily basis and management will schedule safety walk-throughs of the area.

7.7 Emergency Planning

Emergency plans follow the requirements of HSD-5007 (HSD9). This is a Laboratory wide plan which addresses emergencies site-wide, and defines responsible individuals, training programs, and emergency drills and exercises.

8.0 ACKNOWLEDGMENTS

The editors wish to acknowledge the hard work of the authors which are listed for the various sections and on the title page of this report. In addition the work of H. Takahaski, M. Pelovitz, F. Lawn, S. Kaye, M. Okabayashi and L. Gereg in providing inputs to the weekly meetings which bears on the safety of the project is gratefully acknowledged.

Project leadership was provided initially by D. Kungl and later by D. Huttar. K. Bols and M. Okabayashi provided the overall direction for the project.

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HSD5 PPPL Health and Safety Directive, HSD-5002, Safety Organization.

HSD6 PPPL Health and Safety Directive, HSD-5028, Training.

HSD7 PPPL Health and Safety Directive, HSD 5015, Written Operating Procedures.

HSD8 PPPL Health and Safety Directive, HSD 5014, NJ Worker Right to Know Compliance Program.

HSD8 Health and Safety Manual HSD 5008, Section 8, "Industrial Hygiene."

HSD9 PPPL Health and Safety Directive, HSD 5007, Emergency Preparedness Plan.

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QUALITY BULLETIN

APPENDIX A

SUBJECT	PROCEDURE EP-PBX-M-001 PBX Modification Plan of Conformance

NUMBER QAB-018

DATE 14 February 1986

PAGE 1 OF 13

SUPERSEDES NO

DATED

Please review the attached procedure, and retain for reference.

H. Allen
J. Alton
D. Barnes
K. Bol
J. Clark
S. Davis
H. Eubank
E. Fredd
C. Gegick
R. Gould
D. Grove
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D. Huttar

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H.P. HOWARD

MANAGER OF QUALITY ASSURANCE

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DISCARD THIS BULLETIN AFTER NOTING CONTENTS. ☐

THIS BULLETIN WILL BE INVALID AFTER (DATE)______. ☐

THIS BULLETIN WILL BE INCORPORATED INTO QUALITY PROCEDURE NO.__________BY (DATE)______. ☐

Form 2.1.2-1

TITLE			PROCEDURE NO.
PBX MODIFICATION PLAN OF CONFORMANCE			EP-PBX-M-001
PREPARED R.F.Parsells	REVIEWED H.P.Howard	APPROVED K.Bol	DATE 11 February 1986
			REPLACES ISSUE
			REV / PREPARED / APPROVED

1.0 INTRODUCTION

1.1 Purpose

This plan describes those PBX-M policies, practices, procedures, and protocols that are (or will be) in place to:

a) Provide the project framework for achieving the specified project goals.

b) Provide and control the documentation to support system design, building, and commissioning requirements, and to baseline operation and maintenance.

c) Provide for problem visibility so that the system performance can be optimized by appropriate improvements.

1.2 Applicability

This plan is applicable to all hardware, software, and facilities associated with the design, modification, commissioning, operation, and maintenance of the PBX-M.

1.3 Heritage

This document complies with the intent of ANSI/ASME NQA-1, Chapter II, and PPPL-QAP-001.

2.0 REFERENCED DOCUMENTS

The following referenced documents are applicable to the extent specified:

ANSI/ASME NQA 1 (1983)		Quality Assurance Program Requirements for Nuclear Facilities
PPPL QAP-001	(June 1984)	Quality Assurance Program
PPPL QAP-009	(January 1985)	Nonconforming Material Control
PPPL EP-001	(TBD)	Design Review

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3.0 REQUIREMENTS

The following generally follows the paragraphing of NQA-1 and PPPL QAP-001.

3.1 Organization

3.1.1 Project Organization

The organization chart for the PBX-M and the PPPL Quality Assurance group is shown on Appendix 1.

3.1.2 PPPL Quality Assurance Scope

PPPL Quality Assurance is responsible for assuring that a Quality Assurance Program (QAP) is established and that activities affecting qualilty have been accomplished in accordance with prescribed plans. Quality Assurance has sufficient authority, access and organizational freedom to identify quality problems; initiate, recommend, or provide solutions to such problems; and to verify implementation of solutions.

3.1.2.1 Quality Assurance Personnel

Quality Assurance personnel assigned to the project have the following duties in meeting the above objectives:

- o Identify procedures and other documents needed to support the PBX-M Quality Assurance Program.
- o Develop, approve, maintain, and implement quality assurance procedures and other documents.
- o Determine the need and scope of qualilty assurance inspections and audits.
- o Support and approve the selection of quality assurance requirements.

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- o Review all procedures, instructions, and policies which make up the Quality Assurance Program.
- o Participate in decisions concerning the qualifications of supporting suppliers and subcontractors.
- o Establish requirements for quality assurance training and indoctrination.
- o Report periodically to management on the status of the Program, its accomplishments, and its problems.
- o Approve the disposition of nonconformances and corrective actions. (See PPPL QAP-009, Nonconformance Control)
- o Provide a permanent member to project boards associated with change control, design review, test procedure, test acceptance, system and subsystem readiness, etc.

3.1.2.2 Project Review Boards

The following boards have or will be established to control the approval, release, and change of various critical project elements.

Design Review--per PPPL EP-001 (TBD)

Configuration Control--per the PPPL Drafting Manual, but tailored to specific PBX-M requirements.

Material Review--per PPPL QAP-009, tailored for PBX-M conditions.

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3.2 PBX-M Quality Assurance Program

3.2.1 *Objective*

The primary objectives of the PBX-M are defined in A Proposal for an Upgrade of PBX (PBX-U) 3 July 1985.[1] The scope of work to implement these objective is defined in the PBX-U Offical Planning Document June 14, 1985.[1] The framework for structuring this effort is defined in this document. Project success will be achieved by PBX-M Management providing the motivation and support for assuring that this framework for project activities is defined, communicated, and inplace throughout the design, build, commissioning, and operational phases. The focus of this program is the early detection of problems, timely fixes and subsequent correction action.

3.2.2 Relationship to PPPL Quality Assurance Program

QAP-001 (and its supporting procedures) is supplemented by this document. Both shall be used to baseline design, installation, commissioning, operations, and maintenance, of the PBX-M. This Quality Assurance Program Plan may be modified to meet changed requirements.

3.2.3 Codes and Standards

Nationally recognized codes and standards, such as ANSI, ASME, or IEEE shall be used in the design, fabrication, testing, installation, operation, and maintenance of the PBX-M. When a recognized standard is not available but the need is obvious, a suitable project standard shall be formulated. H&S Manual

3.2.4 Training of Personnel

Technical and craft personnel who perform special process or who require unique system knowledge shall be given appropriate training. The extent and status of this training shall be documented.

1. Project name revised to PBX-M (modification)

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3.2.5 Responsibility

Management of the organizations using project resources shall verify the validity of this framework for their activity and shall assure its effective implementation.

3.3 Design Control

3.3.1 Procedures and Policies

PPPL established procedures and policies shall be used in developing design disclosure documents (specifications, drawings, procedures, manuals, etc.). These procedures and policies may be supplemented by equivalents that establish project unique policy for design, build, and operational documentation requirements.

3.3.2 Design Reviews

All design packages shall be verified by design reviews compliant with the intent of PPPL-EP-001. The design reviews shall be aided by alternate calculations or qualification testing programs, if needed. Personnel performing design reviews shall have the knowledge, experience, and skills appropriate to the subject design, but shall not have direct design responsibility.

3.3.3 Change Control

Design changes subsequent to FDR shall be approved at the weekly meeting of the PBX-M Project coordinators. Design changes shall be controlled and performed according to approved project procedures. (TBD). Subsequent to achieving full operational readiness all change control shall be incorporated into the PBX-M ERB/MCCB. (TBD)

3.4 Procurement Document Control

3.4.1 Procurement Practice

PPPL Procurement Manual procedures (specifically the "Requisitioner's Manual") describe the system that shall be used for procurement of project items.

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3.4.2 Quality Requirements

Cognizant technical personnel, (subject to Quality Assurance review and approval per Technical Operations Directive 002,) have the responsibility to determine quality requirements of purchased items.

All basic technical requirements such as drawings, specifications, codes, and standards shall be a part of the procurement documents. Procurement documents shall separately define all deliverable documentation.

3.4.3 Post Award Controls

The applicability of a preaward survey, source inspection, and site audits shall be jointly determined by Quality Assurance and the congnizant engineer. Access to supplier's plant facilities and inspection records shall be specified in procurement documents when determined to be necessary.

3.4.4 Subtier Supplier Requirements Passdown

When a PPPL supplier uses a subtier supplier for an item or service, the requirements of the PPPL contract shall apply.

3.5 Instructions, Procedures, and Drawings

3.5.1 Critical Fabrication, Test, Inspection, or Operational Procedures

PBX-M technical management and project Quality Assurance will determine the applicability of formal procedures based upon the criticallity of the event, its ability to be retrieved when improperly performed, and the value in assuring system or component readiness. Activities affecting quality shall be prescribed and accomplished in accordance with instructions, procedures, or drawings which have been prepared, reviewed, and approved by both technical and quality assurance personnel. When applicable, instructions, procedures, and drawings shall include appropriate quantitative or qualitative acceptance criteria.

3.6 Document Control

3.6.1 Procedure/Instruction Control

Procedures and instructions shall be controlled in accordance with the PBX-M Document Control Procedure, (TBD) including preparation, review, approval, distribution, storage, and revision.

3.6.2 Change Control

Released documents shall be subject to change control. Changes must be approved prior to implementation. Revisions shall be approved by the same functional groups involved in the approval of the original release.

3.6.3 Distribution

Controls shall be established to ensure that documents are current and are available at locations where activities are performed. These controls shall ensure that superseded documents cannot be inadvertently used. An identification system shall be established that is compatible with program objectives.

3.6.4 Project Quality Assurance Responsibility

PPPL Quality Assurance has the responsibility for assuring the use of current and valid procedures, drawings, and working documents. This will be accomplished by maintaining transmittal records of documents released and issued for project use.

3.7 Control of Purchased Material, Equipment, and Services

Control of the quality of instruments, equipment, parts, materials and services purchased for use in the PBX-M shall be accomplished through reviews of purchase documents prepared in accordance with Section 3.4 of this plan. Items which do not conform to contract requirements are subject to the controls defined in PPPL-QAP-009.

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3.8 Identification and Control of Materials, Parts, and Components

Where applicable, procedures, drawings, and specifications shall provide for the identification and control of materials, parts, and components. These documents shall provide for integral identification markings, or records traceable to the item. This requirement includes troubleshooting, repair, and the prevention of incorrect or defective materials being used. Markings shall be clear, legible, and indelible, shall not affect the overall function or performance of the item, and shall be visible when installed in the system. The identification of materials shall be verified and documented by Quality Assurance on a surveillance basis.

3.9 Control of Special Processes

Welding, heat treating, brazing, nondestructive testing, or other activities which are dependent on operator skill or where quality cannot be determined by post processing inspection or test are special processes. Verification is obtained through process controls including, procedures, equipment, and personnel qualification. Special processes shall be accomplished in accordance with applicable codes, standards, specifications, criteria, or other special requirements. When applicable, procedures will be prepared, approved, and made available to the personnel performing the process work before the work is actually performed.

3.10 Inspection

Inspections required for structures, systems, and components shall be identified and performed in accordance with approved procedures. Inspection procedures shall provide for:

- Characteristics and activities to be inspected.
- Function responsible for the inspection operation.
- Accept-reject criteria.
- Inspection methods and tooling required.
- Records and reporting.

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Individuals who perform the inspection operations shall not have been responsible for the work being examined and, should be qualified in accordance with applicable procedures, codes, or standards.

3.11 Test Control

3.11.1 Test Plans and Procedures

Test plans shall be prepared that relate specified requirements to test(s) and to integrate all test activities. Test procedures shall be prepared which show setup, interfaces, environment, tooling, calibration, instrumentation, data collection, tolerances etc.

Test plans and test procedures shall be prepared, reviewed, and approved per par 3.5 and 3.6.

3.11.2 Test Evaluation

The test results shall be documented and evaluated by a qualified individual. The documented and approved test data shall be retained in project records.

3.12 Control of Measuring and Test Equipment

3.12.1 Acceptance Measuring Equipments, Calilbration

Tools, gages, instruments, and other measuring and test equipment (M&TE) used in the measurement, inspection, acceptance, or evaluation shall be included in the PPPL calibration program(s). (Electrical/Mechanical)

The PPPL calibration systems provide for the identification and labeling of measuring and test equipment which shows that the item has been calilbrated, provides traceability, and the date recalibration is due.

3.12.2 Traceability

Reference standards used to calibrate the measuring and test equipment shall be traceable to the National Bureau of Standards (NBS) or equivalent.

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3.12.3 System Integrated Devices, Calibration

Measuring or control devices incorporated into the PBX-M shall be subject to periodic calibration and/or preventative maintenance. PPPL Quality Assurance will be responsible for coordination and records for this system. The PBX-M calibration and maintenance Program (TBD) baselines this activity.

3.13 Handling, Storage, and Shipping

3.13.1 General

Cleaning, handling, processing, packaging, shipping, and storage of materials, parts, and components shall be controlled in accordance with standard laboratory practice. Where there exists special concern for contamination environmental exposure, age sensitivity, etc. special project procedures will be written.

3.14 Inspection, Test, and Operating Status

To assure that critical items which have not passed the required inspections and tests are not installed, used, or operated the status of such items shall be maintained through an appropriate indicator, such as tags, markings, stamps, records, or operating logs.

3.15 Nonconforming Materials, Parts, or Components

3.15.1 Nonconforming Materials Control System

Materials, equipment, items, or processes shall be considered to be nonconforming when they do not meet established requirements or their quality has been rendered indeterminate. Such nonconforming conditions shall be processed in accordance with PPPL-QAP-009.

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3.15.2 Trouble Reporting System

During operation, problems encountered will be documented and processed per the PBX-M Trouble Reporting System which will be adopted for the present PBX systems.

3.15.3 General

Significant conditions adverse to quality identified either formally by test, inspection, or audit, or informally by technical or quality assurance personnel are subject to project evaluation using the NCR, Trouble Report, Audit Report, or Procurement QA Trip Report to document disposition.

3.16 Corrective Action

All sources of problem documentation will be analyzed by Quality Assurance for trends, the effectiveness of corrective action, and the identification of other areas capable of improvement.

3.17 Qualtiy Assurance Records

Project Quality Assurance records shall be controlled per PBX-M Document Control Procedure (TBD) which identifies specific documents retention period, location, and responsibilities. Records may be designated for permanent or nonpermanent storage and shall be so marked. Records to be maintained in permanent storage shall be identified and retrievable.

Quality Assurance records include, but are not limited to:

- Operating logs.
- Design Review Reports.
- Quality Assurance reviews.
- Inspection reports.
- Purchased item deliverable documentation.
- Equipment certifications.
- Material certifications.
- Audit reports.
- System Design Descriptions.
- Personnel qualification records.
- Drawings, Specifications, Plans, Procedures.
- Calibration records.

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3.18 Audits

Quality Assurance shall perform audits per PPPL-QAP-011 of selected PBX-M activities to determine the degree of compliance and the effectiveness.

PBX-M DESIGN REVIEW PROCEDURE

1.0 DESIGN REVIEWS

The Designs will be reviewed for:

a) Functional requirements.
b) Design documentation.
c) Cost of the design and its implementation.
d) Interfaces, manufacturability, safety, quality, and maintenance considerations.
e) Approval to release the drawings to the next phase.
f) "Chits" (by reviewers) documenting issues not capable of on-the-spot-resolution.

2.0 DESIGN REVIEW PHASES

Design Reviews will be held at three stages of design.

a) Conceptual (CDR)
b) Preliminary (PDR)
c) Final (FDR)

Documentation (PDR & FDR) will be delivered to the Design Review Working Group one (1) week prior to the scheduled review.

2.1 Conceptual Design Review (CDR)

The CDR is held after the scoping study and before the start of formal drafting. The functional requirements, design concept, preliminary analysis, sketches, and documentation will be presented.

2.2 Preliminary Design Review (PDR)

The Preliminary Design Review is held after the design layout stage and before detailed design. The CDR will be updated and extended.

2.3 Final Design Review (FDR)

The Final Design Review is held after all drawings are complete and before release to manufacture.

3.0 PROCESS

The Tuesday weekly project meeting will add to its agenda, as required, the function of Design Review Management Board (DRMB).

3.1 Design Review Management Review Board will consist of:

a) Chairperson - Dan Kungl.
b) Project Head - Kees Bol.
c) Engineering - work package coordinators.
d) Quality Assurance - Bob Parsells
e) Safety Office - Joe Stencel.

and be responsible for:

a) Establishing the level of Design Review for each job.
b) Appointing the ad hoc Design Review Working Group Chairperson (generally the work package coordinator).
c) Reviewing and approving the conclusion of the Design Review Working Group.
d) Resolving open issues.
e) Authorize the implementation of all approved chits.
f) Maintain a file of all Design Review documentation.

3.2 Design Review Working Group will consist of:

a) Chairperson, who selects other group members from the following disciplines:
b) Engineers and Physicists to assess the functional needs and the proposed design.
c) User technical representative.
d) Technical representative from design interface groups.
e) Safety representative.
f) Quality Assurance representative.
g) Others as appropriate.

and the Chairperson will be responsible for:

a) Organizing the composition of the Design Review Working Group as defined in par. 3.2.
b) Arrangements for the Design Review and Working Group meetings (scheduling time and place).
c) Inviting other members of the professional and support staffs.
d) Assuring timeliness, adequacy, and availability of documentation.
e) Control of the review meeting and participant focus on the issues involved.
f) Secure DRMB approval of chit dispositions (sample attached).
g) Responding to all chits approved by the Design Review Working Group in a timely manner.
h) Generation of summary statement closing the Design Review.
i) Resolution of issues at appropriate management or technical levels.
j) Distribution of all correspondence and reports to participants, the DRMB, and the project designated configuration control person.

and the Working Group will be responsible for:

a) Reviewing engineering documentation for adequacy and accuracy.
b) Evaluate the design features and characteristics.
c) Review questions of reliability, maintainability and safety.
d) Review interferences and interface compatibility.
e) Generate chits (all interested parties may generate chits, not only the working group).
f) Review chits at the conclusion of the review and recommend disposition.

3.3 Presenter

The presenter(s) are the responsible cognizant person/group and are responsible for:

a) Preparing the documentation review of the design.
b) Deliver the documentation to the Working Group at least five (5) days prior to the schedule FDR.
c) Presenting and defending the design and design options at the Review
d) Complying with the recommendations of the DRWG and/or DRMB.
e) Securing project approval for required change to existing controlled drawings.

APPENDIX

1. Exceptions

Exceptions to this procedure may be authorized by the Design Review Management Board where the cost, criticality or schedule impact of a proposed design are judged to be relatively insignificant.

2. Criteria

In general a Design Review is not required where the value of the design is less than $10K, and failure would not significantly impact the machine schedule or affect the safety of equipment or personnel. This determination shall be made by the Design Review Management Board (par. 3.1), upon recommendation of the cognizant project or engineering groups.

If the value of the design is in the range of $10K to $150K, or if the design impacts the machine schedule or is critical to machine safety (to the extent of the value range above), or concerns the safety of personnel, a Design Review will be required. Within this range, a CDR a d FDR are recommended. The Design Review Management Board will make this determination based on the recommendation of the project or engineering cognizant groups.

If the value of the design exceeds $150K, or if the design impacts the machine schedule or is critical to machine performance to the value of $150K, a complete Design Review cycle is required.

TABLE 2.0-1*

TOPIC	CONCEPT DESIGN REVIEW	PRELIMINARY DESIGN REVIEW	FINAL DESIGN REVIEW
Functional Requirements	Baseline, Approved	Changes	Changes
Specifications	List	Modification, Status	Approved Specification
Design Approach	Sketchs & Family Tree	Layouts, Family Tree	Drawings, Complete
Reliability	Preliminary Assessment	Update	Update
Fabrication Methods	Anticipated	Update	Update, Special Tools
Procurements	List, preliminary	List	Final List
Schedule	Preliminary	Update	Update
Cost	Preliminary Estimate	Status	Status
Verification			
Inspection		List critical	Special Instruction, Procedures, Tooling etc.
Test	Preliminary Test Plan	Test Plan, Draft	Test Plan/Test Procedures/ Test Equipment
Qualification	Proposed	Update	Quality Test Results
Risk	Preliminary	Critical Areas	Final Assessment
Integration & Assembly		Preliminary Plan	Plan & Procedures
Safety	Preliminary	Update	Update

* The above partial listing of topics and documentation to be evaluated at each Design Review is for guidance only, subject to appropriate modification, expansion, or revision by the Design Review Working Group Chairperson.

PPPL	COIL MANUFACTURING PROCEDURES	COIL BRANCH

TITLE: PBX-M Pre-Power Test Joint Inspection Procedures | **PROC:** CS-PBX-07

APPENDIX C

APPROVALS

NAME: James H. Chrzanowski DATE: 7-25-86
Written By:

NAME: Thomas H. Meighan DATE: 11-11-86

NAME: [signature] DATE: 11-11-86

NAME: Robert Majeski DATE: 11/20/86

NAME: DATE:

REVISIONS

REV. NO.	DESCRIPTION	DATE:
00	JHC	11/20/86
01	Bolts must be flush or extend past the nut to be acceptable. JHC	2/2/87

1.0 HARDWARE/TOOLS/EQUIPMENT

1.1 Biddle Digital Low Resistance Ohmeter (Model No. 2471000)

1.2 Feeler gauge set

1.3 Calibrated torque wrench

1.4 Small hand tools, wrenches, files, scrapers, etc.

1.5 Silver plating equipment

2.0 JOINT INSPECTION

2.1 This section is for checking all of the Poloidal Field Coil bus systems preceding 1st Power Test for PBX-M.

Rev. 1 Bolts must be at least flush with, or extend past the nut.

2.2 Visually check the Belleville washers for correct installation direction. The crowned surface of each washer must face the bolt head or the nut, not the joint face. Rectify any washers not installed properly. (FIG. 1)

2.3 Using a pre-calibrated torque wrench with a valid calibration sticker, torque each bolt of the joint. The correct values are as listed below:

5/8-11 NC Hex Bolt	30	Ft-lb +/- 2
1/2-13 NC Hex Bolt	26	Ft-lb +/- 2
3/8-16 NC Hex Bolt	20	Ft-lb +/- 2

These torques are to be witnessed and verified by the Cognizant Engineer, or his designate.

2.4 After torquing the joint, check the gap between the bolted joint. The .002 feeler gauge must not penetrate the joint to a depth of one half inch. If the gap exceeds .002 inches or if the .002 gauge goes into the joint one half inch or more, notify the cognizant engineer for determination.

2.5 Using a "Biddle" D.L.R.O. (Digital Low Resistance Ohmeter - Model No. 2471000) measure the resistance of each joint. Use the following sequence to set up and use the D.L.R.O.:

2.5.1 Connect the test probes P_1, P_2, C_1, and C_2 to the appropriate terminals on the measuring module.

2.5.2 Use the battery check to verify that the batteries are in an acceptable state of charge before checking any joints. The charge state must show in the green area of the meter, or the batteries must be replaced before proceeding further.

2.5.3 Set the ON/OFF switch on the measuring module to the "lock" position.

2.5.4 Position the probes on each side of the bus joint with P_1 and P_2 facing each other. Measure the resistance of the joint. Probes must be in contact with copper or flex bus only, and not with washers, bolts, backing plates or stand off blocks. See Figure 1 and Figure 5.

2.5.5 The joint resistance must be no greater than .002 milliohms. Any higher readings are unacceptable. The Cognizant Engineer will make a determination on the extent of any rework for joints with resistances greater than .002 milliohms. See step 2.7

2.6 Temperature stickers, such as the Wahl Template brand, will be placed on each copper joint. (These stickers are to be placed as far from water fittings and known water passages as possible). The Cognizant Engineer shall provide for and verify the placement of these stickers. Stickers with a minimum value of 100°F are preferred; stickers with a minimum value of 120°F are acceptable. No higher minimum values for stickers are allowed.

Record all inspection and test data on sheets attached as Appendix 1.

2.7 Should any joint fail either the resistance, torque, or gap test, then the joint must be remade per direction of Cognizant Engineer.

2.8 A signed off and dated inspection sticker will be placed on every joint, once all acceptance criteria have been met. The sticker will be located as close to the joint as possible. (See Page 3 for sample)

3.0 DATA SHEET

3.1 This appendix (Data Sheet) will be filled out when the PBX joints are inspected for Pre-Power Tests. The completed copy will then be filed in the Power Test Log Book after obtaining the proper cognizant engineer's approval signoff at the bottom of each sheet.

3.2 The following are general guidelines for filling out these data sheets.

3.2.1 The date the inspection is performed will be filled in.

3.2.2 The feeler gauge check will be made with a .002 gauge. Any gaps found over .002 must be measured and recorded. If the joint has gaps of .002 or less, then record those measurements as .002 or <.002 respectively.

3.2.3 Temperature stickers will have been placed on every joint. Those stickers are to be read and recorded during joint inspection. Record the value of the sticker if it's tripped. If it's not tripped, then record it as less than the lowest value on the sticker (i.e., <100 or <120).

3.2.4 All resistance values will be recorded in milliohms. Be sure that the scale is properly set before using the meter.

3.2.5 Torques will be recorded in foot-pounds.

3.2.6 When each joint inspection is complete, the technician inspecting the joint will sign off in the space provided.

3.2.7 The Cognizant Engineer or his designate will witness every joint inspection, verify all the recorded data then, if satisfied, will sign off all the data sheets.

4.0 <u>QA SIGN-OFF</u>

4.1 Cognizant Engineer will sign off on all data sheets. See Attachment 1. His signature will verify the review of all test data and the acceptability of all bus joints for full power operation.

4.2 All work has been performed in accordance with this procedure.

COGNIZANT ENGINEER:____________________ DATE:________

COG. DESIGNATE ....____________________ DATE:________

INSPECTION STICKERS

INSPECTED BY:

DATE

JOINT TESTED

TORQUE ______ GAP ______

RES ______ INIT ______

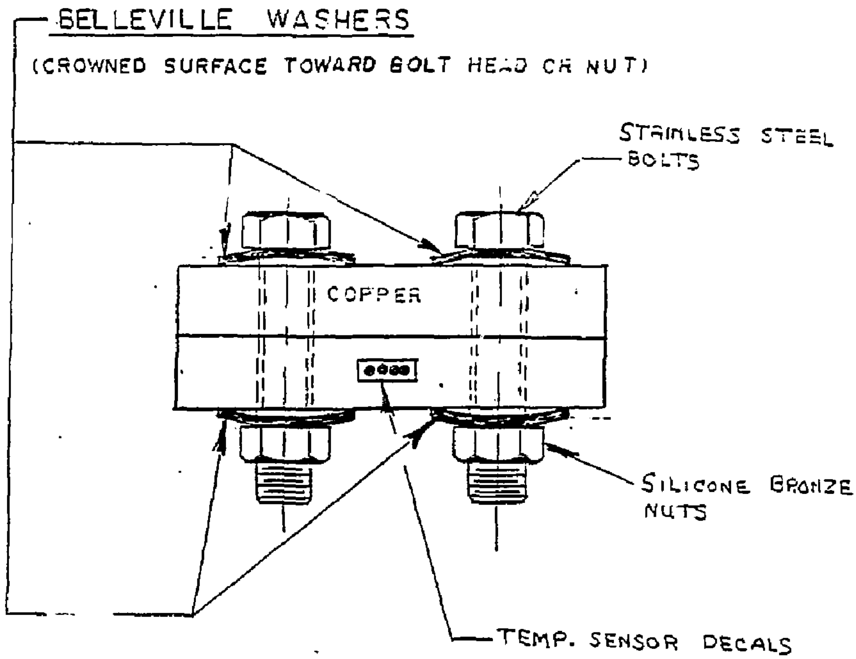

FIG. 1

TYPICAL BUS JOINT

PBX - UPGRADE - BUS SYSTEMS
JOINT I.D.

SYSTEM	COILS	JOINT PREFIX
EF-SYSTEM	CF-10, EF-20-22	A
SHAPING FIELD	CF-8, IF-1	B
DIVERTOR (A)	NF-11, DF-7	C
DIVERTOR (B)	DF-1	D
TRIM 1	DF-2	E
TRIM 2	DF-3	F
TRIM 3	DF-5	G
TRIM 4	DF-6	H
ACTIVE FEEDBACK	NF-1[illegible], EF-SOL	J

PBX BUS JOINT INSPECTION AND REWORK PROCEDURE

System: ____________________ System Color: ____________________

Date	Joint Number	Location	Feeler Gauge Gap (Inches)	Temp Sticker (Degrees F)	Resistance Value (Micro ohms)	Torque Value (Foot-lbs)	Tech's Signoff

____

Cognizant Engineer Acceptance Signoff

APPENDIX D

REVIEW COMMITTEE ASSESSMENT AND PROJECT RESPONSE

1. Stress calculations for passive stabilizers.

   P. Bonanos has checked the design conditions and talked with the designer, and is satisfied that reasonable standards were set.

2. Bracing of O.H. leads.

   After discovering in 1981 that it was unsupported, the OH lead pair to the lower solenoid was braced with a stainless steel pillow inserted between the leads and the vacuum vessel. The pillow was then inflated with epoxy until it pressed the leads against the adjacent OH coils. In 1982, we cut holes in the vacuum vessel wall, removed as much of the pillow as we could (unbeknownst, it had veered off to the side while being inserted) and used a glass bead/epoxy mix to accomplish what had been anticipated of the pillow. The upper lead pair was found to be braced and has not been touched.

   On the same occasion in 1982 we drilled a hole to the joint where the leak had been found to be to insert a tube for catching the drip. This failed, but did have the subsequent benefit of reassuring us that we were dealing with a pinhole rather than the crack we had feared. That is, as long as all the insulation was there to impede the water flow, it created enough back pressure to make the observable leak rate highly variable and sensitive to motion of the leads; with that impediment removed we found the leak rate to be quite constant. If the joint really were to have a crack in a loadbearing part, it is hard to see how it could have stayed so remarkably constant through the ensuring years of operation.

   In 1987 the solenoid lead was repaired by flowing epoxy through the water path. Subsequently we also reopened the leak in OH7U and repaired that as well.

3. Seismic analysis of PLT-PBX shield wall.

   The wall does not meet current standards and we have submitted a job request to fix it. In 1980 E.L. Kaminsky and E. Nilsson analyzed the problem and presented their results and proposed solutions in two reports titled, respectively, "Design of PDX South Shielding Wall to Withstand Seismic Load" (August 1980) and "Revised Design of PDX South Shielding Wall etc." (October 1980).

4. Minimizing exposure of personnel in PBX Control Room to radiation.

The basic safeguard is close monitoring of the integrated radiation dosage to the control room and adjacent areas. When PBX was generating high radiation levels we kept a daily log and presented the results in graphic form at the main control room entrance, and we will do this again. Awareness by the parties most directly concerned is the best way we know for minimizing exposure.

As is well known, the motivation for injecting D^o into D+ is the higher beam power available and the better confinement typically observed with deuterium. Since these benefits will no doubt prove to be important or even essential for carrying out the PBX-M program, the associated radiation exposure will have to be taken as a given. But of course we will not exceed permitted exposure levels and either the mode of operation will be restricted or else more shielding will have to be installed if these are approached. The Safety Office will be kept fully aware of our operating schedule and will certainly continue to monitor the whole area as they have in the past.

5. Accuracy of diagrams.

Peter Mathe generally agrees with specific criticism John Murray has of the way the control system is presented in the SAD, but we do not believe the safety analysis to be at issue. Peter has a bookfull of documentation in varying levels of detail which we do not consider to belong in the SAD but which is available to anyone wishing to understand the full control system.

6. Single grounds on load disconnect switches.

Grounding only one side of the disconnect switches for the SF supplies allows an inactive coil system to be grounded without presenting an inductive short circuit to the remaining active coils. Having the switch go to an open circuit position leaves the coil floating electrically, which we consider to be a danger to coil insulation. The objection to grounding only one side is the potential personnel hazard it creates, should coupling to active circuits elsewhere result in dangerous voltages on the ungrounded terminals.

The PBX interlock system ensures that under normal operating conditions no coil is accessible unless all systems are disabled Cause to violate the interlocks would of course be dealt with administratively, and partial grounding of any coil would not materially change the hazard level for someone in an area already deemed unsafe. Should PLT again be operated, or perhaps a successor machine, then this argument naturally fails. The most straight forward way to deal with the question would be to include in the procedure for transferring power supplies from one machine to the other a requirement to ground both sides of every coil in the inactive machine. Nevertheless, it should be realized that the problem is not a severe one, as the following rough calculations will show.

Reducing the coupling problem to that between two coplanar rings separated by R, where R is large compared to the ring size, one finds a mutual inductance given by:

$$M_{12} \cong N_1 N_2 A_1 A_2 R^{-3} \times 10^{-7}\ H. \quad \text{(mks)}$$

where A_i is the coil area.

The voltage appearing across coil (1) as a result of applying V_2 to coil (2) will be

$$V_1 = M_{12}/L_2\ V_2$$

For PBX the coil systems with the highest NA are: EF ($1000 m^2$), OH ($380 m^2$) and T_4 ($185 m^2$). PLT has just the OH and SF coils, which have about the same A as the corresponding PBX coils, but twice the turns. The PLT OH has the potential for inducing the highest voltages, its smaller NA product being more than offset by the higher voltage available (20 kV vs 5 kV). The results are as follows, where R = 15 m, $NA_{OH}(PLT) \simeq 800\ m^2$, L_{OH} = 30 mH and V_1 = 20 kV.

EF(PBX)	=	16 v
OH	=	6
T_4	=	3

Another voltage source would be plasma disruptions in PLT. A very unrealistic estimate can be easily made if one neglects the flux conserving properties of both the PLT OH and SF systems. For example, a 1MA plasma disappearing in 1 ms would induce 170 V in the PBX EF winding. However, it would also induce 150 kV across the PLT OH coil, which could obviously not be sustained even if the coil weren't protected by spark gaps and a crowbar all set for (at present) 10 kV.

The conclusion is that having all PBX coils grounded on one side when they are in the disabled state would not create life-threatening conditions even if PLT were to resume operation.

7. Emergency Stops.

A "qualified operator" should always be the one to make an emergency stop decision in the machine area, but since there are ES buttons in areas remote from the machine, we agree to dropping that requirement.

8. Operating procedures.

Operating procedures developed for PDX and PBX will be expanded to cover PBX-M operations.

9. Laser power supply enclosures.

The enclosures are being constructed and will be protected in accordance with PPPL Safety Directives, and will be checked by the Safety Office before being put into operation.

10. TF hydraulic system.

The personnel hazard associated with a hydraulic system operated at 8000 psi is hard to assess. The amount of oil released from a line break would be small since the steel piping and the oil are relatively incompressible and the pump throughput is extremely low. (Also, the pump is automatically shut off when there is a sudden pressure drop in the system.) Furthermore, the only failure modes we have encountered in the past 9 years are with leaky connections or split "mushrooms". The latter are completely inaccessible without dismantling the clamping structure; in the case of the former the oil emerges at atmospheric pressure. We suspect it would be difficult to create a break that would have oil emerging at high pressure, but not impossible. We believe the hazard level to be sufficiently low so that no additional precautions are necessary.

11. Insulating breaks.

All control and monitoring devices in unsafe areas are carried into safe areas via either optical fibers or PPPL-approved safety breaks.

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