SAFETY ASSESSMENT FOR THE
RF TEST FACILITY

Edited By

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FOR THE
RF TEST FACILITY**

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SAFETY ASSESSMENT DOCUMENT

FOR THE

RF TEST FACILITY

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SAFETY ASSESSMENT DOCUMENT1.1 INTRODUCTION

The Radio Frequency Test Facility (RFTF) is a part of the Magnetic Fusion Program's RF Heating Experiments. The goal of the Magnetic Fusion Program (MFP) is to develop and demonstrate the practical application of fusion. RFTF is an experimental device which will provide an essential link in the research effort aiming at the realization of fusion power. The advantages of fusion power are often stated:

- a. Inexhaustible, low cost fuel;
- b. Fail safe reactor operation;
- c. Absence of weapons potential;
- d. Combustion products are not radioactive.

An experimental device - such as RFTF - has the following role in developing a fusion reactor:

- a. It facilitates the understanding of the underlying theoretical and experimental principles of plasma physics.
- b. It permits the development of new ideas and directions in advancing the application of scientific principles.
- c. It permits proving and testing RF antennae before insertion into a large tokamak, thereby, reducing the chance of component failure.

This report was compiled as a summary of the analysis done to ensure the safe operation of RFTF.

1.2 GOALS AND OBJECTIVES

The RFTF is a research device devoted to testing RF components in simulated tokamak reactor conditions. To attain the above goals, several conditions need to be accomplished:

- a. Attainment of a reasonable pure hydrogen plasma at moderate densities and temperatures with stable confinement.
- b. Development of hardware to initiate, control, and dissipate discharges.
- c. The RFTF vacuum vessel is based on full-scale Princeton Large Torus (PLT) cross-sectional dimensions.
- d. The connection of those RF sources to be used on PLT to the RFTF for power testing of RF components.

1.3 PARTICIPANTS IN THE RFTF DESIGN

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

- a. DOE through its Office of Magnetic 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 general public. The relationship of PPPL (Princeton University) and DOE is governed by U.S. DOE Contract #DE-AC02-76-CHO-3073.

1.4 SUMMARY OF SIGNIFICANT ITEMS

The safe design, development, manufacture, fabrication, construction, installation, test, operation, maintenance, modification, and eventual decommissioning is being accomplished in accordance with the 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 Order 5480.1, Chapter XI¹ requirements. Applicable sections of the DOE orders have been interpreted and established as design requirements on detailed site related characteristics, buildings and facilities, systems components and equipment, and operational organization. The site is located in an existing building and was designed and built to assure safe operation. The RFTF is not considered a radiation hazard since no radioactive materials are used in its construction or operation. There also will be no ionizing radiation produced by the atomic particle energies during full operation.

It is possible for the Radio Frequency (RF) systems to generate non-ionizing radiation. Most of this radiation will be contained within the systems. Radiation leakage will be limited to be within the RF Protection Guidelines of ANSI C95-1982. The systems will be surveyed, measured, and documented when changes are incorporated, after major maintenance, and periodically to ensure compliance with ANSI C95-1982.

2.0 SUMMARY SAFETY ANALYSIS

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 RFTF device and its electrical connections to external power sources.

Specific hazards analyzed were:

A. Experiment Gases and Associated Hazard

1. Toxic or carcinogenic materials are not employed in the machine operation.
2. Fire hazards may exist if a leak in the gas supply system develops. This condition is protected against by the procedure of installing and hooking up new gas cylinders to the system in accordance with the PPPL Safety Manual.² The gas supply system was leak-checked using soap bubble and helium leak detection tests prior to being put into service.
3. Hydrogen detonation conditions were postulated and studied. It was determined that these conditions will not occur under any accident occurrences either inside the vacuum vessel or in the test cell due to the limited hydrogen supply. Note that only one gas cylinder (of 220 cubic feet in volume) will be used at any one time.
4. Pressurized gas cylinder missile condition is protected against by securing all gas cylinders to a fixed structure

using a cylinder rack or its equivalent (straps around cylinder are at 2/3 of the cylinder height). The following gas bottles will be used during machine operation for the gas delivery system and the RF coaxial line: hydrogen, helium, deuterium, argon, nitrogen, and sulphur hexafluoride.

5. Oxygen deficiency conditions may exist in a confined area such as the vacuum vessel. A vacuum vessel entry procedure similar to the TFTR procedure will be used to safeguard against this condition.
6. Compressed air outlets in the test cell have individual shutoff valves for isolation in case of a leak. The supply manifold which runs about 7 feet above the machine false floor was leak-checked prior to operation.

E. Electrical hazards

Large power supplies are used to provide plasma confining fields during RFTF operation. All supplies are clearly marked and provided with the necessary safety interlocks to prevent accidental contact with energized components. All leads are carefully protected against mechanical stress or abrasion by three (3) layers of tape [two (2) mylar and one (1) black electrical tape] and braced by phenolic supports.

There are exposed elements of Mirror Field Coils (used for plasma confinement) at the coil connection. These elements are subject to possible overheating due to a bus joint deterioration with use and time. Wohl Temp-plate temperature recording

deuuls, which turn black when rated temperature is reached, are installed on these elements in this location for periodic inspection and maintenance. The exposed elements are not of any danger to personnel since access to the machine area is interlocked with Kirk Keys, and personnel are not permitted on the machine room floor during Mirror Field (MF) operation (Figs. 3 & 4).

A master lockout switch is provided to de-energize the appropriate power supplies during machine access times and emergency situations. Control computer trip functions, backed up by protective relays, are installed to de-energize the RFTF in case of abnormal operation. The laboratory interlock coordinator has set up a testing program for personnel safety interlocks.

RF sources greater than 10 kW are Kirk-Key interlocked with the RFTF master safety system so that all interlocked access areas (see Fig. 1) must be cleared of personnel before power can be turned on. All RF lines are coaxial with bolted outer conductor joints. All outer conductors are operated at ground potential. The outer conductor has a DC break to isolate it from the vacuum vessel (Fig. 8).

C. Mechanical Construction and Assembly

The vacuum vessel is constructed mainly of five flange bolted sections with the three middle sections of the same configuration and dimensions as the PLT machine. The two end sections were salvaged from the Heating Experiment Vessel (H-1). An additional port opening was machined in the H-1 section to allow access for diagnostic experimental equipment.

The integrated vacuum vessel structure was satisfactorily leak-checked to 10^{-9} torr level after completing its assembly.

The MF coils, which are toroidal around the vacuum vessel structure, are from three previous devices, PLT, FM-1, and H-1. The maximum coil current will be within the limits of their original design.

The coil supports were conservatively designed with a safety factor of two at fault conditions, i.e., positive generator feedback, $10 \text{ kA } I_{\text{max}}$.

Heavy machine components and magnetic materials that are a potential source of mechanical hazards to personnel have been secured.

1. Vacuum Pumps

Conventional mechanical vacuum pumps and turbomolecular pumps are used in a formation of two

independent pump trains which operate simultaneously to pump out the vessel to a low 10^{-7} base pressure. These pumps are the manufacturer's standard design and do not have any mechanical hazards.

2. Heavy Objects

Many heavy objects require handling during construction and will require handling during maintenance operations. These objects take the form of mechanical equipment, structural members, electrical apparatus, field coils, large electrical bus bars, and similar equipment.

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 (see Fig. 13).

D. Radiation Hazards

Due to the low temperature (< 10 eV), low density ($< 10^{12}$ cm $^{-3}$) plasma, the operation of RFTF is not expected to have any ionizing radiation hazards.

2.2

FIRE SAFETYCombustible Materials

The Hazards Analysis of the RFTF Project identified the following combustible materials:

A. Hydrogen

To be used in limited quantities, inventory will be kept small, and when not in use, it will be removed by hand to a secure storage area.

B. Plastic Conduits

To be used in limited runs, where electrical noise reduction is required. Plastic conduit is installed in open areas so that any fire would be detected immediately by the detection system.

C. Wood

Wood with a fire retardant is the principal construction material of the machine area floor and the elevated equipment platform (8' x 15') on the south side of the area.

D. Fire Causes

Fire potential in the RFTF area is confined to electrical faults. These risks have been fitted (where appropriate) with safety devices or with protective guards to prevent fire.

E. Fire Extinguishing Systems

Fire extinguishers are located in the machine room, in the control room, and adjacent to the equipment area. In the event of a fire when no personnel are present, the building smoke and heat detectors would alert the Emergency Services Unit.

The installation of a Halon system in the RFTF control room is not necessary, since the project's loss would not result in an unacceptable program delay or loss exceeding one (1) million dollars. (See Appendix D.)

2.3 PROPERTY DAMAGE

Fire Damage is the principal property damage risk. The facility occupies the first floor of the multistory RF Building. The area includes a control room, a machine room, and an equipment area. These areas are protected by pre-action, dry pipe automatic sprinkler systems. Fire alarm boxes and sprinkler annunciator alarms are connected through the fire alarm system to the Fire and Security Headquarters Emergency Control Center, which is manned at all times. A trained emergency squad will respond to alarms with backup support provided by Plainsboro Township.

2.4 BUS AND COIL FAILURE

A. Bus Failure

Fire retardant barriers are installed to contain damage. Bus design incorporates ample safety to prevent dangerous

occurrences during normal operation. The electrical bus is not enclosed at the coil connection point. The control room wall has been reinforced with fire retardant one-inch plywood, and control room/machine room windows have been installed with one-half inch Lexan. These measures should provide adequate safety during any bus failure leading to a possible explosion.

B. Coil Failure

Coils are conservatively designed and should present no danger during normal operations. Upon the possible event of coil failure, the electrical protection will automatically detect this and shut the system down safely.

2.5 NATURAL PHENOMENA³

2.5.1 Earthquakes

The area is in a low probability earthquake region. The existing building is not earthquake proof so that system seismic considerations are made irrelevant.

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 twenty years.

2.6 NOISE

All noise sources associated with the RFTF device or its equipment are well below 85 decibels.

3.0 SITE

3.1 Location

The experimental area for the RFTF is on the first floor RF Building, Room 104 (Fig. 1) C-Site of the Princeton University Plasma Physics Laboratory. The area was made available February 13, 1982.

4.0 FACILITY AND PROCESS DESCRIPTION

4.1 Experimental Area

See Table 5.

4.2 POWER SUPPLIES

4.2.1 MIRROR FIELD SUPPLY

The RF Building has available the necessary services to provide power and cooling water for the operation of the RFTF device. The bus is routed from the MG room into the East Bus Tunnel [C-Site (CS) Basement] and connected to RFTF MG disconnect switches. The disconnect switch output conductors [Five 1000 kcm single conductor insulated copper cables per bus (2 bus total)] go through the bus tunnel ceiling into the Princeton Beta Experiment (PBX) machine and are routed in cable tray to the DC Generator and Rectifier Bus Enclosure (Fig. 1). The MG bus conductor is transposed to four ($4 \times \frac{1}{4}$) per bus conductor to a field configuration switch in the machine room northwest corner. The bus is then routed to the MF

coils which are connected electrically in series. The field configuration switch is interlocked to prevent an open circuit load during operation, and the E. Bus Tunnel disconnect grounds the MF coils when opened.

4.2.2 COIL COOLING SYSTEM

The coil cooling system for the RFTF experiment is comprised of two independent systems:

A. The MG/CS Water Cooling System

The MG/CS System which originates from the MG room at C-Site is used for water cooling the two (2) PLT coils and the two (2) FM-1 coils with approximately 100 gpm flow at 125 psig pressure (see Fig. 15).

The PLT coils have ten (10) coolant paths per coil and the FM-1 coils have two (2) coolant paths per coil. Each path is individually monitored for flow and temperature on their return to the water enclosure rack and before joining the return header. A low flow or a high pressure condition will trigger an alarm and will bring the RFTF to a safe shutdown.

The supply and return headers of the MG/CS System have manual isolation valves which are accessible outside the interlocked areas during machine operation.

B. Niagara/Courtyard Cooling System

The Niagara/Courtyard System, which originates from the Tech. Shop at C-Site, is used for water cooling the four (4) H-1 coils, the bus bars, and the plasma gun and its cooling jacket, with approximately 130 gpm flow at 320 psig pressure (see Fig. 14).

The H-1 coils have seven (7) coolant paths per coil which are individually monitored for flow and temperature on their return to the water enclosure rack and before joining the return header. A low flow or a high pressure condition will trigger an alarm and will bring the RFTF to a safe shutdown.

The supply and return headers of the Niagara/Courtyard System have a motorized valve with a manual override for isolation accessible inside the control room.

4.2.3 ELECTRICAL BUS

DC current from the PBX area cable/bus connection area is carried through the west wall via four (4" x $\frac{1}{4}$ ") copper bus bars, each having $\frac{1}{4}$ " air gap per conductor leg. This bus is maintained throughout the field configuration switch and through the bus tunnel to the respective coil linking bus. At this point a water-cooled bus is used. All buses are braced for maximum fault currents, insulated for

high voltage, and adequately sized for natural cooling, and, where applicable, water cooling during normal machine operations. It is configured for minimum net field, low self-inductance, and minimum ground current. Each bus connection is designed and treated with the appropriate materials where applicable to provide the least possible amount of resistive losses. Standards used for typical bolted type connections are 0.002 $\mu\Omega$ resistance, less than 0.002 in air gap, no more than 30% of connection contact surface area, and prescribed torque settings to meet respective type Belville washers used.

4.2.4 AC POWER SYSTEMS

The house AC Power System that feeds the various equipment in use on the RFTF device and located within the confines of the controlled/interlocked area is isolated from the "outside world" by an AC Isolation Transformer. This is to assure that in the event of an electrical failure no high voltage levels would transmit via the AC power cables to the outside environment.

The machine area isolated AC power is energized/de-energized via the following disconnects located adjacent to the AC isolation transformer:

- a. PD-36 Isolation Transformer Primary 480 VAC.
- b. PD-37 Isolation Transformer Secondary 480 VAC to step down transformer primary 480 VAC.
- c. PD-38 Step down Transformer Secondary 208 VAC to 208 VAC machine area panel LP-809.

The AC Isolation Transformer is rated at 480 VAC, 1:1 transformer ratio, 75 kVA, with a working voltage of 20 kVDC for 3 minutes, and 40 kVDC test voltage. This transformer is located in the RFTF equipment area against the west wall. A step down 480-208 V, AC, 3 phase transformer is located above the isolation transformer. This provides the power for the machine area and equipment in the RFTF equipment area. All installations are in accordance with the National Electrical Code (NEC) and the National Electrical Safety Code (NESC).

4.2.5 30 MHz RF POWER SOURCE

A 2 MW, 30 MHz RF power source, located on the first floor of the RF building (south end of west wall) is fed into the machine area via a 6" coaxial, SF6, dielectric line. It enters the machine area approximately 10 ft above the floor through the south wall (east side). This RF feed is the power source to be used in testing RF components on the RFTF device. It is interlocked with the door interlocks so that all interlocked areas need to be secured in order to operate the power source into the RFTF device (Fig. 10). Coaxial position switches prevent RF power or radiation from entering RFTF when firing to PLT or dummy load (Fig. 11).

4.2.6 90 MHz RF SOURCE

The 300 kW, 90 MHz RF source is to be used in the future on the RFTF for RF component tests. Its safety system will be handled in the same manner as the 30 MHz system. It is located adjacent to the 30 MHz system along the first floor south wall RF building.

4.2.7 MISCELLANEOUS RF SOURCES

All other RF sources to date are low power sources, 1-2 KW continuous wave (CW), up to 7 kW pulse, 10 ms, and are presently located within the interlocked areas. These sources are not interlocked with doors and, therefore, can be operated when the machine area is open. These sources are not considered hazardous because of low power capability and large (2 meter) wave length.

All necessary precautions are taken when operating the low and high power RF sources. These precautions include:

1. DC isolation of the coaxial line from the vacuum vessel by teflon breaks.
2. RF radiation leakage monitoring via RF radiation monitors (Appendix C), set to trip at 5 mW/cm² maximum.

4.2.8 RADIATION SURVEY

All RF sources will be surveyed for radiation leaks of coaxial line joints upon start-up or after any modification from vessel back to respective RF source.

4.2.9 WARNING SIGNS

RF radiation hazard signs and high voltage signs provided by the Project and Operational Safety Office will be posted around the perimeter of the RFTF area.

4.3.0 RFTF DEVICE

A side elevation view of the RFTF device is shown in Fig. 2.

4.3.1 MIRROR FIELD COIL SYSTEM

Plasma confinement on linear devices utilizes a mirror field configuration consisting of a weak field located between two stronger fields. The RFTF has a mirror field ratio of 1:6 and maximum MF current of 5 kA at 15 secs pulse width. Three sizes of coils are used due to their availability from previous and current devices, PLT, FM-1, and H-1.

A. FM-1 Coils

The FM-1 coils (14 turns ea.) are bundled together into coil packs (Fig. 2) to provide 56 turns/pack. These are part of the low field section.

B. PLT Coils

The two PLT coils (42 turns ea.) are located adjacent to the FM-1 coils, completing the low field section of the mirror field.

C. H-1 Coils

The H-1 coils (29 turns ea.) are bundled together to form two coil packs (203 turns each pack) spaced 15 inches apart on pack center and located (Fig. 2) outside but adjacent to the PLT coils. The H-1 coils make up the high field region of the RFTF device.

All the coils are operated electrically in series so that a uniform current is guaranteed to flow throughout the MF coils. The total DC resistance of the coils is 186 mΩ with a positional total system inductance of 105 mH.

The MF coils are aligned axially along the center of the machine area on an east-west line.

4.3.2 COIL SUPPORT SYSTEM

The MF coil support system is designed to provide safety in the worst case fault of MF current (10 kA) by a conservative design. The solenoid field configuration is run predominantly so that all the coils want to pull together to the midpoint along the axial line. Ten-inch stainless steel heavy wall pipes are used to hold the PLT/FM-1 coil sections apart in four quadrant locations symmetrical about the axis. The H-1 coils resist the MF field forces via spacer blocks to the vacuum vessel wall which is reinforced with ribbing.

The H-1 coil packs are supported on a pedestal which is bolted to the floor. The H-1 coils are secured to the pedestal using coil cradles and through bolted end plates. All structural materials are made of aluminum, except bolts and stress rods which are stainless steel.

The cusp magnetic field is another field capability of the RFTF. This reverses the polarity of each half of the MF with respect to the other producing a bucking field at the midpoint of the axial line. Each MF coil half tries to push the other away from it.

The PLT/FM-1 coil sections are held together using three 1-3/4 inch-diameter stainless steel rods on each tube assembly, located in four quadrant locations.

The H-1 coil packs are held by their respective base plate, pedestal/cradle configuration bolted to the building floor. The H-1 coil packs in the cusp field configuration have a force acting towards the axial line midpoint, as in the solenoid field configuration.

The MF coil base plate's function is to support the gravity weight of the coils only. The two large halves (Fig. 2) are used to move the PLT coils into the machine area with dollies.

4.3.3 RFTF VACUUM VESSEL

The RFTF vacuum vessel is constructed of thick stainless steel sections. The vessel comprises five flange bolted sections with gold seal rings between the H-1 sections and with "O" rings between the PLT sections. The three middle sections have the same configuration and dimensions (1-meter diameter and 1/4" thick) as the PLT machine. The two end sections of the vessel are 9 inches inside diameter, 1-3/4" thick, and are salvaged from the Heating Experiment Machine (H-1). An additional port opening was machined in the H-1 section to allow for diagnostic experimental equipment.

The integrated vacuum vessel structure was satisfactorily leak-checked to 10^{-9} torr level after completion of its assembly.

The large diameter PLT section of RFTF is comprised of three individual segments. The middle segment will be replaced at a future date with a new cross section consisting of a composite design of the Toroidal Fusion Test Reactor (TFTR) and Doublet III (D-III) outer vessel walls (Fig. 12). This new vessel segment design will be used for testing and development of wave launchers for these respective devices. All other components of the RFTF that will mate to this new vessel segment will remain the same in form and function.

4.3.4 VACUUM SYSTEM

The RFTF vacuum system consists of two parallel independent pump stacks, each consisting of a mechanical roughing pump and a turbomolecular pump. Each line can be operated independently of the other in the event of equipment failure in one stack. Time required to pump the system down from atmospheric pressure to 10^{-6} torr is approximately 30 minutes.

Each of the turbomolecular pumps is protected by the following hardwired interlocks for safe shutdown in the following cases:

1. Vacuum pressure to above 200 millitorr,
2. Rise in back pressure of the pump to a level of 200 millitorr,
3. Power failure,
4. Pump overheating,
5. Roughing pump failure.

The safe shutdown of the turbo pumps includes shutting off their isolation valves on the inlet and the outlet.

The roughing pumps are protected in the same manner against the following:

1. Pump overheating condition,
2. Overcurrent condition.

4.4.0 RF TEST FACILITY CONTROLS

Overview

The RFTF control system is an integrated control system based on the Texas Instruments Model 530 programmable controller. The control system incorporates the following:

RFTF MG controls, coil cooling instrumentation and controls, and MF field controls.

The MG controls operate generators 11 and 12 into the RFTF MF coils.

Personnel protection is provided by a hard-wired MASTER SAFETY SYSTEM with appropriate communication link to the programmable controller.

The diagnostic and control system timing functions are provided by a 20-channel timer interfaced to the programmable controller.

Provisions are being made to allow interfacing the central controls to the 30 and 90 MHz RF subsystem.

4.4.1 CONTROL SYSTEM DIAGRAM

The control diagram is represented in Fig. 5. Two remote I/O bases are shown, one at the MG room, another at an RF controls area. All serial communication to these remote bases are via a single twinax cable.

Other signal communications to the MG room are a hard-wired emergency shutdown line, and a hard-wired I²T disable line.

The RF subsystem will have timing signals from the RFTF timer and a disarm/disable/emergency shutdown controls lock, and with the MASTER SAFETY SYSTEM.

The other functional blocks representing systems or integrated hardware (e.g., operating console) and their interfaces, either uni- or bidirectional, are indicated in Fig. 5. All equipment, other than in the MG room or at the RF controls area, is already located in the RFTF control room or in the Machine Area.

4.4.2 MASTER SAFETY SYSTEM

This system ensures personnel safety during machine operation. All access to the machine area is inhibited by mechanical Kirk-Key interlocks. The master key to these interlocks will be held captive by a solenoid key release unit which will be part of a safety lockout switch.

Access to the master key is not allowed until all coil-disconnect switches are opened, all the coils are grounded, and all waveguide paths (except the 1-2 kW and 7 kW path) entering the machine area for the purpose of transmitting RF power are blocked (Figs. 10,11). The summation of these conditions is implemented by the hard-wired connection of position-sensing limit switches of the series switch.

The safety lockout switch also ensures that no power can be conducted or transmitted to the machine area until the lockup of the machine area is complete. When the lockup has been completed, the safety lockout switch is turned to its "unsafe" position, thereby closing a set of normally open contacts permitting operation of disconnect and blocking devices.

The emergency shutdown function is also part of the master safety system. This allows rapid removal of all power (MF & RF [except the 1-2 kW and 7 kW] power) from all the machine loads and closing the valves in the cooling water lines. The signal used in implementing this function is derived from normally open contacts of a normally energized emergency shutdown relay. When the relay is de-energized, an emergency shutdown is commanded.

A separate emergency shutdown contact is wired into all power system controls and into the machine coil cooling controls. As an added reliability measure, this contact is hard-wired into these systems in order to ensure that the command is executed even when the programmable controller fails.

The conditions that will cause emergency shutdown fall into two categories. When the machine area is locked up and the safety lock-out switch is in the "unsafe" position, any door interlock contact, Kirk-Key switch, or emergency shutdown pushbutton can cause emergency shutdown. When the machine area is open for access, only emergency pushbuttons can cause emergency shutdown.

4.4.3 MIRROR FIELD SYSTEM

The Mirror Field (MF) coils are powered by generators 11 and 12 and will use the RPTF area controls. These generators may also be used by PBX. In case of conflict (if deemed necessary in the future), the RPTF area controls can operate generators A and B, instead, with the addition of an additional MG disconnect. (These generators have lower current capabilities and are not capable at present of being programmed into the RPTF).

A schematic diagram of the system connection with generators 11 and 12 is shown in Fig. 4. These generators are each capable of driving a maximum current pulse in excess of 20 kA into a low resistance load, 8 kA max at 1600 V_{DC} max (MG voltage trip point) into RPTF 185 mΩ load.

Adequate personnel and equipment protection against malfunctions will be provided in the system using redundant controls.

In addition to the constraints provided by the master safety system, signals originating from the machine area will either go through a "safety break," such as an optical link, or be protected from coming into contact with high voltage lines or buses by an adequate safety barrier.

The protection of load, i.e., the MF coil, is primarily done by water cooling of the copper conductors. The coil cooling system will be interfaced to the programmable controller. This interface provides status inputs of flow switches and temperature switches and a control output to the motor-operated valves. A total of 18 inputs, representing flow and temperature switches, will be part of the control logic and will disarm the generators if low flow or high temperature is sensed.

A transducer installed over the bus drives two integrating type overcurrent relays for I^2t protection. The two units will be set for selective tripping: the lower set will disarm and the other will disable the MF system. In addition to the PC-controlled action, a hard-wired contact of the higher set unit will provide redundant protection.

A ground fault detector installed on the generator bus will protect the system from accidental secondary grounds.

4.4.4 PROGRAMMABLE CONTROLLER

The programmable controller (PC) selected for this task is a Texas Instrument Model 530 unit based on the following merits. (See Appendix B for brief description of CPU and I/O's.)

- A. 1. 1024 I/O address capability for future expansion.
(Initial system configuration will utilize about 250 I/O points.)
2. Distributed I/O capability allows placing I/O modules near the controlled equipment and connecting to the CPU by one twinax cable for all communication.
3. Modular construction of the I/O's allows easy expansion, simplified troubleshooting and maintenance.
4. A video programming unit (VPU) provides simple programming in ladder logic format and a valuable troubleshooting tool. System status can be monitored and contacts can be software jumpered by authorized personnel. A hard copy of program logic can be obtained by an external printer.
5. Simple software development and changes are anticipated.

B. Operating Console and Mimic Panel

The operating console contains several control panels organized by subsystems. Each of the control panels has

illuminated pushbuttons, which are connected directly to the programmable controller as inputs and outputs. Several thumbwheel switches provide for reference current settings and timing controls. A digital display shows the flat-top current level after each shot. Shot number readout will also be provided by digital displays.

The mimic panel contains the schematic representation of the MF system, with lights indicating the status of all important elements. Green lights indicate the "safe" position of a particular element, while red lights warn of "unsafe" conditions.

4.4.5 TIMER

A 20-channel digital timer is provided. Each channel can be adjusted by thumbwheel switches to a maximum of 9999.99 milliseconds time delay with respect to the start of the cycle. At the end of the time delay, a 175-volt 2-microsecond output pulse is produced.

The timer is interfaced to the PC adding multicycle capability, display of count, and audio indication of counting. In addition, some machine protection features require stopping the timer. All logical decisions affecting timer status will be performed by the PC.

Provisions for reading the setting of each timer channel are carried out by interfacing the timer to a Camac Crate which relays the timer channel setting to the diagnostic computer.

4.4.6 MISCELLANEOUS

Five fiber-optic analog links are provided to transmit signals from the machine area to the control room. This provides an isolation safety break.

4.4.7 RPTF SAFETY SYSTEM

The machine area is accessed by three entrances. Each of these doors is provided with the following devices:

- A. Kirk-Key Interlocks (SK);
- B. Electric Door Interlock (DI);
- C. Emergency Shutdown Station (ES);
- D. Kick-out panels (except RPTF equipment area).

The PBX Bay area bus connect enclosure locker is also fitted with the above safety devices; however, it does not open to the RPTF machine area. The Kirk Key system is shown in Figs. 1 and 3.

The safety lock-out switch (referred to at PPPL as a "Grove" switch) is the heart of the system. It provides access to the master key when the drum is turned to the safe position. This can be performed only when all the power supplies are disabled and disconnected and the coils are grounded. In this position all disconnect switch control power is removed by a contact on the safety lockout switch. The circuit to energize the shorting/grounding switch "open" solenoids is also disabled.

4.4.8 EMERGENCY SHUTDOWN

The emergency shutdown stations located outside the machine area are not accessible from inside the machine area except for the RFTF equipment area station. An emergency shutdown station will be made accessible from inside the machine area prior to July 1, 1984. Each station consists of a red mushroom button with a reset button below it. Each station also includes a red indicating lamp: LAMP ON - Emergency Shutdown Station Reset, LAMP OFF - Emergency Shutdown Station Activated.

A hard-wired series circuit with normally closed contacts maintains a relay energized under normal condition. Operation of any shutdown station causes an immediate shutdown of all systems, including the water system. Every station is monitored by the programmable controller to provide detailed annunciation.

Emergency stations located in the MG area interact with MG control systems in the event of an MG-associated emergency in the respective area.

The RFTF control room emergency stations interact with the RFTF control system as stated above.

The electrical interlock and Kirk-Key switch position on each access door are monitored by the programmable controller. No subsystem may be energized unless the emergency shutdown system is in the reset (normal) mode, all door interlocks indicate doors closed, and the

safety lockout switch is in the unsafe position.

4.4.9 MG CONTROL SYSTEM

A. System Configuration

The MF (Mirror Field) coils on RPTF are powered by a pair of 600 volt "Model C" motor-flywheel-driven DC generators, generators 11 & 12, (Fig. 4), each of which is capable of driving maximum current pulse in excess of 20 kA. These generators are connected in series via the east bus tunnel RPTF disconnect switches to provide a maximum of 1600 volts DC across the RPTF MF field coils.

Several electrical interlock contacts must be transmitted both ways between RPTF operating controls and the generator control center (MG control room), following a standard protocol used for various experiments since the C-Stellarator. Safety grounding and disconnect switches, and resistor and high speed breakers must be operated by RPTF controls.

Water coolant flow paths are monitored for the MF coils and water-cooled buswork; acceptable flows and water temperatures in these paths are required for MF operation.

RPTF operating controls produce a timed analog current reference signal pulse proportional to the desired MF current, as a command input to the generator control systems.

The MF Coil System includes 38 Coils:

1. 28 H-1 Coils 29 Turns each,
2. 8 FM-1 Coils 14 Turns each,
3. 2 PLT Coils 42 Turns each.

These coils are connected in a series configuration for uniform current throughout each coil type. A solenoid/cusp electrical switch enables the magnetic field to be altered in any one of two desired field configurations. Each position of the switch is interlocked by a position indicating switch. The switch is monitored by the programmable controller to verify that the circuit is correctly connected before permitting operation.

The RFTF operating controls monitor actual MF currents via a resistive shunt, located in the PBX bus connection enclosure. These currents are monitored for proper operating levels. Also the programmable controller limits the maximum coil current via MF current trip points for both pulse and steady-state operations. This is used to abort MF operation if necessary.

As a backup to this protection, a transducer with two associated time overcurrent relays performs I^2t integration and will also cause an independent trip.

MG local controls are provided by a programmable controller located in the MG area. This controller transmits and receives appropriate signals for proper MF field control to generators 11

appropriate signals for proper MF field control to generators 11 & 12 via a single twinax cable.

B. System Operation

The control of the generators follows the standard protocol which is used for all experiments. For the purpose of this discussion the following functions were defined:

SHUTDOWN:

This function disables the MF circuit and trips the generator field circuits.

DISABLE:

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

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 generator breakers by the MG.

DISARM:

This function disconnects and shorts out the reference signal path to the generator comparator.

ARM:

This function closes a permissive contact in the reference signal path to the generator field controls.

In order to operate the disconnects and the generator breakers totally from the RFTF control room, both MG and RFTF controls must be set to the OPERATE mode. This can be done either in the fully enabled state or in the disabled state. (Note: Normal start-up procedure requires the first enable to be performed in the check mode. After the breakers are closed in by MG operators, the control is then transferred to RFTF.)

In the OPERATE MODE the enable command causes the disconnect switch to close and to be followed by the automatic closure of the generator breakers.

4

When ENABLED in the OPERATE MODE, the system can be ARMED and subsequently pulsed into the MF load.

In any of the states, either the operator or the computerized control system can command DISARM or DISABLE.

4.4.10 VACUUM SYSTEM

The RFTF vacuum system (Fig. 6) is expected to be operated continuously and unattended for long periods between RFTF experimental periods as well as during the experiments. Its interlocks are thus implemented in a self-contained local controller.

A control system specifically designed for the RFTF vacuum system is used. All pump and valve sequencing protection features are implemented by this local controller located in the machine area.

The RFTF vacuum system includes two identical vacuum pumping lines; each contains: a chain of two pumps [a mechanical pump, (two speeds) and a turbomolecular pump]; three electropneumatic valves (a high-vacuum valve, a foreline valve, and a vent valve); one convection pressure gauge; and one ion pressure gauge. Line 1 contains a vessel roughing valve in addition to the others listed above. The mechanical pump reduces the pressure from atmospheric (760 torr) to 150 mTorr, and the turbomolecular pump reduces the pressure the rest of the way to about 10^{-6} torr.

The following controls and interlocks are implemented:

1. The mechanical pump is normally controlled on/off with no interlocks except for internal overload protective functions.
2. The roughing valve is only opened under manual control when both high vacuum valves are closed. The roughing valve will

automatically close when a high vacuum valve is opened after the pressure reaches the mechanical/turbo crossover point of 150 mTorr. The opening of the roughing valve is inhibited when either high vacuum valve is open.

3. Line 2 is used for roughing out the vessel to the low mTorr range with the foreline valve and high vacuum valve closed. The turbo in line 1 can be roughed out simultaneously to the vessel roughing operation provided by line 2.
4. Both turbomolecular pumps have vent valves that open automatically upon power failure or pump shutdown. Each respective foreline valve also closes with turbo failure or manual shutdown.
5. The foreline valve is opened under manual control subject to the condition that a protection bypass switch is activated. This switch allows initial manual start-up of each pumping stack. The bypass switch is then deactivated once the vessel is opened to the turbomolecular pump for interlock protection.
6. Protection is provided by convection pressure gauges on the main vacuum vessel (for high vacuum valve closure in the event of base pressure > 200 mTorr) and the foreline (for high vacuum valve closure, turbo shutdown, and foreline

valve closure foreline pressure > 200 mTorr, indicating high vessel base pressure, rough pump mechanical failure, or air leaks).

7. The turbomolecular pump is started only by manual control. It can be turned off manually, and will be turned off automatically if a temperature overload exists due to a water cooling failure or other internally sensed problem development.
8. The high vacuum valve is opened only by manual control. The permissive conditions are that both roughing and venting valves must be closed, RFTF vessel pressure must be below a setpoint and the turbopump must be running.
9. The RFTF vacuum system is not connected to emergency power. The system shuts itself down when a power failure condition exists with the air-operated high vacuum valves closing, and all other electrically operated equipment operations ceased. The turbo pumps are then vented up with the springloaded foreline valves enclosed. The mechanical pumps have automatic self-closing check valves.

Upon power restoration, the system remains shut down and has to be restarted manually. The vessel vacuum integrity is maintained throughout a power failure by the above functions.

4.4.11 RFTF WATER CONTROL AND MONITORING

A. Water Control

For water control, valve actuators with single phase reversible motors are used. These valves are wired for sequential operation, i.e., at startup the return valve must be open before the supply valve opens, and at shut down the supply valve closes before the return valve. Turning the water system on or off is initiated by operator command and coordinated by MG control.

B. Water Monitoring

Sixty-six normally open flow switches and sixty-six normally closed temperature switches monitor the coil and bus cooling water. (Six additional flow and temperature switches remain as spares.) These contacts are wired into nine coolant groups (Fig. 7). All flow and temperature switches must be closed as a prerequisite to enabling any of the power supplies. During operation any switch opening will disarm the MF coil power. The system may then be disabled by operator command if necessary.

4.4.12 RFTF PROGRAMMABLE CONTROLLER AND MAN-MACHINE INTERFACE

A. Programmable Controller

The TI 530 Programmable Controller resides in the RFTF control room. It consists of a dedicated programmable CPU and dedicated I/O ports. The control logic is software oriented and effected via hardware synthesis.

B. Man-Machine Interface

The man-machine interface allows complete control of all RFTF parameters required for machine operation. A control panel housing the control function buttons and annunciators is mounted in the control room for operator monitoring and control. A mimic panel is mounted above the control panel for generator switch position monitoring.

4.4.13 GROUNDING

A. Introduction

Grounding has to satisfy a number of considerations.

1. Minimize Interference

The magnitude of the ground current must be kept to a minimum, and its spread along spurious ground paths should be restricted. The basic approaches are:

- a. symmetrical capacitance distribution,
- b. single point ground,
- c. avoid loops (within close proximity of RFTF device approximately 5 ft.),
- d. low inductance ground connection.

2. Personnel as well as equipment safety depends on minimizing voltages that appear at nearby points, i.e., adjacent to each other or at space occupied by personnel.

3. It must provide a return for power short circuits, which is a requirement of the National Electric Code. It is also common sense not to let the short circuit current of the AC power spread along the grounding grid. Also, the equipment grounding conductors must run with or enclose the circuit conductors (NEC).
4. The layout of the grounding grid must not lend itself to picking up induced voltages from the stray flux of the experimental machine (Fig. 10).

Steps taken for the RFTF include:

- a. Ground currents will be minimized by symmetrical stray capacitance distribution.
- b. A single point ground will be utilized. [This is important from the diagnostic signal standpoint. Ground loops decrease the signal to noise ratio (SNR) by increasing the noise factor via inductive coupling to the MF field.]
- c. The NEC and NESC will be observed.
- d. Simple monitoring will be instituted that will sound an alarm if a violation of step b. occurs. (Sounding alarm presently not installed, electronics are installed.)

B. Machine Ground

The RFTF machine inherited a building ground grid from the H-1 machine installation.

The single "ground point" located on a ceiling beam is brought down via a main cable to 1 ft above the floor on the south wall. This is the ground system tributary branch-out point (fig. 9).

C. Control Room Ground

The control room ground will be a driven ground connected with an insulated conductor. This ground will be installed if it is found that the SNR is not large enough due to the larger ground loop that would exist with the building steel. (This is thought at present to be a remote possibility but will be proved empirically before installation of a driven ground.)

Grounds on cables will have an insulating break as they go through the machine/control room wall (once again to provide an adequate SNR). Inside the control room cables will be run on overhead trays.

D. AC Power Ground

The AC power is supplied to the machine room through an isolation transformer to the following loads:

1. Lower power (less than 5 kW) RF sources located in machine room or RF equipment area.
2. RFTF Crane.

3. Vacuum system power.
4. Power for diagnostics and Camac crates (on machine floor).
5. Lights and convenience outlets for machine area. Emergency lights (battery backup) are installed in the machine area in case of power failure and also will be installed in the control room.

E. Wall Grid and Conductor Sheath Grounds

Aluminum support structures in the machine room walls are separated from the machine by an air gap of a minimum of 5 ft. These supports will be bonded to building steel at each vertical upright by a bare copper ground cable. All electrical conductors going to the machine area are either isolated or enclosed in a grounded conducting sheath.

F. Machine Conduit Ground

Conduit used for roughing lines and diagnostics are electrically isolated at the vessel interface and grounded through the ground branch point as are electrical conduit and cable trays. The conduit and pipe that pass through the machine area are attached to the ceiling beams and are thereby grounded to building steel.

G. Cable Tray Ground

Cable trays, like conduit that pass lower than the ceiling beams, originating or terminating in the machine area will be properly separated (considering voltage level) and will carry grounding cables or straps.

H. Instrumentation Leads, Interlock, Control Cables, and Monitoring Connections

Signal leads from instrumentation and diagnostic devices will be carried through coaxial or shielded cables. The shields of coaxial cables are grounded at one end.

Diagnostics (computer linked) are input via shielded cable (at diagnostic ground) to a Camac crate located on the machine room floor and linked to the DAS computer via optical fibers.

Diagnostics monitored in the control room pass through fiber-optic isolation breaks.

Instrumentation/Diagnostics monitored/controlled via machine room/control room wall racks are connected via shielded cable grounded at the rack. The rack controls on the control room side are separated from the machine room by a plexiglass shield and manipulated with isolating rods.

I. Structure Ground

The RFTF machine is grounded to the single machine ground. Metallic structures near RFTF are grounded at only one point and configured to avoid creating loops.

The machine structure is broken into four segments which are grounded at a single point with ground loop and ground fault monitoring on each segment (Figs. 8,9). Coil support structure components are isolated from each other to eliminate loops.

J. Vacuum Ground

The vacuum vessel is grounded at the machine ground and is part of the monitored ground segments. Pump forelines are broken from vessel ground through vessel isolation rings.

4.5.0 FIRE PROTECTION

4.5.1 Fire Protection System

Fire damage is the principal property damage risk. The RFTP occupies a ground floor of a multistory building. The room is adjoined on all four sides by associated equipment, shop, bus locker, and control rooms. All rooms are protected by preaction, dry pipe automatic sprinkler systems. Fire alarm boxes and sprinkler annunciator alarms are connected through the fire alarm system to the Fire and Security Headquarters Emergency Control Center, which is manned at all times.

4.5.2 Fire Fighting Personnel and Equipment

The Laboratory Emergency Services Unit, consisting of 25 employees, providing at least 5 full time fire fighters for each shift, 24 hours per day, 7 days per week respond to all fire alarms. This unit answers each call with one pumper, one chemical truck, and a fully equipped emergency truck or an ambulance depending upon the needs. (Another pumper and chemical truck serve as backup.) Other volunteer personnel from PPL and support from Plainsboro Township respond to larger emergencies under mutual aid agreements.

Any new power supplies that present an additional fire hazard will be installed in conformance with existing strict fire protection codes at PPPL.

5.0 HAZARD ANALYSIS

5.1 Accident Analysis

Tables 2, 3, and 4 note the components of the RPTF which could be involved in an accident along with a mitigation by detection and corrective actions.

5.2 Failure Mode Analysis

Table 4 notes components and modes considered in a failure mode analysis along with the potential effects and corrective actions.

6.0 QUALITY ASSURANCE

During the design, fabrication, construction, and operational phases of RFTF, the background Quality Assurance Program at PPPL has been evolving from one of project level policy/procedure to one where laboratory-wide quality assurance top level policies limit the extent of project differences in applying appropriate design, process, and operational controls. The assurance disciplines currently imposed during RFTF operation and during planned or unplanned maintenance shutdown and start-up are identified in detail in PPL-QA-002, Quality Assurance Program Plan (in preparation) and Supporting Procedures.

7.0 CONDUCT OF OPERATION

7.1 Organization

The Laboratory has published a Health and Safety Directive (HSD's) system which describes safety organization and responsibilities.⁴ Safety at PPPL is considered to be a line responsibility⁵ extending throughout the line organization to all laboratory employees. The Project and Operational Safety Office maintains a close liaison with the RFTF to provide input at all RFTF operational meetings. A project safety coordinator has been assigned to provide a single point of contact between Project and Operation Safety and the RFTF. In addition, the PPPL Occupational Medicine and Safety Branch provides an independent audit function of safety policies.⁶ Also area safety coordinators are assigned to all areas of the laboratory in accordance with HSD-5002.⁴

7.2 Training

The Laboratory is in the midst of a comprehensive training program.

All devices at PPPL, including RFTF, require skilled and well-trained employees. Specifically, safety training sessions have been held on fire protection systems. All training will meet the requirements and standards of the Laboratory.⁷ The RFTF project managers will be responsible to identify employee deficiencies and ensure their enrollment in required courses.

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 Safety personnel (Appendix A). New operating parameters which have a potential for radiation production are monitored by Safety and subsequently released for routine operation by a written memo. The Master Safety System is tested twice per year in accordance with a safety procedure (Appendix A).

7.4 Configuration Control

Configuration Control is carried out by the project coordinator in charge of review of changes and new designs to be implemented on RFTF in conjunction with designated support groups appropriated for the respective task. The QA department will be contacted for a formal procedure strategy.

7.5 Procedures

HSD-5015⁸ encourages written procedures for most operations and requires them for unusual hazards.

7.6 Safety Review System

The PPPL Occupational Medicine and Safety Branch will provide an independent review of the RPTF project. In addition, area safety coordinators 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-5007.⁹ This is a Laboratory-wide plan which addresses emergencies throughout the site and defines responsible individuals, training programs, and emergency drills.

7.8 Standard Operating Procedures

Search and secure procedures will be used daily prior to closing the interlocked machine area and equipment enclosure.

REFERENCES

- 1 Operational and Environmental Safety Division, Environmental Protection, Safety, and Health Protection Program for DOE Operations DOE order 5480.1, Chapter XI U.S. Department of Energy, Washington, D.C. 8/13/81.
- 2 PPPL Health and Safety Directive (HSD-5008), Health and Safety Manual, 6/83.
- 3 PPPL Tokamak Fusion Test Reactor Facility, Final Safety Analysis Report, Section 2.
- 4 PPPL Health and Safety Directive (HSD-5002), Organization, 7/28/82.
- 5 PPPL Health and Safety Directive (HSD-5001), Safety Policy, 7/28/82.
- 6 PPPL Health and Safety Directive (HSD-5024), Independent Review, 2/01/83.
- 7 PPPL Health and Safety Directive (HSD-5028), Training, 12/6/82.
- 8 PPPL Health and Safety Directive (HSD-5015), Written Operating Procedures, 12/6/82.
- 9 PPPL Health and Safety Directive (HSD-5007), Emergency Preparedness Plan, 10/82.
- 10 NFPA 50A-1978, Standard for Gaseous Hydrogen Systems at Consumer Sites.

- 11 Pinter, G., Fry, T., Hydrogen Explosion Potential in Torus Vacuum Pumping System (TVPS) and Neutral Beam Vacuum Subsystems (NBVS), June 27, 1978, EP-M8116, Fig. 2.
- 12 NFPA 50A-1978, Standard for Gaseous Hydrogen Systems at Consumer Sites.

TABLE 1

MF FIELD WINDING PARAMETERS

MAJOR RADIUS	36 Inches	99 Inches	104 Inches
MINOR RADIUS	11 Inches	61 Inches	98.5 Inches
TOTAL TURNS/COIL	29	42	14
TOTAL COILS	28	2	8
I_{MAX} DC STEADY STATE	2 KA	10 KA	8 KA
GPM/COIL at ΔP	~ 5 GPM @280 psi	4.5 GPM @120 psi	4.5 GPM @120 psi
I_{MAX} RFTF OPERATION	Total MF Coils	5 KA Pulsed	2.5 KA Steady State
INSULATION	Fiberglass taped epoxy impregnated		
REP. RATE	To be determined by Coil tests		
B_T AT CENTER H-1 SECTION	30 kG		
B_T AT CENTER PLT/FM-1 SECTION	51 kG		
MIRROR RATIO	6		
TOTAL COIL RESISTANCE	185 m Ω		
TOTAL COIL INDUCTANCE IN MF CONFIGURATION	185 mh		
$L/R = 1$ Sec			

TABLE 2

HAZARD EVALUATION AND DESIGN PROVISIONS

<u>CONSIDERATION</u>	<u>PROVISION</u>
Hydrogen	<p>Installation per established safety codes.</p> <p>Air/H₂ mixture concentrations safe for all failure modes.</p>
High Voltage	<p>Interlocks, ground provisions, insulation, marking, controls limited access areas.</p> <p>All interlocks identified in operations procedure and verified prior to facility operation, tested periodically.</p>
Radiation	<p>Should not be any ionizing radiation emitted from this device.</p> <p>Continued monitoring as experiment progresses.</p>
Coils and Mech. Equip.	<p>Design margins adequate for stress and deflections.</p> <p>Design margins verified by tests.</p>
Fire Enclosure	<p>Enclosure is within a building protected by automatic sprinkler system.</p> <p>Building materials and construction are in accordance with fire protection codes.</p>
Power Supplies	<p>Installed per fire protection codes and NEC HI dielectric isolation.</p>

TABLE 3

COMPONENT	FUNCTION	ACCIDENT MODE	ACCIDENT DETECTION AND CORRECTIVE ACTION
Hydrogen	Fuel for Plasma	Accidental Release	Because of the small quantity fire and/or explosion hazard is virtually nil.
Toxic Materials	Not Used		
Pressurized Gas	Fuel for Plasma	Bottle Explosion	Small inventory minimizes risk. Firm mechanical support required to eliminate accident.
Compressed Air	Maintenance Aid	Pressure Line Break	Conservative Design. Installation elevated where feasible.
High Pressure Water	Cooling Water	Line Break	Conservative Design. Effect not dangerous, consequences won't endanger people.
RF Power	Plasma Heating	RF Radiation Leakage	RF Radiation Monitor preset to trip at 0.5 MW/cm^2 level alarm (Appendix C). Provide RF Shielding

TABLE 4

COMPONENT	FUNCTION	ACCIDENT MODE	ACCIDENT DETECTION AND EFFECT CORRECTIVE ACTION
Electrical Bus	Power Conduction	Short Circuit	Conservative design makes occurrence probability low. Surrounded by enclosure to prevent line of sight damage.
Coils	Experimental Equipment	Short Circuit	Conservative design. Area surrounded by walls.
Plastic Conduit	Encloses	Fire	Fire protection and fire installed.
FAILURE MODES	EFFECT	DETECTION	PROTECTION/PREVENTION
Waterflow Stopped on Coil	Overheating Machine Coil	Flow + Temperature Switch	Prevent Next Cycle Alarm
Bus Connection Failure	Connection Overheating	Over Voltage Trip	Appropriate Connection Make-Up Procedures <ol style="list-style-type: none"> 1. Torque Check 2. Gap Check 3. Bus Enclosed in Fire Retarded Materials
Vacuum Failure	Let Vacuum Vessel Up to Atmosphere	Vacuum System Shutdown High Pressure	Leak Check Vacuum System Equipment Regular Maintenance

TABLE 5

<u>AREA</u>	<u>FLOOR SPACE</u>
Machine Area	20 ft. x 18 ft.
Shop Area (Open to Machine Area)	25 ft. x 16 ft.
RFTF Equipment Area	20 ft. x 8 ft.
All above areas have 16 ft. ceiling	
Machine Platform	15 ft. x 8 ft. x 6 1/2 ft.
(Located South Side Machine Area)	Figure 1

FIG. 1

#84E0069

FIG. 2

KIRK KEY SEQUENCING

FIG. 3

#84E0065

MF SCHEMATIC DIAGRAM

FIG. 5

RFTF VACUUM SYSTEM SCHEMATIC

#B4E0072

RFTF WATER COOLANT GROUPS

FIG. 7

#84E0067

63

MACHINE GROUND SEGMENTS

FIG. 8

#84E0068

RFTF GROUND SYSTEM

FIG. 9

#84E0070

30 MHz RF SOURCE KIRK KEY INTERLOCKS (1ST FLOOR)

FIG. 10

#84E0064

30 MHz RF SOURCE COAXIAL SWITCHES

Coaxial
Switch

Coaxial Switches Have Positional Microswitch Contacts
Side Not Connected Is Grounded

FIG. 11

#84E0063

TFTR/DIII RFTF VESSEL CROSS SECTION

CLASSIFICATION OF LIFTS

CLASSIFICATION	INJURY TO PERSONNEL	SCHEDULE IMPACT	COST IMPACT	RADIATION EXPOSURE
ORDINARY	MINOR, NO LOST TIME	LESS THAN 2 WEEKS	LESS THAN \$50K	0 TO 1 REM
LIFT COMMITTEE REQUIRED HIGH CONSEQUENCE	LOST TIME ACCIDENT	2 TO 4 WEEKS	BETWEEN \$50K & \$250K	1 TO 5 REM
LIFT COMMITTEE REQUIRED SPECIAL HIGH CONSEQUENCE	DISABILITY OR FATALITY	OVER 4 WEEKS	OVER \$250K	OVER 5 REM

FIG. 13

#84E0079

Flow Chart

FIG. 14

#84E0080

Flow Chart

FIG. 15

#84E0074

4-11C#110 & 1-1/C#6 BARE
FROM PLT-31 VIA 150A FUSED SW
DWG 6840-D-102-OL SH.1

SERVICE DESCRIPTION	WIRE SIZE	BKR SIZE, TYPE	CKT NO	Y Y Y Y	Y N/S	CKT NO	BKR SIZE, TYPE	WIRE SIZE	SERVICE DESCRIPTION
BENCH WIREMOLD	12	20A	1	(	Y	2			
WEST RECP'T	12	20A	3	(	Y	4			
SOUTH RECP'T	12	20A	5	(	Y	6			
SOUTH RECP'T	12	20A	7	(	Y	8			
SOUTH RECP'T	12	20A	9	(	Y	10			
SPARE	12	20A	11	(	Y	12			
			13	(	Y	14			
208 RECP'T	6	30A	15	(	Y	16			
			17	(	Y	18			
			19	(	Y	20			
			21	(	Y	22			
			23	(	Y	24			
			25	(	Y	26			
			27	(	Y	28			
			29	(	Y	30			

ITE
120/208V 3Ø 4W
200 AMP MAINS

LP-809

1ST FL. R.F. BLDG RFTF EXP. ROOM

FIG. 16

#84E0081

FIG. 17

APPENDIX A

TESTING PROGRAM

FOR

PERSONNEL SAFETY INTERLOCK SYSTEMS

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Safety Interlock Coordinator

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APPROVALS

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Revision No.	Revision Date	Approval Signature
Rev.1 (5.0-5.2)	6 June 84	EE

TESTING PROGRAM FOR PERSONNEL
SAFETY INTERLOCK SYSTEMS

APPENDIX A

1.0 Purpose

Because of the potentially serious consequences of a Safety Interlock failure, there is a need to ensure, by timely and adequate tests, the integrity and reliability of interlock systems and their components. It is the purpose of this program to provide such assurance.

2.0 Scope

The Testing Program consists of two parts and will cover all the enclosures, experiments, and experimental devices at the Princeton Plasma Physics Laboratory in operation.

- A. Part I: This will confirm the proper mechanical functioning of Kirk-Key Systems.
- B. Part II: This will verify the correct electrical operation of Warning Systems (audible and visual), Access Control Systems (doors and electrical Key Interlocks) and Emergency Shutdown Systems under a simulated running configuration and/or Mock-Up mode.

3.0 Definitions

3.1 Safety Interlock Systems:

This term will be used to identify one or more of the following systems - Warning System, Emergency Shutdown System, Interlocked Access Control Systems.

3.2 Area Safety Coordinator:

A person authorized to coordinate activities related to the Laboratory Safety Program in his or her area of responsibility. Also conducts and records periodic safety inspections and provides follow-up to ensure that deficiencies are corrected.

References: Health & Safety Directive 5002.00

3.3 Safety Interlock Coordinator:

A person authorized to document, test, and retain records of all devices in the Safety Interlock Systems. Further described in 8.4.

TESTING PROGRAM FOR PERSONNEL
SAFETY INTERLOCK SYSTEMS

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4.0 References

- A. PPPL Health and Safety Manual, HSD 5008, Sect. 2.0, Supp. 2.1, and Draft 2.2.
- B. Department of Energy Order Ch. 5480.1A Chapter XI Section 6
Dated: 4/26/82
- C. ANSI N43.1 1969
- D. Department of Energy Order 1342.2 Schedule 25 Item 1-B

5.0 Frequency of Testing

- 5.1 All Personnel Safety Interlocks that sequence and/or access electrical equipment will be tested on a yearly basis.
REFERENCE: HSD 5008 Safety Manual, Supplement 2.1 Part IV Para. G.
- 5.2 All personnel safety interlocks that control access areas or equipment for the purpose of protecting personnel from radiation will be tested at intervals not to exceed 6 months.
REFERENCE: ANSI N 43.1 Dated 1978 Par. 3.6.1.

6.0 Safety Considerations

Under no circumstances shall Safety Interlocks be tested while related experimental machines are running. All experimental devices and their sub-systems shall be de-energized before testing begins.

7.0 Testing Protocol

In accord with the final version of the attached schedule, the Interlock Coordinator shall send to the cognizant engineer or physicist in charge of the related experimental device or system all Drawings & Procedures which relate to Part I & Part II of this program, to perform the interlock tests (drawings, procedures) in a safe and orderly fashion.

Cognizant engineer or physicist shall appoint trained operating personnel, or such other persons as he chooses, to perform the tests.

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8.0 Responsibilities

- 8.1 The Cognizant Engineer or Physicist shall schedule enough time to permit operating personnel to perform the Safety Interlock Tests in a safe and orderly fashion.
- 8.2 The Cognizant Engineer or Physicist or their Designee Chief technician is responsible for supervision of operating personnel in the performance of the tests.
- 8.3 The Project & Operational Safety Office is responsible for the verification of the completeness of the Safety Interlock Test.
- 8.4 The Safety Interlock Coordinator:
 - 8.4.1 Shall review the designs of new Personnel Safety Interlock Systems and modifications to existing systems in light of existing and new standards for such systems.
 - 8.4.2 Shall monitor Search and Secure Procedures, repair and Maintenance Procedures, and the documentation of the Personnel Safety Interlock Systems.
 - 8.4.3 Shall set-up and perform periodic testing of the Personnel Safety Interlock Systems.
 - 8.4.4 Shall encourage standarization and uniformity in the design of new, and the modification of existing systems.

9.0 Testing Schedule

Testing schedules will be forwarded to the Cognizant Engineer or Physicist on the first workday of the month in which testing is scheduled for that system. The tests must be completed prior to the end of the month.

6 Month Testing Schedule
Yearly Testing Schedule

See attachment A
See attachment B

TESTING PROGRAM FOR PERSONNEL
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10.0 Approval

The safety interlock Coordinator by his signature on the Safety Interlock Test affirms that the test has been performed in accordance with Department of Energy orders, H&S manual, and directives.

11.0 Operational Verification

An easily visible indication of current status (paste on label) will be affixed to each Kirk-Key Lock or Safety Interlock System Tested.

12.0 Record Retention

The Safety Interlock Coordinator will retain all completed Safety Interlock Tests for Department of Energy audit or appraisal. in accordance with DOE order 1324.2 schedule 25 Item 1-B.

(A)

INTERLOCK TESTING PROGRAM (6 MONTHS)

SYSTEM	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ACT 1 ELEC. & MECH.		⬡						⬡				
NEUTRON GENERATOR TEST FACILITY	⬡						⬡					
RADIO FREQUENCY TEST FACILITY						⬡						⬡
SPHEROMAK ACCESS CONTROL		⬡						⬡				
PLT/PBX RADIATION INTERLOCK	⬡						⬡					
PLT E. STOP SYSTEM						⬡						⬡
PBX E. STOP SYSTEM			⬡						⬡			
800 MHZ RF SYSTEM TOTAL SYSTEM				⬡						⬡		
90 MHZ RF SYSTEM			INACTIVE FOR 6 MONTHS									
10 MHZ RF SYSTEM			⬡						⬡			
2.45 GHZ RF SYSTEM		⬡						⬡				
30 MHZ RF SYSTEM NO. 1			⬡						⬡			

(A)

INTERLOCK TESTING PROGRAM (6 MONTHS)

[illegible]

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INTERLOCK TESTING PROGRAM (YEARLY)

[illegible]

(B)

INTERLOCK TESTING PROGRAM (YEARLY)

SYSTEM	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
PLT/PBX HARD TUBE AMPLIFIER	INACTIVE - UPGRADING WHEN FUNDS AND MANPOWER ARE AVAILABLE											
MG CONTROL TRANSFER SYSTEM		⬡										
EQUILIBRIUM FIELD SUBSYSTEM 1 & 2		}										
EQUILIBRIUM FIELD SUBSYSTEM 3 & 4												
OHMIC HEATING SUBSYSTEM 1 & 2												
OHMIC HEATING SUBSYSTEM 3 & 4			UNDER COMPLETE DESIGN REVIEW									
OHMIC HEATING SUBSYSTEM 5 & 6												
TOROIDAL FIELD SUBSYSTEM 1												
TOROIDAL FIELD SUBSYSTEM 2												
HORIZONTAL FIELD SUBSYSTEM												
VARIABLE CURVATURE FIELD SUBSYSTEM												
SUB-STATIONS		DURING POWER OUTAGE										

APPENDIX B

MODEL 530 PROGRAMMABLE CONTROLLER

CPU

The Model 530 interacts with Series 500 I/O modules to perform the control functions by sampling discrete points, word values, or analog values on a repeated basis. The CPU makes an evaluation of the inputs with a previously stored ladder logic program, then controls outputs to cause the appropriate responses for a programmed application.

In addition to performing the usual PF function of executing relay ladder logic and simulating timers and counters, the Model 530 performs powerful high-level instructions. These instructions are memory-efficient and user friendly. The Model 530 provides an efficient and easily implemented solution to control applications for industrial automation.

The CPU consists of a microprocessor and a high-speed discrete Boolean processor with associated memory and control circuits. The memory consists of an operating system memory and more than 5K of CMOS RAM user memory for the Model 530-1102 or more than 7K of CMOS RAM user memory for the Model 530-1104. Sockets are provided for either 2K or 4K of EPROM ladder memory.

Fixed- and variable-scan modes may be selected by using a VPU. A typical scan time for 1K words of relay ladder logic type instructions is 8 milliseconds.

The CPU performs on-line diagnostics on all serial I/O data when the unit is powered up, and continues the diagnostics routinely thereafter.

The CPU continuously updates status words to indicate the current status of I/O bases, battery, communication port, scan, and I/O modules. These words are available to the user through a VPU or for use in ladder logic. Indicator

lights on the CPU give a quick visual indication of CPU status. Therefore, the Model 530 CPU makes it easy for maintenance electricians to isolate quickly a module failure.

The Model 530 CPU addresses up to 1023 I/O points and features a keylock to protect the user program once stored in memory. The 530 CPU has an integral power supply which provides power for all the CPU internal circuitry and up to 32 I/P modules (256 I/O points).

SERIES 500 INPUT/OUTPUT

The Model 530 features an I/O capability of up to 1023 I/O points. These I/O points allow all discrete inputs, outputs, all word/analog inputs, all word/analog outputs (limited only by the number of I/O modules), or any combination of discrete and word/analog inputs and outputs.

TI's "intelligent" I/O module concept moves high-performance or special functions from the CPU to the module. Modules such as the ADCII Output Module provide additional storage and communication without taxing the control functions of the Model 530 CPU.

Intelligent I/O modules reduce scan time requirements on the CPU and do not overload the user memory. With intelligent I/O modules, the user pays only for the performance and features needed. TI will introduce new Series 500 I/O modules to provide more system versatility.

APPENDIX C

BROAD BAND RF RADIATION MONITORING SYSTEM

METER SPECIFICATIONSNARDA MICROWAVE CORPORATION
MODEL 38616

Dynamic Range	30 db
Full Scale Ranger	0.2, 2, 20 mW/cm ² ; 1, 10, 100 mW/cm ² 2, 20, 200 mW/cm ² ; 20, 200, 2000 mW/cm ² 0.1, 1, 10 W/cm ² ; 2, 20, 200%
Accuracy	± 3%
Response Time (Approx.)	1 sec. in fast position, 3 sec in slow
Power Density Alarm	An adjustable audible alarm preset by panel control for a percentage of full scale
Battery Type	25 Volt rechargeable Nickel
Battery Use Time (Approx.)	40 hours, 3:1 use to charge time
Additional Features	Automatic Zero, Maximum Hold Method of Operation, Battery Test
Line Operation	115/230 VAC 50-400 Hz
Use with Probes	All NARDA Probes

RF PROBE SPECIFICATIONS

ELECTRIC FIELD

<u>MODEL</u>	<u>FULL SCALE POWER RANGES*</u>	<u>FREQUENCY RANGE</u>	<u>FREQUENCY SENSITIVITY</u>	<u>PROBE OVERLOAD</u>
8621B	0.2, 2, 20 mW/cm ²	0.3-26 GHz	+0.75 db	300 mW/cm ² (CW)
		0.85-16 GHz	-3	60 W/cm ² (Peak)
		1-12 GHz	+0.75 db	
			-1.0	
			+0.75 db	
8631	0.2, 2, 20 mW/cm ²	13-200 MHz	±0.5 dB	60 mW/cm ² (CW)
		10-300 MHz	2 dB max	20 W/cm ² (Peak)

*The term Power Density is equivalent power density; space independence is assumed to be 377 Ω

APPENDIX D

RPTF Halon Fire Protection System
Cost/Effectiveness Study

RPTF CONTROL ROOM CONTENTS	DOLLAR VALUE
TI 530 Programmable Controller	\$= 30,000
1 Tektronix Oscilloscope	\$= 10,000
2 CTTY Computer Terminals	\$= 15,000
2 613 CRT's	\$= 2,000
Miscellaneous	\$= 10,000
TOTAL	<hr/> \$ 77,000

1 Million dollars is the level of material and equipment value needed to be exceeded to justify installation of Halon Fire Protection System.

APPENDIX E

The RFTF operation under normal conditions uses hydrogen at a pressure of 10^{-4} torr. An accident condition causing air inrush to the vacuum vessel bringing the pressure to atmospheric will never reach the detonation mixture (see Fig. E1).

Another accident condition may cause hydrogen to leak into the vessel (worst condition will be the whole inventory of the hydrogen bottle). Under this condition air is not present in the vessel, and consequently a detonation mixture is not reached.

It takes a double failure condition to bring substantial amounts of air and hydrogen into the vacuum vessel. The system cannot be designed for very low probability double failures.

FIG. E-1