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Alcator C-MOD Final Safety Analysis

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I. Introduction and Summary Safety Analysis

This document is designed to address the safety issues involved with the Alcator C-Mod project. This report will begin with a brief description of the experimental objectives which will be followed by information concerning the site.

The Alcator C-Mod experiment is a pulsed fusion experiment in which a plasma formed from small amounts of hydrogen or deuterium gas is confined in a magnetic field for short periods ($\sim$ 1 s). No radioactive fuels or fissile materials are used in the device, so that no criticality hazard exists and no credible nuclear accident can occur. During deuterium operation, the production of a small number of neutrons from a short pulse could result in a small amount of short- and intermediate-lived radioactive isotopes being produced inside the experimental cell. Chapter IX of this report will demonstrate that this does not pose an additional hazard to the general population.

The health and safety hazards resulting from Alcator C-Mod occur to the workers on the experiment, each of which is described in its own chapter with the steps taken to minimize the risk to employees. These hazards include fire (Chapter IV), chemicals and cryogenics (Chapter V), air quality (Chapter VI), electrical (Chapter VII), electromagnetic radiation (Chapter VIII), ionizing radiation (Chapter IX), and mechanical (Chapter X) and natural phenomena (Chapter XI). None of these hazards is unique to the facility, and methods of protection from them are well defined and are discussed in the chapter which describes each hazard.

The quality assurance program, critical to ensuring the safety aspects of the program, will also be described.

The MIT Safety Office and the MIT Radiation Protection Office review and audit the safety systems and procedures instituted at the Alcator C-Mod project. Table Ia. and Ib. detail the organizational structure of these offices.

In particular, all fire systems and procedures are specified by the MIT Safety Office, and inspections are conducted by that office. Required radiological reporting to DOE is carried out by the Radiation Protection Office.

The principal investigators and supervisors are ultimately responsible for ensuring safe operation and are responsible for meeting the requirements and implementing the recomendations of the MIT Safety Office and the MIT Radiation Protection Office.

Table I.a Organization Chart for the MIT Safety Office

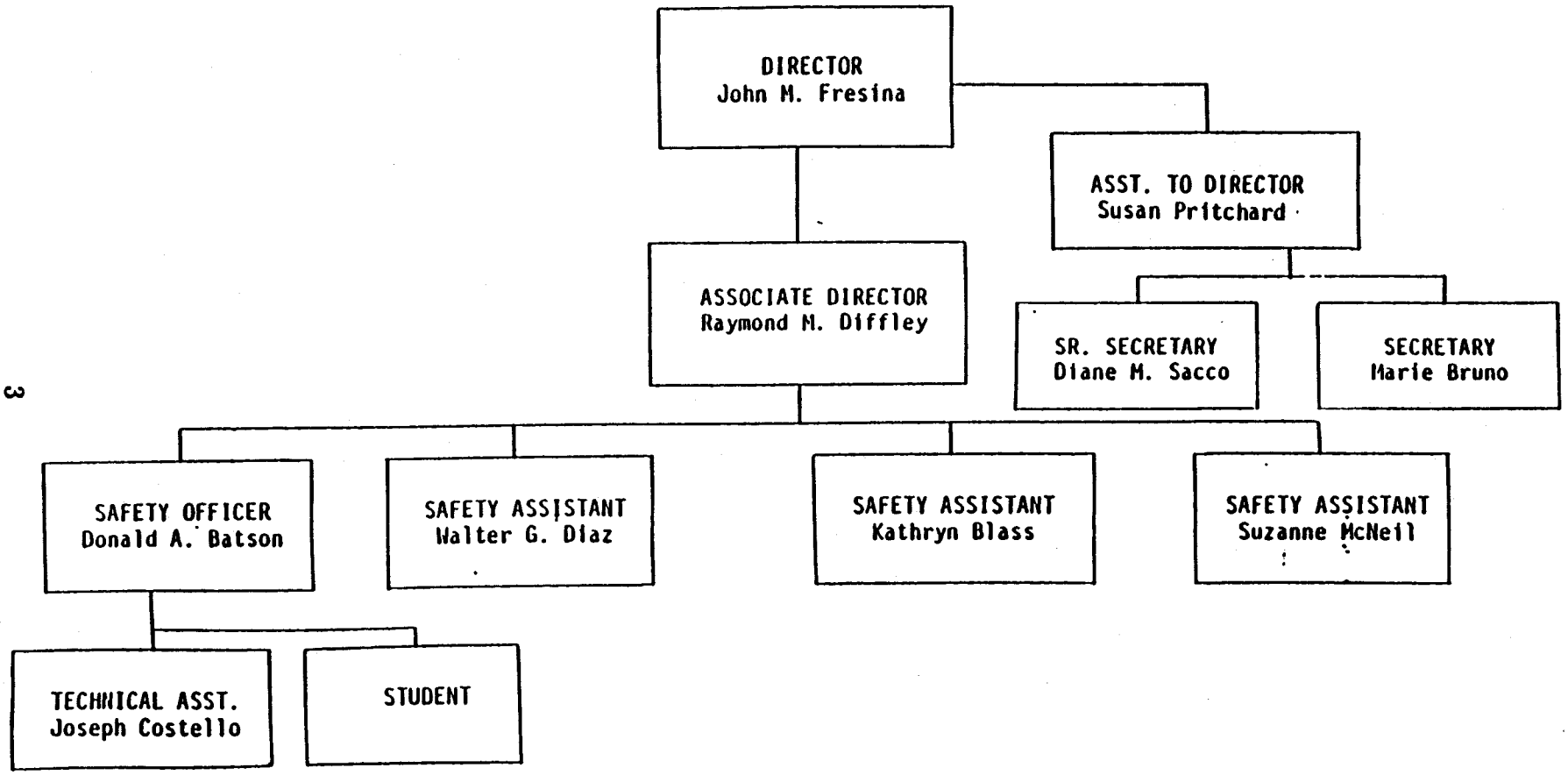
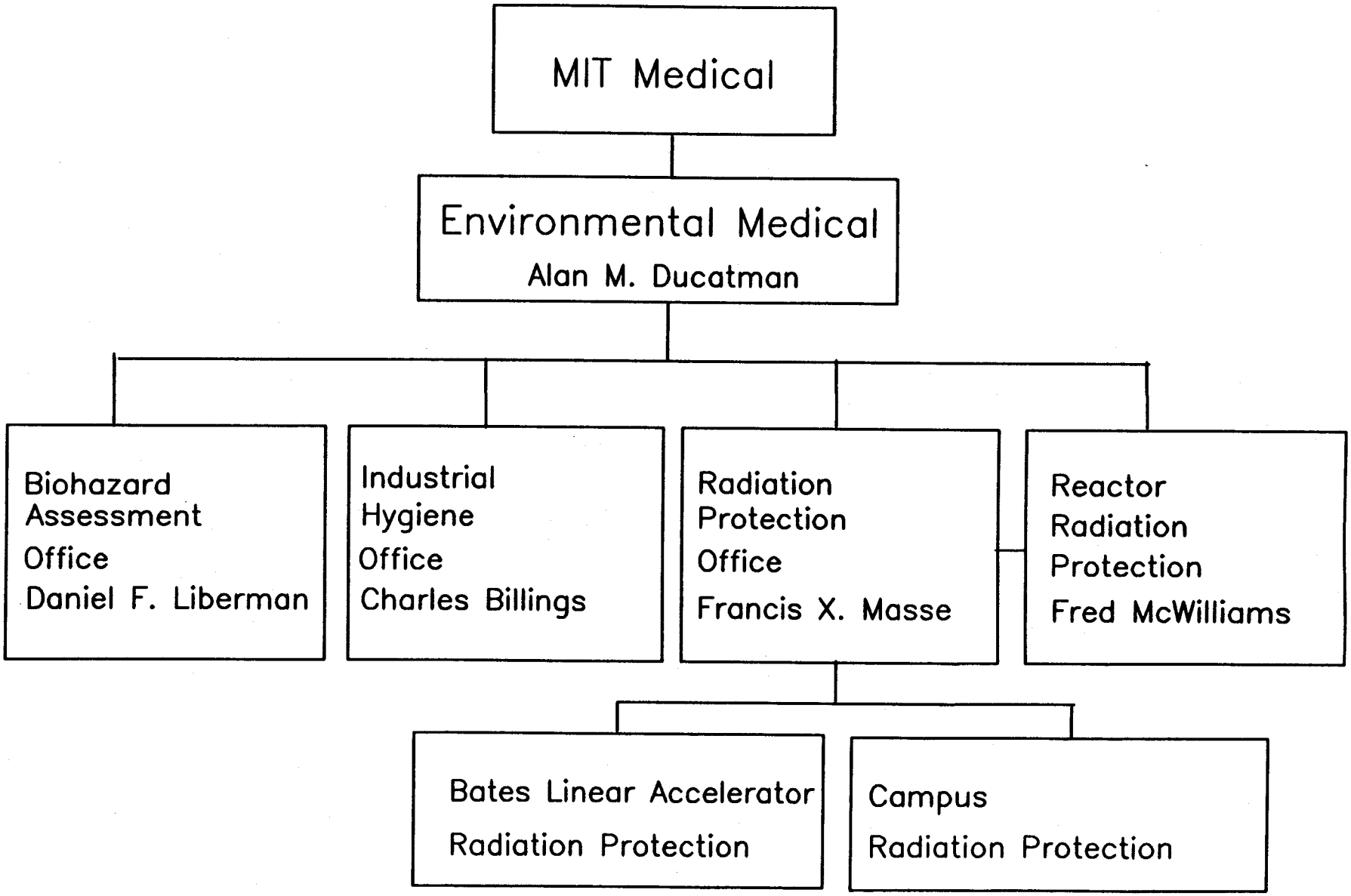


Table I.b Organization Chart for the MIT Radiation Protection Office



II. Experimental Description

The Alcator C-Mod experiment will contribute to the understanding of confinement optimization, RF heating, and impurity and edge control in tokamaks. This continuation of the Alcator compact high field tokamak concept (see the conceptual drawing in Fig. 1) is expected to achieve densities of $1.5\times10^{21}\mathrm{m}^{-3}$, and operate at temperatures in the 4-8 keV range. The parameters of the experiment are listed in Table II.

The Alcator C-Mod experiment is designed to address a number of physics issues. High density ICRF heating in a fully diverted and shaped high field tokamak will be pursued. The 6 MW ICRF power (at 80 Mhz) will allow study of the minority to second harmonic transition in a hydrogenic plasma, as well as contributing to the understanding of confinement issues during high power RF injection. Optimization of the Ohmic heating operation in Alcator C-Mod will address the question of whether ignition could be obtained without auxiliary heating. Plasma density and pressure control will be explored using pellet fueling and localized rf injection. The magnetic divertor will contribute to the understanding of how edge and impurity control together with profile effects can be exploited to improve confinement and stability. Electron cyclotron heating at high densities will also be explored, as well as the extension of RF current drive techniques to near-reactor plasmas.

The anticipated neutron production rate for deuterium operation in the Alcator C-Mod ICRF and Ohmic regimes as a function of average plasma density is shown in Fig. 2. The upper and lower limits of neutron production are determined by the assumptions governing the ion energy confinement in the plasma, $\chi_i = 1 - 3\chi_{i\ neoclassical}$ for the Ohmic operation. The limits in the ICRF heating case depend on whether or not the ion confinement is degraded with increasing RF power. These expected neutron production rates of 1×10^{15}n/sec (1 second pulse) for optimized Ohmic pulses and 5×10^{15}n/sec (1 second pulse) for ICRF heated discharges could constitute a radiation exposure hazard to Alcator C-Mod personnel and to the general public.

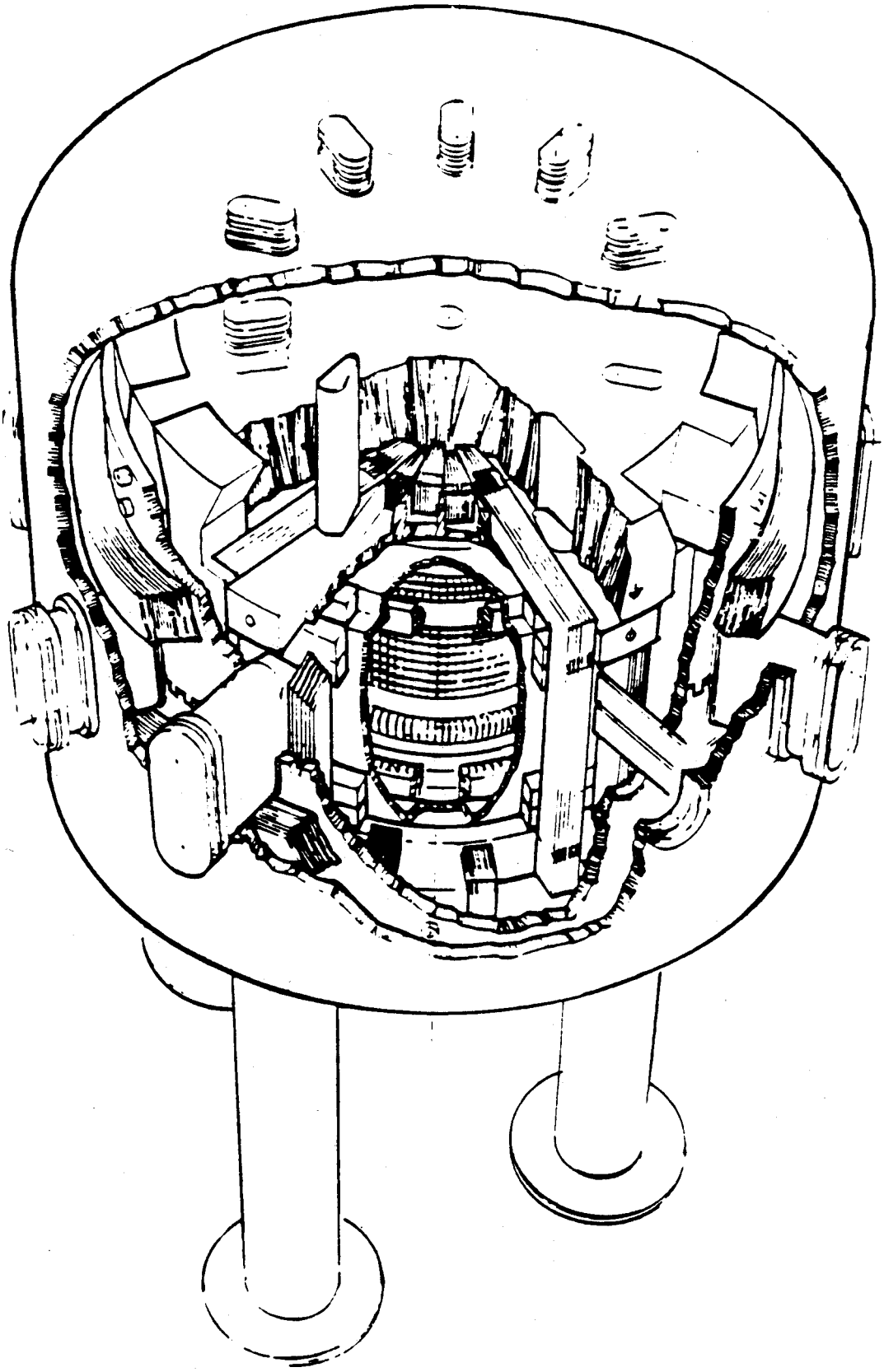


Figure 1. Conceptual drawing of the Alcator CMOD tokamak experiment.

Table II. Alcator C-Mod Parameters

Engineering Parameters	
Major Radius (m)	0.665
Minor Radius (m)	0.21
Magnetic Field (T)	9.0
Elongation (Nominal)	1.8
Triangularity	0.4
Plasma current (MA)	3.0
Flat-top Pulse (s)	1
Flat-top Pulse @ 5 T (s)	7
Volt-sec	7.5
RF Heating (MW)	6
Average Heat Flux (MW/m^2)	0.8
Plasma Surface Area (m^2)	7.4
Stored Energy Required (MJ)	380
Expected Plasma Parameters	
Murakami Density† ($\times 10^{20}$ m^{-3})	15
Temperature Range (keV)	4-8
Beta (%)	1.9-3.8
Troyon Beta Limit‡ (%)	6
Maximum Average Pressure (atm)	14

† Assumes Murakami Limit, $n_0 = B(T)/R(m) \times 10$

‡ Troyon Formula: β (%) = 3I (MA)/B(T)a(m)

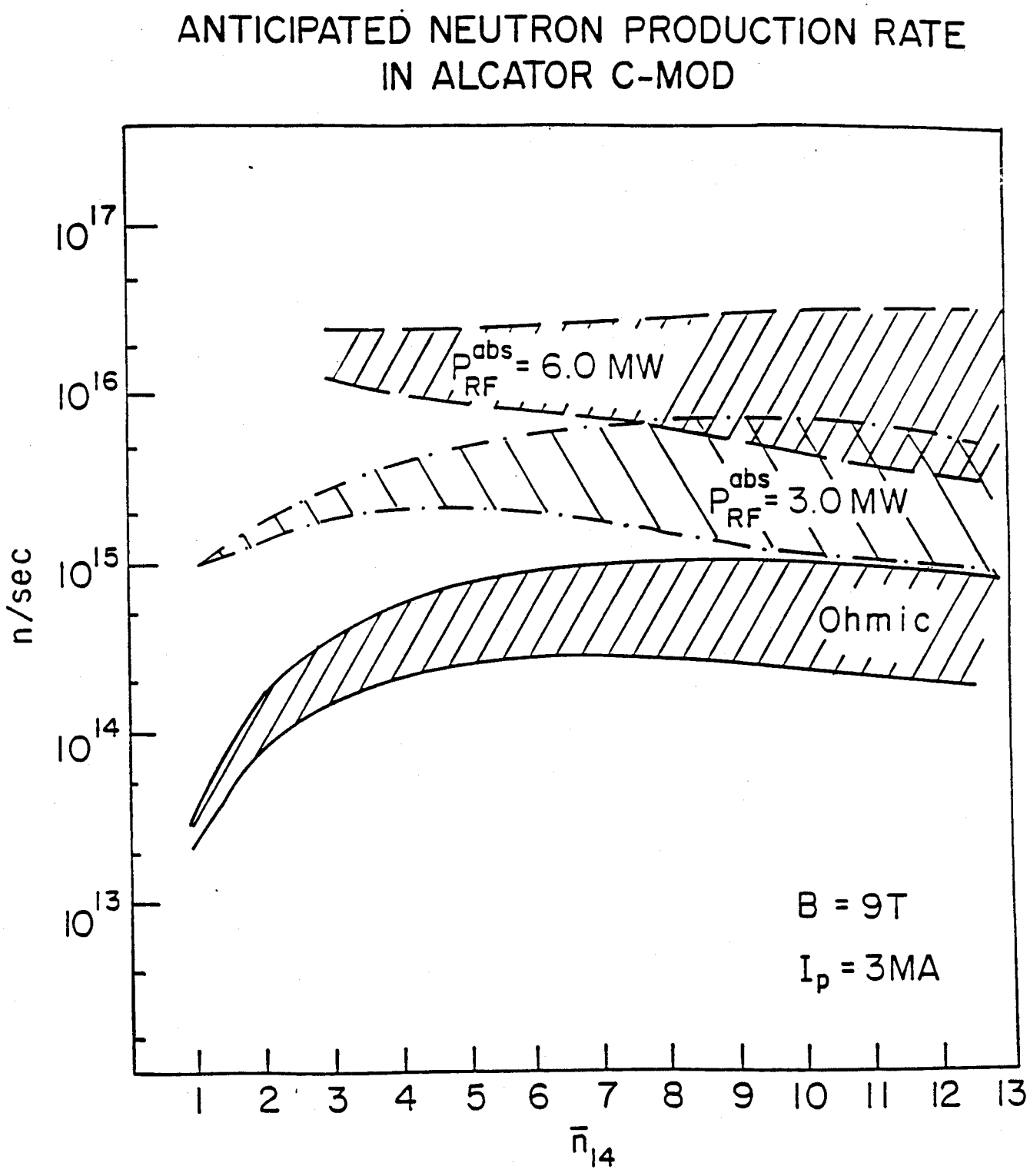


Figure 2. Anticipated neutron production rate in Alcator CMOD.

III. Site Information

The Alcator C-Mod experiment is located on Albany Street in Cambridge, Massachusetts in the Northwest section of the MIT campus, at the eastern end of building NW21 (Fig. 3). The southern boundary of the site, marked by a fence 15′ from the concrete cell wall, abuts the railroad right of way. The eastern cell wall, which is 8-15′ from a boundary fence is located 25′ from the pedestrian pathway lying between NW14, NW21 and NW20. The northern limit of the site is at Albany St., which is 120′ from the experimental cell wall. The nearest occupied areas to the experimental cell will be the unrestricted areas in NW21 (see Fig. 4) which include the control room and adjacent rough lab area (22′ from the cell wall), the pedestrian walkway and occupied areas of NW14 and NW15 (the generator shed next to NW14), Albany Street and the rail road tracks.

3.A. Experimental Cell

The experimental cell consists of a 50′ × 50′ × 36′ high room built with 5′ concrete walls, 4′ concrete ceiling, and 40″ concrete floor. It is located at the southeasternmost point of NW21. The cell floor lies 6.5′ below the exterior grade.

The cell is entered through a vestibule located in the center of the north wall which exits into the power room area. Emergency egress is provided through a second vestibule located at the southeast corner of the cell in the east wall. Both vestibules are constructed with 3′ concrete walls and ceilings.

Equipment will be brought into the cell through a 13′ by 13′ opening in the northern wall which is normally closed with a 5′ thick concrete door.

The radiation produced during plasma pulses and the electrical and mechanical hazards present during operation require that the cell not be occupied when the experiment is running.

3.B. Power Room

The power room extends from the north experimental cell wall to the wall adjacent to Albany St. This room contains the power systems for the experiment (other than the

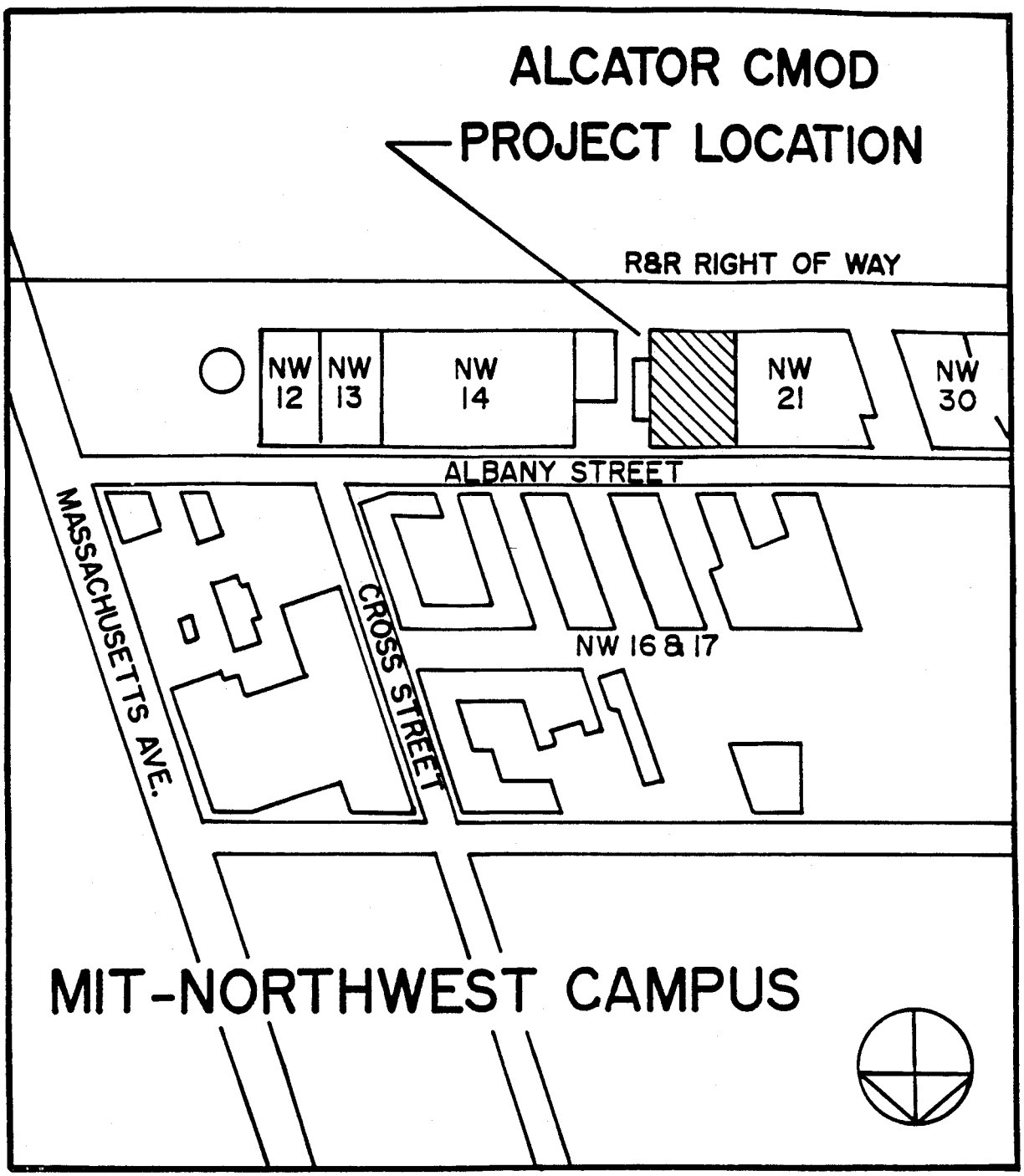


Figure 3. Site of the Alcator CMOD experiment.

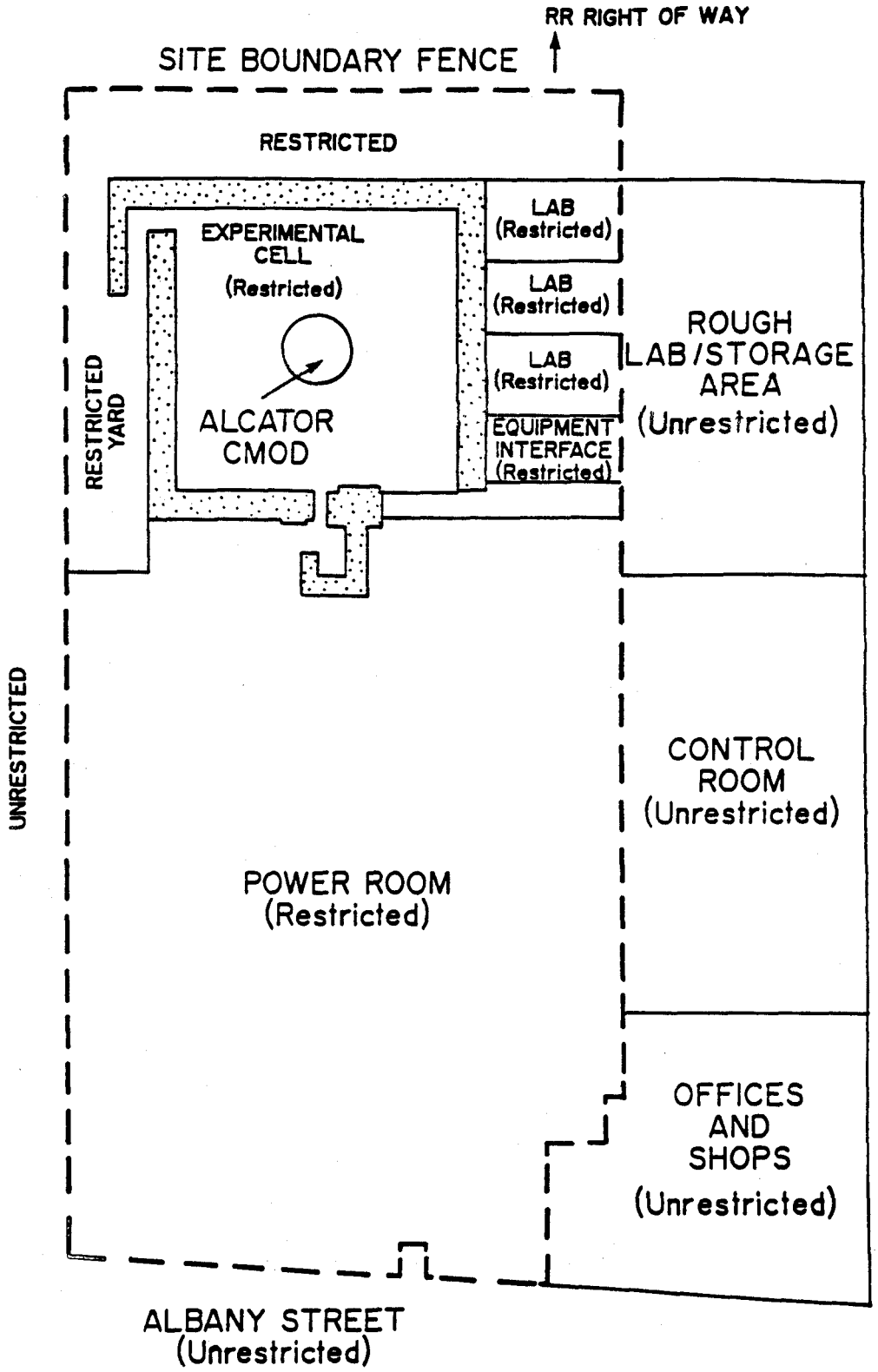


Figure 4. Restricted site boundaries for the Alcator CMOD experiment.

alternator) as well as the RF power systems for ICRF experiments. There will be 10-12 converter systems (10-40 MW each) for the poloidal field system and one 200 MW converter for the toroidal field. Each of the converters requires 13.8 kV input voltage and operates at $\approx$ 1000 V. The RF system consists of 4 sources (2 MW @80 Mhz each) for the ICRF experiments, and ultimately may include 4 power stations for the lower hybrid current drive experiments (1 MW @ 4.6 Ghz each).

Hazards to personnel in this room are present from the high voltage and high power capabilities of the power systems as well as from leakage of RF power. There is also a potential radiation hazard from neutron and γ-ray emission through the electrical buswork penetration through the cell wall. This requires that access to this room be controlled during experimental pulses. Fire also poses a hazard to equipment and personnel in this area.

3.C. Laboratory Areas

Four diagnostic laboratories lie adjacent to the west wall of the experimental cell, and extend 22′ from that wall. Line of sight access into the cell can be obtained through 12″ diameter holes penetrating the concrete shield wall. (There are 4 in one lab and 6 in each of the other three for a total of 22.) These diagnostic ports are plugged with neutron shielding material when not in use, and require surrounding shadow shielding when being used. In addition, the 4 intake vents for the air in the cell open into these rooms. Also there are two 5″ diameter sweep channelways connecting each lab with the experimental cell for electrical connections, and the data acquisition room has 19 of theses sweep holes. The potential radiation hazard from neutron and γ rays penetrating the diagnostic holes and also the potential electrical hazard from electrical connections into the test cell area requires that these laboratories not be occupied during plasma pulses.

In addition, a rough laboratory area lies beyond the west wall of the diagnostic labs. (If necessary, access to this area can be restricted during experimental operation, which would extend the site boundary by an additional 53.5′). This area is designed to accommodate diagnostic assembly prior to installation in the test cell or in the diagnostic laboratories.

It is planned that this area will be unrestricted during experimental operation.

3.D. Control Room

The control room is located north of the rough laboratory area and west of the power room (Fig. 5). The programmable controllers, computer work stations terminals and TV monitors for operating the experiment will be located here. Work stations and terminals for diagnostic experiments will also be located here. No direct electrical connections from the control room to the cell, power room or diagnostic laboratories will be allowed. The area will be unrestricted. Damage to equipment or personal injury due to fire are the only anticipated hazards for these areas. (Fire systems are described in Sect. 4.A).

3.E. Office Areas

Eight offices are located at the northwest corner of the site (Fig. 5). These areas are unrestricted. Damage to equipment or personal injury due to fire are the only anticipated hazards for these areas.

3.F. Workshops (Machine, Vacuum, Electronics)

The location of several workshops and storage areas can be seen in Fig. 5. Safety hazards in these areas arise from the specific work related activities which are normally performed here in support of the experiment. All personnel working in these areas will be instructed in the safe use of the equipment and will be provided with protective clothing or other precautions required for the activity.

The vacuum shop, located west of the control room as indicated in Fig. 5, is used for cleaning, preparing and storing vacuum system parts and internal hardware for Alcator C-Mod and related diagnostic systems requiring high vacuum. Cleaning of these materials involves the use of solvents such as chlorethane, ethanol and freon, which requires precautions to prevent inhalation and skin contact by personnel and also to prevent ignition of some of these solvents. Electropolishing of small items will occasionally take place. This makes use of several concentrated acids. Ventilation hoods are provided for handling of these materials, and proper waste disposal will be provided as described in Sect. 5.B).

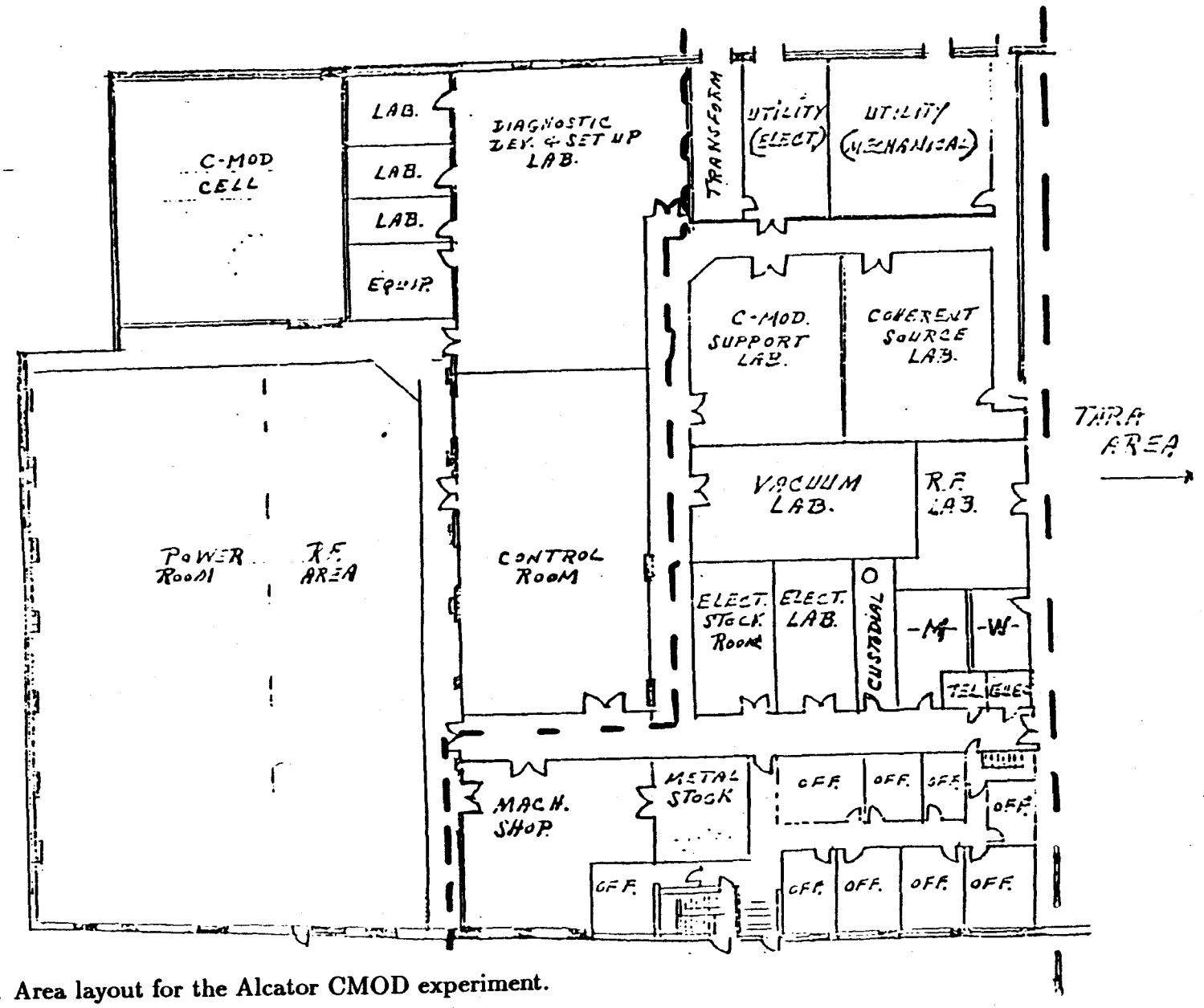


Figure 5. Area layout for the Alcator CMOD experiment.

The machine shop, shown on Fig. 5, will house a number of metalworking machines such as milling machines, lathes, bandsaws, and drill presses. Safety hazards in this area arise from use of this equipment.

The electronic shop provides work space for 6 technicians. Up to 480 V electrical power sources are provided at a central distribution panel so that power supplies and other equipment can be adequately tested. A small amount of work with paint or solvents will take place under an exhaust hood, but the major hazards in this area are from routine electrical test work.

3.G. Alternator

The alternator provides electrical power to the magnet systems on Alcator C-Mod. The present installation was used to power the Alcator C experiment for over 7 years with no serious accidents or incidents. A flywheel will be added to the alternator in order to provide the energy required for the larger C-Mod magnets.

The alternator is located in its own building (NW20) located on Albany St. between NW14 and NW21.

IV. Fire Safety

All fire systems are subject to inspection and approval by the MIT safety office and by Kemper Insurance, the insurance underwriters for MIT. The fire protection systems are also subject to approval and inspection by DOE.

4.A. Smoke Detection and Sprinkler Systems

Sprinkler heads are installed throughout the project, in a grid arrangement typically spaced 14′ in one direction and 9′ apart in the other. The system was designed to provide a density of 0.15 gpm/ft^2 over the hydraulically most remote 3000 ft^2 in the rough laboratory area and the control room, 0.21/1500 (wet pipe) in the diagnostic labs and power room, 0.21/2000 (dry) underneath the floor areas, and 0.19/1500 in the offices shop areas. Table III. provides a summary of the smoke and fire detection systems.

The sprinkler system is required to have a minimum coverage of 0.16/1500 (the materials in these areas are expected to be of the ordinary hazard (group 1) type.) The heads located in the power room, control room, shop areas, rough lab areas and underneath the wooden floors are rated for 165° while those in the diagnostic labs have 212° heads.

The water source is Cambridge city water. A measurement taken at a hydrant at 190 Albany St., May 12, 1982 demonstrated water values of 52 psi static, 48 psi residual and 1072 gpm. This was the basis for the hydraulic calculations for the sprinkler system installation.

Smoke detectors which are connected to the M.I.T. Proprietary Fire Alarm System are located in the diagnostic laboratories, the experimental cell, and the power room. Smoke detectors which alert Alcator personnel prior to notifying the Cambridge Fire Department are also located inside several power supply cabinets as needed.

Fire extinguishers will be provided and located as directed by the MIT Safety Office.

4.B. Alternator

The alternator building is protected by a preaction sprinkler system that has been extensively reviewed and approved by both the MIT Physical Plant and representatives of

Table III Fire Protection For Alcator C-MOD

AREA	NFPA13 CLASSIFICATION	TYPES OF MATERIALS	PROTECTION AND NOTES
Offices	Light Hazard	Office furniture(steel, some wood); Cushioned chairs; Business equipment.	Sprinklered; Ordinary hazard (Group 2) density 0.19/1500.
Laboratories Electronic Shops	Ordinary Hazard Group 1	Light appliances; Electronic equipment Tools; Steel work benches with wooden tops; $\lesssim$quart flammable liquids for cleaning.	Sprinklered; Ordinary hazard (Group 3) density 0.15/3000.
Machine Shops	Ordinary Hazard Group 2	Machine shop equipment; Limited amounts of flammable and combustible liquids; No combustible metals.	Sprinklered; Ordinary hazard (Group 3) density 0.15/3000.
Diagnostic Rooms	Ordinary Hazard Group 1	Electronic equipment; Lasers & associated power supplies; Instrumentation and cables.	Sprinklered; Ordinary hazard (Group 3) density 0.21/1500; Smoke detectors; Cables extend through 5′ thick concrete into experimental cell which increases the combustibility, but it should not exceed ordinary hazard (Group 2).

Table III-cont Fire Protection for Alcator C-MOD

AREA	NFPA13 CLASSIFICATION	TYPES OF MATERIALS	PROTECTION AND NOTES
Control Room	Light Hazard	Computer terminals; Tables, desks(usually metal, some wood); Cushioned chairs.	Sprinklered; Ordinary hazard (Group 3) density 0.21/1500.
Experimental Cell	Ordinary Hazard (Group 2)	Alcator C-MOD (non-combustible, currently 60 tons stainless steel); Diagnostic equipment (final configuration unknown); Combustible materials are prohibited as far as possible.	This room has 5′ thick concrete walls, 4′ thick roof, 50′x50′x36′ high;Smoke detectors; Protection for component systems added as needed.
RF and Power Room	Ordinary Hazard (Group 2)	High voltage and power equipment for Alcator C-MOD and the RF transmitters.	Sprinklered; Ordinary Hazard (Group 3) density 0.21/1500; Smoke detectors All equipment is housed in metal cabinets.
Under Wooden Floors			Sprinklered(dry); density 0.21/2000.

the insurance underwriters for MIT. Alcator maintains an independent smoke and fire detection system that is monitored 24 hours a day by MIT Physical Plant personnel. Alarms during working hours are verified by Alcator personnel before calling the fire department. After working hours Physical Plant calls the Fire Department immediately. The Cambridge Fire Department has reviewed the system and is notified of any changes. Annunciators and maps showing the location of each sensor are placed in conspicuous locations at the entrance to the building.

4.C. Inspection Schedule

The sprinkler systems are tested quarterly. The sprinkler systems and fire extinguishers are serviced once a year. The smoke detectors must be inspected semi-annually. The MIT Safety Office will inspect the site quarterly for flammable loading.

The Plasma Fusion Center Safety Committee inspects all facilities twice a year.

The site is inspected by DOE at their discretion (usually once a year.)

The Cambridge building inspector and electrical inspector in conjunction with the MIT Safety Office inspect the site once a year.

The Cambridge fire department will receive a tour of the facilities included in the directly connected smoke detector system prior to initial operation. They also inspect the facilities at the discretion of the Fire Chief.

Documentation of inspections are maintained by the MIT Safety Office.

V. Chemical Hazards

5.A. Hazardous Materials

The most frequently used hazardous materials present in the Alcator C-Mod facility are flammable gases, liquefied gases, solvents, lubricating oils, pump oils, and corrosive agents. Occasional handling of Lithium metal and Beryllium metal may be necessary. Activated material handling will be discussed in Sec. 9.D.

5.B. Handling, Storage and Disposal

Flammable gases (such as hydrogen, deuterium, and oxygen) are contained in pressurized gas cylinders which are secured against falling. Oxygen is stored separately from other flammable gases. The quantity contained on site is kept at a minimum (< 10 bottles) and storage will be in well ventilated areas to minimize the likelihood of explosive releases. An outdoor bottle storage area is provided. The feed system piping to the experiment is checked for leaks prior to operation by pumping out the lines with a vacuum pump.

Cryogenic gases used are liquid nitrogen and liquid helium. The liquid nitrogen will be stored in a large dewar located outside the experimental cell building. Transfer lines will be insulated to prevent skin damage from contact. Liquid helium is obtained in small quantities as needed. Protective equipment is provided as needed.

Solvents such as chlorethane, alcohol, and freon are used primarily in the vacuum shop where ventilation hoods and safety cans are used to limit air concentrations. Gloves, face shields and aprons are provided to prevent skin contact with these solvents. Used quantities are stored and disposed of in 5 gallon lots through MIT disposal procedures.

Lubricating and pump oils are stored and disposed of according to MIT procedures. Pump oil used on the Alcator C-Mod experiment must be collected, analyzed for tritium content, and possibly disposed as radioactive waste, as supervised by the Radiation Protection Office.

Hazardous metals and other materials are stored and handled according to MIT policy, and as recommended by manufacturer supplied Material Safety Data Sheets (MSDS's).

5.C. Right to Know Law

The OSHA Hazards Communication Standard requires that workers be made aware of hazardous materials with which they may come into contact and be instructed in proper handling procedures for those materials. Although MIT qualifies under the Research Laboratory Exemption from certain requirements of the act, Institute policies and procedures are designed to comply with the essence of the law. MIT maintains a file of MSDS's on all hazardous materials known to be in use at the Institute, requires inventories from each department of such materials, provides MSDS's to any personnel requesting them, and requires personnel exposed to hazardous material to be instructed in proper handling of these substances.

The Alcator C-Mod program operates in compliance with the MIT procedures. MSDS sheets are maintained on all hazardous substances and these are provided to employees or students who have reason to work with or to come into contact with these materials.

VI. Air Quality

6.A. Exhaust System

The experimental cell exhaust system is designed to cycle the air in the experimental cell once every hour. The 1500 CFM exhaust fan will be interlocked with the experimental sequence so that a pulse cannot be initiated unless the air is circulating, in order to insure that activated products present in the cell air are not accumulating. The intake and exhaust from the cell is designed so that the cell is at a slightly negative pressure relative to the surrounding areas. The exhaust ductwork is designed so that 2/3 of the flow comes from the floor area of the cell, and the remaining 1/3 from the ceiling.

Three of the four diagnostic laboratories adjacent to the cell are equipped with 1600 CFM fan coil units for heat and air conditioning. The air intake for these is from the roof area adjacent to the labs. The experimental cell air intake is in these labs, and the cell is kept at a slightly negative pressure so that the laboratory air will flow into the cell. The 4th laboratory, the data acquisition room, has a 2400 CFM fan coil unit, also with an intake on the adjacent roof. There is no vent connection with the test cell, however.

6.B. Monitoring

The use of large quantities of liquid nitrogen in the Alcator C-Mod experiment could cause a depletion of oxygen in the experimental cell should a problem develop with the exhaust system or a major leak occur. Thus, oxygen levels in the cell will be monitored and an alarm will be sounded if levels fall below a safe amount, which varies from 16% to 19.5% depending on atmospheric conditions and altitude [9].

VII. Electrical Safety

All Alcator C-Mod electrical systems must meet requirements of the Massachusetts and the National electrical codes. Alcator employs at least one licensed electrician who ensures that these standards are met. All facilities are routinely inspected for compliance by the Plasma Fusion Center safety committee. Interlock and safety systems are tested on a monthly basis following an established procedure.

7.A. Hazards

The high power and high voltages routinely used in the Alcator C-Mod experiment pose a danger of electrocution to personnel working with certain equipment. Most of the high power equipment is located in the power room adjacent to the experimental cell, where access can be routinely controlled.

Individual diagnostic experiments may require the use of high voltage or high energy equipment, such as the capacitor banks used for many laser experiments. Users of such equipment will be expected to provide the required interlocks and other safety features which will be subject to routine inspection by the PFC safety committee.

7.B. Interlocks and Procedures

7.B.1 The Power Room

The Alcator C-Mod power systems will operate with a Kirk safety interlock system (see Appendix B). Such a system was successfully used on the earlier Alcator experiments. This system is designed to protect the power systems as well as personnel.

The entire power room and RF areas will be interlocked so that no power system can be initiated, the alternator can not ramp up, and the control sequence will not be able to start until the system has been properly set. Audio and visual signals will indicate violation of the interlocked system along with the location of the violation. Communication is provided between all parts of the interlocked system, so that violation of any subsystem will effect a controlled shut down of the power systems. If a violation occurs during a pulse sequence, the system will shut down and all breakers will open immediately in a controlled

manner.

The power room is monitored by closed circuit television during operation. Procedures for entry to the power room as well as for clearing the power room of personnel prior to setting the interlock system will be initiated. These procedures will be in place prior to initial power room operation.

The interlock and safety systems are tested monthly, and the results are recorded.

7.B.2 The Alternator

The alternator is throughly protected by a redundant interlock control and monitoring system. Critical temperatures, pressures, air, water, and oil flows are continuously monitored. Any problem is annunciated to both the alternator operating crew and to the C-Mod control room. The action taken depends upon the exact nature of the problem, but is always automatic and requires no human intervention to keep the system in a safe state. Many faults will disable the drive system and prevent excitation of the machine.

The large rotating mass of the alternator requires over an hour to slow to a stop after the drive is removed. During this time it is imperative that cooled lubricating oil be continuously supplied to the bearings. The current system relies on a large station battery to run a DC oil pump and Cambridge city water as an emergency cooling source should there be an area-wide blackout while the machine is rotating. (There are also 2 independent AC feeds from Cambridge Electric Light Company; in over 7 years of operation both feeds have never failed simultaneously.) The addition of the flywheel will substantially increase the run-down time, and the station battery has insufficient capacity to maintain the require emergency power. MIT has installed a 250 KW diesel motor-alternator as an emergency power source. The alternator will use the station battery to provide power to essential systems during the few seconds required for the diesel to come on-line.

All safety systems are regularly tested and the results of the tests are recorded.

VIII. Electromagnetic Radiation

8.A. Lasers

A number of diagnostic experiments on Alcator C-Mod will utilize lasers of sufficient power to cause serious burns or eye damage to personnel exposed to the beams and to scattered light from the beams. Several of these lasers require high voltage and high energy capacitor banks for operation, which poses an additional electrocution risk to personnel.

The diagnostics which require the use of lasers are summarized in Table IV with the type of laser used, the expected hazard to personnel, and the precautions which will be taken to prevent injury. In most cases, an enclosed beam path will prevent access to the laser light. Interlocked power supplies will prevent exposure to high voltages. Access to the diagnostic laboratories will be limited to authorized personnel, and will be controlled during plasma pulses. Warning lights will indicate when these lasers are operating.

All laser installations will be registered with and inspected by the MIT Radiation Protection Office.

8.B. RF Systems

8.B.1 ICRF

The main safety concerns are RF burns from direct contact with exposed RF voltage on ungrounded conductors and electromagnetic radiation above safe levels in areas where personnel have access. Hazards to personnel from high power operation are controlled by evacuating and locking the experimental cell and power room during plasma pulses. During normal operation there is no exposed RF because everything is enclosed in grounded conductor. The transmitters will not run when there are high reflections so gross errors such as running the RF into an open-ended transmission line will cause immediate transmitter shutdown. Also high power cannot be transferred through the coaxial line unless it is pressurized and the antenna cannot support the voltages associated with high power when the experiment is not under vacuum. Nevertheless the RF will be interlocked such that it cannot be operated into an antenna when the experiment is at air nor when there is a

Table IV Lasers used as Diagnostics on Alcator C-MOD

Diagnostic	Type of Laser	λ	Power or Energy	Location	Danger	Precautions
Two Color Interferometer	CO_2	10.6μm	5 W CW	Experimental Cell	Eye Damage	Enclosed Interlocked Path
	HeNe	0.6328μm	0.01 W CW	Experimental Cell		Enclosed Path
CO_2 Scattering	CO_2	10.6μm	200 W CW	Diagnostic Laboratory	Burns Eye Damage	Enclosed Path Room Interlocked
Laser Blowoff	Ruby	0.6943μm	1 J (20 ns)	Diagnostic Laboratory	Eye Damage Electrocution	Interlocked Room & Cell Lab. Area Restricted
FIR Interferometer	CO_2	9.7μm	9.7μm 50 W	Diagnostic Laboratory	Burns Eye Damage Electrocution	Enclosed Path Confined to Lab Interlocked Enclosure Protective Eyewear at 10μm Lab. Area Restricted Warning Lights on Lab
	$CH_3OH(2)$ HeNe	119μm 0.6328μm	< 0.1 W $< .01$ W	Diagnostic Laboratory		Beam Path Partially Enclosed
Thomson Scattering	YAG	1.06μm	1 joule/pulse (20 ns) at 50 hz	Diagnostic Laboratory	Burns Eye Damage Electrocution	Enclosed Beam Lab & Cell Interlocked Light Tight Beam Dump
Edge Thomson Scattering	Ruby	0.6943μm	10 J (20 – 30 ns)	Cell	Eye Damage Electrocution	Enclosed Path Cell Interlocked Light Tight Beam Dump

discontinuity in the ground of the transmission system indicating that something is not attached properly.

The principal concern will be during times between experimental runs when testing or conditioning of RF equipment might occur in the cell when other personnel are present. The goal of this analysis is to determine where the main dangers lie and whether personnel can safely work in the vicinity of the RF systems during testing. There is no real danger of direct contact with RF voltages. The main sources of RF radiation are the DC break in the transmission line between the experiment and the transmitters, leakage of RF excited by the antenna in the vacuum chamber out of windows in ports, and poorly connected joints in the transmission system that allow RF leaks. The safe level of RF radiation is 1 mW/cm^2 (ANSI C95.1.1982 Standard) in the range of 30-300 MHz. This level assumes a 6 minute average. (The Commonwealth of Massachusetts under CMR 122.010 requires that exposure of the general public to RF radiation at this frequency be limited to 0.2 mW/cm^2 per half hour.) The Alcator C-Mod system produces up to 1 second long pulses with a 0.1% duty cycle, so the average power is in fact 2 kW for 2 MW pulsing. The following analysis uses the peak rather than average power.

During testing in vacuum the voltage limit on the antenna will not allow full power operation. A load resistance in vacuum of 0.1 Ω is assumed. This is 1/10 of the anticipated lowest plasma load which can be driven at full power. Since the antenna voltage, and therefore current, is fixed by the standoff limit, this means that only 1/10 the power or 200 kW per antenna can be used during testing in vacuum. (The Oak Ridge TFTR antenna ran on a test stand at 70 kV and 170 kW, but it has two current loops, each of which is longer than the C-Mod antenna.) Thus this analysis uses a conservatively high power level. The first suggested source of RF in the cell, the DC break will be designed to keep RF levels below the safe limit. The two other sources of RF in the cell will be analyzed in more detail.

When RF at 80 Mhz is excited in the vacuum chamber, the chamber itself is too small to allow propagation. However the vertical height of the chamber is not that much less than a half wavelength at 80 MHz (1.75 m) so significant RF levels might exist at

adjacent ports. The succeeding analysis assumes that 200 kW goes into an antenna and exits entirely through the adjacent horizontal port. In fact most of the power will be dissipated by the antenna itself and that which does get around the vacuum chamber will not go out only one port. The ports have long extensions which act as waveguide below cutoff, attenuating the RF.

For the lowest order rectangular waveguide mode, TE_{01}, the attenuation constant for the RF field level is

$$\alpha = \sqrt{(\frac{\pi}{b})^2 - \omega^2 \mu \epsilon} \quad ,$$

where b is larger waveguide dimension. The power attenuation in db can be written as

$$db = 20 log_{10}(\frac{V_{out}}{V_{in}}) = -20\ \alpha\ L\ log_{10} e$$

where L is the length of the waveguide. The vacuum chamber height is 1.2 m and would attenuate the power by about 7 db between horizontal ports. The horizontal ports are 63 cm high and 73.5 cm long, attenuating the power by 30 db. This drops 200 kW to 40 W. The port opening is 1188 cm^2 so there would be 34 mW/cm^2 in the port opening if it was completely transparent to RF. This is a high estimate for two reasons. The antenna orientation in the vacuum chamber does not couple effectively to the TE_{01} mode, the antenna current is vertical instead of radial. Also any port window would cover only part of the opening, further attenuating the RF. Assuming that the port radiates isotropically, the RF level will be down to 1 mW/cm^2 at a distance r such that $4\pi r^2 \times 1$ mW/cm^2 equals the power out of the opening. The RF level would be safe 56 cm away. Even assuming the port radiates with some gain, say 3-6 db, several meters from a port opening would be safe during testing. Direct access to the Alcator C-Mod experiment will be controlled during testing, but it is not necessary to prohibit other activities in the cell. The top and bottom ports, which are much smaller and longer, will be much safer from RF leakage.

Another source of RF levels in the cell would be a poorly attached joint in the RF system. (Procedures for routine testing of joint connections will be instituted prior to initial RF operation.) It is assumed that the flanges between two lengths of coaxial line are not tightened, leaving a 1 mm gap. The surface area of the flanges is roughly 300 cm^2,

giving a capacitive impedance of 0.13 Ω . For 50 Ω line this would divide the voltage and power by 1 / 385 and 520 W of 200 kW might leak out. This corresponds to 52 W/cm^2 at the outside edge of the flange. Assuming isotropic radiation, the level would be safe 2 m from the leak. Access to within 2 m of the coaxial lines will be controlled during testing and conditioning of the ICRF system.

This calculation assumed a matched coaxial line. This is not true in the matching section where voltages can easily be as much as ten times higher when running into a vacuum load. This would increase the safe distance by a factor of three. However the calculation is an overestimate of the power leakage. It assumes a very large gap and uses the reactive impedance of the gap to compute the leakage power. The resistive losses should be much smaller. Access to the area around the RF matching circuits and transmission lines will be controlled during testing. RF monitors (pick up loops) will be set up along the perimeter to make sure safe levels are maintained.

To ensure safety, extensive RF surveys will be done during the initial operation and periodically thereafter, in order to ensure that exposure levels are not exceeded. Monitors will be positioned near areas where RF levels might be the highest.

It will be necessary for RF personnel to approach the RF equipment during testing. They will have monitors equipped with meters to measure RF levels. The equipment will be surveyed for leaks periodically to insure personnel safety as well as to limit induce noise levels for other diagnostics.

8.B.2 Lower Hybrid and ECH

It is possible that lower hybrid current drive experiments will be conducted on Alcator C-Mod using the 4 MW 4.6 Ghz system which was used on Alcator C. The exposure limits at this frequency are 5 mW/cm^2 for 0.1 hour (ANSI c95.1-1982) and 1 mW/cm^2 for 0.5 hour (CMR 122.010). ECH experiments in the 240-280 Ghz range are also anticipated. The shorter wavelengths of these systems increase the likely level of RF leakage from the Alcator C-Mod windows over what is expected from the ICRF system. Therefore, access to the cell and to the sources will be controlled during testing, conditioning, and high

power operation of these systems.

8.C. Magnetic Fields

Plasma confinement and shaping on Alcator C-Mod is obtained by using high magnetic fields. The toroidal field (9T at the plasma center) is confined to the region inside the magnetic field windings. The poloidal fields, however, extend well beyond the tokamak structure. The expected field contours are shown in Fig. 6. For the highest current operation, a magnetic field of 5 Gauss lasting 1 s could be reached at the unrestricted site boundaries to the southeast of the experimental cell. This level is 50% of the 10 Gauss limit used as a guideline for excluding people wearing pacemakers at LLNL [1]. The field levels at all other unrestricted boundaries are well below this value. Thus it is not expected that magnetic fields generated during the Alcator C-Mod experiment will pose health hazards to MIT personnel or to the general public.

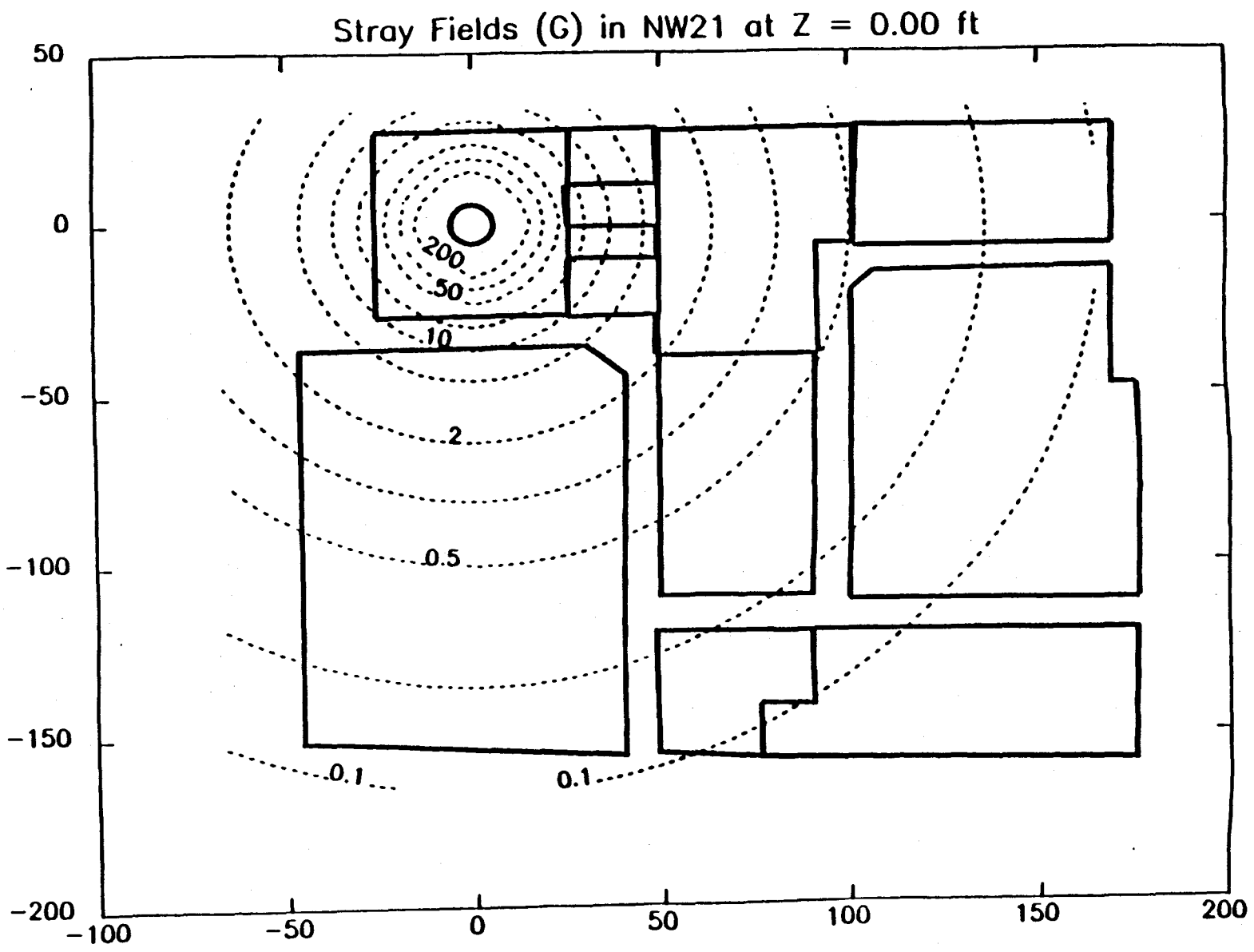


Figure 6. Poloidal magnetic field contours for a high current Alcator CMOD shot.

IX. Ionizing Radiation

9.A Method of Calculation

9.A.1 Introduction

The Alcator C-Mod experiment is expected to produce neutron rates as high as 5×10^{15} n/sec (1 second pulse) during high performance deuterium operation. This presents a potential hazard to Alcator personnel and to the general public from both direct neutron and γ radiation produced during an Alcator C-Mod pulse as well as from activated isotopes resulting from neutron capture. The radiation shielding developed for Alcator C-Mod is designed to restrict radiation doses to the general public to within the guidelines required for DOE facilities (see Appendix C). In addition, exposure to Alcator personnel is restricted to 1.25 Rem per quarter, as required by 10-CFR-20 [2] and DOE 5480.1 Chg 6 Chapter XI [3].

9.A.2 Neutron Transport Codes

The neutron and γ shielding requirements have been assessed using two coupled neutron photon transport codes. The ANISN code [4] numerically solves the one dimensional Boltzman transport equation for neutrons by a discrete ordinates method. ANISN provides a fast calculation of neutron penetration and γ production through thick shielding materials, and has a convenient post-processing program for determination of activated isotope concentrations in surrounding materials, but provides only one dimensional information. The MCNP code [5] tracks neutron and photon transport in three dimensions using a Monte-Carlo technique. Three dimensional analysis is necessary for determination of transport through penetrations in the shield walls, but requires a large amount of computer time.

The neutron source energy for all of the code calculations is assumed to be distributed with 97% of the neutrons at 2.5 MeV from DD reactions and 3% of the neutrons at 14 MeV from DT reactions.

The ANISN code was applied to a spherical shell model of Alcator C-Mod in order to

obtain the neutron and γ flux which penetrates the shield wall through the solid concrete structures. The results of this model were compared to a 1985 MCNP study [6] prepared for the Alcator C-Mod proposal. The neutron and γ fluxes incident to the inner shield wall obtained from the two codes are compared in Figs. 7a and 7b. The agreement is very good, although the total γ flux found by the ANISN code is twice that found by MCNP. Similarly, the total neutron flux outside of the 5′ concrete shield wall was found by the MCNP calculation to be 5×10^{-13}n/cm^2/source neutron and 4.5×10^{-13} n/cm^2/source neutron by the ANISN code. The ANISN calculated γ flux was $1.3\times10^{-11}\gamma$/cm^2/source neutron outside of the concrete cell wall, a factor of 2 higher than that found using MCNP.

For analysis of the penetrations in the Alcator C-Mod shield wall, ANISN was used to generate the flux energy distribution of neutrons incident to the shield wall. This distribution was used as the basis for a surface source for an MCNP calculation of the transport through the wall penetrations.

Calculation of the activity of isotopes present in the ground water, the concrete shield, and the air in the cell was done using ANISN generated neutron flux profiles and applying an activity post processing program, AAP [7]. The machine structure activities were adapted from those published in [6] using a lower neutron rate and a lower pulse repetition rate to reflect the updated machine design performance criteria.

Dose rate calculations are done by integrating the energy dependent neutron and γ flux values at the point where the calculation was made with the energy dependent dose conversion factors listed in Table Va and Table Vb. The accumulated yearly dose assumes that each pulse in the year produces 5×10^{15} n/sec (1 second pulse), and that 3750 pulses (25 pulses per day, 5 days per week, 30 weeks per year) are taken per year. This assumption will produce an overestimate of actual dose rates, because it is highly unlikely that every pulse will achieve the highest level of performance, and it also assumes that all operation will be in deuterium while some hydrogen operation is anticipated.

The calculated activated isotope levels also assume that 3750 high performance pulses are produced per year.

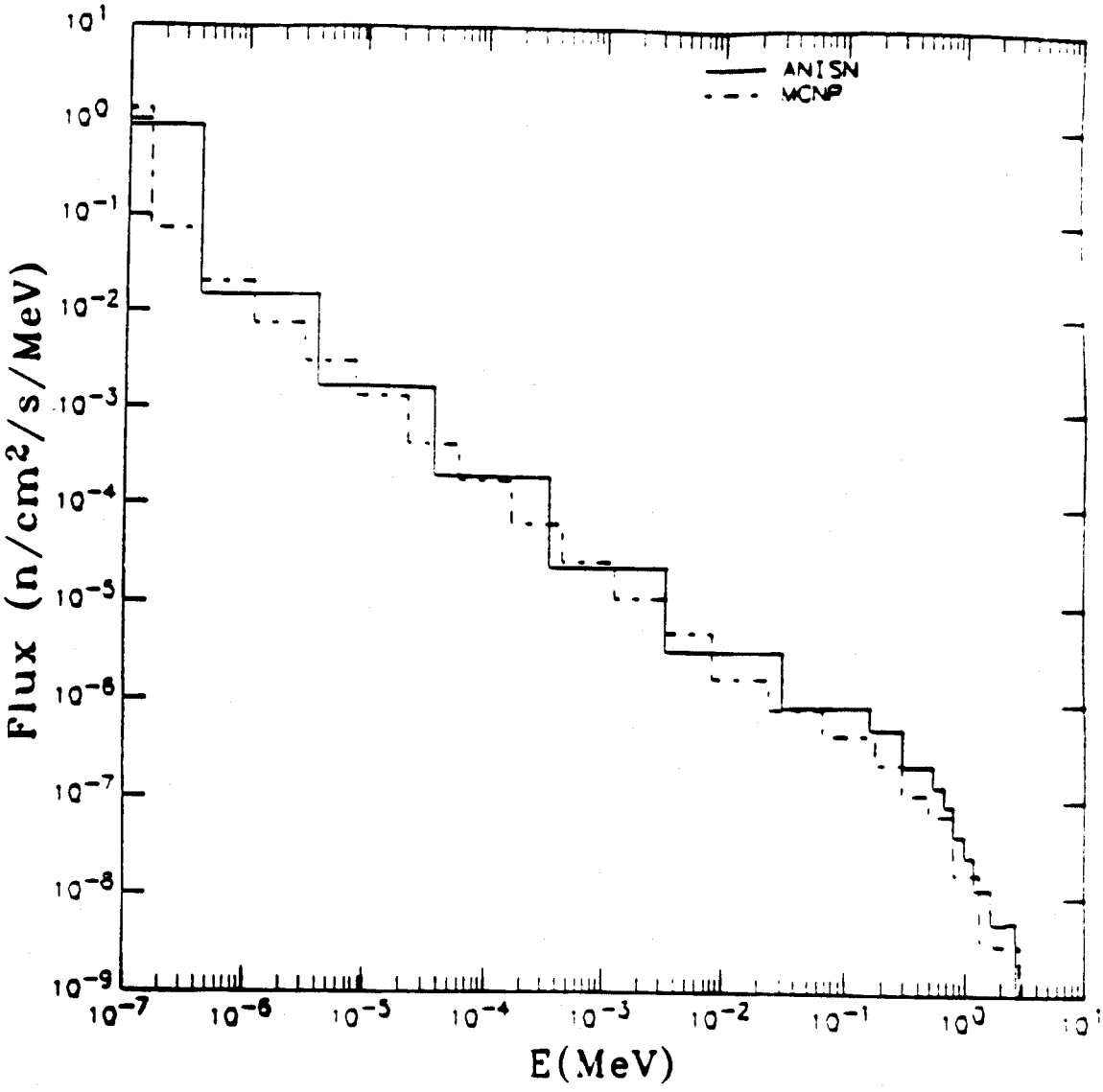


Figure 7a. Comparison of neutron flux as a function of energy at the Alcator CMOD biological shield wall calculated by ANISN (solid line) and MCNP (dashed line).

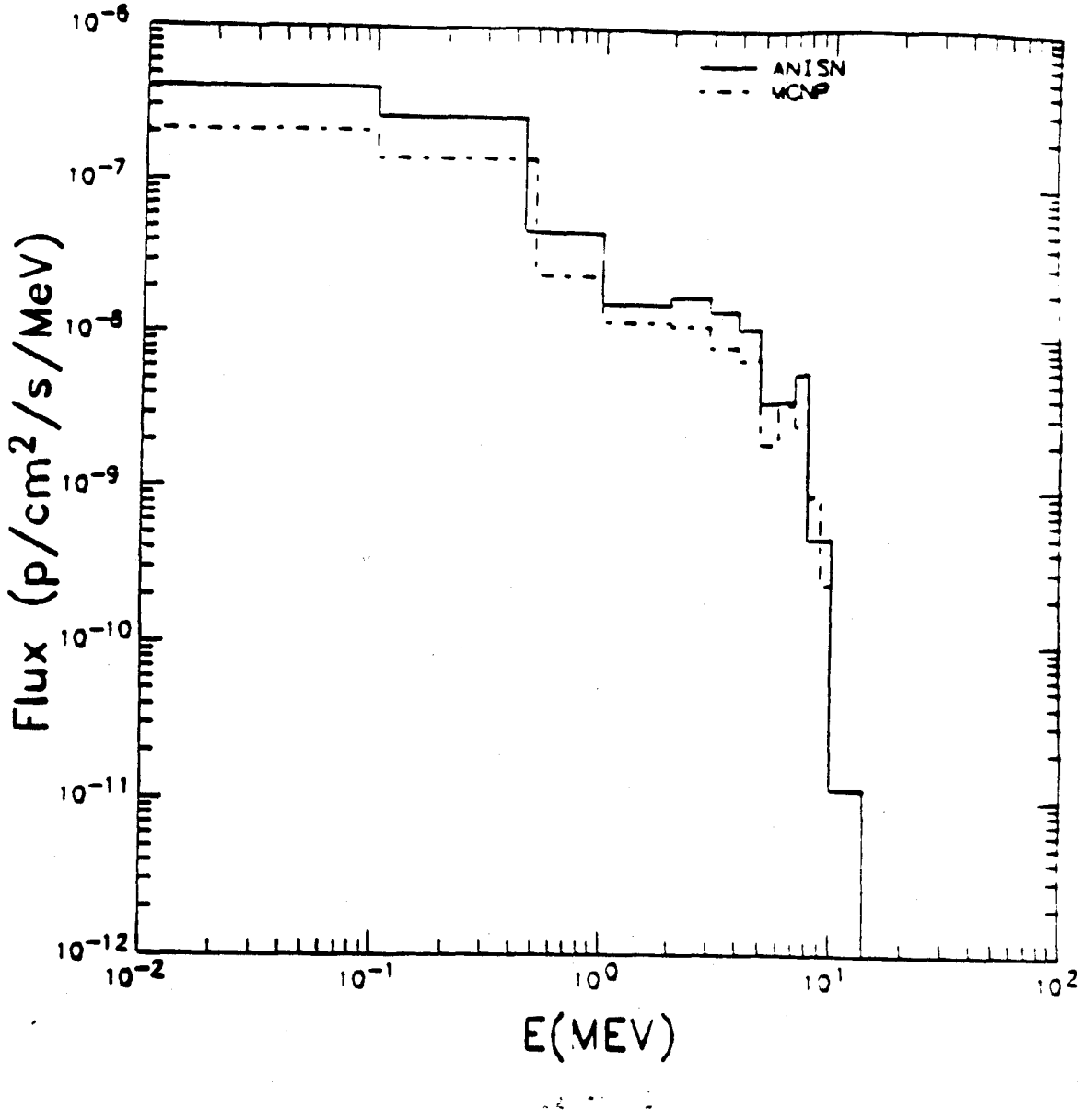


Figure 7b. Comparison of γ flux as a function of energy at the Alcator CMOD biological shield wall calculated by ANISN (solid line) and MCNP (dashed line).

Table V.a Neutron Fluence to Dose Rate Conversion Factor*

Neutron Energy (MeV)	rem/(n/cm^2)
2.5×10^{-8}	1.02×10^{-9}
1.0×10^{-7}	1.02×10^{-9}
1.0×10^{-6}	1.24×10^{-9}
1.0×10^{-5}	1.26×10^{-9}
1.0×10^{-4}	1.16×10^{-9}
1.0×10^{-3}	1.04×10^{-9}
1.0×10^{-2}	9.89×10^{-10}
1.0×10^{-1}	6.03×10^{-9}
5.0×10^{-1}	2.57×10^{-8}
1.0	3.67×10^{-8}
2.5	3.47×10^{-8}
5.0	4.33×10^{-8}
7.0	4.08×10^{-8}
10.0	4.08×10^{-8}
14.0	5.78×10^{-8}

*Determined from NCRP - 38, ANSI/ANS-6.1-1-1977.

Table V.b γ Fluence to Dose Rate Conversion Factors*

γ Energy (MeV)	rem/(γ/cm^2)
0.01	7.72×10^{-10}
0.015	3.22×10^{-10}
0.02	1.63×10^{-10}
0.03	7.11×10^{-11}
0.04	4.33×10^{-11}
0.05	3.33×10^{-11}
0.06	3.08×10^{-11}
0.08	3.33×10^{-11}
0.1	4.08×10^{-11}
0.15	6.61×10^{-11}
0.2	9.58×10^{-11}
0.3	1.54×10^{-10}
0.4	2.14×10^{-10}
0.5	2.53×10^{-10}
0.6	3.17×10^{-10}
0.8	4.08×10^{-10}
1.0	4.97×10^{-10}
1.5	6.78×10^{-10}
2.0	8.42×10^{-10}
3.0	1.11×10^{-9}
4.0	1.32×10^{-9}
5.0	1.54×10^{-9}
6.0	1.74×10^{-9}
8.0	2.14×10^{-9}
10.0	2.53×10^{-9}

*Determined from ICRP-21

9.B Direct Radiation

9.B.1 The Biological Shield

The experimental test cell is constructed with 5′ thick concrete walls with a 40″ concrete floor and a 48″ concrete ceiling in order to attenuate the neutron and γ radiation. The cell layout provided (Fig. 4) shows the boundary areas for unrestricted access by members of the general public. The unrestricted areas are 15′ from the cell south wall, 8-15′ from the east wall, 22′ from the west wall, and 128′ from the north wall.

The penetrations through the shield wall are shown in Fig. 8 and Fig. 9. The north wall has an 10′ × 4′ door leading into a vestibule constructed of 3′ concrete walls. A 4′ × 4′ penetration is directly above the door, also leading into the vestibule, for the power buswork, RF transmission lines, and machine cooling to enter the experimental cell. The power and cooling systems exit the vestibule area through a 4′× 6′ hole in the ceiling.

A 14′ × 13′ opening adjacent to the vestibule designed to allow large equipment to be moved into the experimental cell is sealed with a 5′ thick concrete door during operation in order to preserve the integrity of the shield wall in that area.

The east wall is penetrated by an 8′ × 4′ emergency exit located at the southernmost corner of the shield wall. The emergency exit leads into a vestibule area which is constructed of 5′ thick concrete along the south wall, and 3′ thick concrete as its eastern wall. The exit from this vestibule is at grade, 6.5′ above the experimental cell floor. The ceiling is 3′ concrete.

There are four types of smaller penetrations as shown in Fig. 9. Electricity and fiber optics cables enter the experimental cell through a series of 5″ diameter sweep pipes which penetrate the shield wall horizontally then bend through 90° and exit in the floor. There are 6 of these adjacent to the vestibule in the north wall and 25 entering the laboratory area through the west wall. The area surrounding the bend in the pipes is filled with gravel extending a distance of 11′ or greater from the bend. The sweep pipes entering the laboratory areas are clustered in such a manner that 19 exit in the data acquisition area (the northernmost laboratory) and 2 each are located in the remaining three rooms.

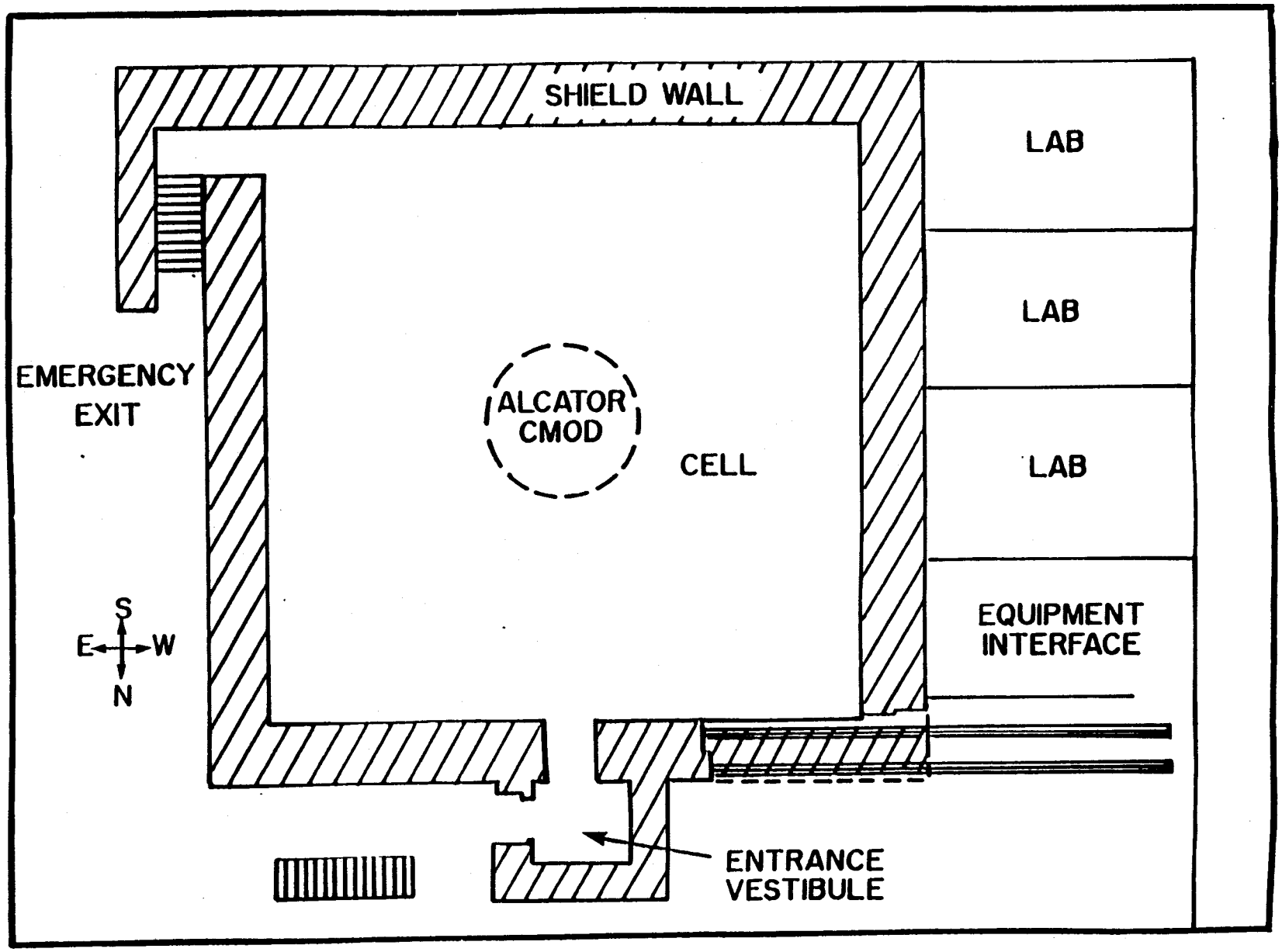


Figure 8. Alcator CMOD biological shield with major openings.

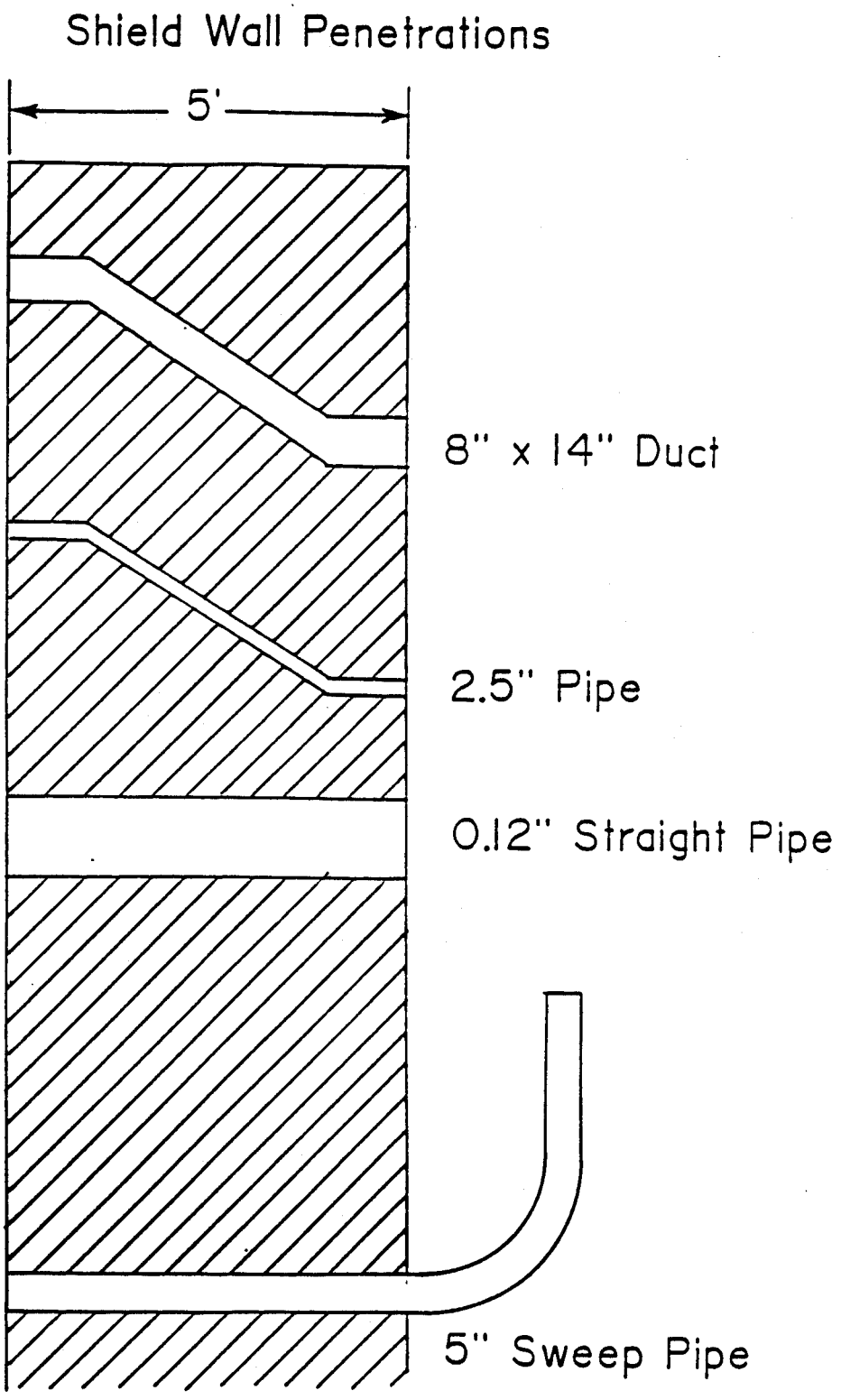


Figure 9. Minor penetrations in the Alcator CMOD biological shield wall.

The next type of penetration is for the air intake into the cell and consists of four 8″ × 8″ duct which were designed to undergo two 45° bends in the shield wall. The entrance and exit are displaced 2′ vertically. These are located in the west wall, one exiting in each of the laboratory rooms. These were not installed to the specified design, and the final configuration involves reduction of the vertical dimension by installing 2″ Masonite blocks in the entrance and exit holes. The neutron leakage of this configuration will be tested with a neutron source, and shadow shielding will be installed if needed.

The fifth duct for exhausting the cell air exits through the east wall into the emergency exit vestibule. This 12″ × 14″ duct was also installed incorrectly. Reducing the neutron transport through this duct involved removing much of the concrete and completely reconfiguring the vent. The neutron leakage through this vent will also be tested, and shadow shielding will be installed if necessary.

The cooling water for the air conditioner enters the experimental cell through three 2.5″ diameter pipes which undergo two 45° bends in the shield wall, with entrance and exit pipes displaced 2′. These all penetrate the West wall into the southernmost laboratory room.

Finally diagnostic access into the laboratory areas can be provided through a number of straight through pipes. Twenty-one 12″ diameter pipes have been cast through the concrete shield wall, but will be plugged with water extended polyester (WEP) plugs when not in use. Shadow shielding is required for any experiment utilizing straight through access to the experimental cell of sufficient quantity to lower radiation levels outside the laboratory area to less than the levels recommended by DOE for the unrestricted boundary. Access to the laboratory areas is controlled during experimental operation.

There are no penetrations through the south shield wall.

9.B.2 Dose Rates

The combined neutron and γ radiation dose at the inside wall of the biological shield was found from the ANISN calculation to be 21 Rem from a 5×10^{15} n/sec pulse of 1 second duration. This requires that personnel be excluded from the experimental cell

during operation.

The neutron and γ flux penetrating the unbroken concrete shield wall at the shortest distance between the experiment and the wall are plotted as a function of energy in Fig. 10a. and 10b. Using the assumptions of 9.A.2 (3750 high performance pulses per year),the expected neutron and γ dose rates per pulse at the outside of the concrete are 1.73×10^{-6} Rem and 2.53×10^{-5} Rem respectively. This is equivalent to 8.44×10^{-2} mRem/hour during an 8 hour (25 pulse) day. At the fence along the southern perimeter of the site, the maximum yearly dose rate for this type of continuous full performance operation would be 37 mRem. Although it is clear from Table VI that the dose rate at the eastern perimeter could be as high as 58 mRem in any given year, this area is between two MIT buildings and access can be controlled if continual high performance operation is achieved. Steps will be taken (as described in Appendix C) to ensure that the site boundary dose is kept well below this value. The concrete shield wall provides sufficient attenuation of the neutrons and γ rays for typical operation.

Dose rates calculated at different site boundaries outside the shield wall produced by MCNP analysis of the penetrations are detailed in Table VI. Limitation of the dose rates to the design values due to the two large penetrations (the entrance vestibule and the emergency exit) requires the installation of several large Benelex or Masonite doors in those locations. Sliding doors will be installed over those openings inside the biological shield and swinging shield doors may be installed at the exits if required by the operation of the experiment. Site boundary dose rates from the electrical sweep penetrations and water lines are quite low. Shadow shielding will be required surrounding any open diagnostic port, and may also be required for some of the air intake vents.

Table VII details expected dose rates from direct radiation in areas accessible by Alcator C-Mod personnel.

9.C Activation Hazards

9.C.1 Ground Water

The ANISN code was used to calculate the neutron flux which would be present in a

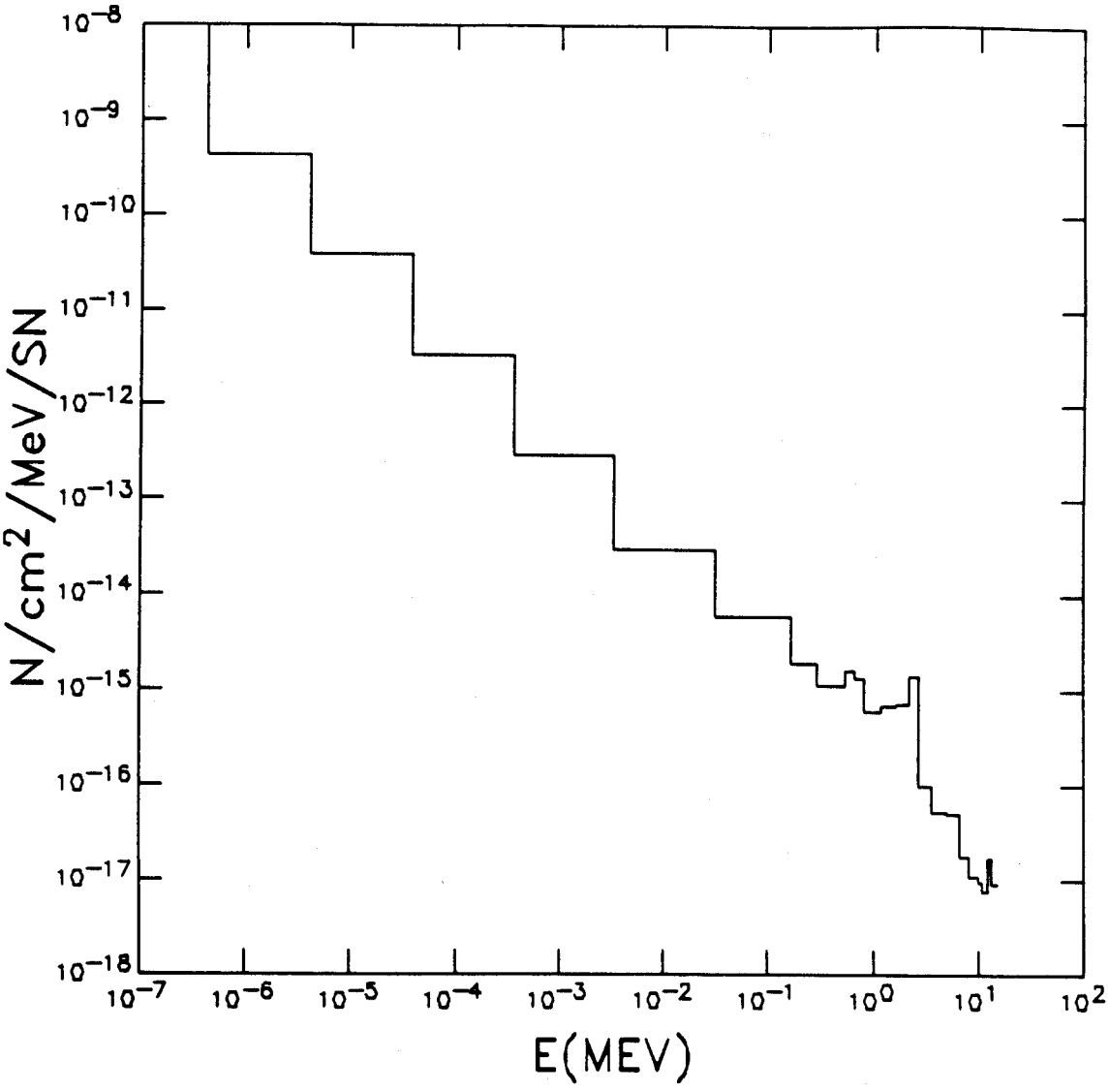


Figure 10.a ANISN calculation of the neutron flux as a function of energy outside the Alcator CMOD biological shield.

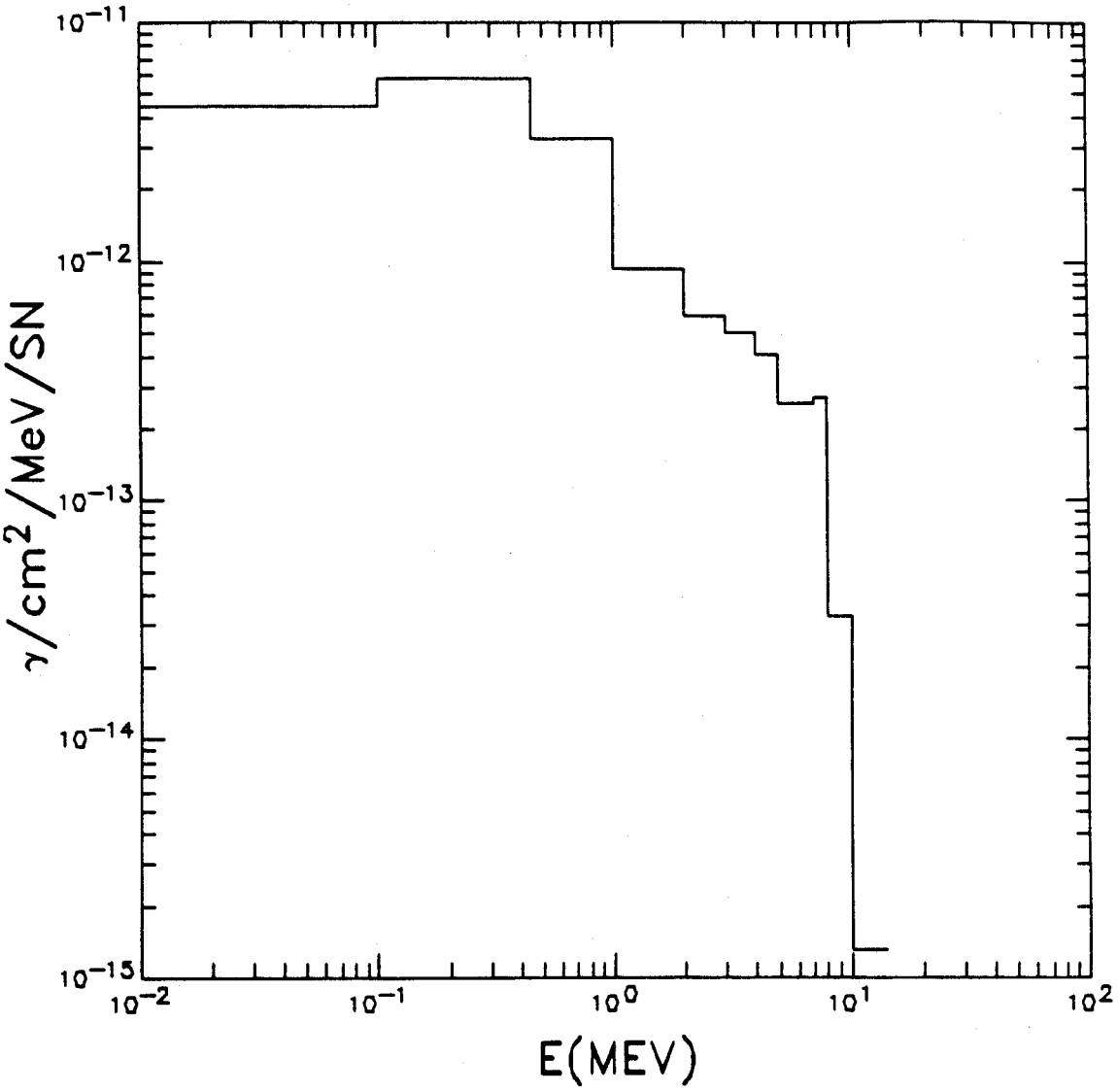


Figure 10.b ANISN calculation of the γ flux as a function of energy outside the Alcator CMOD biological shield.

Table VI

Site Boundary Dose Rates from High Performance Deuterium Shots at 5×10^{15} n/s

Location	D_n (Rem)	D_γ (Rem)	D_{Total} (Rem)	mRem/1000 Shots
Cell Wall (not accessible)	1.73×10^{-6}	2.53×10^{-5}	2.70×10^{-5}	27.0
South Boundary Fence (15′ from cell wall)	6.13×10^{-7}	9.49×10^{-6}	1.01×10^{-5}	10.1
East Boundary Fence (8′ from cell wall)	1.08×10^{-5}	4.74×10^{-6}	1.55×10^{-5}	15.5
West Laboratory Wall (22′ from cell wall)	4.02×10^{-7}	6.96×10^{-6}	7.36×10^{-6}	7.4
Possible Hot spot on West Laboratory Wall (From Vent)	8.12×10^{-6}	1.18×10^{-5}	1.99×10^{-5}	19.9
Control Room Wall	3.7×10^{-10}	3.12×10^{-8}	3.16×10^{-8}	0.031

Table VII

Typical Restricted Area Dose Rates from High Performance Deuterium Shots on Alcator C-Mod

Location	D_n (Rem)	D_γ (Rem)	D_{Total} (Rem)	mRem/hr (3 shots/hour)
Inner Cell Wall	21	0.47	21.47	64,410
Vestibule Doorway (with 6″ Masonite Door)	1.28×10^{-2}	1.02×10^{-3}	1.38×10^{-2}	41
Above Electrical Sweep	6.6×10^{-6}	8.8×10^{-6}	1.54×10^{-4}	0.5
Emergency Exit-Mid Structure (with 6″ Masonite Door)	2.82×10^{-3}	3.90×10^{-4}	3.2×10^{-3}	9.6
Emergency Exit-Exit Door	9.02×10^{-4}	1.45×10^{-4}	1.05×10^{-3}	3.1
Diagnostic Laboratory (Mid Lab)				
12″ Diagnostic port (hot spot)	2.21×10^{-2}	2.67×10^{-4}	2.24×10^{-2}	67.1
6″ Diagnostic port (hot spot)	5.88×10^{-3}	6.14×10^{-5}	5.94×10^{-3}	17.8
3″ Diagnostic port (hot spot)	1.4×10^{-3}	1.53×10^{-5}	1.42×10^{-3}	4.25

1′ deep layer of ground water tangent to but outside of the cell floor, directly underneath Alcator C-Mod. A sample of the ground water from the Alcator C-Mod construction site was analyzed by the MIT Nuclear Reactor Laboratory to determine the nature and concentration of contaminant isotopes present. These concentrations were used with the calculated neutron flux distribution to determine the expected activated isotope concentration immediately following a 5×10^{15} n/sec Alcator C-Mod pulse of 1 second duration in the ground water. The results, shown in Table VIII, demonstrate that immediately following 5 years of high performance operation, the levels of activity in the ground water are six or more orders of magnitude lower than is permitted in the 10-CFR-20 guidelines for exposure to the general public.

9.C.2 Airborne Isotopes

The expected neutron flux distribution generated inside the Alcator C-Mod experimental cell by the ANISN calculation was used to calculate the Ar^{41} concentration expected to be present immediately following a 5×10^{15} n/sec pulse of 1 second duration. The expected concentration of this isotope is $4.8 \times 10^{-7} \mu Ci/cm^3$ immediately following a pulse, which results in a total yearly production of 3.69 Ci in 3750 high performance pulses. The air in the cell is changed once an hour which results in an Ar^{41} concentration at the exhaust stack exit (36′) above ground level of $5.52 \times 10^{-8} \mu Ci/cm^3$. Following guidelines prepared by the National Committee on Radiation Protection [8] and using wind speed data provided in the MIT Nuclear Reactor SAR, this results in a yearly dose to persons in the railroad track area underneath the exhaust stack (an area which is occupied less than 10% of the time) of 4 mRem/year due to this isotope. This calculation, detailed in Table IX, is repeated for a tritium production rate of 5×10^{15} tritons per pulse, and results in a radiation dose at the railroad tracks of 0.1 mRem/year from the tritium. The total dose from airborne isotopes is then less than 5 mRem/year, which is smaller than the 25 mRem/year limit on the dose delivered to the general public via air pathways.

A small amount of N^{13} ($t_{1/2}$ =9.9 m, β^+) may be produced in the cryostat surrounding Alcator C-Mod from the $N^{14}(n, 2n)N^{13}$ reaction. During a shot, there will be $\approx$ 4000 gallons of cold N_2 vapor, of density 9.5×10^{19} molecules/cm^3. A pulse of 5×10^{15} n/s for

Table VIII

Activity from Neutron Induced Isotopes in Ground Water Underneath the Alcator C-Mod Cell.

Parent	Parent Concentration (PPM)	Isotope	$t_{1/2}$	Concentration (just below cell floor) $\#/cm^3/s$/source-neutron	Activity after a 1 s shot at $5 \times 10^{15} n/s$ $\mu Ci/cm^3$	5 Year Multiplier	Activity after 5 Years operation ($\mu Ci/cm^3$)	Maximum Permissable Concentration* ($\mu Ci/cm^3$)
$_{11}Na^{23}$	120	$_{11}Na^{24}$	15 h	2.2×10^{-17}	3.8×10^{-11}	36.1	1.37×10^{-9}	6×10^{-3}
$_{12}Mg^{26}$	20	$_{12}Mg^{27}$	9.5 m	3.13×10^{-20}	5.16×10^{-12}	1.3	6.7×10^{-12}	3×10^{-6}
$_{12}Mg^{24}$	20	$_{11}Na^{24}$	15 h	2.74×10^{-24}	4.74×10^{-18}	36.1	1.71×10^{-16}	6×10^{-3}
$_{25}Mn^{55}$	0.37	$_{25}Mn^{56}$	2.58 h	7.2×10^{-19}	7.27×10^{-12}	10.9	7.92×10^{-11}	3×10^{-6}†
$_{25}Mn^{55}$	0.37	$_{25}Mn^{54}$	303 d	5.78×10^{-26}	5.66×10^{-25}	2.25×10^4	1.27×10^{-20}	1×10^{-4}
$_{17}Cl^{35}$	190	$_{17}Cl^{36}$	$3.1 \times 10^5 y$	1.42×10^{-15}	1.36×10^{-17}	2.25×10^4	3.61×10^{-13}	8×10^{-5}
$_{17}Cl^{37}$	190	$_{17}Cl^{38}$	37.3 m	4.4×10^{-18}	1.84×10^{-10}	3.22	5.94×10^{-10}	4×10^{-4}
$_{35}Br^{81}$	0.14	$_{35}Br^{82}$	35.5 h	2.3×10^{-20}	1.69×10^{-14}	69.1	1.164×10^{-12}	4×10^{-5}
$_{35}Br^{79}$	0.14	$_{35}Br^{80}$	4.4 h	2.3×10^{-20}‡	1.36×10^{-13}	15.9	2.17×10^{-12}	3×10^{-6}†

⋆ Title 10, Chapter 1, Code of Federal Regulations Part 20 (10CFR-20) Maximum permissable Concentration of Soluble Isotopes for Non-Radiation workers.

† Maximum permissable concentration of isotopes not specifically mentioned which decay by paths other than spontaneous fisson or α-decay.

‡ Estimate from thermal cross section.

Table IX Activation of Airborne Isotopes by Alcator C-Mod

Isotope	Ar^{41}	H^3	N^{13}
Production method	$Ar^{40}(n,\gamma)Ar^{41}$	$H^2(d,p)H^3$	N^{14} $(n,2n)N^{13}$
Location	Cell Air	Vacuum Chamber	Cryostat
Volume produced/pulse(m^3)	2.55×10^{3}	0.53	15 (vapor)
Concentration/pulse(Ci/m^3)	4.82×10^{-7}	4.72×10^{-4}	2.79×10^{-6}
Maximum yearly production(Ci)	4.61	0.93	0.16
Maximum yearly production rate(Ci/s)	1.44×10^{-7}	2.96×10^{-8}	5.0×10^{-9}
Disposal	Cell exhaust	Cell exhaust	LN_2 exhaust
Exhaust rate(m^3/s)	0.71	0.71	0.3
Exhaust point concentration(Ci/m^3)	2.03×10^{-7}	4.17×10^{-8}	1.67×10^{-8}
Concentration(Ci/m^3) at nearest accessible area	7.14×10^{-10}†	1.47×10^{-10}†	4.1×10^{-9}‡
MPC(Ci/m^3)	4×10^{-8}	2×10^{-7}	3×10^{-8}
Dose rate at site boundary (mRem/yr)	4.9	0.1	

†Includes: Average Boston wind speed: 5 m/s, occupancy factor within nearest accessible area: $< 10\%$, and air stagnation factor: 30. The exhaust point is 11 m above grade.

‡This is the concentration near the exhaust point, which has not yet been determined. (The effective whole body dose at this point is 20 mRem/year) It will be inside the boundary fence, at least 3 meters from any area accessible to the general public.

one second will induce a total activity of ≤ 42.3 μCi, which would lead to a total yearly production of ≤ 0.16 Ci after 3750 pulses. The concentration at the point of exhaust, also listed in Table IX, is nearly an order of magnitude lower than the Maximum Permissible Concentration for non-radiation workers. The anticipated dose rate at the site boundary from this isotope has not been calculated at this time because the cryogenic exhaust line has neither been sited nor designed. A requirement of the design will be that no significant increase in the dose rate from airborne isotopes will occur.

The exhaust will be monitored for Ar^{41} and and tritium activity.

9.C.3 Machine Structure

Residual activity in the machine structures presents a potential hazard to Alcator C-Mod personnel working in the vicinity of the experiment following high performance deuterium operation. The expected hourly dose rates from the isotopes present in those structures were initially calculated in [6] using the MCNP code. Those values, adjusted for the actual neutron production rate of 5×10^{15} n/sec (1 second pulse) and for the increased time between pulses (20 minutes rather than 10 minutes) are detailed in Table Xa. Immediately following the last pulse of continuous high performance operation for a 1 year period the anticipated dose rate at the machine midplane would be 77 mRem/hour, primarily from Mn^{56}. This dose rate is reduced to 1 mRem/hour after 24 hours, predominately from Cu^{64} (see Table X.b.) Inside the vacuum chamber, residual activity in the Molybdenum tiles could lead to a dose rate of 410 mRem/hour. This will require an 8 day cool down to reach 50 mRem/hour. Anticontamination clothing and goggles may be required by the Radiation Protection Office for workers in this region.

9.C.4 Concrete Structure

The specific activity in the concrete structures of the biological shield wall is shown in Table XI at 24 hours after ceasing 5 years of continuous high performance operation and after a 1 year cool down period. The total activity level of the concrete of 1.68×10^{-6} Ci/ton is dominated by the Ca^{45} contribution. (Although the Fe^{55} activity is higher, it decays by electron capture, producing 5.9 keV x-rays.)

Table X.a Post Operative Isotopes in the Alcator C-Mod Structure

All pulses produce $5 \times 10^{15} n/s$

Isotope	$t_{1/2}$	Dose after: (mRem/hr)	1 Shot	30 Shots	5 Days	30 Weeks
Cu^{64}	12.7 h	Midplane at	.06	1.4	1.9	1.9
Cu^{66}	5.1 m	Cryostat	2.85	3.05	3.05	3.05
Cr^{51}	27.7 d		6.5×10^{-5}	1.94×10^{-3}	9.2×10^{-3}	5.7×10^{-2}
Mn^{56}	2.58 h		6.55	71.25	71.36	71.36
Mn^{54}	312.2 d		1.5×10^{-5}	4.4×10^{-4}	2.2×10^{-3}	5.3×10^{-2}
Fe^{59}	44.6 d		1×10^{-4}	2.99×10^{-3}	1.44×10^{-2}	1.35×10^{-1}
Co^{60m}	10.48 m		3.5×10^{-5}	4.77×10^{-5}	4.77×10^{-5}	4.77×10^{-5}
Ni^{65}	2.56 h		8.5×10^{-3}	9.2×10^{-2}	9.2×10^{-2}	9.2×10^{-2}
Co^{58}	70.8 d		6.5×10^{-5}	1.95×10^{-3}	9.5×10^{-3}	0.125
TOTAL			9.46	75.8	76.4	76.78
$Mo^{99\dagger}$	66h	Inside torus	3.8	91.2(25 shots)	293	410

† With Molybdenum tiles lining the walls of the experiment. The dose rate inside the torus will decrease to 50mr/hr 8 days after extended high performance operation.

Table X.b Cool Down After 30 Week Run Period

	Dose after 24 hrs	Dose after 48 hrs
Cu^{64}	0.513 mRem/hr	0.14 mRem/hr
Cu^{66}		
Cr^{51}	5.5×10^{-2}	5.4×10^{-2}
Mn^{56}	0.113	1.79×10^{-4}
Fe^{59}	0.133	0.130
Co^{60m}		
Ni^{65}	1.4×10^{-4}	2.1×10^{-7}
Co^{58}	0.124	0.123
Mn^{54}	5.3×10^{-2}	5.3×10^{-2}
TOTAL	0.99	0.5

Table XI Activity in the Experimental Test Cell
After 5 Years Continuous High Performance Operation

Isotope	$t_{1/2}$	Specific Activity 24 hrs after last shot	Ci/ton After 1 year cool down
Si^{31}	2.6 h	1.4×10^{-7}	–
Na^{22}	2.6 y	3.0×10^{-10}	–
Na^{24}	15 h	8.6×10^{-5}	–
Al^{26}	7.4×10^{5}y	3.2×10^{-15}	3.2×10^{-15}
Ar^{39}	265 y	2.1×10^{-10}	2.1×10^{-10}
Ar^{37}	35 d	3.7×10^{-6}	2.7×10^{-9}
Cl^{36}	3.1×10^{5} y	4.7×10^{-14}	4.7×10^{-14}
K^{42}	12.4 h	1.1×10^{-5}	–
Ar^{41}	1.85 h	1.4×10^{-13}	–
Ca^{41}	8×10^{4} y	5.6×10^{-9}	5.6×10^{-9}
K^{43}	22.4 h	2.0×10^{-11}	–
Ca^{45}	165 d	7.3×10^{-6}	1.6×10^{-6}
Ca^{47}	4.5 d	7.3×10^{-7}	–
Mn^{53}	2×10^{6} y	2.3×10^{-16}	2.3×10^{-16}
Mn^{54}	303 d	3.0×10^{-9}	1.3×10^{-9}
Mn^{52}	5.7 d	2.5×10^{-12}	–
Cr^{51}	27.8 d	1.3×10^{-9}	–
Fe^{55}	2.6 y	7.3×10^{-6}	5.6×10^{-6}
Mn^{56}	2.57 h	1.7×10^{-11}	–
Fe^{59}	45 d	4.7×10^{-7}	1.7×10^{-9}
TOTAL		1.2×10^{-4}	7.2×10^{-6}

9.D Activity Control

Nonessential materials (such as tools, portable equipment, etc) will be removed from the cell as part of the search and lock up procedure prior to operation of the experiment. Any material to be removed from the cell will be surveyed for residual activity if it has been located in the cell during deuterium operation. If warranted, it will be stored in a "hot room" which will be located in the rough laboratory area.

Activated materials which are to be processed will be surveyed by an authorized representative of the Radiation Protection Office who will determine the necessary level of precautions required for handling of the particular items. Procedures will be developed in conjunction with RPO for handling, cleaning, machining and storing such materials.

Items which have become contaminated from contact with activated materials (such as cloths used for cleaning) will be stored and disposed of as low level radioactive waste, as directed by RPO.

Vacuum pump oil will be collected and checked for tritium content.

If the activity levels in the experimental cell become sufficiently high, as determined by the radiation safety officer, frisking of shoes and clothing will be initiated.

9.E Radiation Monitoring and Access Procedures

All procedures for access to controlled areas are subject to approval through the Quality Assurance program for the Alcator C-Mod project. The procedures will be reviewed and approved by the MIT radiation safety officer for the project as well as by the appropriate representative of the Alcator C-Mod staff.

All Alcator C-Mod personnel who work in restricted areas will be required to wear film badges. Self reading dosimeters will be provided for working in the cell at times when the dose rate from activated products exceeds 2.5 mRem/h.

9.E.1 Experimental Cell

The experimental cell is restricted to all personnel during the experimental pulse. The

cell will be cleared by a search procedure and locked prior to operation. The doors will be interlocked so that the power sequence will not proceed unless properly locked. The area will be monitored by remote television during operation.

Neutron and γ radiation will be monitored in real time during the experimental pulse.

Accumulated dose levels will be monitored with either Thermo-luminescent detectors (TLD) or film badges at selected locations near the experiment and at the cell walls.

Post operative activity will be monitored by survey meters located in the cell.

Procedures will be developed for checking residual activity in the cell prior to deuterium operation and clearing the area for general access. Controlled access procedures will be in effect until dose levels fall below 2.5 mRem/hour.

9.E.2 Laboratory Areas

The laboratories adjacent to the experimental cell will be cleared by search and locked prior to production of deuterium plasmas.

In the event that a diagnostic access hole is used, shadow shielding will be installed which is sufficient to reduce radiation dose levels at the laboratory wall to levels appropriate for unrestricted areas. The efficacy of the shielding will be tested with a neutron source and approved by the appropriate radiation officer. Once approved, changes in the shielding will require permission of and reinspection by the radiation officer.

The most likely hot spots will be monitored by film badges or TLD's at the laboratory wall.

9.E.3 Power Room

This area will be cleared by search and locked prior to all machine operation. The doors will be interlocked as described in the section on electrical safety.

Shadow shielding will be installed around the hole for the buswork in the roof of the entrance vestibule. This will be tested with neutron sources and approved by the appropriate radiation officer prior to deuterium operation. Changing or moving of this

shielding will require reinspection and reapproval by the radiation officer.

Likely hot spots in the power room walls will be monitored with film badges or TLD's.

9.E.4 Emergency Exit

This area will be cleared by search and locked prior to deuterium operation. If necessary, shadow shielding will be installed around the east wall vent, which exits into this area. This shielding will be tested and approved by the appropriate radiation officer, and likely hot spots will be monitored by film badges or TLD's.

9.F. Anticipated Operating Dose

The calculations presented in the previous sections of this chapter represent the highest possible radiation exposures which could be achieved with Alcator C-Mod operation. As the experiment will actually be operated, the dose levels will be much lower for several reasons. The purpose of this section is to provide a more realistic estimate of the actual site boundary dose levels which would occur during the Alcator C-Mod operation.

First, a concrete igloo will surround the experiment (See Fig. 11) for the purpose of reducing the radiation dose to the plasma diagnostics and to the Alcator C-Mod personnel to as low a value as is reasonably achievable. The installation of this igloo, which is the most cost effective technology for shielding a source of this type, will also reduce the production of radioactive isotopes by neutron capture throughout the facility.

Secondly, the previous dose rate calculations assumed 3750 high performance pulses per year, which consisted of 25 pulses daily, 5 days per week, 30 weeks per year. In actual operation, hydrogen rather than deuterium is likely to be used for at least 20% of the operation. A number of pulses are necessary to "tune up" the plasma for each run, so that typically less than half of the pulses each day could achieve high performance. In addition, the experiment will probably be operated 4 days per week rather than 5. This would result in a maximum of 1000 pulses (1 second pulse) per year which might achieve the 5×10^{15} n/sec rate.

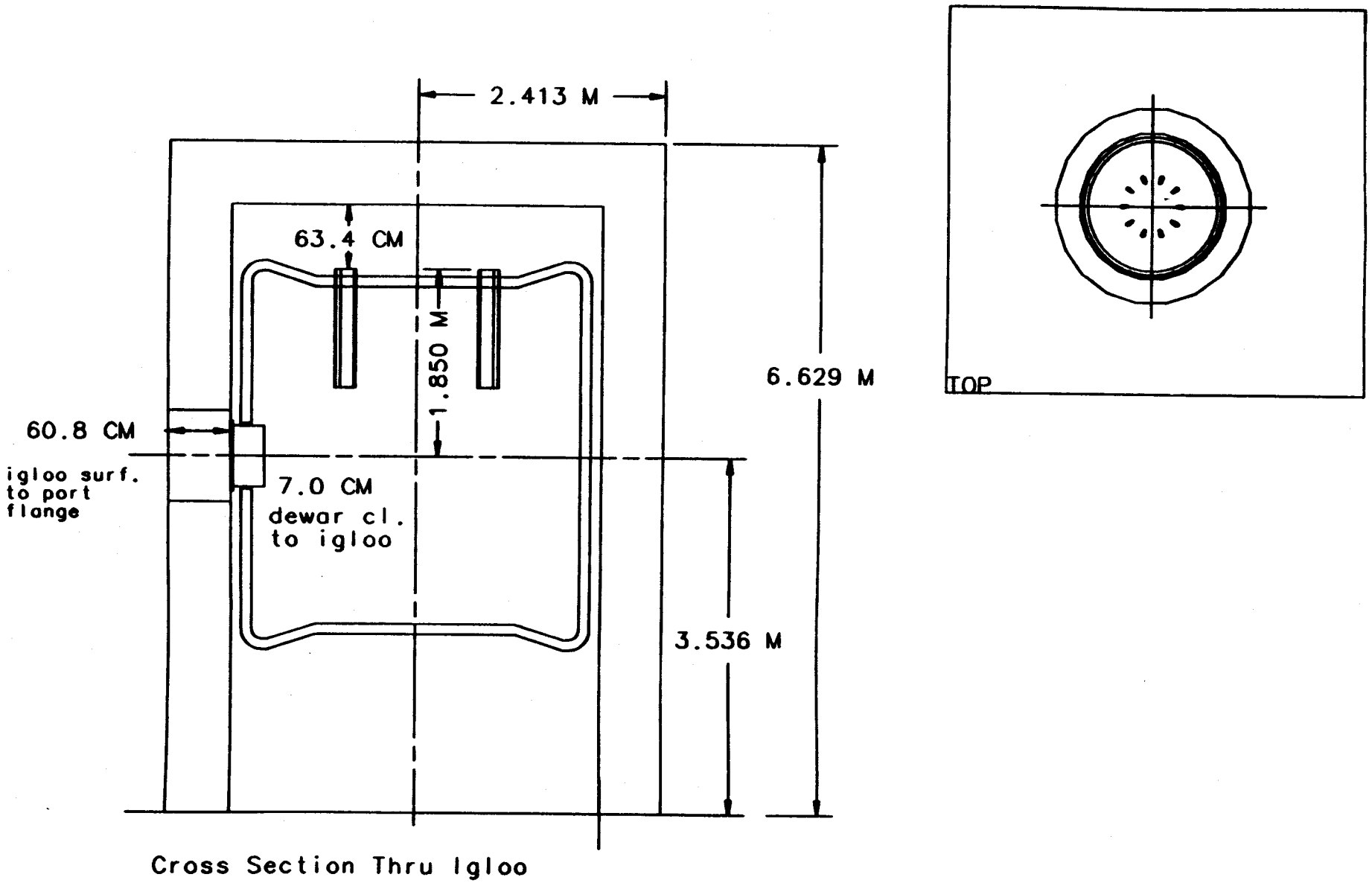


Figure 11. Schematic Drawing of the Igloo for Alcator C-Mod.

9.F.1 The Igloo

The best available technology for reduction of radiation dose rates and activation of argon inside the experimental cell is the installation of a 2′ thick concrete igloo surrounding Alcator C-Mod. This structure will begin just outside the cryostat for the experiment and will extend from the floor to above the experiment. It will have a 2′ thick concrete cap. It is likely that the igloo will contain from 0.1% to 0.5% boron by weight in order reduce (n,γ) reactions in the structure.

This additional concrete reduces the radiation dose immediately outside the biological shield wall to 1.48×10^{-6} Rem per high performance pulse or 1.5 mRem/1000 pulses. At the fence, which forms the nearest accessible area, this is reduced to 0.55 mRem/1000 pulses.

The production of Ar^{41} in the experimental cell is reduced by one order of magnitude by the installation of this concrete igloo, and by two orders of magnitude if the igloo contains only 0.1% by weight boron. This lowers the total possible production of this isotope to 128 mCi/year without the boron and 12.8 mCi/year with 0.1% boron. In the manner used in section 9.C.2, this would result in a yearly exposure at the base of the exhaust stack from Ar^{41} of 0.5 mRem/year without the Boron and 0.05 mRem/year with 0.1% boron.

While use of the igloo reduces the overall radiation dose rate production of the experiment, the site boundary doses without it are low enough that its presence is not required in order to operate the experiment. It is likely that this igloo will be installed on the experiment early in its operation, even though it is not strictly necessary.

9.F.2 Actual Operating Dose

The results of using the more realistic estimated rate of 1000 high performance pulses per year and using the improvement in dose rates due to the igloo are that the likely site boundary direct dose rate is less than 0.55 mRem/year. The Ar^{41} production will be less than 35 mCi/year, which results in a dose at the base of the stack of less than 0.14 mRem/year from that isotope.

X. Miscellaneous

10.A. Machine Shop Safety

Machine shop equipment will be operated by personnel familiar with proper operation of the equipment. Protective equipment such as safety glasses, goggles or face shields are required, as are steel toed safety shoes. Loose clothing, ties, jewelry, loose long hair, and short pants are prohibited when operating machinery.

Respirators and dust masks will be used when hazardous materials are machined.

Procedures for handling and machining of radioactive materials will be instituted and monitored by the radiation safety officer.

10.B. Fork Lift

Those authorized to use the fork lift must take a course in proper operation. The keys are kept in a secure place and only given to authorized operators.

10.C. Crane

The Alcator C-Mod experiment has two cranes in the experimental cell. The large crane is rated for 35 tons, and can move with two speeds, $50'/\mathrm{m}$ or $5'/\mathrm{m}$. The acceleration and deceleration are flywheel controlled. The span is $48'$ and the lift height is $30'$. This The smaller crane is mounted on the lower flange of one girder of the larger crane and is rated for 3 tons.

A jib crane rate for 2 tons is located on the loading platform outside the cell.

All cranes are key switched and will only be operated by authorized personnel. Approved operators will be trained by the manufacturer and documentation concerning allowed operators will be maintained on site.

XI. Natural Phenomena

Although no major earthquake has occurred in the Boston area in several hundred years, the potential for seismic activity exists. Therefore, the support structure for the Alcator C-Mod experiment was designed to withstand 1 g lateral force in the event of an earthquake. This exceeds the requirements of the Massachusetts Building Code by a factor of 8.

XII. Accident Analysis and Reporting

The Alcator C-Mod experiment and related systems do not use either fissile materials or highly toxic materials which could cause a hazard to the general public through explosion or accidental release. The risk of accident is limited to MIT personnel working on and around the experiment. Potential accidents (which have been identified and discussed in the previous sections) include accidental exposure to radiation, electric shock, oxygen deprivation, cryogenic burns, fire, and explosion.

If an employee is accidentally locked in the experimental test cell during a plasma pulse, that person could be potentially exposed to a radiation dose of 20 Rem (A short term total dose of 200-600 Rem is fatal to half of those exposed. Measurable physiological effects, such as decreased white blood cell counts, are found at short term doses between 10 and 50 Rem.[10]) There is also a potential for exposure to flying debris should an explosion occur, and the possibility of exposure to high voltages, high magnetic fields, laser radiation and radio frequency radiation. The power systems, rf and laser systems will be interlocked to the cell doors so that it is not possible to initiate a pulse sequence until a search and lock procedure is followed once a door is opened. The space will be monitored with closed circuit television and an intercom system as well. A "scram" button in the cell will make it possible to abort a pulse from inside the cell.

The hazard of electrocution is everpresent. Whenever possible, high voltage and high power systems are interlocked so that they cannot be accessed while a hazard is present. All work on these systems is supervised by a licensed electrician, and work is carried out by pairs of workers to minimize the possibility of an accident.

The cryogenic system on Alcator C-Mod poses an accident risk in three ways. Blockage of the exhaust without proper pressure release could cause an explosion of the dewar or pipes involved. A break or leak in the liquid nitrogen delivery system could cause both depletion of available oxygen in the area (leading to suffocation) and cryogenic burns to anyone coming into contact with the leaking material. The suffocation hazard is minimized both by the use of audible oxygen level alarms in the experimental cell and by frequent

integrity tests of the liquid nitrogen delivery system. The design of the liquid nitrogen system will include the proper pressure relief valves in order to minimize the explosion hazard.

The threat of fire is present in most laboratory situations, and the fire prevention systems are covered in chapter IV.

The most likely point of explosion is in either the power room or the experimental cell during an experimental pulse. Access to these rooms is prohibited during a pulse and the power sequence is interlocked to the doors. A search and lock procedure is followed any time a door if opened prior to resuming operation.

Accident reporting procedures at MIT are designed to meet the requirements of the Occupational Safety and Health Act of 1970 and the Commonwealth of Massachusetts Workmen's Compensation Act. Accidents must be reported to the project supervisor immediately, and injuries must be reported to the Industrial Accident Board within 5 days. The MIT Safety Office must also be notified immediately. All accidents will be investigated by the supervisor and steps taken to prevent a recurrence.

Compliance with DOE Order 5481.1A for reporting of radiological events is handled by the MIT Radiation Protection Office.

XIII. Quality Assurance Program

The Alcator C-Mod Quality Assurance Program is designed to apply the standards of ANSI/ASME NQA-1-1983, Chapter II (Quality Assurance Basic Requirements) to any project systems the failure of which could result in undue hazard to the public or project personnel, damage to equipment, or loss of operating time. The description of the program is included in Appendix D.

All safety interlock systems, access and control procedures are subject to review and approval through the QA program.

XIII Acknowledgements

The author would like to thank Charles Park and Dave Gwinn for their advice and for reviewing this document. Material for this report was provided by Steve Fairfax, Steve Wolfe, Frank Silva, Mark Iverson, Jim Rosatti, Steve Golovato, Bob Childs, and Bill Parkin. Frank Tambini and Dick DeWolfe provided site information. The help provided by Jerry Diaz on fire safety systems and the advice on radiation protection from Fred McWilliams were invaluable. Kat Daley assisted with running the neutron transport codes.

XIV. References

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Appendix A. MIT Safety Programs

All employees at MIT are provided with a set of 6 booklets which describe the MIT safety program. Safety hazards occurring at MIT are described along with the proper procedures for dealing with the most common situations. New radiation workers are instructed by the Radiation Protection Office on radiation hazards and protection.

The Plasma Fusion Center, in conjunction with the MIT Safety office offers a regular program of lectures on all aspects of safety likely to be encountered by PFC personnel. Attendance at these lectures is required for technicians, electricians, machinists, shop supervisors and is recommended for all others.

Classes in CPU are offered on a regular basis at the PFC, and all personnel are encouraged to take them.

The Plasma Fusion Center maintains a Safety Committee who provide regular inspection of the PFC facilities. This committee includes at least one licensed electrician.

The MIT Safety Office conducts regular inspections for fire hazards at MIT facilities. The Radiation Protection Office regularly provides radiation surveys of the facilities.

Appendix B. Kirk Locks

The Alcator C experiment made extensive use of the Kirk key interlock system. While the interlock system for the Alcator C-Mod experiment has not yet been designed, it is expected that a similar interlock system will be installed.

The Kirk key interlock utilizes a lock design in which the key cannot be removed from the lock until the lock is placed in the pre-determined position.

An interlock system using Kirk locks can be designed in many configurations and can be used as the basis for both mechanical and electrical interlocks. A typical use on the Alcator experiment would involve having a Kirk lock on each door which should not be opened during machine operation. The key from a Kirk lock cannot be removed until the lock is in the correct position. Once the area is searched and locked, the key is removed and placed in a multi-lock transfer interlock which controls the initiation of the power sequence for the experiment. All of the keys for the each separate controlled access areas must be present and in the proper position in the multi lock transfer interlock in order to energize any equipment.

A second common use of these locks is in an exclusive arrangement which ensures that two devices cannot be operated at the same time. An example of this would be a configuration which did not allow a door to be unlocked at the same time a breaker is engaged. The key controlling the breaker would cause it to be opened before it could be removed from the lock, then would be used to unlock the door to the controlled area. The door to the controlled area would then have to be closed and locked so that the key could be removed and used to re-energize the breaker.

Appendix C Dose Reporting Requirements for Alcator C-Mod

Department of Energy
Chicago Operations Office
9800 South Cass Avenue
Argonne, Illinois 60439

MAY 1 1 1988

Mr. Paul C. Powell, Assistant Director
Office of Sponsored Programs
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, Massachusetts 02139

Dear Mr. Powell:

SUBJECT: DOSE REPORTING REQUIREMENTS FOR ALCATOR C-MOD
CONTRACT NO. DE-AC02-78ET51013

Recent discussions among Plasma Fusion Center (PFC) and Department of Energy (DOE) personnel have focused on the selection of the dose objectives for Alcator C-Mod. The PFC has stated in its Alcator C-Mod Project Management Plan, that, "shielding shall be adequate to reduce the dose rate to the public to less than 100 mr per year..." It should be noted that this level is the allowed limit of continuous (or prolonged) exposure (not including exposure from natural background and medical procedures) to general public personnel. This limit has been recommended by the National Council on Radiation Protection and Measurements (NCRP) and adopted by DOE (see Attachments 1 and 2), to be implemented in DOE operations such as those under the subject contract.

Discussions with PFC personnel indicate that operation of the device would deliver exposures approaching 100 mrem/yr to general public personnel only under idealized conditions. These include machine operation at full parameters for all testing, and conservative assumptions regarding shielding and public personnel occupancy. If more realistic conditions are assumed, the estimated exposure level drops significantly.

Regardless of the estimated exposures to be produced by the device, it is important to note the action levels discussed in Attachment 2. DOE is required to be informed (at the Headquarters level) if exposures to any member of the general public reach 25 mrem (from all operational sources) or one-half of the applicable limits (radionuclide air transport only). To assure that this office is aware of such exposures well in advance, you are requested to formally inform us if any general public exposure from contract operations has reached 10 mrem (5 mrem if by air transport only). In determining these exposures it is appropriate to employ realistic occupancy factors, direct exposure data, and exposure estimates derived from radionuclide transport codes.

Y.C. RON PARKER
DAVE GWINN
JOHN COCHRANE
FRANK HASSE

B.C.B.
5/17/88

MAY 1 1 1988

Mr. Paul C. Powell -2-

If you have any questions in this regard, please contact Paul Neeson, of our Environment, Safety, and Health Division, at (312) 972-2258.

Sincerely,

Martin A. Langsam, Branch Chief
Contracts Division

Enclosures:
As Stated

cc: C. Bolton, Office of Fusion Energy, HQ, w/encls. (ER-55/GTN)
W. Marton, Office of Fusion Energy, HQ, w/encls. (ER-55/GTN)
M. Scott, AMLM, w/encls.

|N|C|R|P| NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS
7910 WOODMONT AVENUE / BETHESDA, MD 20814

CONTROL OF AIR EMISSIONS OF RADIONUCLIDES

The National Council on Radiation Protection and Measurements (NCRP) has considered the problems raised by the Congressional requirement that the Environmental Protection Agency (EPA) develop standards for radionuclides as part of the National Emission Standards for Hazardous Air Pollutants. The EPA has proposed rules under 40 CFR Part 61 and the NCRP President, with the advice of an ad hoc group of Council members, has commented on these proposals by correspondence and during EPA and Congressional Hearings. The Council considers it desirable at this time to present positive recommendations based on published Council Reports and current work in progress.

The NCRP Scientific Committee 1 on Basic Radiation Protection Criteria has drafted a report defining the relevant recommendations of the Council. While this draft is still unpublished, some of the pertinent numerical values are included in NCRP Report No. 77, *Exposures from the Uranium Series with Emphasis on Radon and its Daughters.*

These are detailed here.

1. The limit of 500 mrem whole body dose equivalent in a year, not including medical and natural background radiation, is still recommended for individuals in the population when the exposure is not continuous. As a corollary, the NCRP advises remedial action, where possible, when the external whole body dose equivalent exceeds 500 mrem/year from all environmental sources, including natural background.

2. The recommended limit for continuous exposure of an individual in the population to external radiation is 100 mrem/year whole body dose equivalent, not including exposure from natural background and medical procedures. A dose equivalent rate of 100 mrem/year is considered to be associated with a lifetime risk of developing cancer of about one in a thousand.

3. These recommendations on limits are only part of a total system of dose limitation which must also include justification and considerations of ALARA (As Low As Reasonably Achievable).

While the NCRP has in the past specifically declined to introduce a sub-set of limits, it is sympathetic to the needs of regulatory bodies who must control individual sources of radiation exposure. In particular, it is necessary to consider the situation where a member of the public may be exposed to radiation from more than one of the controlled sources.

In looking at the possibility of multiple exposures, it seems that large installations which could cause exposures that are a significant fraction of the 100 mrem/year limit are unlikely to be geographically located in such a manner that the sum of the exposures from two sources would outweigh the exposures to individuals closer to either of the separate sources. At the other end of the scale, small installations that may be more closely spaced should produce only relatively small exposures, so that even the sum of their exposures would not approach the 100 mrem/year limit for continued exposure.

The Council (NCRP) appreciates, however, that a regulatory agency charged with protection of the public may consider it necessary to regulate individual sources in order to assure that no individual receives a continuous radiation dose above the 100 mrem/year recommended limit. Thus, whenever the potential exists for an individual to exceed 25% of the limit, for whole-body dose equivalent from any single site, the site operator should be required to assure that the exposure of the maximally exposed individual from all sources would not exceed 100 mrem/year on a continuous basis.

This recommendation of the NCRP concerns whole-body irradiation but the Council has also considered the situation for the exposure of individual organs, such as lung or bone. Dose limits for individual organs will necessarily be higher than that for the whole body in the inverse ratio of the risk for a particular organ to the total risk for whole body exposure.

Radiation doses at the limits considered are not readily measured for continuous external whole-body exposure and such doses cannot be measured directly for internal emitters. Hence, it has been customary to use mathematical models to relate release quantities and the consequent doses to individuals in the public. This will still be necessary, but the NCRP recommends that implementation of standards for air emission use models that are realistic, thoroughly documented and capable of validation. While the internal doses are usually estimated rather than measured, validating measurements can be made at steps in the environmental chain of exposure that are closer to the receptor than the releases. The need for realistic models is obvious; for example, a calculated dose that is in error by a factor of five in either direction can either misjudge the risk from exposure by a comparable factor, or increase the cost of compliance. This subject is treated more fully in the recently released NCRP Report No. 76, *Radiological Assessment: Predicting the Transport, Bioaccumulation and Intake by Man of Radionuclides Released to the Environment.*

Attachment 2
Revision 1, 9-3-85

RADIATION STANDARDS FOR PROTECTION OF THE PUBLIC IN THE VICINITY OF DOE FACILITIES

A. DOSE LIMITS

1. All Pathways

The effective dose equivalent for any member of the public from all routine DOE operations[1] (natural background and medical exposures excluded) shall not exceed the values given below:

	Effective dose equivalent[2] mrem/year	(mSv/year)
Occasional annual exposures[3]	500	(5)
Prolonged period of exposure[3]	100	(1)

No invididual organ shall receive an annual dose equivalent in excess of 5 rem/year (50 mSv/year).

2. Air Pathway Only (Limits of 40 CFR 61, Subpart H)

	Dose Equivalent mrem/year	(mSv/year)
Whole body dose	25	(.25)
Any organ	75	(.75)

B. ACTION LEVELS

1. To preclude an individual in the general population from receiving more than 100 mrem/year effective dose equivalent, a DOE administrative action level is established at 25 mrem/year (excluding medical and natural background exposures) for its routine operations. This dose value is not a limit but an administrative threshold which will require a specific evaluation of the magnitude of identifiable exposures to an exposed individual by the responsible DOE Field Office. A copy of the evaluation report will be transmitted to the relevant Program Office(s) and the Deputy Assistant Secretary for Environment, Safety and Health, EH-10.

2. To preclude exceeding the air pathway limits in A.2. above, Field Offices shall notify the relevant Program Office and EH-10 of calculated or anticipated doses to individual members of the population in excess of one half the specified dose equivalent limits.

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1. Routine DOE operations means normal planned operations and does not include actual or potential accidental or unplanned releases.

2. Effective dose equivalent will be expressed in rem (or millirem) with the corresponding value in sievert (or millisievert) in parenthesis. As used in this standard, effective dose equivalent includes both the effective dose equivalent from external radiation and the committed effective dose equivalent to individual tissues from ingestion and inhalation during the calendar year.

3. For the purposes of these standards, a prolonged exposure will be one that lasts, or is predicted to last, longer than 5 years.

C. AS LOW AS REASONABLY ACHIEVABLE (ALARA)

Field Offices and contractors shall implement programs to assure that exposures resulting from DOE operations to members of the public are maintained as low as reasonably achievable. The ALARA programs shall be documented. Each Field Office shall periodically audit contractor ALARA programs and contractor progress in attaining ALARA conditions. Assessments of ALARA must include best estimates of actual effective dose equivalent to individual members of the populations as well as collective dose equivalent to a distance of 80 kilometers from the site.

D. DEMONSTRATION OF COMPLIANCE

Demonstration of compliance with these criteria shall normally be done by the following procedure:

a. Calculation of external exposure and internal intakes by use of effluent data and environmental pathway models approved by Office of Operational Safety, EH and/or environmental measurements.

b. Calculation of total effective dose equivalent using the Draft Final Committed Dose Equivalent Tables.

For DOE facilities with airborne releases subject to 40 CFR 61, Subpart H, the AIRDOS-EPA model must be used except as otherwise approved by EPA. Compliance will be determined by calculation of the dose to members of the public at the point of maximum annual concentration in an unrestricted area where any member of the public resides or abides.

E. ACCIDENTS

The exposure limits given above are for routine DOE operations and are not intended for use as criteria to evaluate the acceptability of postulated accidents. Planning for the prevention or mitigation of accidents and their effects shall be accomplished in accordance with the requirements of DOE 5480.1A, Chapter V, "Safety of Nuclear Facilities" and Chapter VI, "Safety of Department of Energy Owned Reactors."

The unanticipated release of radioactivity (venting) from an underground nuclear weapons test is considered to be an accident. The release of radioactivity following an underground nuclear weapons test which is the result of planned sampling or reentry is not an accidental condition, and shall be controlled in accordance with the outlined standards.

F. APPLICABLE DEFINITIONS

The following definitions are derived from ICRP Publication No. 42 (1984).

Dose equivalent - The product of the absorbed dose (in rads) in the tissue of interest, a quality factor (specified by the ICRP), and any other modifying factors specified by the ICRP.

Effective dose equivalent - A quantity defined by the sum

$$\sum_T W_T H_T$$

where W_T is the weighting factor specified by the ICRP to represent the production of the stochastic risk resulting from irradiation of tissue T to the total risk when the whole body is irradiated uniformly, and H_T is the mean dose equivalent in tissue T. H_T may be from external or internal sources. Values of W_T have been specified by the ICRP and were used in preparing the draft final Committed Dose Equivalent Tables.

Committed dose equivalent - The time integral of the dose-equivalent rate in a particular tissue following an intake of radioactive material into the body. In keeping with ICRP recommendations, for DOE this period is set at 50 years.

Committed effective dose equivalent - The sum of the committed dose equivalents to individual tissues resulting from an intake, each multiplied by the appropriate weighting factor W_T.

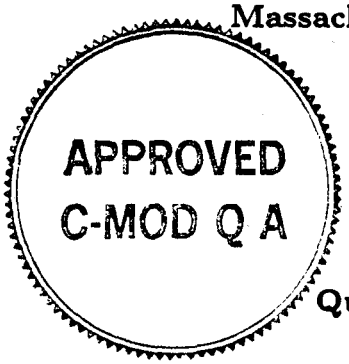
Collective effective dose equivalent - The collective effective dose equivalent is equal to the integrated sum of individual effective dose equivalents times the number of individuals exposed. For purposes of this directive only, the collective effective dose equivalent shall be truncated at 80 km distance from site boundaries and at 50 years following each year's release.

G. EFFECTIVE DATE

These criteria shall be used for all DOE dose calculations effective July 1, 1985, including annual summary reports for CY 1985 and subsequent years.

Appendix D Quality Assurance

Massachusetts Institute of Technology



Plasma Fusion Center

Alcator C-MOD

Quality Assurance Program

July 31, 1987

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Quality Assurance Program

ALCATOR QUALITY ASSURANCE PROGRAM

1.0 Purpose and Scope

1.1 Purpose and Goal

The purpose of this document is to set forth the Quality Assurance Program for the Alcator project. The goal of this program is to sustain the highest level of quality commensurate with project objectives. Responsibility is assigned and authority is established to implement the provisions specified in harmony with project objectives and in compliance with ANSI/ASME NQA-1-1983, Chapter II (Quality Assurance Basic Requirements).

1.2 Applicability

The Quality Assurance Program shall apply to all project systems the failure of which could result in

A. Undue hazard to the public or to project personnel. Also, those systems which are intended to prevent or to mitigate the consequences of such failure.

B. Major damage to equipment or substantial loss of capability to operate the facility to full design performance.

C. Significant damage to equipment or significant loss of operating time.

1.3 Tailoring

It is the responsibility of each project individual performing any action affecting project systems or subsystems in paragraph 1.2 to document a Quality Assurance Plan of Conformance (QAPC) to the Quality Assurance Program and to obtain approval of that plan as outlined in Paragraph 5 (Implementation). This QAPC will require documentation of independent checks on each stage of design, fabrication, installation, operation, and maintenance including the writing of related procedures for all applicable systems or equipment. Complete and accurate records of each step in the program including controlled copies of the QAPC and all documents required by the QAPC will be maintained by the QA office.

2.0 Applicable Documents

2.1 Referenced Documents

ANSI/ASME, NQA-1-1983, Chapter II Quality Assurance Program requirements for Nuclear Facilities.

2.2 Appendices

A. Alcator Quality Assurance Policy Statement.

B. QA Plan of Conformance Documents Checklist.

2.3 Figures/Tables

QA/Organization Chart — Figure 2 of Section 4.

3.0 Program Administration

3.1 Organization

The Associate Directors for Toroidal Confinement and Fusion Technology have delegated to the Quality Assurance Officer the responsibility and authority and will provide the required resources for planning, developing and implementing a Quality Assurance Program. The organization established to accomplish that end is shown in Figure 2 of Section 4.

3.2 Responsibilities

The project's Quality Assurance Program delegates the following responsibilities:

The organizational divisions are responsible for developing appropriate standards and levels of quality for their organizations, with the support of QA.

The individuals performing applicable activities (e.g. subcontractors, project shops, design teams and operations) are responsible for achieving these standards and levels of quality.

Quality Assurance is responsible for the measurement and independent assessment of the degree to which all project elements achieve quality goals and for providing guidance for correcting observed deficiencies.

QA is further charged with: defining and serving as the catalyst for standards development; aiding in the development and implementation of quality systems and controls appropriate to cost, schedule, safety, and program risk; auditing compliance; and measuring the effectiveness of the program.

4.0 Requirements

The following paragraphs (4.1 through 4.18) describe briefly the program requirements of ANSI/ASME NQA-1, Chapter II, and review the essentials of the project Quality Assurance Program and Procedures.

4.1 Organization

The project Quality Assurance organization is structured as shown in Figure 2 of Section 4. Responsibilities of the organization are as described in paragraph 3.0.

4.2 Quality Assurance Program

The requirements of this Quality Assurance Program (and thereby NQA-1) are implemented via the mechanism of specific Quality Assurance Plans of Conformance (QAPC) for actions which affect any project system or subsystem subject to the Quality Assurance Program (Par. 1.2). These activities encompass specifically: design, procurement, fabrication, installation, commissioning, operation and maintenance. The QAPC is outlined in a Quality Assurance Documents Checklist, more fully described in paragraph 5, which is a controlled document providing details of the implementation of the applicable requirements of this program for a specific action. Each QAPC shall address all the applicable criteria of paragraph 4.0 of this document.

4.3 Design Control

4.3.1 Responsibilities

Design Control within applicable activities of the project is the responsibility of the corresponding organization and is achieved by documented self control and independent review as described in specific QAPC's and verified by QA.

4.3.2 Design Analysis and Review

Design analyses are the prime, visible means for verifying the adequacy of designs and associated procurement, fabrication and quality planning. These analyses are independently reviewed and approved in accordance with the requirements of the specific previously approved QAPC. Reviewers may include specialists from other laboratories as well as members of the project.

4.3.3 Design Changes

Design changes shall be subject to design control measures commensurate with those applied to the original design.

4.4 Procurement Document Control

Actions involving procurement of equipment, components or services shall assure that design bases and other requirements which are necessary to assure quality are either included or referenced in documents for procurements of materials, equipment or services. All project requisitions must be marked with an approved QA plan number before being processed by the Fiscal Office. Appropriate measures shall be taken to assure that purchased materials, equipment, or services conform to the procurement documents.

4.5 Instructions, Procedures and Drawings

Activities affecting quality shall be prescribed by and performed in accordance with documented instructions, procedures or drawings of a type appropriate to the circumstances and required by the plan of conformance. These documents shall include or reference appropriate quantitative or qualitative acceptance criteria for determining that prescribed activities have been satisfactorily accomplished.

4.6 Document Control

Procedures shall be established to assure that documents such as specifications, instructions, procedures, and drawings are reviewed for adequacy and accuracy and approved for use. Changes to documents shall be subject to the same level of review and approval as the original, and procedures to control superseded approved documents shall be followed. QA documentation, including this document, is controlled and maintained by the QA office.

4.7 Control of Purchased Items and Services

4.7.1 Procurement Activities

Procurement activities are the responsibility of the Purchasing Department of MIT. Appropriate measures shall be taken and documented as required by approved QAPC's to assure that purchased materials or services conform to the procurement documents. Such control shall provide for the following as appropriate: source evaluation and selection, evaluation of objective evidence of quality furnished by the supplier, source inspection, audit, and examination of items or services upon delivery or completion.

4.8 Identification and Control of Items

The identification, control and traceability of applicable items used by the project is the responsibility of the organization or individual and is achieved by documented tagging and/or traceability subject to verification by QA.

4.9 Control of Processes

The control of special processes, such as soldering, welding, etc., employed within the planned activities of the project are the responsibility of the functional organization or individual performing the activity. Control is achieved by qualified personnel using approved QA verification. Approved Quality Assurance Plans of Conformance for specific activities may require QA participation in this control. Generally, this includes provisions for QA qualification of personnel, methods and machinery, review of procedures and certification of objective evidence of qualification.

4.10 Inspection

Inspection of hardware, to verify conformance, being processed within the applicable activities of the project is the responsibility of the performing organization. It is performed by qualified personnel and independently reviewed using qualified plans and procedures as required by the QAPC incorporating approved acceptance criteria and standards.

4.11 Test Control

Testing of hardware or software to verify satisfaction of requirements is the responsibility of the processing organization. The testing, by qualified personnel using approved plans and procedures including acceptance criteria, is described in the QAPC.

4.12 Control of Measuring and Test Equipment

Calibration of measuring and test equipment used within functional organizations is the responsibility of those organizations. Control is achieved as required by approved Quality Assurance Plans of Conformance. Conformance includes: calibration by qualified personnel; plans and procedures; and standards traceable to the National Bureau of Standards or other standards acceptable to QA.

4.13 Handling, Storage, and Shipping

Control, to prevent damage, loss, or deterioration of items processed within the project will be maintained as required by approved QAPC's subject to verification by QA.

4.14 Inspection, Test, and Operating Status

It is the responsibility of the functional organizations to provide status control of items within their activity, in process but not completed, to prevent inadvertent use or operation. Approved Quality Assurance Plans of Conformance shall describe such control and the extent of QA participation in implementation of control methods.

4.15 Control of Nonconforming Items

The reporting of nonconforming, substandard or defective items or services is the responsibility of the individual cognizant of the nonconformance. It is the responsibility of the QA organization to document and control those reported nonconformances to prevent inadvertent use or installation.

4.16 Corrective Action

The determination of cause and the corrective action taken to correct adverse quality conditions is an integral part of the Non-conformance Control Program. A separate QAPC shall be implemented, approved and completed before a non-conforming item can be released by QA for possible use. The control measures of the correcting action shall be commensurate with those applied to the original item.

4.17 Quality Assurance Records

Quality Assurance records provide documentation of quality elements and include, but are not limited to: reports, plans, procedures, instructions, data, computer programs, specifications, field change requests, nonconformance reports, cause and corrective action reports, contract documents, inspection, test and audit results, and construction logs. Controlled copies of all documents required by approved QAPC's including the QAPC, will be maintained by the Quality Assurance office for the duration of the project. A log of all QAPC's, active, completed, and closed will also be maintained by QA.

4.18 Audits

It is the responsibility of the QA organization to organize, conduct and document audits of the Quality Assurance Program. The Audit Program will include verification of compliance to Quality Assurance Plans of Conformance. The audit program shall be implemented by QA with written procedures or checklists.

4.19 Operation Assurance

The responsibility for defining, planning, and documenting requirements for the general operation of an experimental device rests with the Project Manager. As a minimum such project documentation shall include:

(1) Operational Procedure(s) covering responsibility, constraints, safety, required documentation, QA reviews, problem and failure reporting.

(2) Daily logs, records, correspondence, and reports related to operations, operational problems, downtime, and results.

(3) Provision for planned and emergency maintenance and repair, including a requirement for the use of an approved procedure to modify, install, or maintain the device.

(4) Organization Charts and/or lists of personnel (and alternates) responsible for specific systems, subsystems, and administrative/ project matters.

4.19.1 QA Activities

QA shall develop appropriate procedures and instructions to facilitate monitoring all operational activities associated with risk of device damage or loss of data. These will accommodate and cooperate with the objectives of MIT Safety and Environmental Medical Departments.

5.0 Implementation

The individual initiating the design, procurement, fabrication, installation, operation, or maintenance or change in any of these activities not covered by previously approved procedures shall complete and submit a Quality Assurance Plan of Conformance/QAPC. This document is the default plan of conformance. An alternate QAPC is outlined in 5.1.

5.1 QA Documents Checklist: Initiation

The individual initiating any of the actions described in 5.0 may submit, as part or all of a QAPC, a QA documents checklist. This form outlines all actions and documentation which must be completed and reviewed and approved to assure conformance to all elements of the Alcator QA Program. The QA officer assigns a serial number to this checklist and all approved documents which are required will be assigned this serial number as well as an ID number indicating which document title or description on the checklist applies.

The initiator identifies the system or procedure which is affected and briefly describes the proposed action. The initiator then determines what documents and reviews are necessary to assure conformance to all elements of the Alcator QA Program. The initiator, with assistance from QA if necessary, chooses those persons whom he considers qualified to perform both the initial approval and the review and final approval for each of the required documents. The required documents may include (but not be limited to): design analyses, fault analyses, specification, certification, design drawings, construction drawings, special handling procedures, installation procedures, as-installed drawings, test procedures, test results, inspection procedures, inspection results, fabrication procedures, cleaning procedures, calibration procedures, calibration results, initial operation procedures.

In addition to those documents which must be approved, reviewed and finally approved and placed under document control by QA, the initiator identifies a further list of documents required before the action is complete. This list may include: final as-built drawings, previous as-built drawings voided, in-service calibration, maintenance, and operations procedures. These documents must be approved, and placed under document control by QA before the QAPC is complete and closed.

5.2 QA Documents Checklist: Approval

The QA checklist is circulated to the QA Officer, the Project Manager, and the Associate Director. These persons review the proposed QA checklist for completeness and appropriateness of both the documents to be generated and the qualification and suitability of the personnel to be involved in the reviews. Changes in the checklist may be made by any of the reviewers after consultation with the initiator.

Satisfaction with the checklist is indicated by the program reviewers by initialing and dating the appropriate space in Section III of the checklist. When the checklist review is completed, the copy is placed under Document Control by QA.

5.3 Initial Approval of a QA Document

The initial approver of a document required by an approved QA Documents checklist may or may not be the originator of the document. In either case, he reviews the document for: 1) Safety 2) Adequacy to perform intended function. 3) Compatibility with original proposal or specifications. 4) Compatibility with other systems or procedures. 5) Completeness. 6) Possible failure modes and difficulty of repair. 7) Adequacy of testing procedures.

5.4 QA Review

It is the responsibility of the QA reviewer to check independently the document and cover the same general areas as listed in 5.3.

The extent of the independent check should be sufficient to convince the QA reviewer of the completeness, adequacy, and accuracy of the work.

5.5 Document Approval

As each document is reviewed, it is marked with the QA serial number, document ID number, date of QA review, and the initials of the initial approver and the QA reviewer. This assures that every document carries its QA identification. The document is then placed under document control by QA.

5.6 Certification of Satisfactory Completion of the QA Checklist

When the QA checklist is completed, it is submitted to the QA Officer, the Project Manager, and the Associate Director. These individuals ascertain that the checklist has been satisfactorily completed and initial the appropriate space in Section IV of the completed checklist. The checklist is then permanently filed with the supporting documents by QA.

5.7 QAR Computer Network System

A quality assurance reporting system has been implemented for the Alcator project. The reporting system facilitates the tracking of actions required and the assignment to the appropriate personnel. When there are new requirements or the status of existing programs change, all of the appropriate people are notified.

This reporting system is based on a computer utility called "QAR", developed at MIT. Using this utility an engineer or scientist can submit a report indicating that some

action is needed. During this submission process, the submitter specifies a category for the action desired and an indication as to when it needs to be completed. The QAR system then notifies the appropriate personnel of the requested work via electronic mail. In effect, the QAR system constructs a "mailing list" for the report including the submitter and all persons designated as support personnel for the particular category. A mechanism is provided for adding or removing people from this "mailing list".

Once the quality assurance report is submitted, it can be assigned to a single support person who will assume sole responsibility for the work. A mechanism is provided by the QAR utility to append additional information to the report and/or change its status. When any change is made to the report everyone on the report's "mailing list" is notified.

Summaries can be generated using a wide variety of selection and sort criteria. For example, sorted listings can be generated to monitor the progress of the entire project. Likewise, each individual can easily determine the status of work that he/she is directly involved with.

The QAR system provides an easy mechanism for keeping track of the status of the elements of the project. Users do not need to know who to contact about problems or work needed since the QAR system automatically notifies the proper personnel. Reporting facilities permit the construction of informative summaries of the QAR submissions.

The Quality Assurance Documents Checklist requires that all outstanding QAR's relevant to the action involved be addressed and resolved before the QAPC is complete.

APPENDIX A: QUALITY ASSURANCE POLICY

Purposes of This Directive

Provide an unambiguous policy statement concerning the dedication of the Plasma Fusion Center to achieving high quality levels in all activities required to support Program objectives, to delegate responsibility for implementing this policy, and to ensure compliance with applicable Department of Energy Directives.

Policy Statement

It is the policy of the Plasma Fusion Center that all functions, services, hardware, software and operating systems required to support its scientific and technological objectives shall be performed, produced operated or maintained at quality levels appropriate to these objectives. To this end, a formal QA program complying with Department of Energy Directives, and consistent with MIT guidelines, will be established for the Alcator Program.

It is incumbent upon all Laboratory personnel and functional organizations to be familiar with this program and its derived implementing directives and procedures. Enforcement of this policy is the responsibility of all levels of management.

Ronald C. Davidson, Director
Plasma Fusion Center, M.I.T.

APPENDIX B: QUALITY ASSURANCE DOCUMENTS CHECKLIST QA# _____

I. Class: A B C

Item Affected: WBS# _____

Brief Description:

Initiator: Date:

II. Documents and Approval Required:

The following documents must be approved and placed in Q/A file before the item can be put into operation.

See checklist instructions for additional information.

I.D. #	TITLE AND/OR BRIEF DESCRIPTION OF DOCUMENT	Approval & Date	Review & Date