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ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

THE ELECTRON TEST ACCELERATOR SAFETY IN DESIGN AND OPERATION

L'accélérateur d'essai électronique conception et fonctionnement très sûrs

Revised by
Révisé par

J. McKEOWN

Chalk River Nuclear Laboratories
Laboratoires nucléaires de Chalk River

Chalk River, Ontario

June 1980 juin

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SAFETY IN DESIGN AND OPERATION

Based on an Unpublished Report
by
J.S. Fraser
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Conception et fonctionnement très sûrs

Basé sur un rapport non publié de J.S. Fraser - 1972

Révisé par J. McKeown - 1980

Résumé

L'accélérateur d'essai électronique est actuellement conçu à titre d'expérience en physique et en technologie des accélérateurs. La puissance du faisceau électronique de cet accélérateur pourra aller jusqu'à 200 kW. Le fonctionnement d'une telle machine présente un grave danger d'irradiation ainsi que des risques électriques et de radiofréquences. La conception du système de sécurité donne une protection sûre tout en permettant beaucoup de souplesse dans le mode de fonctionnement et tout en minimisant les contrôles administratifs.

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ABSTRACT

The Electron Test Accelerator is being designed as an experiment in accelerator physics and technology. With an electron beam power of up to 200 kW the operation of the accelerator presents a severe radiation hazard as well as rf and electrical hazards. The design of the safety system provides fail-safe protection while permitting flexibility in the mode of operation and minimizing administrative controls.

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1. INTRODUCTION

The Electron Test Accelerator (ETA) is being designed and built as an experiment in accelerator physics and technology. The areas of interest to be explored include the tuning and control of the accelerator under conditions of very high continuous beam current, study of the phase and energy spread of the beam at various levels of beam loading, testing of the limits of beam current and development of new structures and diagnostic devices. The continuous or cw mode of operation will cover new ground in the field of electron linear accelerators and as a result the level of beam power produced will be large in comparison with the power delivered by existing pulsed electron linear accelerators.

The owner of the accelerator is the Director of the Physics Division of CRNL, G.A. Bartholomew. The work is being carried out in the Accelerator Physics Branch under the direction of J.S. Fraser.

The experimental accelerator physics program is under the supervision of J. McKeown. At the present time approval is being requested for operation of the accelerator on an experimental basis up to a maximum electron power of 200 kW.

2. GENERAL DESCRIPTION OF THE FACILITY

2.1 Building

The Electron Test Accelerator occupies the north-east corner of the Accelerator Development Building No. 610. The building is of a light construction with a reinforced floor designed to house a variety of accelerator projects including their shielding. See Figs. 1 and 2. The area to the south of the ETA is occupied by equipment of the High Current Test Facility. To the west and abutting against the ETA shielding wall experiments are proceeding with a pulsed electron linear accelerator with energies up to 35 MeV.

The accelerator proper is enclosed in a shield tunnel on the floor of the building. The walls and roof of the tunnel vary in thickness from 2.3 m to 0.91 m and are assembled with concrete blocks. The basis block is steel-reinforced and has a size 1.82 x 0.91 m x 0.46 m. At the beam dump end of the tunnel and near the tunnel door blocks of size 0.4 m x 0.2 m x 0.2 m are used.

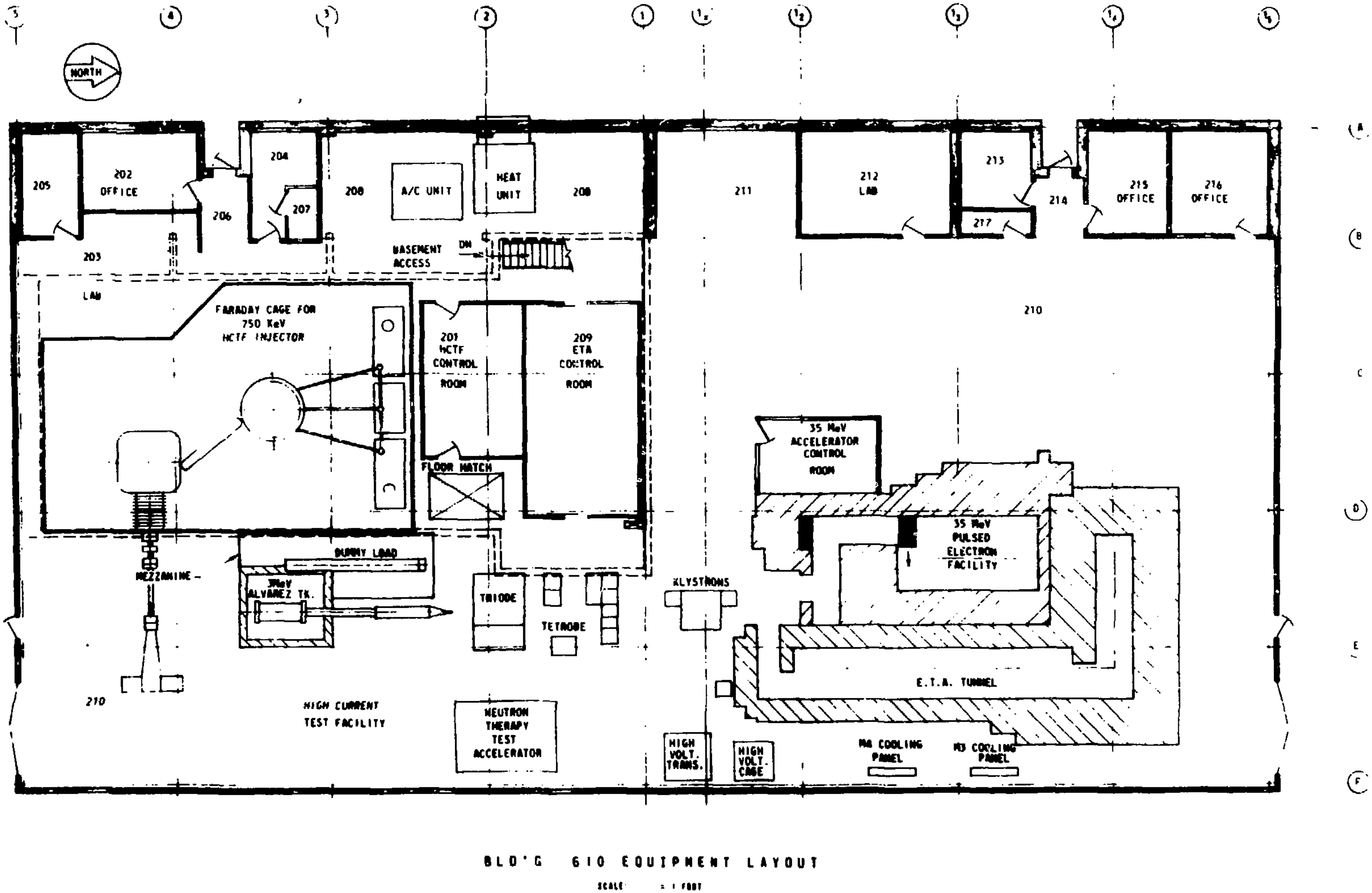

Fig. 1   Building 610 Equipment Layout

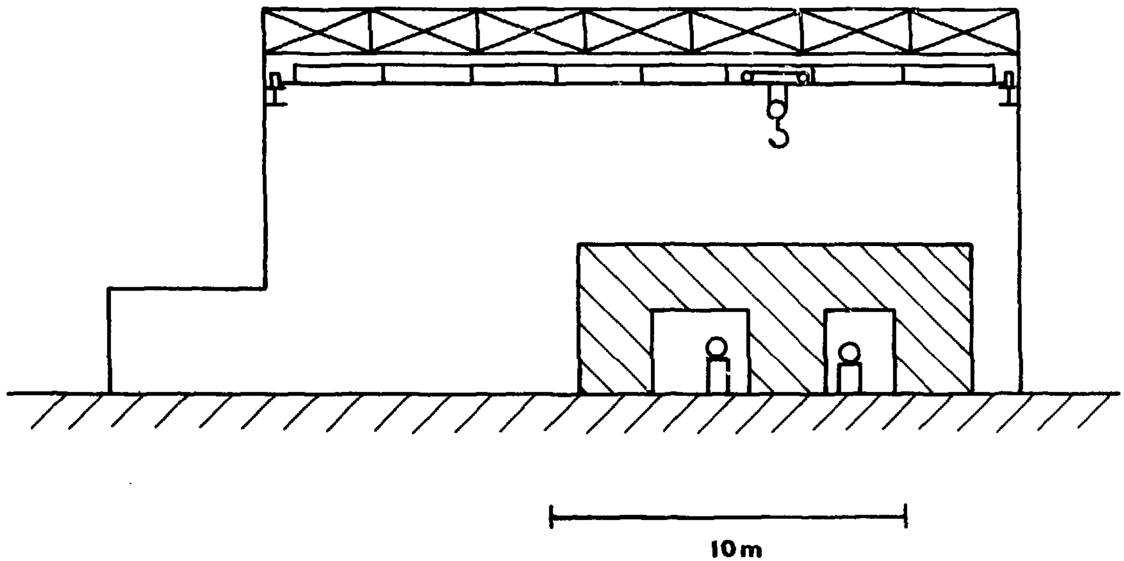

FIG. 2 ELEVATION OF ACCELERATOR DEVELOPMENT BUILDING

Associated power supplies are installed in racks and in shielded cages on the floor. The controls are installed in an air-conditioned control room. Heat exchangers for the radio frequency power tubes and for the accelerator tanks are located in the basement. An auxiliary closed loop cooling system for transport elements has its heat exchanger on the east wall of the building.

2.2 Accelerator

The major components of the accelerator are shown in block-diagram form in Fig. 3.

The accelerator is designed to deliver a beam of 4 MeV electrons at a current that may ultimately exceed 100 mA. The source of electrons is a three-electrode gun with a 3 mm diameter cathode operated at a negative potential of 100 kV. On emerging from the gun, the electrons first pass through a single accelerating cavity having a peak on-axis field of 10 kV/m and then a drift space. The function of this arrangement is to bunch the electrons thereby improving the acceptance of the beam by the accelerating structure. The accelerator structure itself is the so-called side-coupled cavity structure based on the design developed at the Los Alamos Scientific Laboratory and adopted for the ING reference design(1). It operates at a frequency of 805 MHz. The structure operates in the standing wave mode and possesses the distinctive feature of the rf power being fed from one accelerating cavity to the next via a tuned side-coupled cavity. Most of the resistive wall losses occur in the accelerating cavities while very little energy is lost in the coupling cavities. Power is delivered to the structure through a "bridge coupler" (see artist's conception, Fig. 4) located off the beam axis midway along the accelerator tank. Figure 5 shows the two tanks of the accelerator in the testing phase. The structure is pumped through a vacuum manifold mounted in the support structure and connected to the waveguide through the lower side-coupling cavities.

The accelerator consists of two sections each driven by a separate 100 kW klystron rf power supply. The first section, labelled Model 4, accelerates electrons from the injection energy of 100 keV to 1.4 MeV. It is called a graded-β section because the velocity of the electrons ($\beta = v/c$) varies along its axis. The second section, labelled Model 3, is a fixed-β section, β being equal to unity. The electrons are accelerated in this section from 1.4 MeV to a final energy of 4 MeV. This mode of operation is possible with beam currents up to 16 mA with the existing rf power tubes. In a different mode of operation the current could in principle be increased to 50 mA with the present rf sources but the energy of the output electrons would be reduced to about 2.5 MeV. In this mode the electron beam power would be 125 kW.

An on-axis coupled structure has been designed to replace Model 3 early in 1981. Figure 6 shows a photograph of this prototype structure, labeled Model 5, taken during low power tests. The structure is easier to

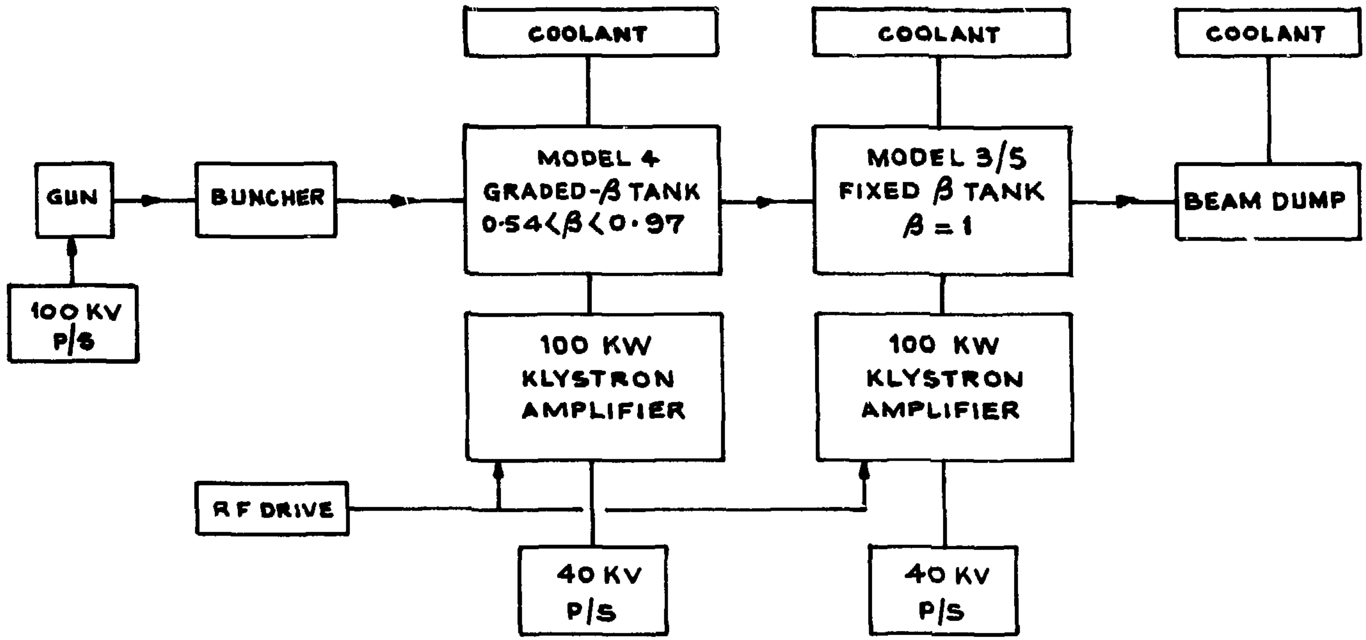

FIG. 3 BLOCK DIAGRAM OF MAJOR ACCELERATOR COMPONENTS.

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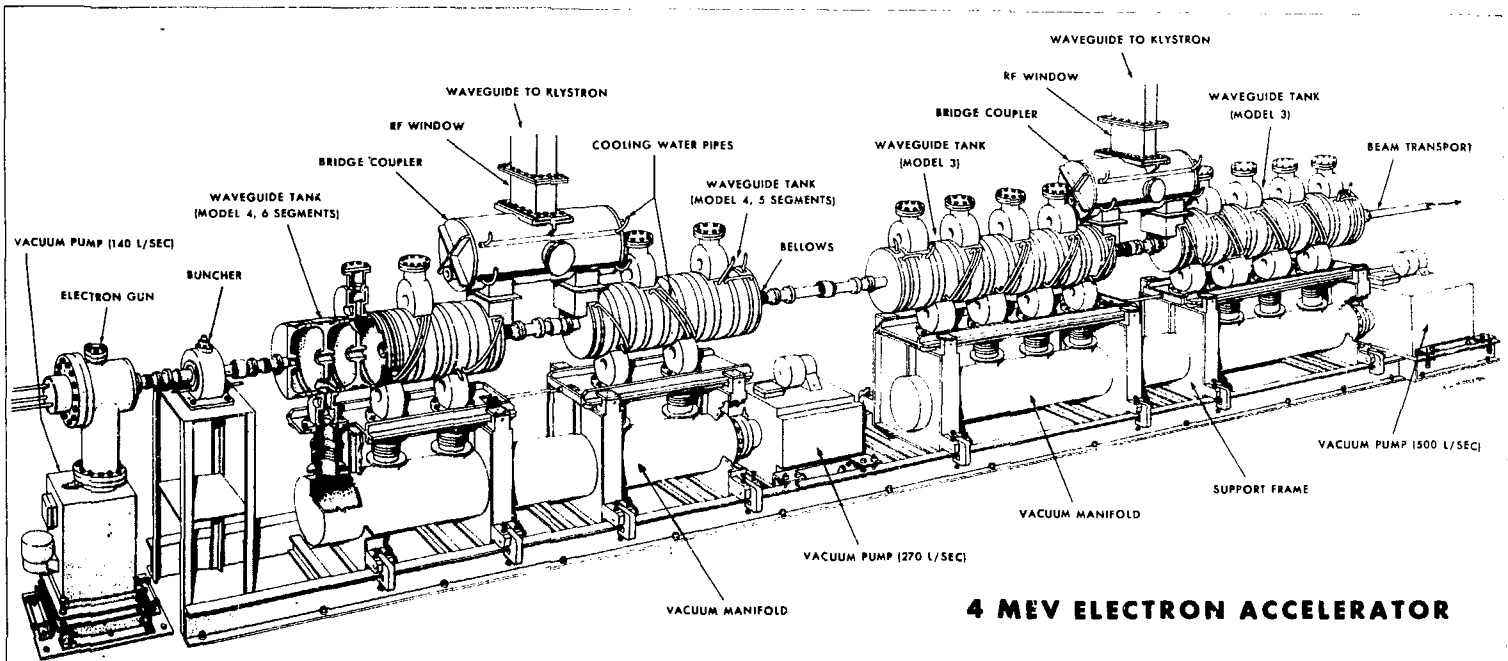


4 MEV ELECTRON ACCELERATOR

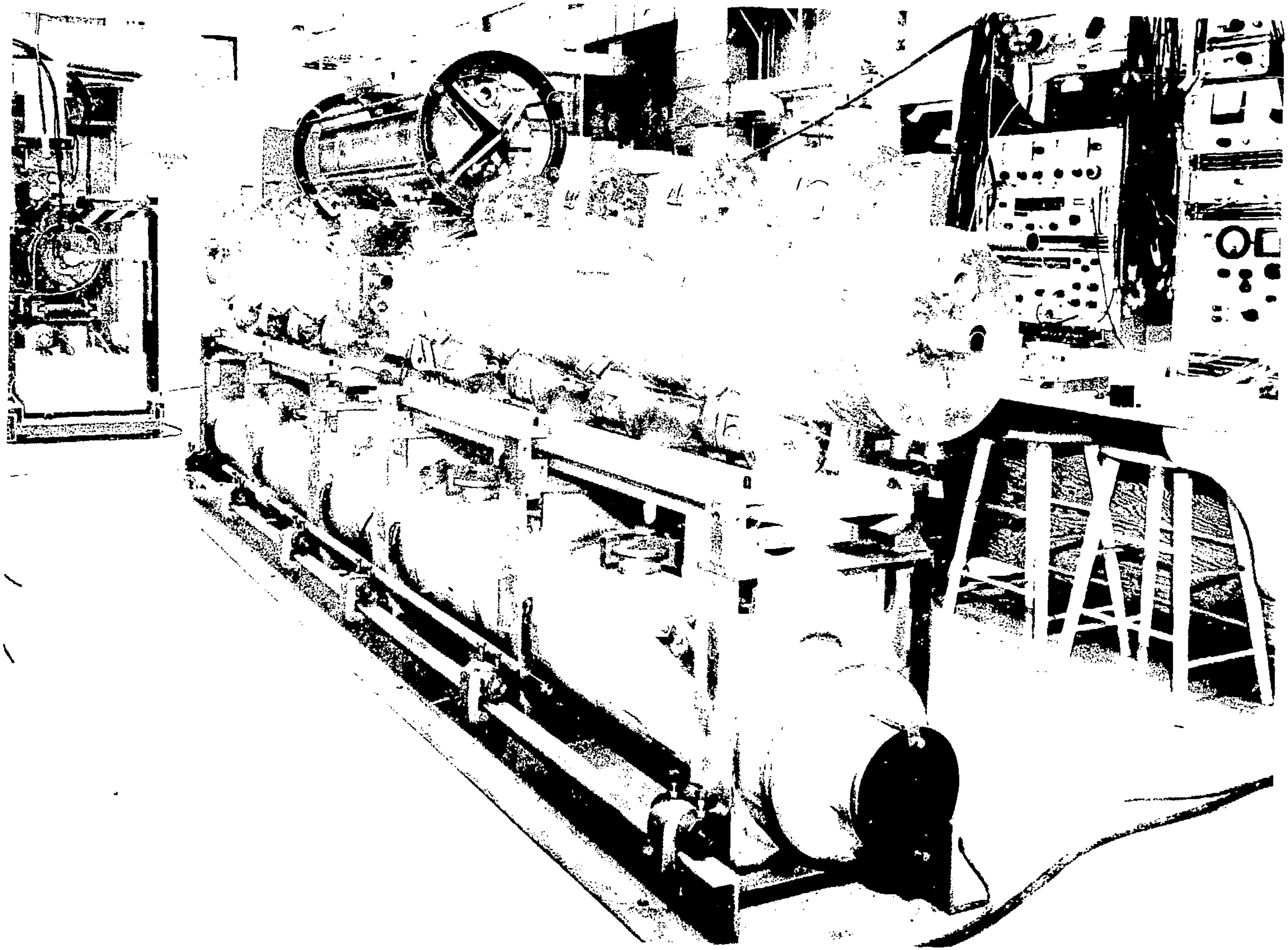


Fig. 5 Photograph of the Two Side-coupled Accelerating Tanks

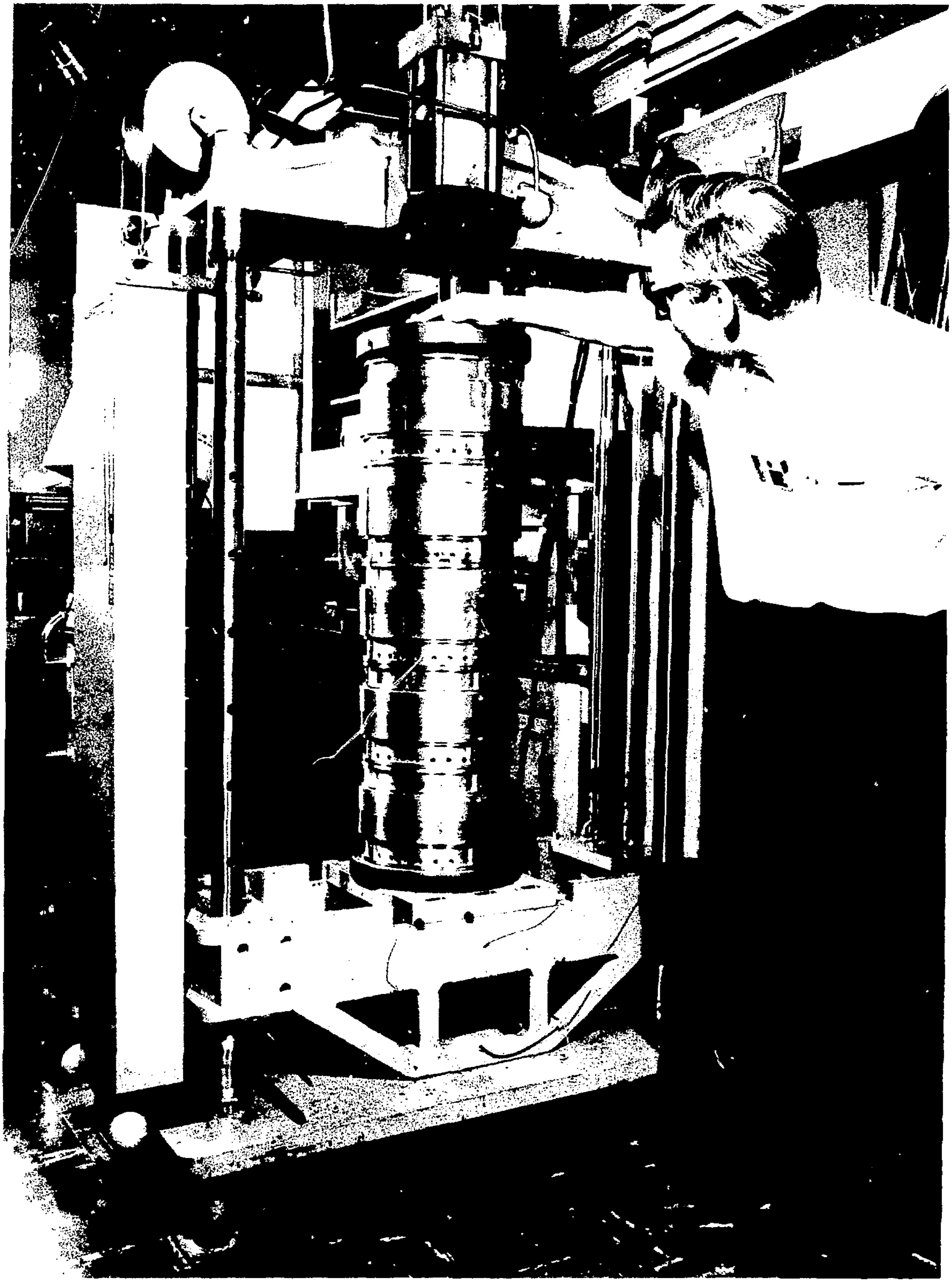


Fig. 6 Photograph of On-axis Coupled Structure during Low Power Tuning

fabricate than the side-coupled structure and beam tests are planned to study its behaviour under beam loading at higher gradient than the Model 3 structure. This is only possible because the structure is designed with only five accelerating cells instead of the 18 accelerating cells of Model 3. With 37 kW to set up the accelerating fields the output energy will be 2.5 MeV and sufficient power is available to accelerate a beam current of 55 mA.

On emerging from the accelerator the electrons are passed through a beam transport system to the beam dump. The beam dump is a two-dimensional beam scanner to cause the beam to uniformly illuminate an area 530 cm^2 at a rate of 1 Hz. The beam pipe between the $\beta = 1$ structure and the beam stop is increased from the normal 3.8 cm ID, to 5 cm ID and is made from OFHC copper pipe. Along the path of the electrons from the gun through the accelerator there are a variety of beam transport elements. These are magnetic thin lenses for focusing and box magnets for steering the beam. A number of water cooled circular apertures insulated from ground are provided at several places along the beam line to detect misalignments and assist in focusing and steering the beam. It is also desirable that these transport elements be capable of transporting the beam at its minimum energy of 100 keV throughout the entire length of the accelerating and beam transport structure. With the accelerator functioning in a normal operation mode, the electrons are highly relativistic throughout most of the beam path so space charge forces, which tend to blow up the beam, are not serious. At an energy of 100 keV, however, the focusing lenses disposed along the beam line must be capable of transporting the beam, without appreciable loss, from the gun to the beam dump.

In addition to the magnetic thin lenses (6), steerers (6 each for horizontal and vertical), and circular apertures, diagnostic devices distributed along the beam line include a 4-quadrant aperture, a non-intercepting beam position monitoring cavity and a low power Faraday cup. The beam stop itself acts as a high-power Faraday cup. The apertures and other diagnostic devices are insulated from ground so that beam current intercepted by them can be measured in the control room.

2.3 Auxiliary and Supporting Facilities

The basement beneath the control room houses heat exchangers for the two klystron rf power amplifiers (each rated at 100 kW output) and for the two accelerating tanks. The latter can be operated at unequal temperatures - a necessary requirement for operating the two tanks at the same resonant frequency.

The HV power supplies for the two klystrons are located about 100 metres distant in an adjacent building, Bldg. 467. The leads are brought under a road in a duct into the basement room and thence up through a grounding box in the control room to the klystron amplifiers. These are mounted on a cabinet containing high voltage protective or "crowbar" equipment. A crowbar switch is employed to short-circuit a high voltage supply in a few microseconds (to the klystrons in this case) in the event of a fault condition arising which might damage the equipment if the HV were left connected for the relatively long time required to open a circuit breaker. In fact it is a spark-gap switch capable of discharging any capacitors that are normally required in the system.

The normal center of activity will be the control room. The control desk contains panels of indicating lights, push buttons, tank resonance control circuits, beam transport controls, diagnostic device indicators, 2 oscilloscopes and some test instrumentation. Three equipment racks house the rf master oscillator, instrument and beam transport power supplies, fault annunciators and the gun power-supply control panel. The gun power-supply proper is located on the main floor beside the east wall.

A digital computer installed in the control room supervises much of the accelerator control functions. The resonance and tank temperature controls are dependent on control tasks executed by the computer and although many control functions are still operated manually the computer plays an increasingly dominant role during beam operation. System shutdown is activated by hardware which is quite independent of the computer.

The radiation surveillance system includes two ion chambers within the shielded area and a G-M tube area monitor outside the shielding. Self-powered gamma detectors (SPGD) will be employed in the beam dump area and as auxiliary fault detectors on the beam line between accelerator tanks and near the bending magnet.

The accelerator tunnel is ventilated to remove dangerous levels of ozone produced by radiation and to provide some convection cooling. The control room is temperature and humidity controlled.

2.4 Status and Future Plans[2]

Early in 1979 a current of 17 mA at 4 MeV was accelerated by both structures. During beam tests of the control systems currents up to 22 mA at 1.4 MeV were accelerated by the first structure. Most failures have been caused by vacuum failure when the beam has burnt a hole through a beam line component or the beam dump. These failures are either due to operator error or technical design and are not a fundamental problem in the performance of the system. Developing the expertise to handle such problems is an important aspect of the accelerator experiment.

Further beam-loading experiments are planned with the present $\beta = 1$ structure and then it is proposed to substitute this side-coupled structure with the Model 5 structure. The maximum energy will not exceed 3 MeV.

Experience has shown that operation is greatly simplified if an in-line beam dump is used. Lead bricks are built around the beam dump to stop 95% of the γ radiation. However the initial proposal to carry the beam around a 90° bend has not been abandoned and experiments to design and test such a system are planned.

3. RADIATION HAZARDS AND SAFETY CONSIDERATIONS

3.1 Sources of Radiation

3.1.1 Soft x-rays from Gun

The gun is a source of soft x-rays. These arise from interception of a small part of the beam on the electrodes of the gun itself.

3.1.2 Aperture Scattering from Beam

Along the accelerator structure and the beam transport connecting the accelerator sections there will be radiation from beam scattered by the beam scrapers and apertures. The x-rays or bremsstrahlung produced will have a range of energies depending on the location of the scattered beam.

3.1.3 X-rays from Field Emission in Cavities

A potential source of radiation exists without an electron source. This is x-radiation produced by electrons originating in field emission from the cavity surfaces and background gas ionization and accelerated in the structure itself. Most of this radiation is absorbed in the thick copper walls of the structure, but on the beam line below the bridge coupler of the graded-β tank there is a local hot spot of 100 mR/h at design power. The whole-body dose rate for an occupant of the tunnel under these conditions would not exceed 1 mR/h.

3.1.4 Beam Dump

By far the most important source of radiation is, of course, the beam dump. Estimates of the radiation field have been made on the basis of the beam being stopped in small volume, that is, a point source of radiation(3). For a beam of 50 mA of electrons at 3 MeV being stopped in a copper target the estimated intensity at 1 metre from the target is 1.3×10^6 rad/h (1.3×10^8 Gy/h).

3.1.5 (γ,n) from D and Be

A source of neutrons exists when either deuterium or beryllium is located near the accelerator. The energy of the bremsstrahlung from the accelerator exceeds the photo-neutron threshold for these elements. In October 1978 the AECL Accelerator Safety Committee granted approval to irradiate a heavy water target in an experiment designed to study parity violation in the strong interaction. The target contains a cooling coil to take away the heat from the radiation. At 10 mA, the beam current for which approval has been given, the neutron yield will be 10^{11} neutrons/s with an expected thermal flux on the surface of the container of 10^7 $n \cdot cm^2 \cdot s^{-1}$.

3.1.6 Microwave E.M. Radiation

The two 100 kW klystrons are dangerous sources of rf radiation. Normally the waveguides used to transmit the rf power to the accelerating structure allow a negligible amount of leakage. The normal practice when making alterations to the rf plumbing is to cover open waveguide sections with metal plates thus preventing accidental leakage.

3.2 Induced Radioactivity and Radioactive Contamination

No radioactivity or radioactive contamination is anticipated during normal high power operation because the end-point of the bremsstrahlung spectrum is below the photo-neutron thresholds of all elements except deuterium and beryllium as noted above. However with the heavy water target mentioned in para. 3.1.5 some of the neutrons which escape from the surface of the container cannot be totally absorbed by the cadmium blanket. It is extremely difficult to estimate the radiation field level from such induced activity but we have been assured by the Radiation and Industrial Safety Branch that the induced activity will be less than the environmental leakage from reactor installations and other accelerators at CRNL.

3.3 Shielding

3.3.1 Bulk Shield Design

The criterion used in calculating the shielding required for the main beam dump is that the field outside the shield shall be less than 2.5 mrem/h. The most intense bremsstrahlung beam will be in the direction of the electron beam. For the purpose of the calculation the electron beam of 50 mA, at an energy of 3 MeV, was assumed to stop at a point one metre from the shield wall. Details of the shielding calculation are given in Appendix D.

The method of Ref. (4) employs a theoretical bremsstrahlung yield curve for the forward direction, the integral of which has been checked experimentally. Build-up factors and the total attenuation in concrete have been taken into account in the calculation of the equivalent field at one metre from a point source. The inverse square law has been assumed for the field at a distance from the point source. The result is that 198 cm of ordinary concrete are required in the forward direction.

The plan view of the Accelerator Development Building (Fig. 1) shows a 214 cm thick wall around the beam dump and along part of the accelerator tunnel. The roof is also 214 cm thick in this area. The wall shared with the 35 MeV accelerator is 183 cm thick. Lead shielding is used around the beam dump. Ample space is available for adding additional concrete shielding blocks in the forward direction.

The fraction of the beam power of 3 MeV electrons that is converted to radiation is 5.5%[4]. At the maximum beam current of 50 mA, 8.6 kW of radiation must be absorbed by the shielding. The copper and steel of the beam dump itself will absorb 85% of this power, leaving 0.13 kW to be absorbed by the shielding. Lead used around the beam stop will be cooled by convection.

3.3.2 Maximum Credible Accident

The maximum unplanned radiation hazard would occur with the full power beam striking some part of the structure between the Model 3 tank and the beam dump. The shield will be 1.8 m thick over all this distance and therefore will provide adequate shielding even in the event of the failure of all trip devices.

In the absence of cooling a 150 kW beam is capable of melting copper at the rate of 300 g/s. Experience with power levels at 10% of this level shows that it is a virtual certainty that the machine vacuum would be lost before any person outside the shield received a dangerous dose as a result of such an accident. In that sense, the system is fail safe.

If the beam goes astray between the tanks, the radiation field would be reduced by a factor of 4 below that of the full energy beam. In the event of such a failure, the field outside the shield (91 cm thick at this point) is estimated at 2 rem/h.

3.3.3 Beam Dump Area

The primary function of the 90° bending magnet to be added at a later time is to facilitate the placement of more shielding between the beam dump and the accelerator than would be convenient with an in-line layout. Reduction of the radiation field in the accelerator area is required for the protection of organic insulating materials and glasses used in the instrumentation. For this purpose lead shielding around the beam dump is used. The vacuum chamber of the 90° bending magnet will be insulated from ground so that in case of magnet failure the beam current striking the chamber is used to trip the accelerator.

3.3.4 Gun Shielding

The soft x-rays t' t result from stopping of the electrons from the gun and from field emission electrons in the structure are largely shielded by, in the first instance, the steel of the gun and, in the second, the copper of the structure. The extension of the concrete wall behind the gun (Fig. 4) provides adequate shielding in the area of the door. In 1976 the original wooden door was replaced by a 1.3 cm thick steel door and additional concrete shielding was added around the maze in the summer of 1978. An internal secondary door lined with lead sheet was also installed at this time. This has eliminated back-scattered radiation which existed during initial accelerator operation.

3.4 Monitoring

Within the accelerator tunnel there will be two ionization chamber area monitors (Victoreen Model 845), one at the high-energy end of each accelerator tank. See Fig. 7. These area monitors are equipped with two trip level relays which may be set anywhere on an 8-decade scale from 0.1 mR/h to 10^4 R/h. The high-energy end of each accelerator tank is the most likely source of radiation due to scattered beam. In the initial stages of operation with low beam currents, extensive surveys will be carried out with standard LiF thermo-luminescent dosimeters (TLD). Correlation of the TLD data with the ion chamber readings will provide a guide to the radiation field under various operating conditions.

In the beam dump area the radiation field is much higher than the area monitor's upper limit of 10^4 R/h; investigation of the suitability of self-powered gamma ray detectors (SPGD) for measurements in this area have been made. A coaxial detector with mineral insulation and platinum central conductor appears to be promising for this application. They can also be used as beam spill monitors in the accelerator tunnel.

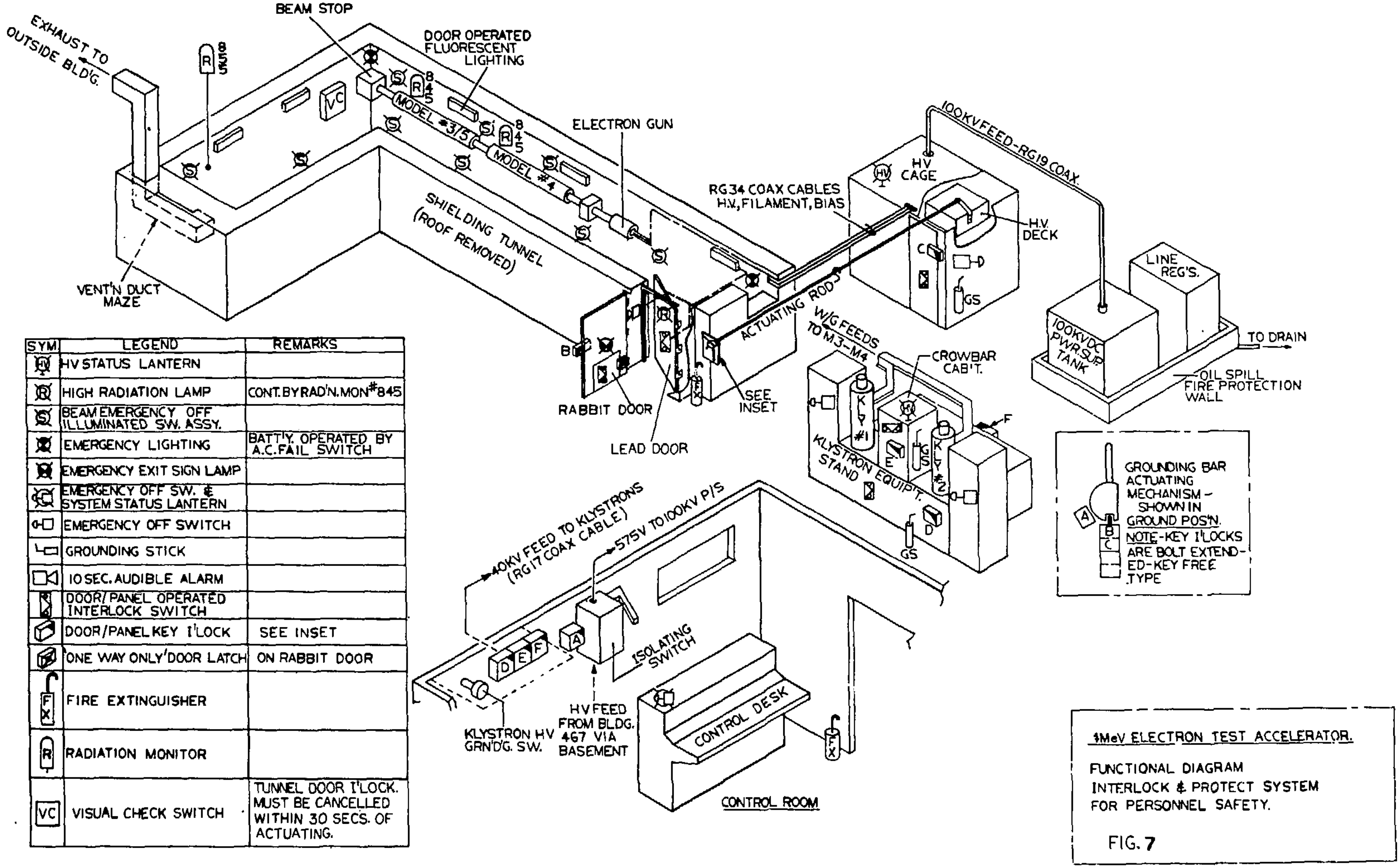
Immediately outside of the north wall of the shielded enclosure a G-M tube area monitor (Victoreen Model 855) will be mounted. For general survey use, portable β, γ, neutron and rf survey instruments are available and maintained by the Radiation and Industrial Safety Branch (R. & I.S.). One of the portable β, γ survey meters (Victoreen 440RF) provided by the R. & I.S. Branch is protected against rf interference.

3.5 Interlocks and Warning Devices

The alarm levels on the ion chambers in the accelerator tunnel are set at 5 mR/h. These turn on warning lights above the door indicating a dangerous radiation level inside and if the door is open the rf drive is shutdown automatically. Such a situation could arise during vacuum conditioning of the rf structures. In normal operation radiation levels are small when only the rf fields are excited in the structures but it has been found that poor vacuum conditions permit these levels to rise. When the electron gun is in operation the tunnel door must be closed.

The G-M tube area monitor outside the shielding will have a trip level set at 1 mR/h. All three instruments are read out on a single control panel in the control desk. The area monitor is also connected so as to unconditionally trip or shutdown the accelerator if the radiation field outside the shielding exceeds 1 mR/h.

The ion chambers and SPGD's in the accelerator tunnel are used to indicate an abnormal operation such as beam striking some part of the accelerating structure. Also current spilled on quadrant apertures are used to detect deviation of the beam from the beam line axis. Special electronic circuits are provided to give a rapid indication (which is in the order of μs) of abnormal conditions to initiate a shutdown sequence.



SYM	LEGEND	REMARKS
HV	HV STATUS LANTERN	
R	HIGH RADIATION LAMP	CONT. BY RAD'N. MON #845
S	BEAM EMERGENCY OFF ILLUMINATED SW. ASSY.	
	EMERGENCY LIGHTING	BATT'Y. OPERATED BY A.C. FAIL SWITCH
	EMERGENCY EXIT SIGN LAMP	
	EMERGENCY OFF SW. & SYSTEM STATUS LANTERN	
	EMERGENCY OFF SWITCH	
	GROUNDING STICK	
	10 SEC. AUDIBLE ALARM	
	DOOR/PANEL OPERATED INTERLOCK SWITCH	
	DOOR/PANEL KEY I'LOCK	SEE INSET
	'ONE WAY ONLY' DOOR LATCH	ON RABBIT DOOR
FX	FIRE EXTINGUISHER	
R	RADIATION MONITOR	
VC	VISUAL CHECK SWITCH	TUNNEL DOOR I'LOCK. MUST BE CANCELLED WITHIN 30 SECS. OF ACTUATING.

Fig. 7 Functional Diagram of Interlock and Personnel Protection System

4. NON-RADIATION HAZARDS AND SAFETY CONSIDERATIONS

4.1 Electrical

There are electrical hazards associated with two elements of the accelerator system. The first includes a 100 kV, 200 mA power supply for the electron gun cathode and a 15 kV, 20 mA power supply for the gun focus electrode. The second comprises the group of power supplies associated with the klystrons, viz. the Module A (see Appendix A) 40 kV, 20 A supply for one klystron, Modules B and C in series giving 40 kV, 20 A for the other klystron and a 15 kV, 5 mA supply for the crowbar protection system.

The 100 kV supply for the gun is totally enclosed in an oil-filled transformer housing. The gun filament controls and focus electrode supply are mounted in a high voltage deck situated inside a shielded cage. The leads from the supply are exposed where they are attached to the gun. Access is denied to all high voltage enclosures when the voltage is ON.

4.2 Toxic

The estimated rate of accumulation of ozone, with the accelerator delivering a beam power of 150 kW and with no allowance made for ventilation or recombination, is 100 ppm/h[5] in the beam dump area. When handling liquid nitrogen traps in the roughing system in the tunnel it is possible to have a dangerous amount of nitrogen gas concentrated in the tunnel. Both of these hazards can easily be handled by ventilation of the tunnel. The capacity of the tunnel ventilation system is 20 air changes per hour. This should be adequate to handle 5 kW of heat generated in the waveguide runs to the accelerator, heat radiated from the accelerator structure itself and for the removal of toxic gases. The equilibrium ozone level during operation would then be 5 ppm or 50 times the tolerable level. Tests have been carried out with ozone detector monitors at the ventilation exhaust duct following high power runs and these were inconclusive although operator personnel have been able to smell traces of ozone in the tunnel. Hence, following an accelerator run, entry to the tunnel is prohibited until the ozone monitor registers less than 0.1 ppm of ozone with a minimum allowance of one minute for the monitor to register.

The high voltage equipment has been designed to minimize production of ozone in corona discharges. None has been detected to date.

4.3 Mechanical

It is conceivable that a sustained earth tremor could dislodge the shielding blocks to the extent that the tunnel would collapse. The shielding blocks have been constructed with steel reinforcing and a "3 inch" angle iron frame. When completely assembled and tested the rigidity of the structure can be greatly increased by welding together the steel edging of adjacent blocks of the walls. The roof blocks must be left loose for access from above.

The largest of the shielding blocks weigh 2.5 tonnes each, and the lifting capacity of the travelling crane is 3 tonnes.

4.4 Fire and Explosion

The principal fire hazard is the transformer oil in the high voltage supply for the gun. This supply is equipped with a dike surrounding the transformer tank for the control of oil seepage. The dike is 21 cm high and is provided with a drain to the outside of the building. CO_2 fire extinguishers are provided in the control room, at the klystron rack, beside the gun HV cage and at the entrance to the accelerator tunnel. Two memoranda from the CRNL fire chief concerning fire protection are attached as Appendix B.

In the accelerator tunnel the amount of inflammable material has been kept to a bare minimum. No wood is used as a structural material. A smoke detector in the ventilation exhaust duct will disconnect the exhaust fan in addition to sounding an alarm in the fire hall in case of fire.

A potential hazard is caused by radiolysis of the water in the D_2O target. Calculations by Dr. A.W. Boyd, CRNL, showed that 1 litre of D_2 gas could be released in one hour with 10 mA of beam current. Direct release into the accelerator tunnel could be accommodated with the rapid throughput of air necessary for release of other toxic gases. However a tube inserted in the target wall will conduct gas out of the tunnel to atmosphere through a bed of catalyst pellets which act as a hydrogen trap.

4.5 Interlocks and Warning Devices

4.5.1 Operating Modes

It is possible to operate the equipment in three modes:

1. beam and rf on (normal code);
2. with rf alone in the accelerator structure;
3. with beam from the gun only (rf off).

The interlock logic has been designed with these three modes of operation in mind. Figure 8 shows the interlock logic in a simplified form. The interlocks are of two types; electrical and mechanical. The electrical contacts are either switch contacts or relay contacts in the control desk or on remotely located equipment. The mechanical interlocks are not susceptible to jumpering. They include the key interlocks on the klystron HV leads (see Section 4.5.2) and on the gun HV cage (see Section 4.5.3) and all of the emergency "OFF" buttons (see Fig. 7 and Section 4.5.3). Figure 9 summarizes the key interlocks on the klystron and gun HV circuits. The solid letters illustrate the position of the keys for operation. Removal of any key and insertion in the corresponding position shown as a dotted letter is required before access can be gained to the designated

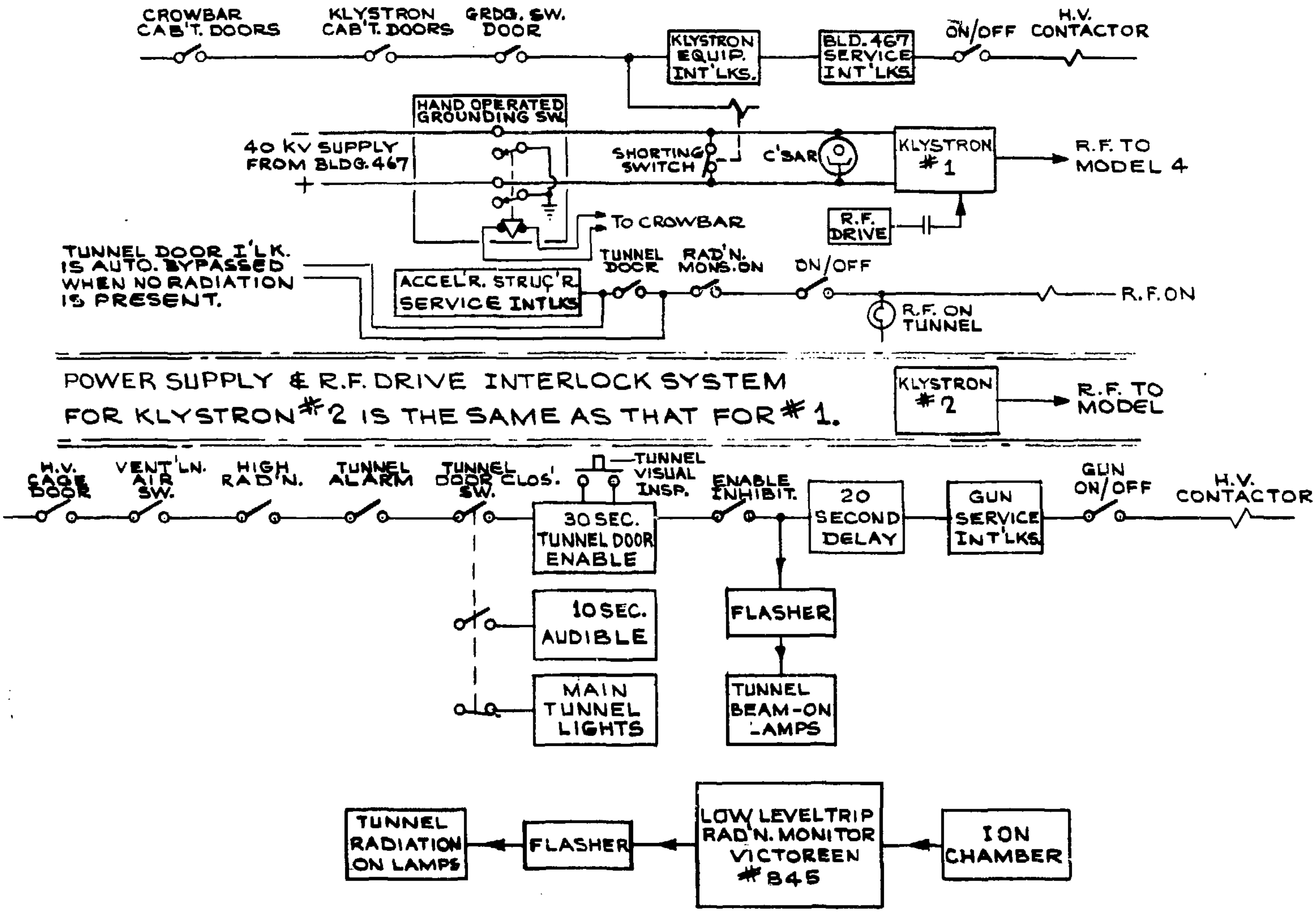


Fig. 8 Simplified Interlock Logic

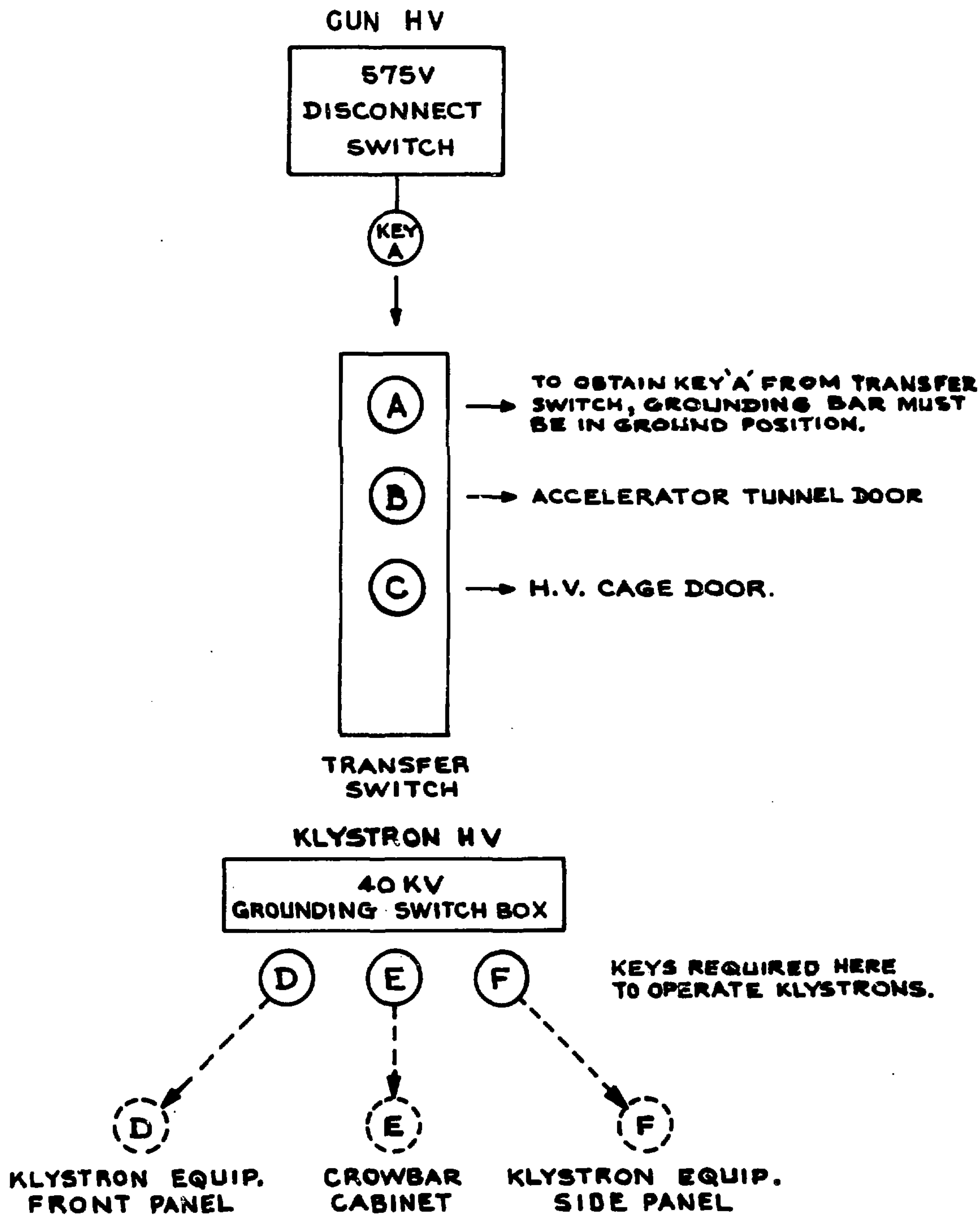


Fig. 9 Key Interlock Systems for Accelerator Tunnel, and for Gun and Klystron HV

area. A key can only be removed from its normal position by disabling the associated HV supply.

The interlock chains for the two klystrons and the electron gun are logically separate. This structure is desirable so that the gun can be operated without the complication of the rf supply (Mode 3) or alternatively the rf power can be delivered either to the Model 4 tank or to the Model 3 tank or to both (Mode 2). Radiation protection in this mode is described in paragraph 3.5. In the normal mode of operation, Mode 1, all systems are operative.

4.5.2 Rf Power

Referring to Fig. 7, it can be seen that before the HV contactor in either klystron power supply can be closed a series of interlocks must be closed. These ensure that the doors of the crowbar and klystron cabinets and the grounding switch are closed and that all systems associated with the klystrons are normal, e.g. internal vacuum coolant flows, temperatures, electromagnets, body and heater currents, and that interlocks on the HV supply and distribution in Bldg. 467 are normal. Before the rf drive can be delivered to the klystron, interlocks ensure that the accelerator vacuum be good, that the tank coolant flows and temperatures be within normal limits and that radiation monitors be turned on and registering low levels. The klystrons are protected against self oscillation by output power level trips set at 150 kW, 50% higher than the nominal maximum output power.

The klystrons are protected against a sustained abnormally high reflected power from the waveguide by a crowbar system. An rf arc, for example, in the structure, waveguide, or isolator, produces a severe mismatch resulting in a large reflected power which could damage the klystrons if present for the order of milliseconds. The crowbar eliminates this condition in μs by shorting the HV across the klystron.

The dc power supplies for the klystron amplifiers are located in Bldg. 467. These are modular power supplies, five in number, which are available to several users in Bldg. 467 and Bldg. 610. Patch panels are available for connecting any one of five power supply modules to a variety of user terminals. The physical and administrative controls governing these modular supplies are described in Appendix A. The two high voltage leads pass through a locked grounding box in the ETA control room in Bldg. 610 en route to the klystrons. Figures 7 and 9 illustrate this and other protective measures. An operator may gain access to the klystron enclosure only by first grounding the HV leads to the klystron at the 40 kV grounding box. This permits removal of one or more of three keys (D, E and F in Figs. 7 and 9) opening locked panels on the klystron enclosure. The action of grounding the HV leads also interrupts the HV contactor line and opens the main power feed to the crowbar supply. Two portable grounding rods are available within the klystron enclosure.

4.5.3 Electron Gun

Before an electron beam from the gun can be introduced into the accelerator structure, with or without rf fields present, a series of interlocks must be closed. These include coolant flow and temperature interlocks on beam transport devices, the tunnel door, the tunnel ventilation fan, the gun HV cage door, radiation levels inside and outside the tunnel, the tunnel emergency "OFF" switches and the "BEAM ENABLE" switch on the control desk. Before the tunnel door can be closed, the operator must proceed to the far end of the tunnel, press a push button switch and then return to lock the tunnel door within 30 seconds. Only within that time interval can the beam inhibit interlock on the control desk be cancelled. When the tunnel door is closed an audible "beep" alarm operates for 10 s to warn any personnel within the tunnel that the accelerator is soon to be started up. The closing of the door also extinguishes most of the fluorescent lighting. Background lighting is provided by twelve illuminated "OFF" panels which when pressed, will interrupt the "BEAM ENABLE" line. These emergency OFF buttons, in common with those on the HV power supplies, are mechanically latched so that they must be reset by an operator locally. This ensures that an operator cannot override the emergency shutoff condition by any action taken at the control desk.

Access to the screened cage housing the gun controls and focus electrode supply is controlled by key interlocks. First the 575 V ac mains disconnect box on the control room wall must be turned off to allow a key (B) to be removed from it. This key is then used to operate a grounding bar in the cage. When the grounding bar is in the grounded position a second key (C) may be removed from its mechanism to open the door to the cage proper. Within the cage a portable grounding rod is available for use by the operator to discharge static electricity on the bare insulated cables at the top of the cage. Removal of the rear panel on the gun high voltage deck opens the mains supply to the focus electrode supply.

In emergencies the accelerator may be shut down by pressing well marked buttons in several locations. Emergency "OFF" buttons are located on the control desk, the vault entrance, the gun cage and two are located on the klystron stand. These turn off the klystron and gun HT supplies.

Access to the tunnel is also controlled by the gun cage key interlock. First the gun supply disconnect switch must be turned off to allow a key (A in Figs. 7 and 9) to be removed from it. This key is then used to open the door to the tunnel. The door is provided with an escape panel which may be opened from the inside only. Opening this panel also interrupts the "BEAM ENABLE" line.

A third key labelled "MASTER" is available on the ac mains disconnect switch key system. This may be used as a personal protection key. Possession of the key prevents activation of the gun HV supplies. This is the only key that is not captured in a lock while access is gained to an enclosure. The MASTER, or any of the keys A to F, may be carried by an operator, if he wishes, to prevent operation in his absence.

Finally, the "BEAM ENABLE" condition is established if the vault and the beam transport interlocks are normal. Warning lights in the vault are turned on by "BEAM ENABLE". Before the dc power can be applied to the gun a mandatory 20 s time delay must elapse after "BEAM ENABLE" is on.

4.5.4 Visible Jumper Panel

At times electrical interlocks normally in the logic chain will have to be by-passed if a restricted mode of operation is to proceed. An example would be operation of the Model 4 tank without Model 3. Normally all of the coolant flow and temperature interlocks for Model 3 are required to be closed before any operation of the accelerator can proceed. A clearly visible, but locked, panel is provided on the control desk to which are brought selected interlock leads for jumpering. The selected interlocks do not include personnel safety interlocks but only those associated with parts of the accelerator system that may be locked out to permit operation of other parts of the system. The key is held by the area supervisor.

5. FACILITY ORGANIZATION

5.1 Operating

5.1.1 Staff

The Electron Test Accelerator will be operated by an experimental accelerator group in the Accelerator Physics Branch of the Physics Division. The group comprises two physicists and three technologists.

5.1.2 Responsibilities

The owner(6) of the Electron Test Accelerator is G.A. Bartholomew, Director of the Physics Division, CRNL. The ETA will be operated in experiments designed to study the characteristics of the accelerator and its control systems. The operation of the accelerator and the experiments on it are the responsibilities of a group of two physicists and three technologists in the Accelerator Physics Branch headed by J.S. Fraser.

As a consequence of the fact that the safety precautions against the non-radiological hazard of the ETA are governed by the High Voltage Safety Code(7) for the CRNL Physics Division, the staff organization for the whole operation of the accelerator has conformed to that code. This is appropriate because safety considerations for radiation hazards are different in kind, not in principle or philosophy, from those for non-radiological hazards. For convenient reference, extracts from CRNL-200 are attached as Appendix C.

In accordance with the provisions of the High Voltage Safety Code[7] the responsibilities for the operation of the Electron Test Accelerator are assigned by the owner and at present are as follows:

Area Supervisor	:	J. McKeown
Officer-in-Charge	:	K.C.D. Chan
Operators	:	J. McKeown
		K.C.D. Chan
		S.H. Kidner
		R.T.F. Bird

The safety of personnel in the area of the Electron Test Accelerator is the responsibility of the Area Supervisor.

From time to time scientists from other branches within AECL and laboratories from outside AECL may collaborate with ETA personnel on accelerator physics experiments. Such personnel may assist in machine operation at the area supervisor's discretion but they will not be permitted to have full responsibility for operation of the machine without proper training and without informing the Accelerator Safety Committee of their appointment by the owner as an operator.

5.1.3 Training

The experiment is a research and development project in accelerator physics and will be operated only by those who have participated in the design and construction of the accelerator, the controls and associated equipment. Effective training is implicit in this process. Supplementary training in first aid and artificial respiration has been acquired by all of the staff.

5.2 Support and Experimental Groups Involved in the Operation

The Radiation and Industrial Safety Branch of CRNL, in addition to providing the usual film badge monitoring services, maintain portable β and γ monitors and rf radiation monitors. Film badge and thermo-luminescent dosimeter exposures are also made and analyzed by the R. & I.S. Branch as part of their surveys of the radiation fields produced by the accelerator.

A Divisional Safety Committee makes a quarterly tour of the premises occupied by the Physics Division. They ensure that provision of the High Voltage Safety Code[7] and the Radiation and Industrial Safety Manual[8] are adhered to.

5.3 Operating Policy

5.3.1 General

With respect to the safety of personnel, the operating policy for a high power accelerator is essentially the same as for the high voltage equipment which forms an important part of the system. The hazards encountered and protective devices employed for β and γ radiations are different from those for high voltage equipment in kind but there is no basic difference in the philosophy of the safety system. The protective devices and operating policies for the accelerator as a whole are in accordance with the high voltage code.

The operating modes, in the terminology of CRNL-200[7] will be either A, B or F. The equipment will be completely enclosed and fitted with interlocks (Mode A) but provision is made for a visible and accessible jumper panel where jumpers may be used. It is intended that unattended operation (Mode F) be permitted for special purposes such as voltage conditioning of the gun or the rf conditioning of the accelerator tanks.

Generally, the operation will be on a one-shift-per-day basis. A single operator may continue an experiment into the evening but no maintenance of the high voltage equipment will be permitted unless a second operator is present.

5.3.2 Standing Orders

Detailed start-up and operating procedures will be determined by the particular experiment that is being carried out. The following is a list of standing orders governing operating procedures and administrative safety controls:

(1) The officer-in-charge will be responsible for designating an operator for the day. The operator is responsible for

 (a) displaying his name on the control desk;

 (b) ensuring that the machine is operated in accordance with the administrative directives specified in the machine safety regulations;

 (c) informing the operator responsible for signing daily work permits for Bldg. 610 of areas that will be restricted for the day.

(2) Presence in the building after 5:30 PM must be recorded on the attendance board provided at the entrance to Bldg. 610.

(3) A visual inspection of the patch panel in Bldg. 467 must be carried out by the operator for Mode 1 and 2 operation.

(4) For Mode 1 and 2 operation each waveguide run must be visually inspected before high voltage is applied to the klystrons.

(5) Before operation in Mode 1 and 3 a visual inspection of the full length of the tunnel is required.

(6) Maintenance of equipment carrying voltages greater than 110 V is not permitted after scheduled working hours unless two experimenters directly concerned with the experiment are in the building. All provisions of the High Voltage Safety Code, CRNL-200[7], are to be observed.

(7) Not more than 200 mL of inflammable solvent is permitted within the shielded enclosure. It must be contained in a plastic bottle fitted with a screw top.

(8) If a change in the shielding block assembly is made in such a way as to decrease the effectiveness of the shield, a special radiation survey outside the shield must be carried out by the R. & I.S. Branch with the accelerator operating at low power before operation at high power is permitted.

(9) A log book is provided for a summary of operation. Details are recorded in files covering accelerator experiments. Any mechanical or wiring changes must be noted in the book and recorded on the drawings kept in the control room.

(10) Machine operation will have priority for use of the computer over off-line work like data analysis or program debugging.

(11) Maintenance and safety checks, as detailed below, will be carried out.

(12) Personnel are not permitted in the control room unless they require the control room facilities to carry out their duties.

(13) No liquid nitrogen is permitted in the accelerator tunnel during accelerator operation.

5.3.3 Experiments

At the present time most experiments on the accelerator are part of a program of accelerator research and development. In the future, where experiments are done with the beam , the operating policies, as it effects safety of personnel, will be essentially the same as those operative during the accelerator experimental period. Personnel will be excluded from the accelerator tunnel and, of course, the beam dump area. At the present time no provision is made for an operating staff other than the accelerator physicists and senior technicians.

5.3.4 Maintenance and Safety Checks

Quarterly checks will be carried out on the crowbar equipment which protects the klystrons. Monthly checks or calibrations of the radiation monitors will be carried out to ensure that the alarms associated with safe operating levels are maintained. Checks will also be made of the validity of the emergency OFF buttons and verification of the electrical interlocks will be carried out at this time.

A drawing file is maintained and updated in the control room. The file includes mechanical and electrical drawings.

6. HAZARD AND SAFETY ASSESSMENT

The Electron Test Accelerator has great high voltage and radiation hazards but it is felt that the precautions which have been taken in the design of the physical layout and in the control interlocks are thorough. Ample warnings on start-up are given for personnel who may be occupying the accelerator tunnel. The key interlock system is made as foolproof as is possible. If by any chance someone is trapped in the tunnel he is given ample visual and aural warning and an adequate time interval in which to get out. If he fails to open the door a trap door is available and emergency shutdown buttons are available. The outer area is well protected by adequate shielding and the high voltage equipment fully enclosed.

Exposure to the external design field of 2.5 mrem/h for a full working year corresponds to the maximum permissible whole-body dose for an atomic energy worker. The probable maximum exposure of workers outside the exclusion area of the ETA in Bldg. 610 to radiation from the ETA would be very much less than the maximum permissible level for several reasons. First, the accelerator is an experimental one which will probably operate for no more than a few hours per day. Second, the area of most intense penetration of the shield wall is at present used as a passageway on the open floor. When used in this manner the maximum probable exposure would be less than one percent occupancy of the area by an individual every day for a year. Third, the legal limits have been used as a guide. In practice, the field outside the shield wall will be reduced below this level by the judicious placement of lead shielding around the beam dump.

If, in the future, the usage of the accelerator approached 100%, the shielding will be increased if necessary. If the area in question becomes part of the exclusion area of another accelerator, the shielding requirement will be mitigated.

Even in the event of failure of the radiation trips the shielding around the accelerator tunnel is such that no serious exposure would result to a worker immediately outside the shield. Assuming that the beam strikes some part of the beam pipe between the two accelerator sections where the shield is 1 m thick the radiation field at the outer surface of the shield would not exceed 2 rem/h. It has been our experience that the equipment cannot continue to operate with a beam power of the order of 150 kW impinging on a beam pipe for more than a few milliseconds without a catastrophic increase in pressure and consequent destruction of the electron gun. In other words in the unlikely situation of the simultaneous failure of a component which allows the beam to go astray and the failure of all trip devices, the accelerator would destroy itself before a dangerous dose could be delivered to anyone outside the exclusion area.

7. REFERENCES

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(7) High Voltage Safety Code, CRNL-200 by C.B. Bigham, J.C. Brown, R.E. Green, F.J. Heath and P.J. Waterton - unpublished Atomic Energy of Canada Limited Report.

(8) Radiation and Industrial Safety Manual, J.M. White - unpublished Atomic Energy of Canada Limited Report.

APPENDIX A

DESCRIPTION OF MODULAR HV SUPPLY IN BLDG. 467

ATOMIC ENERGY OF CANADA LIMITED

MODULAR DC POWER SUPPLIES

POWER SAFETY

by

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CONTENTS

MODULAR DC POWER SUPPLIES

USER SAFETY

1. PURPOSE

Four high-voltage high-capacity dc power supplies were constructed in Bldg. 467 for the development of high power rf sources and on a time sharing basis, for supplying two accelerator rf sources in Bldg. 610. This document is intended to outline how certain design features in combination with operating practices contribute to the control of electrocution hazards arising from the use of these supplies with experimental equipment located in two separate buildings. The procedures contained herein constitute the special application of those defined in CRNL-200 High Voltage Safety Code[7].

2. DESCRIPTION OF POWER SUPPLIES

2.1 Power Supply Ratings

The three larger supplies, Modules A, B and C, each have an output rating of 20 kV dc at 40 A, 800 kW. Output voltages from 6.5 - 20 kV can be obtained in continuously adjustable steps using a 30% range primary voltage regulator, transformer primary delta-wye switching and transformer secondary high or low voltage taps.

Higher voltages, up to 60 kV, or larger current ratings, up to 120 A, may be accommodated by series or parallel operation. Modules B and C may now be changed on short notice from independent operation to series operation at up to 40 kV output but with a reduced current rating of 20 A.

For additional flexibility Module A was made with two sub-modules which may be series operated to deliver 40 kV at 20 A or parallel operated to deliver 20 kV at 40 A.

Module D has a smaller rating of 170 kW at fixed output voltages of 9 or 15 kV obtained by transformer secondary wye or delta connection. Early in 1972 this supply was made continuously adjustable over a range of 25-100% by the addition of a primary voltage regulator.

2.2 Typical System Description

Since the basic design of the three larger supplies is essentially the same, a general description follows with reference to Fig. 1. The dual sub-module arrangement for Module A is shown in Fig. 2.

2.2.1 Primary Circuit

Each supply is fed from a 2400 V 3 ϕ 60 Hz source through a fused disconnect switch. Vacuum circuit breakers provide on-off control and fast shutdown following crowbar or other short-circuit overloads. The air-core reactors provide sufficient series reactance to limit secondary short-circuit currents to about 5.5 times full load current.

The induction regulator provides continuous linear voltage control over a range ± 15% of that set by the selected transformer turns ratio. Two secondary tap connections are available, 100 and 75%. Secondary adjustments are cumbersome and inconvenient to make particularly during winter. The wye-delta switch provides for a convenient but off-load voltage reduction to 57%.

2.2.2 Secondary Circuit

The regulation capacitors correct for the effects under load of the current limiting reactors and the transformer leakage reactances. The overload relays provide overcurrent protection and since they operate in 1 cycle, give back-up short-circuit protection within 2 cycles (assuming no fast trip command). This is well within the 10 cycle short-circuit current limit of the rectifiers.

A full wave, three phase rectifier assembly is used. Each leg is a series string of 52 rectifiers which are individually fitted with commutation capacitors, damping resistors and a neon lamp to indicate failure (short circuit).

A single section choke input filter reduces output supply ripple to 0.175%. The choke is fitted with a shorting relay and resistor to limit voltage overshoot following turn-on due to initial charging of the filter capacitors. A vacuum switch (back-up crowbar) shorts the output terminals on turn-off to discharge the filter capacitors. It is operated by a fast trigger system to back-up external crowbar systems.

2.2.3 High Voltage Patch Panel

The power supply output terminals are arranged in pairs at the bottom of the high voltage patch panel. Load terminals are arranged in pairs at the top. Siting of these has been chosen so that for current and foreseeable applications, patching-cable crossovers are reduced and visual tracing of routings is convenient.

Clear plastic separator panels with numbered routing holes ensure spacing adequate for the maximum possible voltage stress between any two cables. Patching cables are unique, having been cut to satisfy a specified routing between each required source/load combination.

2.2.4 Control System

The control system has been divided into two sections. The control chassis contains the low voltage relay supplies, trigger circuits and common interlocking circuits. On-off, voltage adjust, delta-wye controls and supervisory status indication are mounted on a separate panel located either at the local control console or at the user's equipment site.

2.2.5 Documentation

Drawings of interest to the user are listed below:

D 4420 - 54159	Electrical Schematic High Voltage Cct. Module A.
D 4420 - 54160	Electrical Schematic High Voltage Cct. Modules B and C.
D 4420 - 54161	Electrical Schematic High Voltage Cct. Module D.
E 4420-4-SK-6	Electrical Control Schematic.
D 4420 - 55221	Electrical Schematic/Patch-Panel and Remote Control.
E 4420-2-SK-5	Ground Floor Equipment Layout.

2.3 General Arrangements

2.3.1 Layout

The modular supplies are located in three enclosures at the south end of Bldg. 467. The four fused load isolators are part of the main building substation which forms the east wall of one of the enclosures. A safety lane connecting the substation to the south east fire-exit, Bldg. 467/610 outer door, provides a clear emergency exit route or direct access to the isolators for fire-fighting personnel.

All primary components which include the induction regulator, transformer banks, current limiting reactors and switch devices are located in an outdoor enclosure. Secondary circuit components are located in two indoor enclosures; Modules A and D components are in the west unit and Modules B and C components are in the east unit. The high voltage patch-panel is located at the north end of the east enclosure. The control patch-panel is mounted on the outside of the enclosure wall close to the high voltage patch-panel. Hence the patching status of both may be inspected conveniently by Bldg. 610 users as they pass through Bldg. 467 en route to Bldg. 610.

2.3.2 Enclosures

Since the equipment occupies large areas open top walk-in enclosures are used. Indoors, a 2.6 m high fence, constructed of expanded sheet metal is used. Outdoors, a 2.6 m frost fencing is used. Four gates provide access; two to the outdoor transformer bay and one each to the indoor enclosures. Each is fitted with a lock that is part of the key interlock system. All four locks are keyed identically but only one key, identified as the gate key, is used. Hence only one enclosure can be entered at a time.

The control patch-panel is fitted with a clear plastic front door to permit inspection of patching status. This door is equipped with an interlock system lock and is keyed for operation with the gate key. Hence patching operations are restricted to those conditions prevailing when the gate key is available.

3. DESIGN CONTROLS FOR HIGH VOLTAGE SAFETY

3.1 Key Interlock System

3.1.1 Purpose

The purpose of the system is to prevent:

Entry until:

- all primary sources (2400 V) are disconnected;
- all output terminals are grounded.

Operation until:

- safety grounds are removed;
- operation is authorized.

3.1.2 Description and Interlock Provisions

The system consists of four basic components:

Grounding Switch
Interlock Key Banks
Gate Locks and Key
Isolator Locks and Keys.

The GROUNDING SWITCH consists of eight ganged switches arranged to short and ground the eight output terminals of the four power supplies on the high voltage patch-panel. It is driven by a crank handle mounted at the enclosure fence next to the interlock key banks, through a shaft-gear linkage. A keeper plate is fixed on the shaft so that it travels on the shaft as the crank is turned. Alignment is such that the interlock key bank bolts engage the keeper plate slots only when the grounding switch is fully open or closed.

The INTERLOCK KEY BANKS are located on the east indoor enclosure next to the grounding switch crank handle. The banks are designed to retain (prevent removal of) its key(s) until the bolt is extended into a keeper plate slot. They control seven keys:

one - MASTER (Supervisory) key
four - ISOLATOR keys A, B, C or D
one - GATE key
one - WATER LOAD key.

The MASTER key serves primarily to protect the power supply operator or tradesman during maintenance. Inadvertent operation of the interlock system is prevented by holding this key on his person. Also, it serves to facilitate administrative control of operation.

An ISOLATOR key can be removed from its bank for closing of its isolator or for access to its isolator fuse compartment only when:

a) the GATE key is in its bank;
b) the grounding switch is OPEN.

An ISOLATOR key can be removed from its isolator for return to the interlock bank or for access to its isolator fuse compartment when the isolator operating lever is locked OPEN.

The GATE key can be removed from the interlock bank for opening an enclosure gate or for opening the control patch-panel door only when:

a) four ISOLATOR keys are in their interlock bank, and
b) the grounding switch is CLOSED.

The GATE key can be removed from an enclosure gate or from the control patch-panel door when that gate (door) is closed and locked.

Similar provisions apply to the WATER LOAD key. The water load enclosure lock was not keyed for operation by the gate key since the facility was installed for commissioning tests and hence considered temporary.

The GROUNDING SWITCH can be operated from either position to the other only when all keys are in the interlock banks (bolts withdrawn).

3.2 High Voltage dc Feeds

The positive and negative connections between the power supply and the load must be made with separate coaxial cables. A single coaxial cable is prohibited.

For the 800 kW power supplies, RG-17/U coaxial cable or larger must be used.

For the 170 kW power supply, Module D, RG-34/U or larger must be used.

The shield (braided outer conductor) of cables must be permanently grounded at both ends. In applications where they are exposed such as in cable trays, for one-third or more of their total length, the shields must be grounded at the duct exit point.

The power supply must be grounded at the load, not necessarily at either of the remote cable terminations.

The impedance between the lower potential terminal of any power supply module and the load ground must not exceed 2.5 ohms and 100 μH.

The whole of the conductor from the cable termination to the load ground must be permanent and adequate for a surge current of 4000 A.

For long runs, such as between buildings, an auxiliary ground wire is recommended to reduce ground current loops during transients. It should be laid parallel to the cables of No. 2 AWG or larger in size and permanently connected to the building ground system at both ends.

3.3 Load End Grounding Switch

A mechanically operated grounding switch must be provided at the load end to short and ground the termination of the cable inner conductors.

The grounding switch must be fail-safe interlocked (mechanically) to prevent access to the cable terminations until they are grounded. A low voltage interlock switch must be provided to ensure that shutdown of the power supply has been initiated before the grounding switch is fully closed.

The switch and terminations are considered to be in a part of the power supply enclosure when the feeds are connected to the patch-panel. Access must not be obtained unless:

a) for short periods (half day or less).

   The isolator is padlocked open;

b) for longer periods (more than a half day).

   The cables are grounded at the power supply end, either by operation of the grounding switch or by disconnection and grounding at the patch-panel.

The grounding switch may be locked or key interlocked with the load enclosure for hazard control at the discretion of the user.

3.4 Auxiliary Lockouts

3.4.1 Isolator Padlocks

Upon completion of the initial patching operation (usually at load system commissioning), the user will be issued with a special long shackle padlock and one key for locking the isolator open.

For user protection it must be installed:

a) when access to the load grounding switch or cable termination is required for a short period (half day or less);

b) when the load enclosure must be opened for special tests requiring the load grounding switch to be left open; e.g. crowbar tests.

3.4.2 High Voltage Patch Panel - dc Feed Lockout

The power supply end of a dc feed must be locked out and grounded with a short grounding cable when:

a) construction or commissioning of the load grounding switch/cable termination is incomplete;

b) the load is taken out of service;

c) access to the load grounding switch is required for extensive maintenance or modification (greater than a half day).

Padlocks for locking the engaged grounding cable plugs to the cable terminals are available from the power supply operator. The user must retain the key until patching to a source is required.

3.5 Remote Control Equipment

The basic circuits for the remote power supply control panel must conform to that shown on drawing D-4420-54221 to be compatible with the power supply common control circuits. Crowbar trigger signals for fast shutdown operation must be compatible with the common fast operator firing circuits.

Two remote control panels for any given power supply may be provided but both must include a positive means for ensuring that only one panel is operative at a time. Emergency shutdown controls must operate directly in the line which is common to both panel "high voltage off" circuits.

Control and protection circuits and their connections, particularly the "off" function, must adequately perform their function.

4. ADMINISTRATIVE CONTROLS FOR HIGH VOLTAGE SAFETY

4.1 Equipment Responsibility

4.1.1 Modular dc Power Supplies

The owner/operator is responsible for providing a serviceable facility which includes the four basic power supplies, the ac isolators, local control facilities and patching facilities. Areas of activity include:

- design and installation of modifications;
- interconnection and voltage adjustments;
- maintenance;
- patching and isolator operation;
- scheduling arrangements for shared use.

4.1.2 Remote Equipment

The user is responsible for the provision and maintenance of:

- feed cables and ducts;
- load grounding switch;
- remote control panels;
- remote emergency controls.

4.2 Power Supply Operations

All power supply operations requiring access to the high voltage or control circuits within the three enclosures or to the isolator must be performed by or under the direct control of the power supply operator. Specific operations are outlined in the following.

4.2.1 Routine Operation

1. The normal safe state is shutdown with the isolator open.
2. The power supplies are to be left in a safe state whenever the users or operator(s) are not in attendance.
3. Isolator and control power must be performed by the operator or his designate in Bldg. 467.
4. One operator (user) must be responsible for a remote station at all times when the isolator is closed and the power supply is switched on.
5. Junior and temporary staff must not assume control of a modular power supply until they have demonstrated familiarity with the operating procedures of CRNL-200[7] and this document and the locations of isolator and control power switches.

4.2.2 Adjustments

Adjustments for series or parallel operation or voltage changes (transformer tap changes) must be performed by the power supply operator. Advance notification is required to permit planning and scheduling of work.

4.2.3 Patching

1. The power supply operator must perform all patching operations.
2. The user must verify (with signature and date) that the patching operation performed for the permit in force is correct.
3. The permit in force must be posted in the assigned control patch-panel space so that patching status can be verified with the authorization at any time.
4. Temporary patching to local control for control troubleshooting must be authorized by the user in writing (patching permit).

4.2.4 Maintenance

1. All maintenance operations within the three main enclosures must be performed by, or directed by, the power supply operator.
2. Maintenance, including fuse replacements in the isolators, must be performed by E.I. & P. Branch staff. Fuse failures or loss of 2400 V ac source must be reported immediately to the electrical maintenance foreman.
3. A work permit must be issued for each job performed by tradesmen (see section 5, CRNL-200[7]). The operator's copy must be posted on the display board on the east enclosure until the work is complete and the permit signed off.
4. White 'hold tags' must be posted on the opened gate or the key interlock bank, clearly stating the job, whenever a tradesman has been assigned (see section 5, CRNL-200[7]).
5. The operator or tradesman must retain the master key on his person when working inside an enclosure. When both are working inside, the tradesman must hold the master key.
6. When work is being performed in a load grounding switch/cable termination enclosure, the operator (user) performing the work must hold the isolator or feed-lockout padlock key on his person.

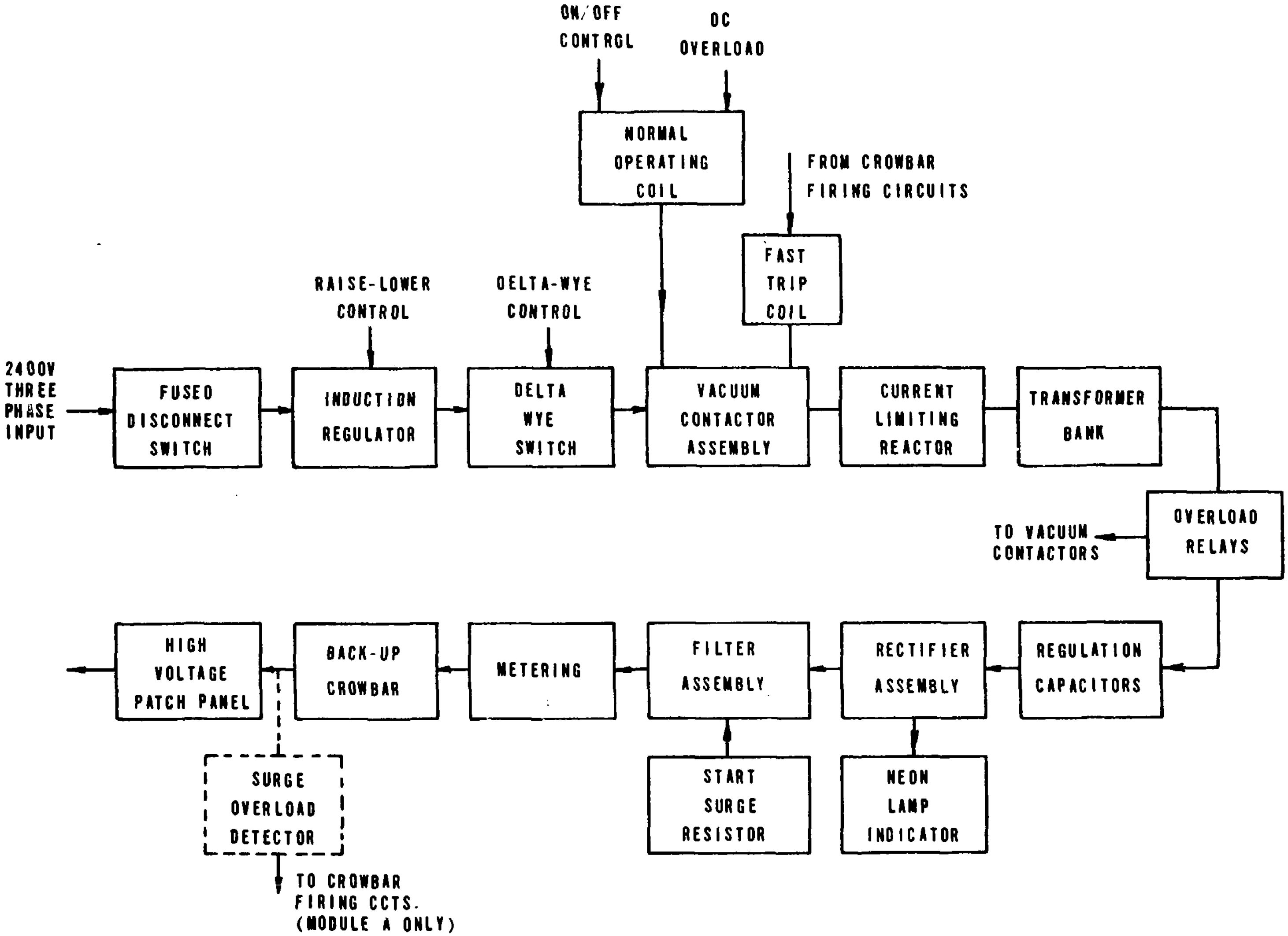

FIGURE 1
800KW DC POWER SUPPLY BLOCK DIAGRAM

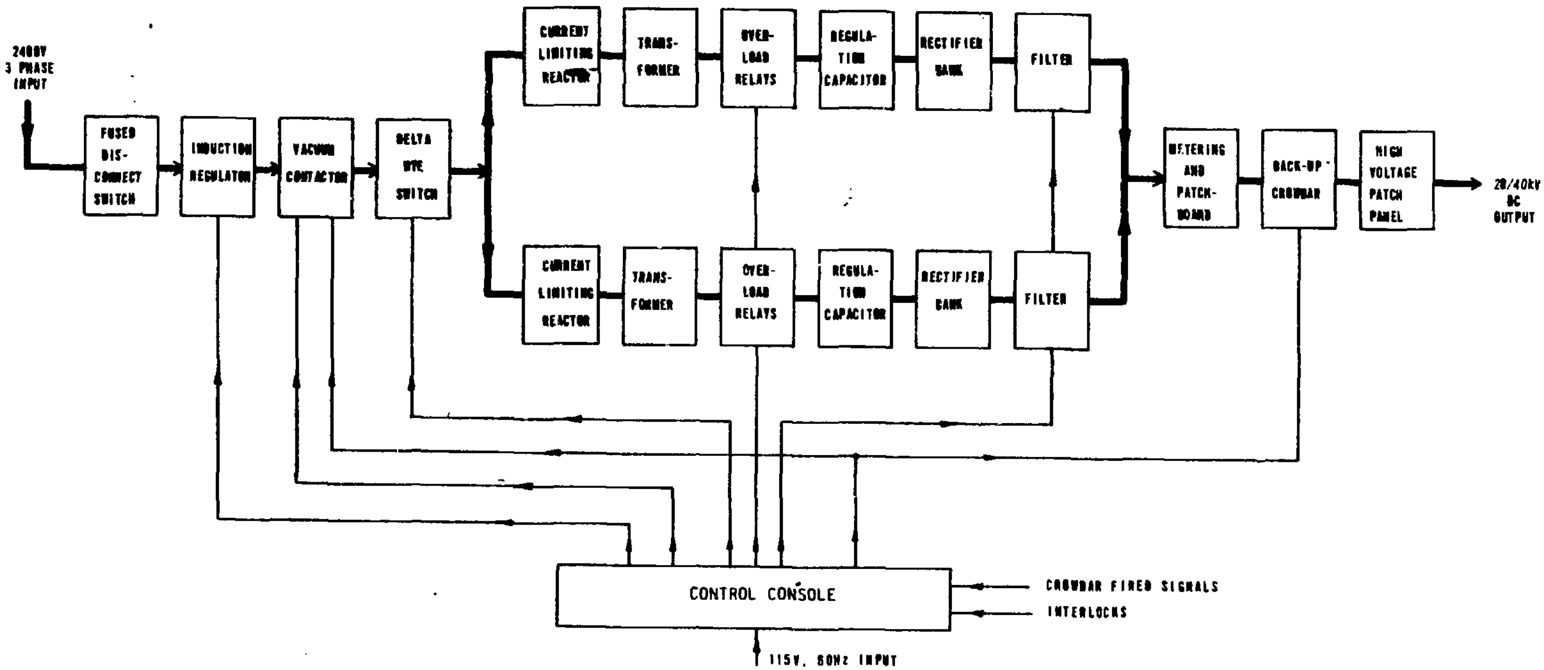

Fig. 2 Block Diagram - Module A, dc Power Supply

APPENDIX B

MEMORANDA FROM FIRE CHIEF BYRNE
RE FIRE PRECAUTIONS

ATOMIC ENERGY OF CANADA LIMITED

CHALK RIVER NUCLEAR LABORATORIES

MEMORANDUM

November 15, 1971

TO: J.S. Fraser
Accelerator Physics Branch

FROM: B.M. Byrne
Protective Services Branch

HIGH VOLTAGE POWER SUPPLIED
FOR ELECTRON ACCELERATOR

This will confirm that the precautions outlined in your memorandum dated 8 November 1971, and intended for the 100KV, 200 MA supply transformer, Building 610, and the 100 KV, 20 MA supply transformer, Building 145, are acceptable, and installation may continue.

While these installations do not conform with the requirements outlined in Section 26, Rule 26-008, and Rule 26-036 of the Canadian Electrical Code, it is felt that the type of work carried out, the performance demanded of the transformer, and the location in each building, will allow the installation as proposed, and subjected to concurrence by E.I. & P. Branch.

B.M. Byrne
Fire Chief

cc. G.B. Harrison
W.D.B. Glass

ATOMIC ENERGY OF CANADA LIMITED

CHALK RIVER NUCLEAR LABORATORIES

MEMORANDUM

December 7, 1971

TO: Dr. J.S. Fraser
Accelerator Physics Branch

FROM: B.M. Byrne
Protective Services

FIRE PROTECTION EQUIPMENT - BUILDING 610

This will confirm that Fire extinguisher locations will be finalized when all equipment has been installed. Extinguisher location signs will be provided by this department and installed by carpenter shop.

Additional extinguishers will be required for installation outside the entrance door of the accelertor tunnel, and will provide protection for surrounding equipment.

It was further agreed that the ventilation fans serving the accelerator tunnel will be fitted with automatic cut off switches to operate in the event of fire within the tunnel.

B.M. Byrne,
Fire Chief

cc: G.B. Harrison

APPENDIX C

EXTRACTS FROM CRNL-200

"HIGH VOLTAGE SAFETY CODE"

2. HAZARDS AND TOLERANCES

2.1 Electrocution

2.1.1 Offhand, it would seem that a shock of 10 kV is necessarily worse than 100 volts. This is not so because the shock's intensity depends on the current passing through the body, not the voltage. Currents over 10 mA produce painful to severe shock; currents between 100 and 200 mA are lethal. Currents above 200 mA produce severe burns and unconsciousness but do not usually cause death if the victim is given immediate artificial respiration.

2.1.2 The current through the body depends on the voltage applied, the resistance of the body and the condition of the skin. The resistance between the ears is about 100 Ω while between hand and foot about 500 Ω. Skin resistance may vary from about 1000 Ω wet to over 500,000 Ω dry.

2.1.3 The physiological effects are summarized in Fig. 1. At about 20 mA, breathing becomes laboured, finally stopping at about 75 mA. At 100 mA, ventricular fibrillation of the heart occurs - an uncoordinated twitching of the walls of the heart's ventricles. Only medically controlled further shocking within three minutes can save the victim. Above 200 mA, muscular contractions are so severe that the heart is forcibly clamped during the shock. This protects the heart from going into ventricular fibrillation, and the victim's chances for survival are better.

2.2 Rf Radiation

2.2.1 The rf sources now in use are at 268-1/3 MHz and 805 MHz. The lower frequency power will be transmitted through coaxial lines up to 23 cm diameter and the higher frequency power mostly through WR 975 waveguide (25 cm by 12.5 cm rectangular pipe). Normally the power will be completely contained, but holes, cracks, or defective joints allow the power to radiate into the room. Power levels may be about a megawatt so that rf fields in the waveguide may be a million biological tolerances (see 2.2.3).

2.2.2 The biological effect of rf radiation is to produce a fever, i.e. the radiation is penetrating and heats the interior of the body. A field of about 25 mW/cm^2 will cause a one degree temperature rise, but for some organs the increase can be an order of magnitude more and reach dangerous levels in the fields of 100 mW/cm^2. At this level, cataracts may form in the eyes. Temporary sterility can be caused by fields perhaps as low as 5 mW/cm^2. (See Appendix 1.)

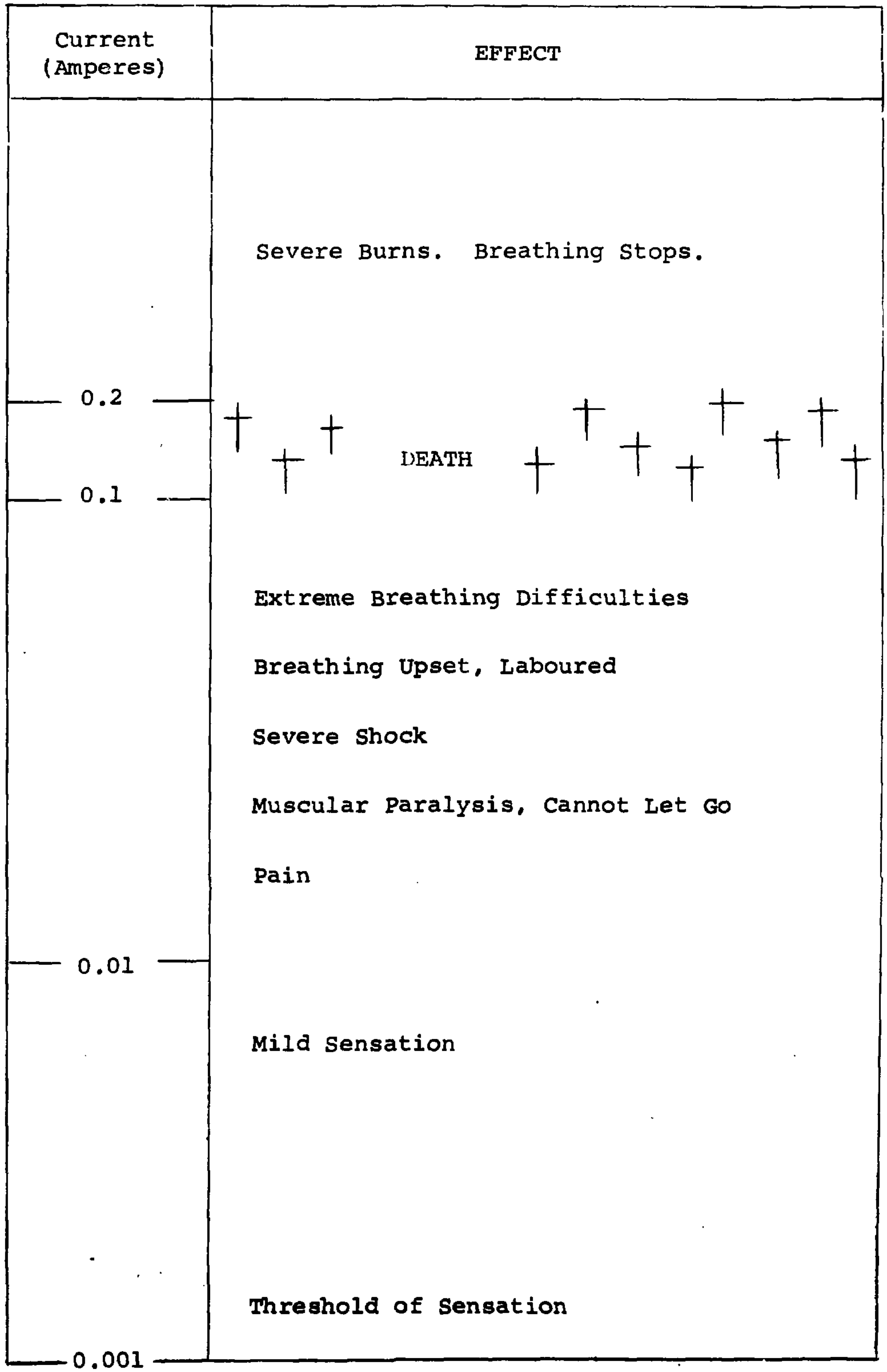

FIG. 1 The Physiological Effect of Electric Currents

2.2.3 We adopt the U.S.A. Standard C 95.1 - 1966, i.e. fields in working areas should not exceed 10 mW/cm^2 averaged over 0.1 hour periods. Fields from rf leakage are difficult to monitor accurately and may vary widely. A safer working limit would be 1 mW/cm^2 since only 10 times the 10 mW/cm^2 level can cause permanent damage. Therefore, efforts should be made to keep these fields below 1 mW/cm^2.

2.3 X-rays

2.3.1 Intense electron beams may produce intense x-ray fields where the beams are stopped. These x-rays have very short ranges at low energies and will mostly be stopped by the vacuum container. If the beams are intense, a small fraction escaping may produce dangerous fields.

2.3.2 Rf tubes may also accelerate electrons to energies above the dc voltage applied to the tube. For example, in the last gap of a klystron some of the electrons will be accelerated to twice the beam energy; a 35 kV klystron will produce some 70 kV x-rays with much higher penetration.

2.3.3 Accelerator cavities in high power tests will accelerate electrons and produce x-ray fields. High energy beams may also produce residual β-γ activities in the accelerator structures.

2.3.4 The tolerances and monitoring practices for x-rays, γ-rays and β-rays are given in the Radiation Health Manual for CRNL. The exposure allowed is a total of 3 rem in a 13 week period or 5 rem in a year. The CRNL control level is 600 mrem in two weeks. Approved measuring techniques are given in 4.3.

2.4 Ozone

2.4.1 Ozone, O_3, an unstable molecular form of oxygen, is formed in corona discharges in air. The molecule breaks up liberating a free oxygen radical that is strongly oxidizing. Concentrations of about 10 ppm are known to cause illness; the allowable level for an eight hour working day has been set at 0.1 ppm.

2.4.2 The production rate of ozone is roughly proportional to the power in the corona discharge and is about 0.05 litres per watt-hour. This means that in laboratories with normal ventilation, discharge of $\sim$ 10 μA from a 50 kV power supply may produce toxic concentrations.

2.4.3 The allowable level of 0.1 ppm can be smelled by someone entering the area but a person there during gradual buildup might not notice it. A chemical test can be carried out periodically. The best method of control is to design for small corona currents and to provide good ventilation.

2.5 Noise

2.5.1 Noise in working areas can be hazardous because of

- permanent damage to the ears;
- masking of sounds that could provide a warning of hazardous situations;
- increased difficulty of communication;
- reduced alertness from fatigue.

2.5.2 The distance speech can be heard provides a rough guide to noise levels. Normal speech can be heard at 2 m with a background level of 50 dB, shouting at 2 m with 70 dB and shouting at 15 cm with 90 dB.

2.5.3 The maximum noise level that allows effective communication is about 60 dB. This will still mask many sounds, such as sparking, that could warn of trouble in equipment. Lower levels are desirable but in systems with high velocity water and air cooling, these can be obtained only by careful design.

2.5.4 Permanent ear damage can be caused by continued exposure to noise levels higher than 90 dB. Continuous exposure to levels above 70 dB should be avoided and ear protection used. At levels above 90 dB, ear protection must be used.

3. STAFF ORGANIZATION

3.1 General

3.1.1 The Director of the Physics Division is the "owner" of all the high-voltage test equipment operated within the division, and carries the overall responsibility for its safe operation. However, for safe and efficient operation of the equipment on a day-to-day basis he may, upon the recommendation of a Branch Head, appoint certain persons to provide the necessary administrative control to ensure this. This section describes the duties and responsibilities of those who may be designated as responsible for the safe operation of the high-voltage equipment of the Physics Division.

3.2 Area Supervisor

3.2.1 The Area Supervisor is responsible for the safe operation of the high-voltage equipment in a specified area, normally a building or laboratory. He is appointed by the Director of the Physics Division upon the recommendation of his Branch Head.

3.2.2 The duties of the Area Supervisor are:

- to grant written permission valid for not more than three months to an Officer-in-Charge (see 3.3) to perform a series of experiments with one of the high-power test facilities (see 1.2.2). Before granting such permission he shall evaluate a written proposal that describes the salient features of the facility and the proposed program of experiments and defines the possible modes of operation (see 4.6). Permission is granted when the Area Supervisor is satisfied that equipment conforms to the requirement of Section 6 and that the experiments will be performed in accordance with the regulations of Sections 4 and 5. At least two competent people must evaluate each proposal.
- to include in the written permission any instructions or restrictions he may feel necessary to ensure safe operation in accordance with the provisions of Sections 4 and 5;
- to recover the written permission upon completion of the experimental program, thereby cancelling the permission;
- to post in his area, a list of operators authorized to sign work permits;
- to retain in his possession any duplicate interlock-keys that may be used under special circumstances to circumvent safety interlocks on the test facilities within his jurisdiction, unless written permission for their use has been given to an Officer-in-Charge;
- to recommend revisions or additions to the safety regulations or operating procedures to his Branch Head;
- to report deviations from the operating rules to his Branch Head.

3.3 Officer-in-Charge

3.3.1 An Officer-in-Charge is responsible for the use of a specified high-power test facility (see 1.2.2). He must prepare a proposal for the use of the facility and obtain written permission from the Area Supervisor before first switching on. He may appoint operators to ensure the efficient execution of the experiments. He shall instruct the operators in the operations they will perform.

3.3.2 The Officer-in-Charge must:

- ensure that his operators have read and understood the safety code;
- nominate, for approval by the Area Supervisor, operators who may sign work permits for the equipment under his control;
- ensure that the safety devices on his test facility function properly before operating the facility;

- maintain good housekeeping in and around the test facility.

3.3.3 The Officer-in-Charge may not:

- operate a high power test facility without written permission from the Area Supervisor;
- use a duplicate interlock-key or jumper any interlock without written permission from the Area Supervisor.

3.4 Inspection

3.4.1 An inspection committee of three members shall be appointed by the Director. The membership should be rotated every three months, to ease the load, to obtain a fresh point of view and to bring a larger number of people into closer contact with safety problems.

3.4.2 The committee should make an inspection of the division laboratories at least once a quarter. Dangerous situations or infractions of the safety code must be discussed with the appropriate Officer-in-Charge and Area Supervisor. If the committee considers that the improvements will not be adequate, a report must be made to the Director.

4. OPERATOR'S PROCEDURES

4.1 Number of Operators

4.1.1 One operator may operate permanently enclosed high-voltage equipment, but he must not seek access.

4.1.2 Two operators must be present for access into high-voltage equipment, which must be off.

4.1.3 Two operators must be present for operating equipment with exposed high voltage and a third person must be available on call (by shouting or by special emergency call system).

4.2 Normal Practice for High-voltage Equipment

4.2.1 The operator must ensure that the required warning lights (see 6.5) are in operation when high voltage equipment is on.

4.2.2 The operator must follow, at all times, good housekeeping practices.

4.2.3 Capacitors capable of storing an energy of 5 J or more must be shorted when not in equipment.

4.2.4 Before starting work, rings and metallic watch straps should be removed to avoid good contact with the skin and a possible burning hazard.

4.2.5 When equipment is exposed but not switched on, high-voltage points must be grounded by a grounding stick to avoid retained charge and accidental re-energizing. Grounding sticks must be inspected once a month and tested at a current of 100 A at least every six months.

4.2.6 The operator must ensure that emergency shutdown and isolation instructions are posted prominently near the equipment control and/or isolating facilities.

4.2.7 Operators must not remain partly or wholly inside an interlocked area when the equipment is on.

4.2.8 Operators must not operate equipment when the floor is wet.

4.2.9 Operators must not run temporary cable or loose wires above open-top walk-in enclosures or exposed high-voltage equipment.

4.2.10 Operators must not permit cranes or other overhead movable equipment above operating open-top walk-in enclosures or other live exposed high-voltage equipment.

4.2.11 Operators must not use a duplicate interlock key, or jumper any interlock without written permission from the Area Supervisor.

4.2.12 Operators must not work on equipment unless it and all other nearby accessible high-voltage equipment is isolated and the isolators tagged.

4.3 X-ray Hazards

4.3.1 To avoid dangerous exposure, survey the area near the equipment with a Victoreen Model 440RF meter (designed to be insensitive to rf) or arrange for film or thermo-luminescent dosimeter tests when power levels are increased but at least once a month. Follow the CRNL Radiation Health Manual.

4.4 Rf Hazards

4.4.1 To avoid burns or dangerous exposure in case of accidental operation, all rf transmission lines connected to a source of power must be properly jointed and terminated in an appropriate load or a conducting cover.

4.4.2 Do not look directly into operating waveguides. Use a long "below cut-off" tubular window. Do not use mirrors which are normally conducting metal and can reflect radio as well as optical waves.

4.4.3 Monitor external rf fields daily after making changes and when power levels are increased. Fields in working areas should not exceed 1 mW/cm^2. Operation may be continued if fields are between 1 and 10 mW/cm^2 but warning signs or tape barriers must be used. If fields exceed 10 mW/cm^2, take immediate corrective action.

4.4.4 Rf survey meters are frequency sensitive and the possible existence of several frequencies must be borne in mind.

4.5 <u>Ozone Hazards</u>

4.5.1 Tests for ozone must be made on first starting equipment, when voltages are increased, but at least every month. Measurements during Hi-Pot testing are also desirable.

4.5.2 Take care when opening enclosed high-voltage equipment; ozone concentrations may be dangerously high.

4.6 <u>Modes of Operation for High-Power Facilities</u>

4.6.1 The operation of equipment with exposed high voltage conductors is undesirable, and where practical, equipment must be designed or modified to avoid this. However, it may be necessary to operate for short periods in this manner and this can be done safely by taking suitable special precautions. The "modes" listed below define those conditions where special procedures must be followed.

4.6.2 Only large equipments are covered here; those having voltages greater than 50 kV and those having powers greater than 10 kW, including both power supplies and driven experimental apparatus. Smaller apparatus, e.g. ion pump supplies, comes under the general provisions of the code and is the responsibility of the user except for periodic inspections.

4.6.3 The modes of operation are:

<u>Mode A</u>: The equipment is completely enclosed and fitted with interlocks and is operated without interlock jumpers in accordance with the regulations given in Sections 4 and 6.

<u>Mode B</u>: Interconnected apparatus that cannot be permanently included in the same interlock system, e.g. the 2.4 MW dc power supplies in Bldg. 467 with alternative connections to several experiments.

<u>Mode C</u>: Equipment as in Mode A or B but operated with an open enclosure and/or a safety interlock jumpered.

Mode D: Equipment not permanently enclosed or interlocked that is required for temporary use or that must be tested before its enclosure or interlocks are complete, e.g. the commissioning of major equipment or the testing of modifications to it.

Mode E: The use of a High-Potential Test Unit.

Mode F: Automatic operation of equipment with no operator in attendance (e.g. life tests) but otherwise as Mode A or B.

APPENDIX D

CALCULATION OF THE SHIELDING REQUIREMENT

CALCULATION OF THE SHIELDING REQUIREMENT

The dose rate in air in the forward direction from an electron beam or energy T MeV, at a current of I amperes stopped in a target of atomic number Z is

$$R(0) = 2.604 \times 10^{11} \left(\frac{\mu_k}{\rho}\right) \tau (T + 0.511)^2 \; T \; I \; \ell n \frac{3250t}{\ell n(183Z^{-1/3})}$$

Rads/h at 1 cm.

where τ is the fraction of electron energy converted to radiation per unit radiation length, and t is the target thickness in radiation lengths(1). For maximum forward radiation yield the target thickness t is given by

$$t = \frac{0.3T}{(a + bT)t_z}$$

where t_z is the radiation length in g/cm^2, a is the target stopping power for electrons and bT the target stopping power for radiation in MeV/g.

Using the forward x-ray yield curve of Fig. 4 of Ref. (1) and converting the indicated yield from W to Cu using Table 1 (loc. cit.), the dose rate from a 3 MeV, 50 mA electron beam is

$$R(0) = 1.26 \times 10^6 \text{ R/h at 1 m.}$$

Taking the outside of the shield as 4 m from a point target, the inverse square law gives

$$R(4) = \frac{1}{4^2} \times 1.26 \times 10^6 = 7.9 \times 10^4 \text{ R/h at 4 m.}$$

The shield thickness d required to attenuate the radiation field to 2.5 mR/h is given by

$$7.9 \times 10^4 \times 10^{-d/t_{1/10}} = 2.5 \times 10^{-3}$$

where $t_{1/10}$ is the 1/10 thickness of ordinary concrete. For 3 MeV bremsstrahlung, $t_{1/10}$ = 26.3 cm (Fig. 10, Ref. 1)

$$\therefore d = 25 \times \log_{10} 7.9 \times 10^4/2.5 \times 10^{-3} \text{ cm}$$

$$= 187.3 \text{ cm (6.15 ft).}$$

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(1) See Ref. 2 in the main body of this report.

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