NEUTRON THERAPY FACILITY
PROCEDURES

PLEASE KEEP IN CYCLOTRON
CONTROL ROOM

CONTENTS

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CYCLOTRON PROCEDURES MANUAL

I. INTRODUCTION

A. Purpose

To outline the cyclotron operating procedures and those maintenance and configuration-change procedures most commonly required in the operation of the 69-inch azimuthally-varying field cyclotron. For background material, a brief description of the cyclotron is first presented.

B. Description of Cyclotron

For the neutron therapy application, the cyclotron and external beam transport system will provide a beam current of 20μa of ~25 Mev deuterons incident on about a 10 mm diameter spot on a thick beryllim target. The required mode of deuteron acceleration is "second harmonic, N = 2", i.e., the accelerating particle makes one revolution for every 2 cycles of the radiofrequency voltage. For clarification of the procedures, the following brief description of the cyclotron subsystems and definition of terms are provided. A schematic diagram of the cyclotron principal subsystems is shown in Figure 1; a photograph of the cyclotron is shown in Figure 2.

1. Magnet System

Production of a beam requires precise settings of the magnitudes of the magnetic fields of four different sets of magnets. All magnets are cooled with de-ionized water flowing through the magnet coils. Current-regulated power supplies are used to drive all the cyclotron magnet coils; these power supplies are located in the equipment room.

a. Main Magnet - produces the main magnetic field required to contain the beam during orbital acceleration. Typically operated at 200 to 450 amps.

b. Profile Coils - required to obtain the proper beam focusing and maintain isochronism during orbital acceleration. Consists of eight pairs of coils which are used to adjust the radial variation of the average magnetic field by a few percent either way from that due to the main-field coils alone. These profile (or trim) coils are located in the face of the main magnet poles. Typically operated at 200 amps or less.

c. Harmonic Coils - two sets of coils (inner and outer) used to make very minor adjustments in the first harmonic (azimuthally) of the magnetic field (first harmonic is nominally zero). Inner harmonic coils are used to correct orbit centering errors; outer harmonic coils are used to provide a first harmonic content of the magnetic field at extraction radius which is necessary for beam extraction. The two sets of harmonic coils are located in the valleys between the hill pieces. NOTE: The hill pieces are large shaped pieces of magnet iron arranged in a three-fold symmetrical array on the main pole tips. The hill pieces produce the large azimuthal (third harmonic) variation in the magnetic field, which is characteristic of the azimuthally-varying field cyclotrons. Inner and outer harmonic coils are typically operated at 200 amps or less.

2. <u>Ion Source</u>

As its name implies, the ion source provides ions for orbital acceleration by the cyclotron. The ion source penetrates the cyclotron vacuum boundary through a hole bored through the top pole and yoke of the main magnet. The gas supply for the ion source introduces the gas at the center of the machine where it is ionized by means of an electrically-heated filament. The degree of ionization of the gas is increased by application of a sufficiently large potential difference across the gas so as to produce a plasma discharge (referred to as "arc") between the electrodes. Two separate gas systems are available, one for use of expendable gases (H_2, He^4, D_2) and the other for the use and recovery of the more expensive He^3.

Capability of ion-source positioning within the machine exists, as required in changing machine operation from N = 1 mode to N = 2 mode. (NOTE: In N = 1 mode, accelerating ion makes 1 revolution per cycle of rf voltage.)

Arc voltages and currents are approximately 100 volts and 5 amps; filament voltages and currents are typically 4 volts and 200 amps.

3. Dees

Each dee consists of a pair of copper plates (water cooled) separated by about 5 cm which form the electrodes for accelerating the charged particles within the machine. The two dees are individually identified as north and south, which are the right and left dee, respectively, as viewed from the entrance to the cyclotron vault. The dees tips normally operate at 20-80 Kv and 12-22 MHz. The dee tap-point connection to the radiofrequency supply is near the root of the dee. The root end of the dee is grounded. Each dee is contained within an evacuated cavity bounded by an upper and a lower liner which are electrically grounded. From the tip of the dees to nearly the midpoint of the dee stem the liners are fixed and the gap dimension between the surface of the dee and the adjacent liner is a constant. For the remaining length of the dee near the root end there are two sets of panels (upper and lower) which form a moveable liner section. Figure 3 is a schematic of a dee-liner assembly. Each panel (2 per dee) is moved by a hydraulic actuator. The moveable panels allow tuning of the dees to the radiofrequency of the voltage input to the dees. Each panel consists of 3 water-cooled copper-faced sheets with a total of 4 hinge points, as indicated in Figure 3. The hinges are foils of soft copper.

A "puller" extracts the ions from the ion source and provides the ions with their initial directed momentum in the magnetic field. The puller is attached to the south dee close to the ion source and is at the same RF potential as the dee. The configuration of the puller, as well as the location and orientation of the ion source, must be changed in going from N = 1 to N = 2 mode of operation.

4. RF Power Supply System

The RF power supply system provides the radiofrequency voltage to the dees. The RF system consists of two separate chains of power amplifiers with each chain driving one of the two dees. Each amplifier chain contains 3 stages of power amplification. The first stage is a 50 watt commercial amplifier; the second stage, referred to as the "driver", is a 2 kw amplifier; and the third stage, referred to as the "final", is a 100 kw amplifier.

A single frequency synthesizer supplies a stable low-level RF excitation at the desired frequency to both amplifier chains.

The power amplifiers are in two air-cooled compartments (one for each dee) located on top of the vacuum tank above the dee tuning panels. The frequency synthesizer is in a rack in the cyclotron control room.

5. Extraction System

The extraction system consists of an electrostatic deflector followed by a magnetic deflector. Both deflectors are necessary for extraction of the beam from the cyclotron from whence the beam is handled by the external beam transport system. The beam particles which reach the orbit radius intercepted by the electrostatic deflector are deflected by the electrostatic field so as to move through the gap between the inner and outer electrodes of the electrostatic deflector. The inner electrode, referred to as the "septum", is a vertical flat plate which is curved to follow the contour of the extraction orbit path and is located adjacent to the tip end of the south dee. The septum is electrically grounded and is cooled by de-ionized water. The outer electrode (the deflector) is an elliptical-shaped tube through which de-ionized water flows for cooling. The deflector operates in the range 30-90 kv depending on the type of ion and accelerated ion energy. The electrostatic deflector (septum and deflector) is hinged supported on the dee tank side wall for easy removal and replacement.

The beam exiting from the electrostatic deflector enters the magnetic deflector. The field of the magnetic deflector opposes the main magnet field in the vicinity of the emerging beam so as to properly direct the beam out of the machine. The magnetic deflector operates at approximately 40 volts and 1000 amps; the magnet coils are cooled with de-ionized water.

6. Radial Beam Probe and Defining Slit Assembly

An assembly consisting of a moveable beam probe and a fixed beam-defining slit penetrates the vacuum tank and runs parallel to and midway between the two dees extending to near the center of the cyclotron. The beam probe is an electrically insulated water-cooled block which can be remotely positioned for radial traverse of the beam current. The beam probe is used in the operation of the cyclotron for diagnostic purposes. With the probe/slit assembly in position, the beam defining slit is in a fixed position near the center of the cyclotron. The beam particles, in making a ½ turn after emergence from the puller, pass through the beam defining slit in beginning the orbital motion to the radius of extraction from the cyclotron.

7. Vacuum System

The vacuum tank consists of an assembly of thick flat aluminum plates with both welded and gasketed joints which permit easy access to the interior of the cyclotron. During cyclotron operation, the vacuum tank is maintained at vacuum by two 16-inch oil diffusion pumps and one titanium ion pump. During normal operation, the vacuum is in the range 8 to 12×10^{-6} Torr. Loss of tank vacuum will cause an alarm to sound and interrupt cyclotron operation. Even before the alarm level is reached there will be operating difficulties, such as loss of beam and arcing.

8. Cooling System

All those components of the cyclotron which encounter either electrical or beam heating are provided with water cooling from a closed loop cyclotron-water system. This system, which is all non-ferrous, circulates distilled/de-ionized water and has flow switches in each branch of the system. Interlocks activated by the flow switches give an alarm and prevent operation of any component subject to interruption of the cooling flow.

C. Cyclotron Control System

The initial RF tuning is performed manually in the equipment room as required everytime the RF frequency is changed. All other cyclotron controls are provided at the control console. The ion source and the RF voltage level are turned on and adjusted manually. All other cyclotron controls are stepping-motor driven through a two-step procedure, namely, (1) first selecting the variable to be changed, and (2) changing the variable via the "INCREASE" or "DECREASE" pushbutton.

The control system is a system of interlocks with suitable time delays which function in a manner resulting in auto-sequencing of the cyclotron subsystems. The control system simplifies cyclotron startup, partial shutdown and complete shutdown procedures. Through the auto-sequencing interlock feature, the operator may request any of three states:

1. START

The START command sets the stepping-motor controlled variables to preset values which may be the values set just prior to the previous cyclotron shutdown. Hence, the START command will perform all operations necessary in starting the machine up to but not including raising the anode voltage for the final stage of RF amplification and turning on the ion source (which as indicated above are performed manually).

2. HOLD

The HOLD command stops all auto-sequencing, thus holding all machine subsystems in the then existing state. An annunciator trip will automatically put the machine into HOLD.

3. STANDBY

The STANDBY command will turn off the machine with the exception of the driver and final amplifier filament power supplies and the cooling systems. Auto-sequencing is also maintained for equipment protection during machine shutdown.

Complete shutdown of the machine is accomplished by turning the ON-OFF permissive key switch to OFF. An additional safety feature of the control system is its monitoring of all power supplies so that, in the event of a power supply failure, the machine goes into a fail-safe mode.

D. Dee Servo Controls

Tuning of the dees and control of the RF voltage amplitude are accomplished by two servo loops. For dee tuning, a signal from a phase detector drives a hydraulic actuator which moves the tuning panel until the anode for the RF "final" amplifier stage is 180^0 out of phase with its grid; when this condition is attained, the load seen by the "final" amplifier tube is purely resistive.

The amplitude servo-control loop compares (1) the sum of the RF voltages to the north and south dees against an amplitude reference; and (2) the RF voltage to the south dee against ½ the amplitude reference. The signal from the first comparison is applied to the amplitude control of the frequency synthesizer; the signal from the second comparison is applied to an equal-amplitude splitter control which adjusts the relative RF signal going to the two separate amplifier chains of the north and south dees.

E. RF Protective Circuitry

During an "ARC", the resultant action of the dee RF amplitude servo-control loop can cause the capability of the amplifier chain to be exceeded. An "ARC" is a momentary short circuit between a dee and any member of surrounding grounded structure. "ARC" protection is provided by detection of the rate of RF amplitude decrease on each dee. Should the RF amplitude decrease at greater than a predefined rate, the RF amplitude on both dees is reduced to zero for about 1 second after which the amplitude is ramped back to the original value.

Vacuum leaks through seals and too low a vacuum level can result in visual glowing of the residual gases in the vacuum tank due to atomic excitation from the interaction with the RF field. Generally a "glow" indicates severe machine problems which must be immediately rectified. An optical "glow" sensor is used to detect the "glow" and its output "GLOW" forms a logical "OR" with the "ARC" signal.

Two additional protective signals are provided and form a logical "OR" with the above "ARC" and "GLOW" signals; these are the "RF excitation" signal and the "Deflector ARC" signal.

F. Cyclotron Alarm System

The cyclotron is equipped with an extensive system of interlocks which monitor cooling water flows, temperatures, voltages, currents, personnel safety devices and vacuum systems; as indicated in Section D above, the system of interlocks functions in a manner to assure that all operations are performed in the proper logical sequence. Failure to satisfy any of the required conditions will result in actuation of an alarm in the cyclotron control room. The alarm consists of an audible signal, which may be quieted by pressing the ACKNOWLEDGE button, and a flashing light on the wall panel which indicates the source of the alarm. On receipt of an alarm signal, the cyclotron control system automatically turns off those systems which might sustain damage and automatically places the remaining systems into a HOLD mode. Following correction of the indicated problem, the alarm system is restored to its normal state by the RESET buttons and the machine may be restarted either manually or by auto-sequencing.

G. Description of Beam Transport System

Figure 4 is a plan view of the external horizontal beam transport system. Identified in Figure 4 are the various beam line components which include the bending and steering magnets, focusing quadruple magnets, beam stops, apertures, beam-defining jaws/aperture assembly, viewers and beryllium target assembly (which includes the water-cooled target, dual monitor ion chambers and light beam). Figure 4 also indicates that portion of the beam line and components which are common to both the horizontal and vertical beam transport system. Figure 5 is a view in the vertical plane of the vertical beam transport system, up to but not including the portion of the beam line which is common with the horizontal beam transport system.

H. General Precautions

The cyclotron is capable of producing potentially lethal radiation levels, and requires at many points large electrical voltages. Specific danger areas are noted as applicable in each of the maintenance procedures described in this manual. Additional safety information for the cyclotron as a whole is contained in the cyclotron safety manual, available in the cyclotron control room.

II. STARTUP PROCEDURES

A. Prestart Checks

1. Check control room annuciator panel and main vacuum system panel for indications of malfunction.

2. Walk through cyclotron vault, checking machine and related equipment for any obvious mechanical or electrical failure. This check should actually be made immediately following step B-1 of STARTUP.

3. Clear the cyclotron vault of personnel and close the interlocked gate and water door.

B. Startup

1. At the cyclotron control panel, turn the OFF-ON permissive key to the ON position and press the auto-sequence START button. The auto-sequence logic will carry the machine up to but not including the point of raising the final anode voltage and of turning on the ion source.

2. Obtain values of the RF and trim coil settings.

   a. If a previously run beam settings will appear in log.

   b. If a new beam, execute computer program PART to obtain the proper settings to be used.

3. Check or set frequency on frequency synthesizer.

4. Check settings and polarity for profile coils using listing in log or from computer program.

5. Check tuning panel settings using listing in log or from computer program (see Energy or Frequency Change: Section III).

6. Raise final anode voltage (VM130) on console control panel to 10 kilovolts.

7. Turn on RF excitation, console panel H645. CAUTION: Coarse-turn helipot must be turned all the way down before this step.

8. Raise RF excitation level control (console panel H642) in steps while checking tuning at each step and begin conditioning RF system. CAUTION: Assure RF reasonably well tuned at low excitation level before raising level.

9. Raise final anode voltage to operating value. NOTE: This step should be done when the RF excitation level is at an intermediate value known by experience to be safe.

10. Raise voltage on electrostatic deflector (VM124) to intermediate value and condition deflector.

11. Move the beam probe (VM134) to approximately a 10-inch radius.

12. Turn on the ion source filament (cabient H606) and raise the filament current (VM131, console panel H643) to approximately 4 amps.

13. Turn on the ion source

    a. Turn on the gas supply.

    b. Turn on the arc supply. The arc should strike, giving an indication of beam on the beam probe.

    c. Set arc current to give required value of beam current on probe.

14. Raise deflector voltage to operating value.

15. Adjust the main magnet (VM2 and VM8) and relative RF phase between north and south dees to maximize beam on the probe.

16. Slowly remove the beam probe to outer position while adjusting main field and harmonic coils as necessary to maintain beam current on the probe.

17. With beam probe at maximum radius, beam will appear on external beam stop. Maximize beam on external beam stop by adjusting:

   a. RF amplitude
   b. Main magnet
   c. Inner and outer harmonic coils
   d. Magnetic deflector current
   e. Electrostatic deflector voltage.

III. PARTICLE ENERGY OR RF FREQUENCY CHANGE

Personnel required: one qualified operator.

1. Turn the machine on up to but not including the point of raising the final anode voltage and of turning on the ion source (see Section II).

2. Obtain computer printout of proper magnet current settings for energy or frequency required.

3. Set frequency synthesizer to required frequency.

4. Set all magnets (main magnet and profile coils) at computer supplied values.

5. Set tuning panel controls according to log for the required frequency. If the required frequency has never been run before, set tuning panel controls (VM46, VM47) to approximately 6.0volts.

6. Set driver amplifier tuning (VM120, VM121) to level indicated on log. If required frequency has not previously been run, an initial approximate setting can be used at this step by interpolating between known settings for other frequencies. Fine adjustment of the tuning can be made later.

7. In the equipment room, cabinet H530, set:

   a. Phase control switch to "OFF".

   b. Phase potentiometer full counter clockwise.

   c. Amplitude control to "MANUAL".

   NOTE: This step places the phase control circuit in manual.

8. Apply RF voltage excitation in the cyclotron control room. Raise excitation to approximately 80 on the coarse helipot dial.

9. In the equipment room, cabinet H530, set COARSE REFERENCE to level previously logged. If settings are not available for the required frequency, adjust COARSE REFERENCE potentiometer until north or south RF READY lights in cabinet H530 flicker. When this has been accomplished, adjust the FINE potentiometers in cabinet H530 for north and south until READY lights are on continuously. NOTE: Upon completion of this step the dees are tuned.

10. Turn off RF EXCITATION (in equipment room or cyclotron control room).

11. In equipment room:

a. Return phase control potentiometers to approximately 10 o'clock position.

b. Place phase control switch in ON position.

c. Place amplitude control in AUTOMATIC position.

NOTE: Upon completion of this step, the phase control system is back in the automatic mode.

12. Turn on RF excitation.

13. Fine tune driver stages and tuning panels.

a. Driver tuning: Observe power amplifiers, cabinet H612. Adjust north and south drivers (VM120, VM122) to obtain minimum readings on power amplifier meters.

b. Tuning panels: Observe ANODE/GRID phase meters (cabinet H642). Adjust north and south tuning panels (VM46, VM47) until meters match marks.

14. To continue startup, now that frequency change and RF tuning has been accomplished, proceed as outlined in Section II starting with step 8.

IV. ION SOURCE REMOVAL

Personnel required: two.

A. At the cyclotron control console:

1. Turn the ARC SUPPLY to OFF.
2. Turn GAS SUPPLY to OFF.
3. Turn FILAMENT CURRENT to OFF.
4. Turn RF EXCITATION to OFF.
5. Place AUTO-SEQUENCE in HOLD.

B. At the source location (atop main magnet yoke)

1. Close gas valves on gas line to ion source.
   - a. On top of ion source plug.
   - b. Inside the ion source plug.
2. Disconnect gas line coupling.
3. Remove filament power lines.
4. Remove water lines.

C. Extract ion source.

1. Connect power lift cable.

2. Prior to lifting, observe the position of pointer, so that ion source may be returned to same position.

3. Slowly retract power cable to raise ion source.

<u>CAUTION</u>: DURING LIFTING, ROTATE THE ION SOURCE SO THAT IT CLEARS DEES AND ION SOURCE CONTROLLER.

a. Raise the ion source to a height of 49¼ inches, measured from the lower side of the ion source position motor base to the bottom of the copper block of the ion source.

<u>CAUTION</u>: REMOVAL TO A GREATER HEIGHT WILL ALLOW AIR TO ENTER THE MACHINE.

4. Close vacuum valve.

5. Finish removing the ion source stem manually.

D. Service ion source.

1. Separate filament stem from ion source.

2. Replace filament and clean hood.

3. Reassemble filament stem and ion source. Use care in assembly, filament is extremely brittle.

E. Replace ion source.

1. Place stem in vacuum lock, and evacuate the lock. When proper vacuum is obtained, close rough pump valve and open machine vacuum valve.

2. Slowly insert ion source into machine, being careful to rotate the ion source and to locate position pointer properly.

3. Connect ion source gas line. Gas line must be evacuated before gas valves are opened.

a. At gas cabinet, open 2 pump out valves. When thermocouple indicates a sufficiently low pressure, gas valve at the top of the ion source plug may be opened. This will evacuate the section of line between the gas shutoff valves.

b. When the pressure in this section of line is low enough, close the pump out valve.

4. Open the gas valve at the ion source.

5. Connect water lines.

6. Connect filament power lines.

V. REMOVAL OF PROBE AND ONE-HALF TURN SLIT ASSEMBLY

Personnel required: three.

CAUTION: RADIATION AND CONTAMINATION WILL BE ENCOUNTERED. PREPARATIONS SHOULD BE MADE TO PREVENT UNNECESSARY EXPOSURE OF PERSONNEL AND TO PREVENT THE SPREAD OF RADIOACTIVE CONTAMINATION.

A. Turn off ion gauges.

B. Turn off titanium ion pump.

C. Vent machine to nitrogen atmosphere.

D. Set up overhead crane.

E. Remove power lines, control lines, and limit switch lines.

F. Make sure probe stand is fastened to probe removal harness.

G. Remove bolts from probe flange.

H. Extract probe, pulling back to stop.

I. Carefully remove stop and pull probe back to get only one wheel off the monorail. Insert stop.

J. Connect crane to probe lifting harness.

K. Remove stop.

L. Carefully remove probe and slit assembly. During this operation personnel are required as follows:

  1. At the crane control.
  2. To counterbalance the probe.
  3. To guide the probe and slit assembly during extraction.

M. When probe assembly is clear of machine, it may be placed on stand or cart as required.

N. To replace the assembly, steps A through M are performed in reverse order.

0. On replacement, the separator at the probe tip must fit around a vertical pin protruding from the lower profile coil platter. This can be observed through the window on the side of the machine opposite where the probe is inserted. When the prongs extending from the probe tip have encased this pin, the probe is properly aligned and completion of assembly can be undertaken.

VI. REMOVAL OF DEFLECTOR AND SEPTUM

Personnel required: two.

CAUTION: RADIATION AND CONTAMINATION WILL BE ENCOUNTERED DURING THIS OPERATION. PRECAUTIONS SHOULD BE TAKEN TO PREVENT UNNECESSARY EXPOSURE OF PERSONNEL AND UNNECESSARY SPREAD OF RADIOACTIVE CONTAMINATION. AREA SHOULD BE SURVEYED BY HEALTH PHYSICS PERSONNEL.

A. Shut off water to deflector and septum. Valves are located in south hydro cabinet. Supply valves are 13 and 14; return valves are 18 and 5.

B. Drain and blow out water lines.

C. Turn ion gauges off.

D. Vent tank to nitrogen atmosphere.

E. Remove locating pins at lower left and upper right corners.

F. Slowly pull plate outward from left side while sliding plate to the right. This motion will permit the deflector tip to clear the box opening.

G. Upon removal, have deflector and septum tip surveyed by health physics personnel.

VII. PROBE REMOVAL

Personnel required: two.

CAUTION: RADIATION AND CONTAMINATION WILL BE ENCOUNTERED DURING THIS OPERATION. PRECAUTIONS SHOULD BE TAKEN TO PREVENT UNNECESSARY EXPOSURE TO PERSONNEL AND TO PREVENT SPREAD OF RADIOACTIVE CONTAMINATION.

A. Shut off water and remove water lines.

B. Remove current pickup leads.

C. Position the probe approximately 3/4 extracted.

D. Remove two Allen head set screws located at the rotational gear drive assembly.

E. Gently lift and rotate rear portion of probe. (Observe gear location and placement position of nylon block.)

F. Slowly extract probe until it seats in air lock chamber located just below the lifting harness.

G. Close and vent air lock.

H. Remove quick, disconnect clamp and finish removing probe.

I. To insert probe, perform steps A through H in reverse order, pumping out the vacuum lock at the appropriate point.

VIII. DEE REMOVAL

Personnel required: three.

CAUTION: RADIATION AND CONTAMINATION WILL BE ENCOUNTERED. ALL NECESSARY PREPARATION AND PRECAUTIONS MUST BE TAKEN TO PREVENT THE SPREAD OF CONTAMINATION.

The area should be covered with plastic. Personnel should wear protective clothing; hats, coats, and gloves are available from health physics. Area should be monitored by health physics personnel.

A. Turn off all ion gauges.

B. Turn off titanium pump.

C. Vent cyclotron tank to nitrogen atmosphere.

D. Remove probe stand (refer to Probe Removal-Section VII.) If dees are to be only partially removed the probe may be only partially retracted and supported by the probe harness.

CAUTION: THERE IS INSUFFICIENT ROOM FOR COMPLETE REMOVAL OF THE DEES WITH THE PROBE STAND IN PLACE.

E. Disconnect water at the north side lower rear of the tuning panel box. (Two quick disconnects)

F. Disconnect flow switch connectors: Two Cannon plugs located at the middle of the carriage on the south side and forward of the carriage on the north side.

G. Disconnect air lines: south upper between rear plate supports.

H. Disconnect vacuum line at same location as item G.

I. Disconnect coaxial line at same location as item G.

J. Disconnect two photomultiplier located on lower window of both north and south removable panel.

K. Remove north and south vacuum cover plates.

CAUTION: TANK INTERIOR IS A NITROGEN ATMOSPHERE, VENTILATE WELL BEFORE ENTRY.

L. Disconnect RF transmission line from dee tie bar, both north and south. Exercise care on removal. Tie bar is two pieces with a slip fitting.

M. Removal of transmission line and shield from both north and south RF boxes.

1. Shut off water to each box.

2. Disconnect water to transmission line.

3. Disconnect power lead from coupling capacitor to transmission line.

4. Remove six Allen head set screws and four round head machine screws. Remove copper ground plate.

5. Remove three Allen head set screws.

6. Remove hold down plate.

7. Shield must now be disconnected from dee. Return to lower level.

a. On the forward side of the shield (toward the dee tip), loosen two round head Allen screws (DO NOT REMOVE).

b. Remove two ¼-20 hex head cap screws located at the other end of the shield "L" bracket.

8. Working again on the upper level, with an assistant on the lower level, slowly remove the transmission line by lifting the line with the glass insulator still intact. Assistant should simultaneously lift and tilt the shield for easy removal.

9. Install lifting Jack on shield and raise shield (make sure support legs are installed).

N. Remove tuning panel hinge from dees. There are four hinges: north upper and lower, south upper and lower. Each hinge contains twenty-four 11/32" nuts. Exercise care not to puncture or tear the hinges.

O. Remove four ¼-20 hex head cap screws from the center separator tie point to the north and south dees.

P. Remove the ion source. Refer to Section IV. Ion Source Removal.

Q. Manually position the tuning panels to approximately 45 degrees.

R. Install the tracks for dee removal on the cyclotron room floor.

S. Remove the bolts from the rear plate.

IF STEPS A THROUGH S HAVE BEEN COMPLETED THE DEES ARE NOW READY FOR REMOVAL. RECHECK STEPS A THROUGH S PRIOR TO PROCEEDING FURTHER.

T. Slowly insert the Jacking screw, located in the south lower corner of the dee carriage. This will pull the rear plate from the guide pins. When the rear plate is clear of the guide pins, the dees can be removed by pulling the carriage along the track. Do not permit any unnecessary vibration of the dees during retraction.

IX. OPERATION OF HELIUM-3 (3He) RECOVERY SYSTEM

Personnel required:

The following procedure is intended to prevent accidental loss of valuable 3He gas. Refer to the 3He system diagram given in Figure .

A. Startup

1. Make certain the liquid nitrogen (LN2) dewar is adequately filled, then turn on the LN2 filling system for the adsorption pump.

2. The hand valve to the mechanical pumps should be closed; the hand valve to the adsorption pump should be open. Turn on mechanical pumps.

3. When adsorption pump LN2 reservoir is full, close forepump valve by holding forepump OFF button pressed until forepump stops. Then open adsorption pump electropneumatic valve. Watch foreline pressure to make sure adsorption pump is working. Foreline pressure should not exceed 200 microns.

4. Close the gas valve from the normal gas bottle and open the gas valve to the 3He system. 3He is now available to the ion source gas control system.

B. Shutdown

1. Close the gas valve to the gas control system. Wait 15 minutes for all the gas to be reclaimed.

2. Close the adsorption pump electropneumatic valve and turn on the forepump. The forepump valve will open when the forepump is working properly.

3. Turn off the LN2 filling system and allow the adsorption pump to warm up. Six to eight hours may be required. Continue running mechanical pumps during warmup.

4. After the adsorption pump is completely warm, close the hand valve to the mechanical pumps and turn the pumps off.

CAUTION: THE 3HE GAS IS NOW TRAPPED BETWEEN THE HAND VALVE TO THE MECHANICAL PUMPS AND THE HAND VALVE TO THE ION SOURCE GAS CONTROL SYSTEM. DO NOT USE THE SYSTEM EVACUATION PUMP. THE SYSTEM EVACUATION PUMP IS FOR MAINTENANCE ONLY.

X. PULLER CHANGE

Personnel required: two.

CAUTION: RADIATION AND CONTAMINATION WILL BE ENCOUNTERED. PRECAUTIONS SHOULD BE TAKEN TO PREVENT UNNECESSARY EXPOSURE OF PERSONNEL AND TO PREVENT THE SPREAD OF RADIOACTIVE CONTAMINATION.

A. Turn off all ion gauges.

B. Turn off titanium ion pump.

C. Vent tank to nitrogen atmosphere.

D. Retract ion source approximately one foot.

E. Remove positive beam exit port.

CAUTION: TANK INTERIOR IS NITROGEN ATMOSPHERE. VENTILATE IF NECESSARY.

F. Using special tools designed for this particular operation completely loosen 2 Allen head set screws.

G. Insert dee spreader at puller.

H. Using proper tool, pull the puller towards the exit port.

I. Relocate dee spreader as necessary.

J. Manually remove puller.

K. Rotate ion source plug to proper position for puller being installed.

L. Install new puller by reversing procedure.

CAUTION: DO NOT DROP SCREWS OR PULLER INTO TANK.

M. In the cyclotron control room, cabinet H612, change the inline transformer on north power amplifier box. Transformer is used for N = 1 mode and removed for N = 2 mode.

NEUTRON THERAPY TREATMENT PROCEDURES & CONTROLS

The following is a brief description of the tentative procedures to be followed, and equipment to be utilized in the treatment of patients using the fast neutron therapy facility currently being constructed at the Lewis 69" cyclotron.

I. DOSE MONITORING HARDWARE. Primary monitors of delivered dose will be a pair of ionization chambers located directly behind the beryllium target, and designed so that any neutron flux reaching the patient must pass through both chambers. (See Figure 1). Secondary measurements of the dose will be provided by the measurement of the integrated deuteron beam incident on the beryllium target.

II. DAILY CALIBRATION. The primary monitors (ionization chambers IC1 and IC2) will be calibrated at least daily against a standard ionization chamber which will be located during this calibration at the patient position. The response of this standard chamber (rads/microcoulomb) will have been determined previously by comparison with NBS standards, and by intercomparisons with other facilities involved in fast-neutron therapy, as well as periodically against a standard source. The daily calibration of IC1 and IC2 then enables the clinic personnel to interpret the output of IC1 and IC2 in terms of dose at the patient position. The data from this daily calibration, including corrections for atmospheric pressure and temperature variations will be recorded on a form similar to that shown in Figure 2, which is that used at the Texas A & M facility.

III. PREPARATION. The required treatment parameters (total dose, field size, filters, depth dose factors, etc.) will be determined by Cleveland Clinic personnel and recorded on a form similar to that shown in Figure 3 (again, that used at Texas A & M).

IV. TREATMENT.

A. Control Panel. Treatment will center about the neutron control panel, located approximately 50 feet from the treatment room, and 150 feet from the cyclotron control room. A sketch of the tentative design of the control panel is shown in Figure 4. The items there have the following functions:

1. Controls

   i. Local-Remote Pushbutton. In local mode, this button will disable all other mechanisms for turning on the neutron beam. In particular, it will be impossible for the cyclotron operator in the cyclotron control room to open the beam shutter. (Hard-wired to beam-stop logic).

   ii. START pushbutton. A spring-loaded key which will turn on the neutron beam, provided all other requirements are satisfied. These other requirements will be determined by the PDP-15 computer, and include a signal from the operator that the cyclotron is ready, and closure of all interlocks, indicating that the treatment area is secure against entry by any personnel. (computer input)

iii. HOLD pushbutton. This permits the therapist to temporarily interrupt treatment, closing the beam shutter, and allowing entry into the treatment room. In this condition, no data is recorded, scalers and counters are not zeroed, and the run may be restarted following interruption. (computer input).

iv. STOP pushbutton. This control allows the therapist to terminate the treatment at any time, with automatic recording on magnetic tape of all pertinent data. (computer input).

v. RESET pushbutton. This control zeroes all counters and scalers. Another treatment may not be initiated until this is carried out. (computer input)

vi. EMERGENCY OFF pushbutton. This control actually turns off the cyclotron itself. It is hard-wired, rather than computer controlled.

vii. Preset Dose. A thumbwheel switch which allows the user to select the required dose. The reading of this set of switches is wired as input to the computer.

2. Digital Information Output.
   - i. Integrated dose. A live display of the dose in rads which has been administered is provided. This quantity is calculated by the computer using the output of IC1 and IC2, and the results of the morning calibration.
   - ii. Integrated beam current. Calculated by the computer using the output of one of the voltage to frequency converters.
   - iii. Irradiation time. The total beam-on time for the treatment.
   - iv. Time of day and day of the year.
   - v. The collimator number. A coded patch plug, attached to each of the interchangeable collimators will provide the user with indication of which collimator is actually in place.
   - vi. Filter number. Same as collimators.
3. Status lights.
   - i. Neutrons On. Flashing light
   - ii. Cyclotron Ready. Determined by cyclotron operator.
   - iii. Run status:
     - a. Run terminated automatically because IC1 (or IC2 or integrated beam) indicated that preset dose had been reached.'
     - b. Run terminated by therapist.
     - c. Run terminated by cyclotron operator.

d. Run holding--therapist

e. Run holding--cyclotron down.

iv. Equipment status.

a. Beam misaligned on beryllium target: vertical and horizontal unbalance indicators (meter and alarm lights)

b. High Voltage indicators for ionization chambers.

c. Total beam on target meter

B. TREATMENT PROCEDURE

1. Computer-controlled operation (normal mode)

Following the morning calibration, the therapist will load the software which will control treatment. The computer will request (via a teletype console) the results of the morning calibration, so that it may calculate dose directly. Thereafter the computer will request a patient number, name, and any comments which the therapist may wish to record. Other data requested will include the preset dose, the requested collimator number, and filter number. In each case, the program will proceed no further until the requests via the teletype agree with the requests made via the control console thumbwheel switch (for the preset dose) or with the collimator and filter actually in place (as indicated by patch plugs). Once agreement has been reached the computer will echo all data to the therapist, asking again for confirmation. At this time, provided a "cyclotron ready" signal has been received, and provided all safety interlocks are satisfied, the computer will type the message "TURN KEY TO START TREATMENT." At this point treatment may be started by turning the key. Treatment will then continue, unless interrupted, until IC1 indicates that the preset dose has been reached, at which time the deuteron beam will automatically be turned off. At termination all data will be automatically recorded on tape. Upon execution of a RESET request from the control panel, all counters, scalers, and displays are zeroed, and the software is recycled, requesting new input data for the next patient.

2. Redundancy

i. Computer backup. In the event the primary monitor (IC1) fails to terminate the run when the preset dose is achieved, the second ionization chamber (IC2) will terminate the run when 1.02x the preset dose is reached, and the beam current integrator will terminate the run if 1.05x the preset is reached. Such a scheme protects against failure of the ionization chambers or the equipment associated with any one of them.

ii. Hard-wired backup. In the event of a malfunction by the computer, two preset scalers have the capability of closing the beam shutter. The preset for these scalers is in terms of counts of the ionization chambers rather than in rads.

3. Non-Computer Controlled Operation

In the event of computer failure, operation is still possible, although with the loss of some redundancy and considerable convenience. Losses would be as follows:

i. Automatic checks of collimator and filter.
ii. Forced "second look" at requested preset dose.
iii. Live displays of integrated dose.
iv. Recording of data on magnetic tape.
v. Ability to request doses directly in rads.

The mode of operation necessary would now be as follows:

i. Preset dose on the two control panel scalers. This must be in units of ionization chamber output rather than rads.
ii. Check in the treatment room to see that filters

and collimators are those desired.

iii. To open the beam shutter, go to the "remote" rather than "local" mode, and have cyclotron operator open shutter on request.

iv. Closing of shutter would be by one of the two console scalers as described under Redundancy in the event of computer failure.

C. EMERGENCY SHUTDOWN

In either computer-controlled or manual mode of operation, the EMERGENCY OFF pushbutton will immediately shut down the cyclotron, thereby immediately stopping all delivery of treatment to the patient, as well as making the treatment room immediately accessible to all personnel.

V. PROTECTION OF PERSONNEL

1. Access to the treatment area will be either from the cyclotron control room or from the neutron control room. There locations are indicated in Figure 5. Both of these paths of entrance will be guarded by physical barriers (gates or doors) which must be closed before any treatment is possible. Both barriers will be electrically interlocked with the beam shutter so that no treatment is possible unless both have been secured, and so that treatment will be interrupted should either one be opened during irradiation.

2. The neutron control room will (tentatively) be equipped with area monitors, and all personnel working there will be badged (Cleveland Clinic personnel monitored by the Clinic).

   Preliminary measurements indicate that with the neutron control room shielding door closed, the radiation level in that area will be less than 2.5 mR/hr.

V. APPROVAL OF DESIGN

At this time Cleveland Clinic personnel have examined these proposed designs and procedures, and have tentatively approved of the equipment and methods described here.

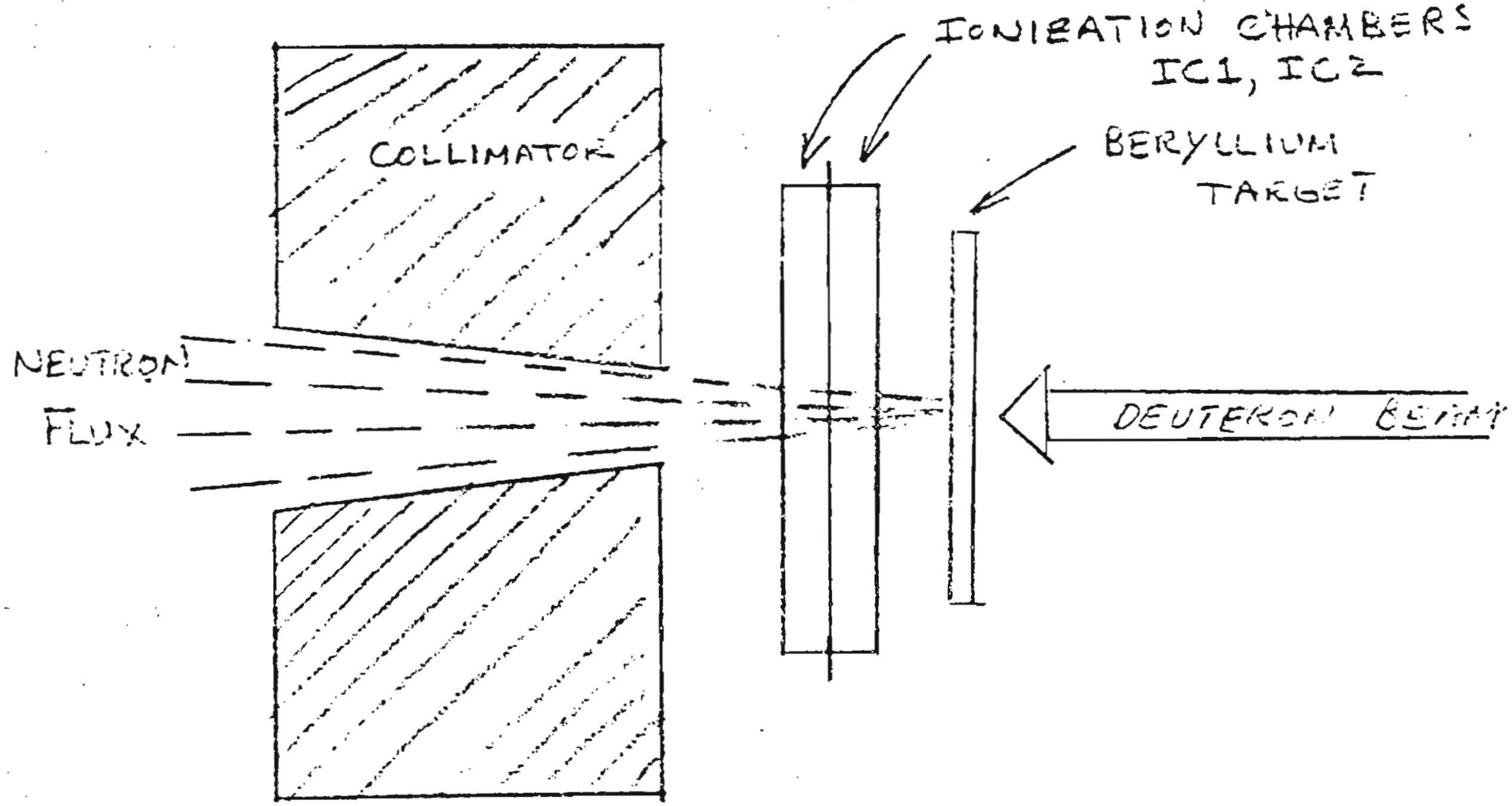

IONIZATION CHAMBERS
IC1, IC2
BERYLLIUM TARGET
COLLIMATOR
NEUTRON FLUX
DEUTERON BEAM

FIGURE 1

name ______________________ date ______________ ______

projectile type __________ beam energy __________ MeV target current __________ μA

target type __________ thickness __________ ID ______ guard ring __________ nA

focus ring left __________ nA right __________ nA top __________ nA bottom __________ nA

collimator ID __________ size __________ cm h × __________ cm w at __________ cm SSD

calibration chamber ID __________ placement __________

____

W_n = __________ eV S_n = __________ R = __________ M_o = __________ mg at 760 mmHg, 22°C

$K = \frac{W_n S_n}{10 R M_o} \times \frac{Q_1}{Q_c} \div \frac{D_1}{D_m}$ = __________ × __________ ÷ __________ = __________ $\frac{\text{rads}}{\text{nC}}$

barometer temperature __________ °C temperature correction __________ mmHg

barometer reading __________ mmHg gravity correction __________ mmHg

P = barometric pressure = __________ __________ = __________ mmHg time __________

T = chamber temperature = __________ °C + 273.2 = __________ °K time __________

C = T-P correction = (760/P)(T/295.2) = __________

INT	#___	#___		#___	#___	Timer
scale	______	(______)		______	______	(sec)
run #	TC #1	cal.cham.	bkg	TC #2	target	time
1						
2						
3						
4						
5						
6						
7						
total		----	----			

Qc = $(10^9) \times$ (__________ - __________) × (__________) = ---- nC

Dm = (K)(C)(Qc) = __________ × __________ × __________ = __________ rads

calibration date __________ today % change ratios

$C_1 = D_m/m_1$ = __________ rads/u; = __________ rads/u: ______ m_2/m_1 = __________

$C_2 = D_m/m_2$ = __________ rads/u; = __________ rads/u: ______ m_3/m_1 = __________

$C_3 = D_m/m_3$ = __________ rads/u; = __________ rads/u: ______ m_3/m_2 = __________

$C_T = D_m/m_T$ = __________ rads/s; = __________ rads/s: ______ m_3/m_T = __________

calculated by __________ checked by __________ comments __________

____

____

____

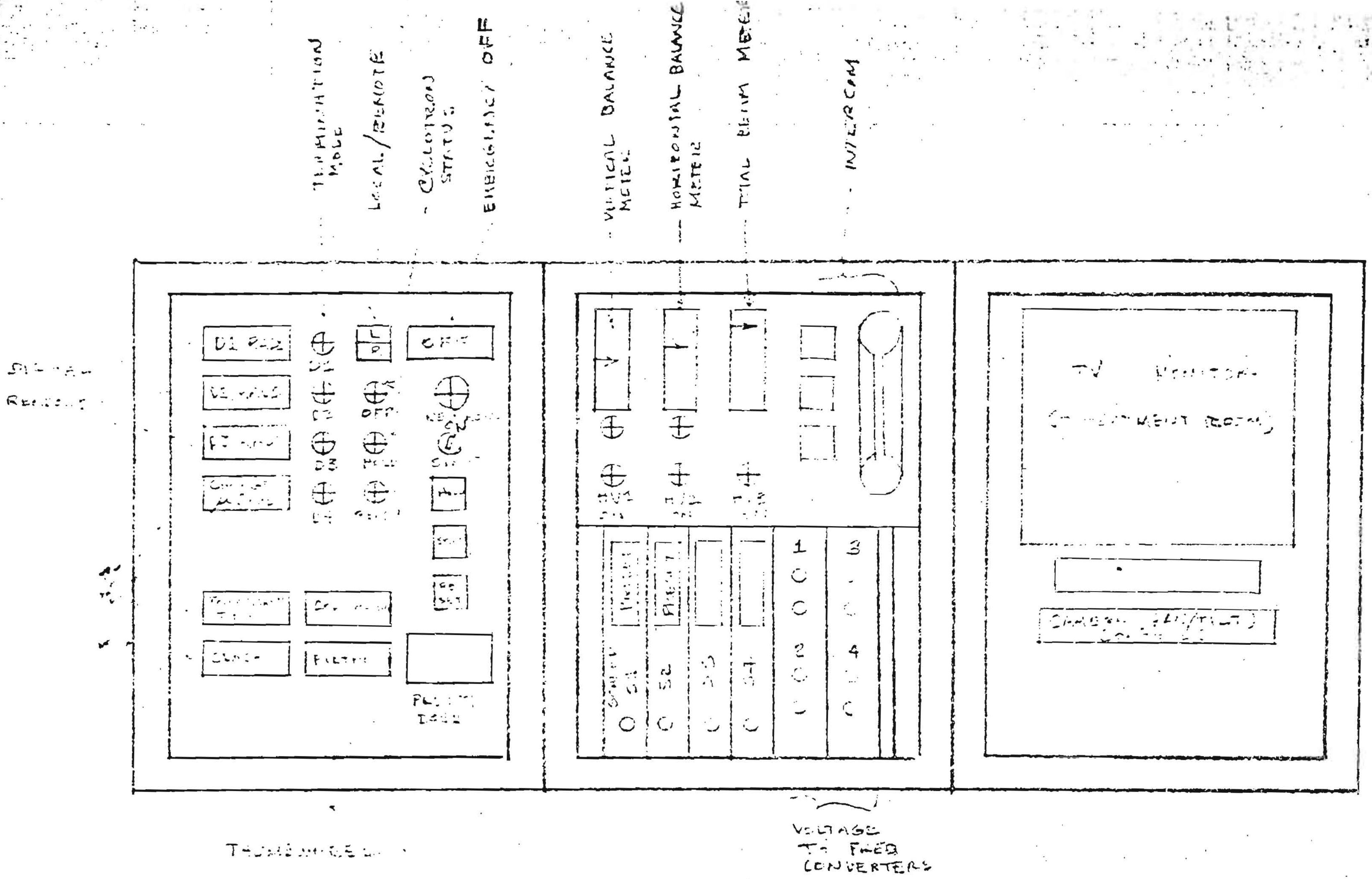
FIGURE 2

name ____________ number ____________ date ____________

field locations ____________

field shaping ____________

field ID & treatment #				
beam & wedge				
collimator ID & SSD (cm)				
field size (cm x cm)				
field size factor $\boxed{F}$				
tumor depth (cm)				
depth dose factor $\boxed{D}$				
"tumor dose" t(rads)				
"given dose" Dg = t/D				
mu_1 = (Dg)/C_1/F – – →				
mu_2 = 1.02 (Dg)/C_2/F – – →				
mu_3 = 1.05 (Dg)/C_3/F – – →				
treatment time	m s	m s	m s	m s
m_1 – – – – – – –				
m_2 – – – – – – –				
m_3 – – – – – – –				
time of day finished	h m	h m	h m	h m
given dose [m_1C_1F]				
tumor dose ( )(D)				
previous given dose				
previous tumor dose				
total given dose				
total tumor dose				
comments	C S T	C S T	C S T	C S T



NEUTRON CONTROL PANEL

FIGURE. 4

JOB NO.

CHKD. BY .... DATE

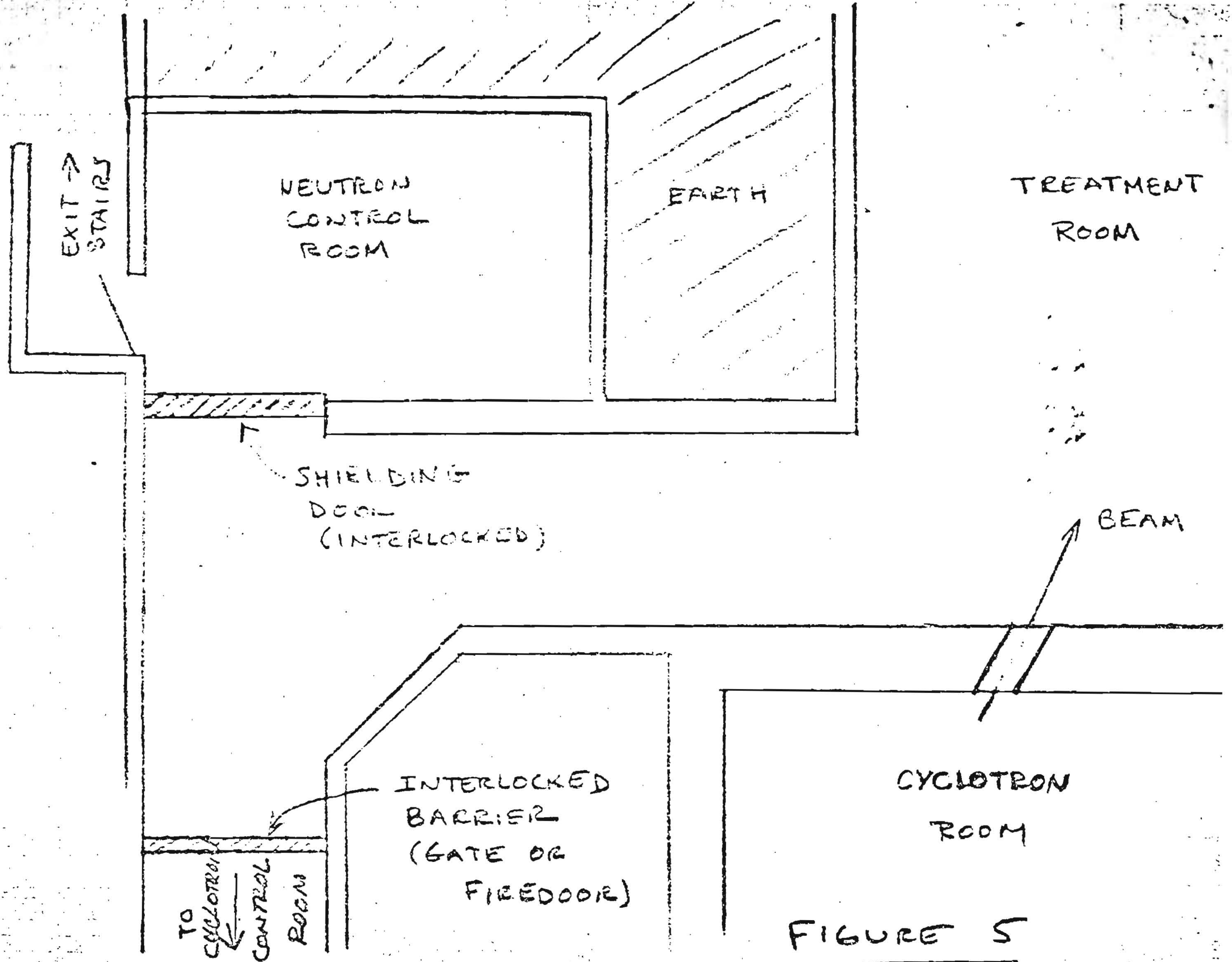


FIGURE 5

PROCEDURE FOR INSTALLING AND REMOVING COLLIMATORS

Prepared by William K. Roberts Date 1/22/78

Reviewed by ____________ Date ____________

1/18/78

PROCEDURE FOR INSTALLING AND REMOVING COLLIMATORS

I. Installation, Vertical Facility

1. Insure therapy room is neutron safe.
2. Take the desired collimator from the collimator rack and set it on the support stand which is mounted on the yellow lift cart. Orient the collimator on the support stand so that it is in its approximate final orientation when subsequently inserted into the delivery port. Install the split aluminum safety ring on collimator so that the split line is approximately North-South with respect to the final collimator orientation.
3. Run safety hand-wheel cranks (2) to full counterclockwise positions.
4. Place collimator clamps in open position.
5. Position both block arms so they will not interfer with the collimator as it is inserted in the delivery port.
6. Center the lift-collimator assembly under the vertical delivery port.
7. Fast run the lift until the bottom of the collimator is flush with the face of the delivery port. Some recentering of the collimator will probably be necessary during this step.
8. With the fine lift control,further run the collimator up until it seats($\sim$1.5-2 cm).
9. Run safety cranks (2) clockwise until they seat (fully-in position). A light activated by microswitches (one on each safety crank) is illuminated just <u>prior</u> to reaching the fully-in position. Turn counterclockwise by one (1) turn. The light should remain

illuminated; if so, the collimator can now not fall out of delivery port even when the lift cart is removed.

10. Lower lift cart and remove from the immediate area of the vertical delivery system. During this step, the collimator will drop about ½ cm.
11. Rotate the collimator to the proper position.
12. Close the collimator clamps (3). During this step the collimator will be pushed up about ½ cm and be seated.
13. Plug in collimator identification cable.

This completes the installation of a vertical collimator.

II. Removal, Vertical Facility

1. Insure therapy room is neutron safe.

1a. Remove collimator identification cable.

2. Position lift cart with support stand under the vertical delivery port.
3. Position block arms so they will not interfer with the removal of the collimator.
4. Fast run lift cart to within about 1 cm of the collimator.
5. Release the collimator latches (3). During this step the collimator will drop about ½ cm.
6. With slow lift cart control, run lift up until collimator is snug in delivery port. During this step, the collimator will be pushed up about ½ cm.
7. Run safety cranks (2) full counterclockwise.
8. Lower lift cart with collimator sitting on the support stand.

9. Remove aluminum ring from the collimator.
10. Remove collimator from the support stand and store collimator in collimator rack.

This completes removal of a vertical collimator.

III. Installation, Horizontal Facility

1. Insure therapy room is neutron safe.
2. Position block arms so they do not interfer with the insertion of a collimator in the horizontal delivery port.
3. Manually remove collimator from the collimator rack and insert in horizontal delivery port.
4. Orient the collimator to its proper position and push into the delivery port until the collimator seats.
5. Plug in collimator identification cable.

This completes the installation of a horizontal collimator.

IV. Removal, Horizontal Facility

1. Insure therapy room is neutron safe.
2. Remove collimator identification cable.
3. Position block arms so they do not interfer with the removal of the horizontal collimator.
4. Manually remove the collimator from the delivery port and place in collimator storage rack.

This completes removal of a horizontal collimator.

IA. Manual Installation, Vertical Facility

1. Insure therapy room is neutron safe.
2. Run safety hand-wheel cranks (2) to full counterclockwise positions.
3. Position block arms so they will not interfer with the collimator as it is inserted in the delivery port.
4. Place collimator clamps in open position.
5. Install the split aluminum safety ring on the collimator so that the split line is oriented approximately North-South with respect to the final collimator orientation.

   NOTE: Two people are necessary for the following steps of this installation procedure.
6. One person lifts the collimator and carries it to the delivery port positioning himself to the west side of the delivery port. The second person then positions himself on the east side of the delivery port and assists in pushing the collimator up into the delivery port until it seats. Both persons then hold the collimator in position and with their free hand run the two safety cranks clockwise until they seat (fully-in position) and the safety light is lighted. The hand holds may now be released and the safety cranks turned counterclockwise about ½ to 1 turn. The safety light should remain lighted.

7. Rotate the collimator to its proper position and close the three (3) collimator clamps.
8. Plug in collimator identification cable.

IIA. Manual Removal, Vertical Facility

1. Insure therapy room is neutron safe.
2. Remove collimator ID cable.
3. Position block arms so they will not interfer with the removal of the collimator.

   NOTE: Two people are necessary for the following steps of this removal procedure.
4. Release the three (3) collimator clamps and push the collimator up until it is seated in the delivery port.
5. While applying upward hand pressure to keep the collimator seated, turn safety cranks full counterclockwise. Let collimator slowly come down out of the delivery port. Remove the aluminum split rings from the collimator and store the collimator.