CLINICAL NEUTRON THERAPY SYSTEM
Control System Specification

PART III:
Therapy Console Internals

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Contents

List of Tables

List of Figures

Part I

Therapy Console Internals

Chapter 1

About this document

The Clinical Neutron Therapy System (CNTS) at the University of Washington is acomputer controlled cyclotron and neutron therapy treatment facility. This document is the third volume of the functional specification of the CNTS control system. The first volume [1] provides an overview of the CNTS facility and its control system. The second volume [2] contains a detailed description of the user interface.

This document describes the operating environment, hardware, files and internal operations that support the users' view of the therapy console described in chapter 8, "Therapy operations terminal," of volume two.

Chapter 2

Hardware and operating environment

The hardware and operating environment are similar to the description in chapter 4, "Control System Overview," in Volume I in this series [1]. However, instead of a single *cyclotron main computer* (CMC) as described in Volume I, we now have a separate *neutron therapy computer* in addition to the *cyclotron control computer*. The neutron therapy computer handles the hardware interfaces and software functions described in sections 4.4 and 4.5 in Volume I. This document only concerns the neutron therapy computer.

2.1 Therapy computer hardware and system software

The neutron therapy computer itself is similar to the CMC described in Volume I. It is a Motorola MVME167 single board computer with a 68040 microprocessor housed in a VME crate running Wind River System's VxWorks real-time operating system [3][1]. The neutron therapy computer has no disk. All therapy programs and data files must reside on a *remote computer* connected to the neutron therapy computer through Ethernet hardware and TCP/IP software[2]

The neutron therapy computer is located in the power supply room near the other control equipment.

[1]At this writing we plan to use the EPICS library [4] for device control and concurrency, rather than calling VxWorks directly

[2]At this writing the remote computer is a cluster of Hewlett Packard workstations running the HP-UX operating system.

2.2 Therapy operations terminals

There are two *therapy operations terminals* in the control room: one for the isocentric treatment room, and a second one for the fixed beam room. Both are X terminals connected to an Ethernet (not VT100-compatible terminals as described in Volume I).

In the rest of this document, the terms "therapy operations terminal" or "terminal" refer to the terminal for the isocentric room, unless otherwise noted.

2.3 Hardware interfaces

The neutron therapy computer communicates with these devices (see sections 4.4 and 4.5, and Fig. 4.2 in Volume I):

Console A VT100-compatible terminal in the power supply room is connected to the console port. This terminal may be used at system startup, and for certain development and maintenance purposes. It is not used during normal operations.

Remote computer The remote computer is connected via Ethernet. The neutron therapy computer loads its control programs and data from the remote computer, and writes treatment records and log entries to the remote computer.

Isocentric therapy operations terminal This X terminal is connected via Ethernet.

DMC-I The Scanditronix dose monitor controller (DMC) for the isocentric treatment room is connected to an RS232 port.

TMC-I The Scanditronix treatment motion controller (TMC) for the isocentric treatment room is connected to an RS232 port.

LCC The Scanditronix leaf collimator controller (LCC) is connected to an RS232 port.

Fixed beam therapy operations terminal This X terminal is connected via Ethernet.

DMC-F A second Scanditronix dose monitor controller for the fixed beam room is connected to an RS232 port.

TMC-F A second Scanditronix treatment motion controller for the fixed beam room is connected to an RS232 port.

PLC A programmable logic controller (PLC) is connected to one of the RS232 ports.

In the rest of this document, the terms “DMC” and “TMC” refer to the controllers for the isocentric room, unless otherwise noted.

The PLC connected to the neutron therapy computer is a new PLC dedicated to therapy functions, not the cyclotron PLC described in Volume I section 4.2. It is a Modicon 984 that communicates with the neutron therapy computer over an RS232 line using the MODBUS protocol. All discrete digital signals to and from the neutron therapy computer, including interlocks, are interfaced through the neutron therapy PLC. These include signals from the hardwired safety interlock system (HSIS) and cyclotron PLC that (according to Volume I) were to be connected to the CMC through the Input/Output System (IOS). In effect, the new PLC serves as the IOS for the neutron therapy computer.

The cyclotron PLC is also a Modicon 984. Both PLC’s are connected by a Modbus Plus connection, so both PLC’s can be accessed by the neutron therapy computer via its RS232 connection to the therapy PLC.

2.4 Operations

The therapy control program will run continuously, for days or weeks at a time. It must be possible to accommodate normal, expected events without having to restart the control program.

Any of the data files on the remote computer, including files of calibration data, might be changed while the therapy control program is running. Controllers might be powered down, disconnected, and reconnected. It must be possible to accommodate these events and then reread files, reinitialize controllers etc. using normal operations that are always provided by the control program.

The neutron therapy computer together with other critical devices is powered by an uninterruptable power supply (UPS).

Chapter 3

Files

The neutron therapy computer has no disk. All therapy programs and data files reside on the remote computer and are accessed over the network.

3.1 Program files

The network and the remote computer must be operational in order to start up or "boot" the therapy control program. After that, the program remains resident in the neutron therapy computer memory and will continue running even if contact with the remote computer is interrupted.

The therapy operations terminal is an X terminal. It is usual for X terminals to boot from a remote host as well, although it is possible to equip some X terminals with programs in ROM.

3.2 Data files

The therapy control program periodically reads and writes data files on the remote host. It is possible that these files may sometimes be inaccessible, due to problems with the network or the remote computer, or a file itself may be missing, corrupted, or locked by a program that is writing it. If the therapy control program fails to access a file, it displays a warning message. Other operations may proceed. The user may attempt the operation that accesses the file at a later time.

The therapy control program is designed so that as much work as possible can go on even when remote files are not accessible. In particular, data previously read in and data to be written out are usually retained in memory until the next read or write succeeds. Subsequent sections describe when each data file is read or written.

3.3 Prescription file

There is a neutron therapy *prescription database* on the remote computer. This database stores all the patient information and field setups that the therapist can select using the therapy control software operations **Select Patient** and **Select Field**.

3.3.1 Prescription file format

The organization of the prescription database in the new therapy control system described here is exactly the same as in the original Scanditronix control system that it replaces. All of the information on all of the patients and their fields is stored in a single prescription file (In the Scanditronix system this file is named `VAXIN.DAT`). In the new system this file has exactly the same format as in the Scanditronix system. In fact, the same prescription file can be used as input to either the Scanditronix control system or the new system. The treatment planning software that writes the prescription file contents will not need to be changed to accommodate the new control system.

The prescription file format is decribed in Appendix A.

3.3.2 Reading the prescription file

The therapy control program maintains a copy in memory of the all the patients in the prescription file as well as all their treatment fields. This makes it possible to continue operations if the file on the remote computer is unavailable.

There is no explicit transfer operation that the therapist must use to read the prescription file. The control program reads the entire prescription file from the remote computer each time the operator invokes the **Select Patient** operation. This ensures that the patients and fields in the control program will always be up to date with recent changes in the prescription file.

When the operator invokes **Select Patient**, the control program attempts to read the entire prescription file. It does not replace its in-memory patient list until the entire prescription file has been read successfully. If the prescription file on the remote computer is unavailable for any reason (problems with the computer, the network, or the file itself) or the entire file cannot be read, the control program retains its previous in-memory contents. This ensures that the in-memory list is always consistent with the latest version of the prescription file that could be read.

When the operator invokes **Select Field**, the control program uses its in-memory data; it does not read the file on the remote computer. In the unlikely event that the file on the remote computer is updated with new field information for the currently selected patient, the operator must invoke the **Select Patient** operation to reread the file.

If the prescription file is not accessible, or cannot be completely read, the control program writes a message in the on-screen log region, and also writes an entry in the log file, to alert the operator that there is a problem with the prescription file, and the in-memory contents might be out of date. Subsequent operations can proceed using the in-memory contents, and the user can attempt the **Select Patient** operation again later.

There are fixed upper limits to the number of patients and the number of fields that can be stored in memory. These limits are set in the program source code; to change them, it is necessary to edit a program file and rebuild the program[1]. If the data file is larger than can be accommodated in memory, the control program will read as much as it can, and indicate the problem in the log file and the log message area.

3.3.3 Maintaining the prescription file

The therapy control software usually only reads the prescription file (it only writes the file for the **Store Field** operation)[2]. The prescription file is maintained by software that runs on the remote computer. This software is not part of the therapy control system, but it does affect neutron therapy from the operators' point of view so it is described in appendix B.

[1] At this writing the limits are 50 patients and ...

[2] We may implement **Store Field** by having the control program write the new field as a separate file, which is appended to the prescription file by software on the remote computer.

3.4 Experiment fields file

Operators who are physicists[3] can put the control program into Experiment Mode by pressing the Experiment/Therapy mode key on the terminal keypad.

In Experiment Mode, the *Select Patient* operation does not display a list of patients; instead, it shows a list of physicists' names and descriptions of experimental studies. After the operator selects a physicist or study, *Select Field* shows the list of fields for the named physicist or study. The operator can return the program to Therapy Mode by pressing the Experiment/Therapy mode key again (it behaves as a toggle). After the operator switches from one mode the other, no patient (or physicist) and no field are selected[4].

All the experiment data are stored in a single file on the remote computer, which is different from the patient prescription file. However the format of the experiment file is exactly the same as the prescription file, so it can be maintained by the same programs (Prism etc.). Moreover, the therapy control program handles the experiment file in exactly the same way: it reads the entire file into memory each time the operator invokes **Select Patient** etc. The therapy control software merely ignores certain settings in the experiment fields file, as described in Volume II.

3.5 Other files

There are other input files on the remote computer. For each file, there is an operation that causes the file contents to be read into the control program memory. This enables the operator to load new values after the file on the remote computer has been modified. As with other files, memory contents are not replaced until the entire file has been successfully read in, and a failure to open and read the entire file is indicated by a log message on the screen and in a file.

3.6 Calibration data files

These are the calibration data files, and the operations that cause them to be read in:

[3] Physicists are identified from their username when they log into the control program.

[4] The method for selecting modes and physicists (or studies) described here is different from the description in Volume II. We have decided to change the specification.

3.6.1 Dosimetry Calibration Factors

This file contains the values of the all the calibration factors named in Section 8.9.13 in Volume II (including those mentioned on p. 215 that do not appear on the calibration factors display). The file is read each time the operator selects the **Cal Factors** display.

Here are the file contents.

Line	Name	Type	Range	Units	Scand. ID
1	Dose Rate of the Day	integer	0 - 100	mu/minute	RATES
2	Treatment Time Factor	real	1.0 - 2.0	none	n/a
3	Standard Calibration Voltage 1	integer	500 - 800	volts	CVOLT1
4	Standard Calibration Voltage 2	integer	500 - 800	volts	CVOLT2
5	Ion-source Servo Feedback	integer	0 - 32000	none	IONFAC
6	x-plane Current Servo Feedback	integer	0 - 32000	none	XCFACT
7	y-plane Current Servo Feedback	integer	0 - 32000	none	YCFACT
8	Current Servo Maximum	integer	0 - 150	microamp	SERVMAX
9	Current Servo Minimum	integer	0 - 150	microamp	SERVMIN
10	Neutron/Proton Ratio Maximum	integer	0 - 32000	none	HIGHFAC
11	Neutron/Proton Ratio Minimum	integer	0 - 32000	none	LOWFAC

As described in Volume II, the operator can enter several other calibrations factors on this display. However these factors remain in-memory only, they are not written back out to the calibration file.

3.6.2 LCC Calibration Factors

are read in at system startup, and also when the operator selects the **Calibrate LCC** operation. (This operation is not described in Volume II; it has not yet been completely specified). When the calibration operation is complete, the new values are retained in memory, and are also written out to a new version of the LCC calibration file.

Here are the file contents:

Line	Name	Type	Range	Units
1	Calibration Factor, Leaves 1-10	real	0.0 - 2.0	none

2	Calibration Factor, Leaves 11-20	real	0.0 - 2.0	none
3	Calibration Factor, Leaves 21-30	real	0.0 - 2.0	none
4	Calibration Factor, Leaves 31-40	real	0.0 - 2.0	none
5	Minimum Position, Leaves 1-10	real	-150.0 - 150.0	millimeters
6	Minimum Position, Leaves 11-20	real	-150.0 - 150.0	millimeters
7	Minimum Position, Leaves 21-30	real	-150.0 - 150.0	millimeters
8	Minimum Position, Leaves 31-40	real	-150.0 - 150.0	millimeters
9	Maximum Position, Leaves 1-10	real	-150.0 - 150.0	millimeters
10	Maximum Position, Leaves 11-20	real	-150.0 - 150.0	millimeters
11	Maximum Position, Leaves 21-30	real	-150.0 - 150.0	millimeters
12	Maximum Position, Leaves 31-40	real	-150.0 - 150.0	millimeters
13	Calibration Distance, Leaves 1-10	real	0.0 - 150.0	millimeters
14	Calibration Distance, Leaves 11-20	real	0.0 - 150.0	millimeters
15	Calibration Distance, Leaves 21-30	real	0.0 - 150.0	millimeters
16	Calibration Distance, Leaves 31-40	real	0.0 - 150.0	millimeters
17	Tolerance Window	real	0.00 - 2.99	millimeters

The default tolerance window after a reset is 0.90.

3.6.3 TMC Calibration Factors

There is no TMC calibration factors file.

3.7 User authorization file

The user authorization file contains each user's username, password, and indicates whether each user is authorized to select Experiment Mode. This file is read each time the login process begins. If the file cannot initially be read, they system does not lock out all logins; it allows operators to log in with any username and password.

3.8 Log file

The log messages that appear on the display screen are also written to a log file on the remote computer.

If the log file becomes inaccessible the control program continues running normally and the log messages continue appearing on the display — including a message that reports the problem with the log file. A certain number of log entries are retained in memory and can be written out when the file becomes accessible again.

(That means we have to provide an operation that writes out stored log messages. None is described.)

3.9 Treatment record file

The control program writes a treatment record file on the remote computer (the treatment record file is different from the log file described above). A treatment record is written each time the beam turns on or turns off for any reason. Each record includes these items:

- Time stamp
- Operator on duty
- Patient name, other relevant patient ID (or Expriment mode)
- Field name, other relevant field ID
- Prescribed and measured values of all settings, and which settings have been overridden.
- Preset dose and time. Actual doses (measured by both channels) and elapsed time most recently reported by the DMC.
- An indication of the event that caused the beam to turn on or off (for example, the message from the DMC).

It is possible that the treatment record file on the remote computer might be inaccessible. In that case the control program writes a message indicating the problem on the display screen. A certain number of treatment records are stored in memory and can be written out when the file becomes accessible again.

(That means we have to provide an operation that writes out treatment records. None is described.)

The control program provides no operations to view the treatment record file. The treatment record file is a text file so it can be viewed by utilities on the remote computer. There will be programs on the remote computer for preparing reports based on treatment record file contents, but these are not part of the therapy control program itself.

(Do we have one big treatment record file that grows indefinitely, or do we have operations to close the existing file and open a new one?)

3.10 Accumulating dose and treatment fractions

The **Select Field** display shows the treatment fractions and total monitor units actually delivered to date, not just the prescribed fractions and monitor units.

These numbers are not stored in the prescription file, but in a separate output file that is updated after each treatment run. This file is read back in each time the patient is selected.

(There are slots in the Scanditronix prescription file for storing these numbers; in the present VAXIN.DAT file these entries are always zero.)

A single fraction will have to be delivered in more than one treatment run if the beam turns off for any reason before the prescribed daily monitor units are delivered. All dose delivered with one DMC setting for preset dose and time, with no intervening DMC reset, is considered one fraction. If a treatment is interrupted but is able to be continued without resetting the DMC, it is considered one fraction. If the DMC has to be reset, dose delivered after the reset is considered part of the next fraction.

Chapter 4

Controllers

The control program accomplishes much of its work by sending commands to the attached controllers (DMC-I, TMC-I, LCC, DMC-F, TMC-F and PLC) and reading data back from them.

This chapter describes features common to all controllers and all stages of operation. Subsequent chapters and appendices describe details specific to each controller and stage of operation. Appendix H describes many of the controller parameters.

4.1 Error handling and recovery

Each controller has its own *protocol* that defines the commands it can handle, and the way it should respond to each command. Each controller's protocol is described in an Appendix. The control program can determine whether the behavior of each controller conforms to its protocol. If not, the controller is considered to have committed an error. Controller errors also occur when a controller issues an error message or times out (fails to respond to a command within a specified period). Details about each controller's protocol, timeout deadline etc. appear in appendices C through G.

When the therapy control program encounters a controller error, it does not halt ("crash") or wait indefinitely ("hang"). Other functions that do not depend on the erroneous controller continue to work normally (although it may not be possible to continue treating).

For each controller the therapy control program has a *software interlock*[1]. When the control program detects a controller error, it sets the software interlock for that controller. The corresponding therapy subsystem becomes Not Ready, and the therapy sum interlock relay in the HSIS opens so the beam cannot run. Any motions driven by the affected controller are disabled by de-energizing the appropriate enable relays throught the PLC. A message is displayed and logged.

It is not necessary to shut down and restart the control program to resume normal operation after a controller error. When the error is thought to be corrected (a disconnected controller is reconnected, or a halted controller is reset locally), the operator can attempt to resume normal operations by selecting a field. If the controller participates successfully in the Select Field operation, the controllers' software interlock is cleared and a message is displayed and logged.

The control program does not attempt to recover automatically from controller errors. These errors are expected to be rare and automatic recovery would add unnecessary complications.

Controller errors are distinguished from problems with the controlled equipment. If a controller follows its protocol and issues no error messages it is considered to be working correctly. If the controlled settings do not reached their commanded values, this is taken to indicate a problem with the controlled equipment, not with the controller itself (for example a moving component might be stuck). In this case the controller interlock is not set but the affected settings will not be ready so that subsystem's check and confirm software interlock will be set and consequently the therapy sum interlock will be set also. This will prevent the beam from turning on.

The PLC is a special case, because all digital input and output from the neutron therapy computer goes through the PLC, including the therapy sum interlock. Therefore, if the control program detects an error in the PLC itself, it cannot be assured that the therapy sum interlock in the HSIS will be set. However the control program does indicate PLC errors on its display and in its log file. The PLC is reponsible for performing its own self-tests and for monitoring the integrity of its link to the neutron therapy computer, and setting appropriate interlocks when errors are detected. General PLC operation is independently monitored by a watchdog timer.

[1] A software interlock is a variable in the control program which can take on two values that denote "set" and "clear"; the *therapy sum interlock* is the sum (logical *or*) of all the other software interlocks; it drives a hardware interlock in the HSIS (Chapter 5).

Chapter 5

Interlocks

Interlocks help prevent hazardous situations. A potentially hazardous action (such as turning on the beam or moving the flattening filter) is prevented from occurring when any interlocks associated with that action are *set* and is only permitted when all interlocks are *clear*.

Hardware interlocks are physical devices. Most hardware interlocks in the CNTS are microswitches or relay contacts. These interlocks are set when the switch is open and are clear when the switch is closed (allowing current to flow that permits the action to occur). *Software interlocks* are variables in the control program which can take on values that denote the two conditions, set and clear. Some (not all) hardware interlocks are control program inputs that affect program variables. Some (not all) software interlocks are control program outputs that drive hardware interlocks.

There are two major kinds of interlocks in the therapy portion of the CNTS. One kind permits the production of beam via the hardwired safety system (HSIS). The other kind permits mechanical motions to occur; they act on a *motion enable* signal which is hardwired to the appropriate motion controller.

5.1 Motion enable interlocks

For safety reasons at least two signals are required to cause each motion: a drive signal and an interlock called the *enable* signal. The *set* and *clear* interlock conditions for the enable signal are called *disable* and *enable*. Motions are usually disabled and are only enabled when motion is explicitly requested by the operator or by the control program.

External motions that can present collision hazards (such as gantry rotation) can only be operated under *local* control by the therapist in the treatment room. In local control motions are enabled by using treatment room equipment, for example by pressing the "dead man switch" on the hand pendant. These local enable signals are entirely controlled by hardware or by the PLC, none are outputs from the control program. However, some local enable signals are control program inputs so they can be displayed on the therapy console screen.

The flattening filter, wedge filter and leaf motions do not present collision hazards. The operators can activate them in local mode but they can also be operated by the control program under *automatic* control (chapter 7 and section 8.5 in [2]). The control program has a variable for each motion enable signal. There is a separate enable signal for each motion driven by the TMC in automatic mode, but there is just one enable signal for all the collimator leaves. The control program only enables motion during the **Auto Setup** operation. Each software enable variable is a program output that causes a hardware enable relay to open and close. Like all other digital outputs from the control program, these enable signals are mediated by the PLC, which actually drives the relays. The motion drive signals are provided by the LCC or TMC. Commands from the control program to the PLC, LCC and TMC are synchronized so that motions are enabled through the PLC when the drive signals are issued by the LCC or TMC (chapter 6).

In addition to the PLC enable signals, there are TMC commands to enable and disable motions also. However the effects of these commands are internal to the TMC. There are no independent motion enable signals from the TMC and we do not rely on its internal disable commands for safety.

There are three PLC signals associated with each motion enable signal. The first is a PLC output that actually enables the motion by closing a relay. The second is a PLC input that senses whether the motion is enabled by sensing the relay contact position. When a PLC enable output is changed, the corresponding input should also change. However the change may not be immediate; a brief interval may occur before the output and input are consistent.

The PLC's own internal program performs consistency checks. In addition to the enable command output and sensor input, there is a third PLC signal for each motion enable: the consistency check output signal. If an enable command output is activated but the enable sensor input does not respond (after an appropriate brief delay), the consistency check output indicates the inconsistency.

Tables 5.1 and 5.2 list the motion interlock signals used by the control program.

Signal	PLC	Type
Flattening filter motion local	Therapy	Input (from PLC)
Flattening filter motion enable sensor	Therapy	Input
Flattening filter motion enable inconsistent	Therapy	Input
Flattening filter motion enable command	Therapy	Output (to PLC)
Wedge selection motion local	Therapy	Input
Wedge selection motion enable sensor	Therapy	Input
Wedge selection motion enable inconsistent	Therapy	Input
Wedge selection motion enable command	Therapy	Output
Wedge rotation motion local	Therapy	Input
Wedge rotation motion enable sensor	Therapy	Input
Wedge rotation motion enable inconsistent	Therapy	Input
Wedge rotation motion enable command	Therapy	Output
Leaf motion local	Therapy	Input
Leaf motion enable sensor	Therapy	Input
Leaf motion enable inconsistent	Therapy	Input
Leaf motion enable command	Therapy	Output

There are actually two signals for every entry in the table, one for the isocentric room and one for the fixed beam room. The fixed beam room has a "bookend" collimator instead of a leaf collimator, but collimator enable signals are present in both rooms.

Table 5.1: PLC internal motion interlock signals used by therapy control program

Signal	PLC	Type
Collimator rotation local	Therapy	Input (from PLC)
Collimator rotation enable sensor	Therapy	Input
Collimator rotation enable inconsistent	Therapy	Input
Collimator rotation enable command	Therapy	Output (to PLC)
Couch turntable rotation local	Therapy	Input
Couch turntable rotation enable sensor	Therapy	Input
Couch turntable rotation enable inconsistent	Therapy	Input
Couch turntable rotation enable command	Therapy	Output
Couch vertical motion local	Therapy	Input
Couch vertical motion enable sensor	Therapy	Input
Couch vertical motion enable inconsistent	Therapy	Input
Couch vertical motion enable command	Therapy	Output
Couch longitudinal motion local	Therapy	Input
Couch longitudinal motion enable sensor	Therapy	Input
Couch longitudinal motion enable inconsistent	Therapy	Input
Couch longitudinal motion enable command	Therapy	Output
Couch lateral motion local	Therapy	Input
Couch lateral motion enable sensor	Therapy	Input
Couch lateral motion enable inconsistent	Therapy	Input
Couch lateral motion enable command	Therapy	Output
Gantry rotation local	Therapy	Input
Gantry rotation enable sensor	Therapy	Input
Gantry rotation enable inconsistent	Therapy	Input
Gantry rotation enable command	Therapy	Output

There are actually two signals for every entry in the table, one for the isocentric room and one for the fixed beam room. The only exceptions are the gantry signals, which are not present in the fixed beam room.

Table 5.2: PLC external motion interlock signals used by therapy control program

During a therapy run all motions must be disabled. The individual motion enable sensor relays are included in the hardwired safety system. If a motion is enabled, the beam is prevented from turning on or if it is already on, it will be shut down.

There are motion enable indicators on the therapy control program screen displays (Chapter 8 in [2], Figs. 8.4 – 8.7 etc.). They show whether the each motion is in local (manual) or automatic (computer control) mode. When the equipment is in local mode these indicators show the manual enable signals from the treatment room equipment. In automatic mode they show the enable input (sensor) signals from the PLC, or an indication that the PLC has found the enable signals to be inconsistent.

5.2 Beam interlocks

This section describes interlocks that must be clear to permit the therapy beam to turn on or remain on. The interlocks discussed here are inputs or outputs of the control program; there are many additional interlocks that do not involve the control program.

5.2.1 Interlocks and subsystems

Table 5.3 lists the interlocks and their subsystems. Each interlock belongs to one of the six subsystems that are indicated by lamps on the console screen: Gantry/Couch, Filter/Wedge, Leaf Collimator, Dosimetry, Room Interlocks and Proton Beam[1]. When an interlock is set, the lamp for its subsystem is red, and the display for that subsystem indicates which of its interlocks are set (for example see Fig. 8.11 in [2]). Interlocks that belong to the Dosimetry or Room Interlocks subsystems both appear on the (single) Dosimetry/Room Interlocks display. Interlocks in the Gantry/Couch, Filter/Wedge, and Leaf Collimator subsystems each appear on their own display[2].

There is no Proton Beam display on the therapy console terminal. The Proton Beam subsystem lamp is the only indication on the terminal that any proton beam interlock is set; this interlock is set when the PROTON BEAM I-LOCK lamp on the therapy console is lit (Section 6.1.3 in [2]). Individual proton beam interlocks (including line selection and test mode) are the responsibility of the cyclotron operator and appear on the cyclotron console

[1] The TMC Error interlock belongs to both the Gantry/Couch and Filter/Wedge subsystems. In [2], the Room Interlocks are called Therapy Interlocks.

[2] This is a change in the specification. Section 8.9.l2, pages 210–212 in [2] says that all interlocks are shown on the Dosimetry/Therapy Interlocks (now Room Interlocks) display. The other subsystem display designs must be revised to show the interlocks.

HARDWARE BEAM INTERLOCK	SUBSYSTEM
Gantry rotation enable sensor	Gantry/PSA
Collimator rotation enable sensor	Gantry/PSA
Couch turntable rotation enable sensor	Gantry/PSA
Couch vertical motion enable sensor	Gantry/PSA
Couch longitudinal motion enable sensor	Gantry/PSA
Couch lateral motion enable sensor	Gantry/PSA
Collision detected	Gantry/PSA
Flattening filter motion enable sensor	Filter/Wedge
Wedge selection motion enable sensor	Filter/Wedge
Wedge rotation motion enable sensor	Filter/Wedge
Leaf motion enable sensor	Leaf Collimator
Dosimetry system not ready (DMC relays)	Dosimetry
Treatment room door open	Room Interlocks
Therapy console enable key not turned on	Room Interlocks
Mobile pedestal enable key turned on	Room Interlocks
Proton beam interlock	Proton Beam

SOFTWARE BEAM INTERLOCK	SUBSYSTEM
Gantry/PSA check-and-confirm not ready	Gantry/PSA
TMC Error	Gantry/PSA
Filter/Wedge check-and-confirm not ready	Filter/Wedge
Filter/Wedge motion fault	Filter/Wedge
TMC Error	Filter/Wedge
Leaf collimator check-and-confirm not ready	Leaf Collimator
Leaf collimator calibration factor out of range	Leaf Collimator
LCC Error	Leaf Collimator
Pressure/temperature correction factor out of range	Dosimetry
DMC calibration factor out of range	Dosimetry
Dosimetry setup timed out	Dosimetry
Dosimetry start timed out	Dosimetry
DMC Error	Dosimetry
No therapy operator logged in	Room Interlocks
Update in progress	Room Interlocks
PLC Error	Room Interlocks
Therapy sum interlock	(Output to PLC)
Therapy watchdog	(Output to PLC)

The TMC Error interlock is considered to belong to both the Gantry/PSA and Filter/Wedge subsystems.

Table 5.3: Beam interlocks

terminal.

5.2.2 Hardware interlocks

Table 5.3 shows the hardware interlocks that are inputs to the control program. If any of these hardware interlocks are set, the beam cannot turn on or remain on, but this is ensured by the PLC and HSIS and is completely independent of the control program. The control program merely senses these interlocks to compute the subsystem status lamp colors and to show on the subsystem displays.

Like all other digital inputs to the control program, hardware interlock signals are mediated by the PLC, which actually senses the hardware interlock switches and relay contacts.

Some hardware interlocks are not used in hardware test mode (Sections 8.1, 8.2, 8.9.12 and tables 8.1, 8.2 and 8.4 in [2]).

Several displays of hardware interlocks show motion enable signals. They show the motion enable sensor inputs read back from the enable relay contacts, not the enable command outputs computed by the control program (Section 5.1). They also show the consistency check signals computed by the PLC program.

5.2.3 Software interlocks

Table 5.3 shows the software interlocks that are computed by the control program. Except for the therapy sum interlock and the therapy watchdog (sections 5.2.4 and 5.2.5, below) they are all internal program variables; they appear on the screen but none drives a hardware interlock.

These are the rules used to compute each software interlock[3].

Check-and-confirm not ready There is a check-and-confirm software interlock for each of the three motion subsystems Gantry/PSA, Filter/Wedge, and LCC. They are set when any setting in the subsystem is not ready, or any motion in the subsystem is enabled or inconsistent.

There are no separate check-and-confirm interlock indicators on the subsystem displays. Instead, the readiness and motion enabled status of each setting is shown.

[3] Several of these are also described in Section 8.9.12 in [2]). Controller Error, Calibration Factors Out of Range, Dosimetry Start Timed Out, and Therapy Sum Interlock are new in this volume.

Filter/Wedge motion fault This fault can occur when a filter or wedge is stuck between settings. This fault exists when there is no positive indication of a valid filter or wedge setting even though those motions are disabled.

There is no separate indicator for this interlock on the Filter/Wedge display. Invalid or in-transition values are indicated by showing a special error indicator (such as ***) instead of the usual number or name in place of the setting value on the Filter/Wedge display.

Calibration factors out of range One or more of the calibration factors for the subsystem is out of range or uninitialized. This occurs when the calibration factors file cannot be read. It can also occur if the file contents or in-memory calibration factors have become corrupted.

There is a separate interlock for each file of calibration data. Currently there is a calibration file for the LCC and another for the DMC (there is no calibration file for the TMC).

Controller error The controller has not responded to a command according to its protocol, has failed to respond to a command within its timeout period, or has issued an error message.

There are separate controller error software interlocks for the PLC, TMC, LCC, and DMC. The indicator for the TMC controller error appears on both the Gantry/PSA and Filter/Wedge displays.

Pressure/temperature correction factor out of range Automatic pressure/temperature correction for the dose monitors has been selected, but the correction factor differs from the nominal value by too great an amount, or the nominal value is out of range or has expired (section 8.9.13 in [2]).

Dosimetry setup timed out The **Auto Setup** operation has been invoked on the dosimetry system, but more than 15 minutes have elapsed without starting a treatment run (by sending the `CON START` command to the DMC). This interlock can be cleared by invoking **Auto Setup** or **Select Field** again.

Dosimetry start timed out The `CON START` command has been sent to the DMC, but more than 30 seconds have elapsed without turning on the therapy beam by pressing the START button (usually the `CON START` command is sent when the therapy room door reaches the closed position, see section 6.5.2). This interlock can be cleared by invoking **Auto Setup** or **Select Field** again.

No therapy operator No operator is logged in at the therapy console.

Update in progress A therapy terminal editing operation is in progress that might cause settings or status to change.

Therapy sum interlock Any software interlock is set. This is the sum (logical *or*) of all the preceding interlocks.

Therapy watchdog Toggles continually when the control program is running.

5.2.4 Therapy sum interlock

The *therapy sum interlock* indicates the merged effects of all the other software interlocks in Table 5.3. It computes their sum (logical *or*): it is set when any of the other interlocks in the table are set, and is clear only when they are all clear.

The therapy sum interlock is a control program output that drives a pair of hardware interlocks via the PLC (two relays are used for redundancy). These hardware interlocks are (perhaps confusingly) also called therapy sum interlocks. They are relays in the HSIS, just like the hardware interlocks in Table 5.3. When the therapy sum interlock is set, the beam cannot turn on or remain on. Therefore, any software interlock in Table 5.3 will stop the beam when it is set. The therapy sum interlock relays are not used when the HSIS is in hardware test mode.

Although the hardware interlocks in Table 5.3 are inputs to the control program, they do not affect the therapy sum interlock. It is possible for the therapy sum interlock to be clear when hardware interlocks are set (in this condition subsystem lamps on the screen will be red, because they indicate hardware as well as software interlocks).

There is no single indicator on the therapy console screen that shows when the therapy sum interlock is set (of course it is possible to determine this from the other screen contents, which indicate whether any software interlock is set). The therapy sum interlocks in the HSIS appear on the cyclotron safety status display[4].

5.2.5 Therapy watchdog

The *therapy watchdog* indicates that the control program is running. It is not computed from any other interlocks, settings or program variables. Instead, it is synchronized to periodic communication with the PLC. Each time the control program polls the PLC, it toggles this output, so it should toggle continually while the program is running. The PLC restarts a timer each time this output toggles; if a (brief) deadline expires before the output toggles again, the therapy control program is considered to have failed and the PLC disables the beam and all computer-controlled motions. This condition is latching and will not be

[4]Our therapy sum interlocks replace the *check and confirm* interlock in the original Scanditronix system.

cleared if the watchdog simply resumes toggling. It is necessary for an operator to clear this condition manually.

5.3 THERAPY I-LOCK lamp

The THERAPY I-LOCK lamp on the therapy control console (Sections 6.1.3 in [2]) indicates the merged effects (the sum, or logical *or*) of all the hardware interlocks in Table 5.3, plus the therapy sum interlock: it is lit when any of these interlocks is set and is dark only when every one is clear (the THERAPY I-LOCK lamp does not include any proton beam interlocks). The lamp is controlled by hardware and does not depend on the control program. The operator can only begin a treatment run when this lamp is dark.

All of the hardware interlocks that contribute to the THERAPY I-LOCK lamp are also inputs to the control program. The THERAPY I-LOCK lamp is off only when all of the subsystem lamps (except the proton beam lamp) on the screen are green (ready) or yellow (overridden). The THERAPY I-LOCK lamp is on when any subsystem lamp (except the proton beam lamp) is red (not ready). The operator can select the display for a subsystem whose on-screen lamp is red to see the indicators for the interlocks that are causing the THERAPY I-LOCK lamp to turn on.

The therapy sum interlock in the HSIS is just one of the interlocks that affects the THERAPY I-LOCK lamp. When the therapy sum interlock is set the THERAPY I-LOCK lamp is on, but it is also possible for the lamp to be on when the therapy sum interlock is clear, if other hardware interlocks are set.

5.4 Cyclotron PLC signals

The treatment room PLC monitors several signals provided by the cyclotron PLC[5]. These signals are not motion enable interlocks or beam interlocks, but each signal is needed to enable a particular step in the treatment sequence (chapter 6). Table 5.4 lists these signals.

[5]There are several ways to communicate these signals between the two PLC's. At this writing we have not yet decided which one to use.

Signal	PLC	Type
DMC timer enabled	Cyclotron	Input (from PLC)
Beam plug open	Cyclotron	Input
X-ray drawer in X-ray position	Cyclotron	Input
Therapy console START button pressed	Cyclotron	Input

Table 5.4: Cyclotron PLC signals used by therapy control program

Chapter 6

Treatment sequence

From the point of view of the controllers, control system operation is a repeating sequence or cycle of operations, where each cycle involves delivering one field.

6.1 Overview

This section presents an overview of the treatment sequence. Subsequent sections describe each step in detail, describing the actions of each controller.

6.1.1 Select Patient

When the operator selects a patient, the control program reads the contents of the prescription file into memory, but the controllers do not participate at this stage. Therefore this operation is not considered part of the treatment cycle considered here.

6.1.2 Select Field

A new cycle in the treatment sequence begins when the operator selects a field from the list of a patient's prescribed fields. The prescribed setting values from the prescription file appear on the display, but they are not loaded into the controllers at this stage because the operator may subsequently edit some of them.

The operator can also use the Select Field operation to recover from conditions where the state of the controllers is unknown, after errors and also after hardware resets. Therefore this operation does whatever is necessary to restore each controller to a known state, such as commanding software resets, performing self-tests and loading certain calibration factors.

All controllers participate at this stage.

After a field has been selected, the operator may edit the in-memory values of certain settings to make them different from the prescribed values in the prescription file. We distinguish the *prescribed* values in the file from the *preset* values in control program memory. Editing only affects the preset values; the controllers to do not participate.

6.1.3 Auto Setup

Next, the operator decides to proceed with treating the selected field and indicates this by selecting Auto Setup. The values of relevant field settings (including any changes edited in by the operator after the field was selected) are read from control program memory and loaded into each controller's own memory. Then the controllers are commanded to change the actual (physical) machine settings to the loaded values (for example by moving filters or leaves into position).

All controllers participate at this stage. For safety reasons motions require two signals, a drive signal and a motion enable signal. The LCC and TMC provide the drive signals and the PLC provides the enable signals.

6.1.4 Port Film

Therapists may take an X-ray port film with the patient and machine in the treatment configuration. All controllers participate, as well as the X-ray controller in the control room.

6.1.5 Beam On/Off

The operator turns on the therapy beam by pressing a button on the console, and usually the beam remains on for one to three minutes until the preset dose has been delivered. The operator can also turn off the beam at any time, and may turn the beam back on if no interlocks have become set and the preset dose has not yet been delivered.

The DMC is the only controller that participates in these operations.

6.1.6 Poll

The control program can command each controller to report the actual values of the settings it monitors. This is called polling. The control program polls all controllers periodically in order to update displays and determine system readiness.

Most controllers cannot be polled at certain times. The polling schedule for each controller is described in section 6.6.

6.1.7 Calibration

In addition to the normal treatment sequence, there are calibration procedures. The LCC participates in a calibration procedure.

This completes the overview. The following sections describe each stage in detail.

6.2 Select Field

This section describes each controller's activity at the Select Field phase. This operation is invoked at the beginning of each treatment cycle, and is also used to recover from errors. It does whatever is necessary to restore each controller to a known state, such as commanding software resets and loading certain calibration factors.

6.2.1 PLC

No commands from the control program are required to reset or initialize the PLC. However, outputs controlled through the PLC may change at this or any stage. Polling of the PLC continues during all stages, and outputs controlled through the PLC are recalculated during each polling cycle. After Select Field, all motions are disabled and the therapy sum interlock is set (in fact these conditions should be true already when Select Field is invoked).

6.2.2 TMC

When the Select Field operation is invoked, the TMC is reset. Then the TMC is commanded to disable all motions internally (the independent motion enable signals are disabled by the PLC).

Here is an example:

<esc><cr>	Command: reset
TMC Vers 1.1 841206 . Pha."	Response: banner
$	Response: completed
CON DIS COL WEDT WEDR VER LAT LON FLO GAN FIL	Command: disable motion
$	Response: ack, completed

The TMC controls the flattening filter, but the flattening filter selection does not appear in the prescription files[1]. Instead the control program calculates the preset flattening filter selection each time a new field is selected. The selection is calculated from the preset leaf settings: the small field flattening filter is selected if all of the narrow leaves are opened less than 6.25 cm from the centerline and none of the wide leaves are open, otherwise the large field flattening filter is selected. That is, the small field filter is selected when leaves 0 – 4 and 10 – 14 have settings greater than -6.25 cm, and leaves 20 – 24 and 30 – 34 have settings less than 6.25 cm, and leaves 5 – 9, 15 – 19, 25 – 29, and 35 – 39 are all set to 0.0. Otherwise the large field filter is selected.

6.2.3 LCC

Each time the Select Field operation is invoked, the LCC is reset. Reseting the LCC clears the calibration factors, so the LCC must then be commanded to load calibration factors (max and min positions, scale factors) and tolerance windows, then output them again so the control program can confirm they have been successfully loaded. The control program compares the output calibration values to the input calibration values[2]. If there are any differences, the LCC is considered to be in an erroneous state: the LCC software interlock is set, and a message is displayed to the operator. To clear the error, the operator must select the field again (possibly after some corrective action has been taken).

[1] The Prism treatment planning system does not model the flattening filter selection explicitly. The effect of the flattening filter is implicit in the tabulated beam data used in the Prism dose calculation.

[2] To save time, the Scanditronix software did not reload and check the calibration factors each time a field was selected. We expect this operation will be acceptably fast in the new system.

Here is an example. In this example the scale factors are successfully loaded.

```
SCANDITRONIX   LCC   VER 2.1#
$
IN MAXPOS 00   290.2   291.8   294.8   293.8   289.3   285.7   298.2   298.2
$
IN MAXPOS 08   291.8   295.9   299.2   301.5   280.2   285.2   294.5   297.4
$
... etc. for 16, 24, 32

IN MINPOS 00    99.7   101.5   107.1   102.2   100.4    94.8   107.1   109.6
$
IN MINPOS 08   102.1   103.9   109.0   109.4    87.6    95.1   103.0   102.8
$
... etc. for 16, 24, 32

IN SCAFAC 00 -3113.4 -3109.8 -3062.1 -3133.2 -3084.3 -3120.6 -3124.2 -3078.8
$
IN SCAFAC 08 -3098.9 -3140.3 -3108.0 -3142.1 -3151.0 -3106.2 -3131.4 -3185.9
$
... etc. for 16, 24, 32 ...

OUT MAXPOS 00 TO 07
+290.2 +291.8 +294.8 +293.8 +289.3 +285.7 +298.2 +298.2 #
$
OUT MAXPOS 08 TO 15
+291.8 +295.9 +299.2 +301.5 +280.2 +285.2 +294.5 +297.4 #
$
... etc. for 16 TO 23, 24 TO 31, 32 to 39 ...

OUT MINPOS 00 TO 07
+099.7 +101.5 +107.1 +102.2 +100.4 +094.8 +107.1 +109.6 #
$
OUT MINPOS 08 TO 15
+102.1 +103.9 +109.0 +109.4 +087.6 +095.1 +103.0 +102.8 #
$
... etc. for 16 TO 23, 24 TO 31, 32 to 39 ...

OUT SCAFAC 00 TO 07
-3113.4 -3109.8 -3062.1 -3133.2 -3084.3 -3120.6 -3124.2 -3078.8 #
$
OUT SCAFAC 08 TO 15
```

```
-3098.9 -3140.3 -3108.0 -3142.1 -3151.0 -3106.2 -3131.4 -3185.9 #
$
... etc. for 16 TO 23, 24 TO 31, 32 to 39 ...

$
IN WIN 1.0
$
OUT WIN
+001.0 #
$
```

6.2.4 DMC

When the field is selected, the DMC is reset. The DMC responds as in this example:

```
"SCANDITRONIX DMC VER 1.2"
$
```

6.3 Auto Setup

At this stage the preset setting values (including any changes edited in by the operator) are read from control program memory and loaded into each controller's memory. Then the controllers are commanded to achieve those settings.

The operator can command Auto Setup for one controller at a time, or all controllers simultaneously. The control program only attempts the Auto Setup operation for motions which the operator has placed in automatic mode and which are not already at their prescribed settings (8.8.1 in [2]).

If any settings or calibration values are invalid, the Auto Setup operation is not performed. The control program checks every preset setting and calibration factor against an internal table to determine whether its value is reasonable; it also checks for inconsistencies between different settings (such as overlapping collimator leaves). If settings or calibration factors are invalid, a message is displayed and logged, indicating the problem and advising the operator to get help before proceeding. This is a serious error because it means that a file is inaccessible or has been prepared with invalid contents, or persistent data (in memory or in a file) have become corrupted. In this condition software interlocks including the therapy sum interlock will be set (section 5.2.3).

6.3.1 TMC

The TMC can automatically set the flattening filter selection, wedge filter selection, and wedge rotation.

The settings controlled by the TMC often retain the same values from one field to the next. The control program only attempts to set up motions which are not already at their preset positions, which are in automatic control mode, and whose preset values are valid. If a motion is already at its preset position the program does nothing. If a motion is in local mode the program displays and logs an error message and does nothing further for this motion.

The wedge filter selection cannot be set up automatically if the X-ray drawer is in the X-ray position (or is in transition to or from this position). An input signal from the cyclotron PLC indicates this condition (Table 5.4). When this condition holds, the program will not attempt to automatically set up the wedge selection; instead, it will display a message saying that the X-ray drawer is in the X-ray position and the wedge selection could not be set up. The wedge rotation and flattening filter will be set up in this condition, however.

The program performs the following actions for motions which are not at the preset positions, are in automatic control and have valid values. First the preset values are loaded into the TMC. Then the PLC is commanded to enable those motions. After a brief delay (0.5 sec) the TMC internal motions are enabled: this causes the motions to occur[3]. Motions can take up to 80 seconds to complete. While motions are in progress, the TMC is polled periodically (Table 6.3). When polling indicates that a motion has reached its preset value, the control program waits 1 to 2 seconds and then sends the internal motion disable command for that motion to the TMC, then it commands the PLC to disable that motion. The delay allows the motion to overshoot and settle (and also allows for sensor contact bounce etc.).

Motions do not remain enabled indefinitely. If a motion does not achieve its preset position within a timeout period, the control program commands the TMC and the PLC to disable that motion. A message is displayed and logged. The timeout periods for each motion are stored in a file on the remote computer that is read in with other calibration factors (at startup, and when the operator selects the Cal Factors screen). Typical values for these timeouts appear in Table 6.1. The values may range from 20 seconds for wedge selection up to 80 seconds for wedge rotation. The actual time required to complete the motion is often much less than the timeout period. In order to avoid leaving motions enabled longer than necessary, we poll rather than waiting the for the timeout to expire, and we disable each motion individually as it completes, rather than waiting for the last motion.

[3]Alternatively, instead of waiting for 0.5 sec, it might be better to wait until the enable inputs from the PLC confirm that motions are enabled.

Here is an example of a dialog with the TMC where all three motions are commanded to change:

`INP SET WEDT` w `WEDR` r `FIL` f	Command: input all settings
`$`	Response: ack, completed
`CON ENA WEDT WEDR FIL`	Command: enable all motions
`$`	Response: ack, completed
`OUT ACT WEDT WEDR FIL`	Command: poll motions
w_1 r_1 f_1 `#`	Response: ack, data
`$`	Response: completed
`OUT ACT WEDT WEDR FIL`	Command: poll motions
w_2 r_2 f_2 `#`	Response: ack, data
`$`	Response: completed
⋮	⋮
`OUT ACT WEDT WEDR FIL`	Command: poll motions
w r_i f_i `#`	Response: wedge selection reached
`$`	Response: completed
`CON DIS WEDT`	Command: disable wedge selection
`$`	Response: ack, completed
`OUT ACT WEDT WEDR FIL`	Command: poll motions
w r_j f_j `#`	Response: ack, data
`$`	Response: completed
⋮	⋮
`OUT ACT WEDT WEDR FIL`	Command: poll motions
w r_m f `#`	Response: filter selection reached
`$`	Response: completed
`CON DIS FIL`	Command: disable filter selection
`$`	Response: ack, completed
`OUT ACT WEDT WEDR FIL`	Command: poll motions
w r_n f `#`	Response: ack, data
`$`	Response: completed
⋮	⋮
`OUT ACT WEDT WEDR FIL`	Command: poll motions
w r f `#`	Response: wedge rotation reached
`$`	Response: completed
`CON DIS WEDR`	Command: disable wedge rotation
`$`	Response: ack, completed

6.3.2 LCC

The control program does not command the LCC to set up the leaves if all leaves are already in their preset positions; however, all leaves must be commanded to move if any leaves are not in their preset positions. If all leaves are already at their preset position the program does nothing. If leaves are in local mode or the preset value of any leaf is invalid (out of range or overlapping the opposite leaf), the program displays and logs a message and does nothing more.

The program performs the following actions for leaves (assuming all have valid preset positions, are not all at their preset positions, are in automatic control). First, the LCC is commanded to load the preset setting values. Then the `CONTROL RUN` command is issued. The acknowledge response is expected within 20 msec but the completion response is not expected for up to 80 seconds, until all leaves have achieved their desired positions, or an error is encountered (such as failure to achieve the desired setting). Commands sent to the LCC during this interval are ignored. If the LCC does not send its completion response within the 80 seconds, a message is displayed and logged (Table 6.1).

Here is an example. First, load the settings:

```
IN S 00  -82.0  -82.0  -82.0  -82.0  -82.0  -82.0    0.0    0.0    0.0    0.0
$
IN S 10  -82.0  -82.0  -82.0  -82.0  -82.0  -82.0    0.0    0.0    0.0    0.0
$
IN S 20   82.0   82.0   82.0   82.0   82.0   82.0    0.0    0.0    0.0    0.0
$
IN S 30   82.0   82.0   82.0   82.0   82.0   82.0    0.0    0.0    0.0    0.0
$
```

Then, command movement:

`CON RUN`	Command: move leaves
`$`	Response: ack (immediately), completed (up to 80 sec later)

This example shows the normal case where the preset settings are reached. It is also possible that the LCC might respond with an error message. When most error messages arrive, a message is displayed and logged, indicating the error and advising the operator to select the field again. However it is sometimes possible to proceed after a `LEAF NO MOTION` error (Appendix F) because this message is sometimes issued when acceptable leaf settings have been achieved (for example, when a pair of opposite leaves are closed, but are not closed exactly on the center line). When this message arrives, the control program polls the LCC to determine the leaf positions. If all leaves are sufficiently close to their preset positions then the settings are deemed acceptable. In this case no error message is displayed and the operator is not advised to reselect the field. However, an informational message is displayed and logged, because the LCC error message suggests that the LCC may need to be recalibrated.

Leaves are considered sufficiently close if the difference between their measured position and preset position differ by less than a tolerance which is read from a file (typically 2 mm). This same tolerance is used as the acceptance window for the check and confirm interlock.

6.3.3 PLC

No field-specific values (preset settings etc.) are loaded into the PLC. At the Auto Setup stage, the PLC controls the motion enable signals.

The PLC provides enable signals for motions whose drive signals come from the LCC and the TMC (Section 5.1). At the Auto Setup operation the PLC first enables, then disables, these motions. The control program must synchronize commands to all three controllers to ensure that motions are enabled when the TMC and LCC issue drive signals, and that motions remain enabled until preset positions are reached or a controller signals an error or the attempted operation times out[4].

Table 6.1 shows the timeout period for each motion that can be controlled in automatic mode.

The PLC provides a single enable signal for the LCC, which enables motion for all the leaves. Synchronization between LCC and PLC is simple: the control program first commands the PLC to enable leaf motions, then commands the LCC to drive the motions. When the LCC internal program determines that the preset leaf settings have been reached, or an error has occurred, the LCC sends a message to the control program. After this message arrives (or if no message arrives before a timeout expires) the control program commands the PLC to disable leaf motions.

[4]This synchronization issue does not arise in the present (Scanditronix) control system because there are no independent enable signals for the motions controlled by the LCC and TMC. The present control system relies entirely on those controllers' internal enable facilities.

Setting	Timeout
Flattening filter selection	40 seconds
Wedge selection	20 seconds
Wedge rotation	80 seconds
Leaf positions	80 seconds

Table 6.1: Timeouts for therapy motions in automatic mode

The PLC provides independent enable signals for three of the motions controlled by the TMC: flattening filter selection, wedge filter selection, and wedge rotation. Synchronization between the PLC and TMC is complicated because the TMC does not report when preset settings have been reached; the control program must poll the TMC to determine this.

First the control program polls the TMC to determine which settings are not already at their preset positions. Then the control program loads the values of those settings into the TMC. Then the control program commands the PLC to enable motions for those settings. Then the control program commands the TMC to drive those motions using the TMC's `ENABLE` command, which affects the TMC internal enable signals (see section 6.3.1). Then the control program repeatedly polls the TMC to monitor those motions. When polling indicates that the preset settings have been reached, or the TMC signals an error, or a timeout period has expired and the preset positions have not been reached, the control program disables motions[5]. First it waits one or two seconds to allow wedge rotation to overshoot and settle (section 6.3.1). Then it commands the TMC to disable motions internally, and commands the PLC to disable the motions as well.

The control program uses the PLC **Force single coil** command (Appendix C) on the pertinent enable output to enable, then disable each motion. The program uses the PLC **Read input status** on the pertinent enable sensor input, and also on the enable consistency signal that is computed by the PLC, to confirm that the enable/disable commands have taken effect. If (after an appropriate interval) the enable sensor input does not indicate the expected enable status, or the the enable consistency input indicates that the PLC internal program has detected a problem, a message is displayed that indicates that enable signals are not consistent and advises the operator to select the field again. This message is also logged in a file.

[5] In the present (Scanditronix) control system, the control program does not poll the TMC. It merely waits for some fixed interval and then disables TMC motions internally.

6.3.4 DMC

At the Auto Setup stage the DMC is loaded with the preset dose and time (which are usually different for each field), as well as several calibration constants which usually remain the same for many successive fields. All of these values are loaded into the DMC each time the Auto Setup operation is invoked, even when the values are the same as for the preceding run.

If any of the preset values and calibration constants are invalid (do not lie within tabulated ranges), the Auto Setup operation is not performed; instead a message is displayed and logged.

When values are valid, the DMC is loaded as follows:

1. Initiate the DMC self-test by sending the `CON SEL ISO` (or `FIX`) command. The self-test takes approximately 25 seconds to complete.
2. From the temperature in degrees centigrade t, the pressure in millibar p, and the standard electrometer gains *stdvolt1* and *stdvolt2*, compute the modified electrometer gains *cvolt1* and *cvolt2* by this formula:

   $$cvolt = stdvolt \times \frac{p}{1013} \times \frac{295}{t + 273}$$

   This calculation is necessary for both dosimetry channels because the two gains *stdvolt1* and *stdvolt2* may differ. The standard electrometer gains are initially read from a file but may be modified by suitably authorized operators. The temperature and pressure may be entered by the operators or read from sensors (section 8.9.13 in [2]).
3. The *pressure/temperature correction factor* software interlock is calculated according to the rules given in section 8.9.13 in [2]. This interlock is set if the pressure or temperature are too different from nominal values, or were entered into the system too long ago.

   If the pressure/temperature interlock is set, a message is displayed and logged and the Auto Setup operation does not proceed. Authorized operators can clear this interlock by entering valid, current values for pressure and temperature (section 8.9.13 in [2]).
4. Input the most recently saved feedback and servo factors, and the modified electrometer gains. The feedback and servo factors are read from a calibration factors file; they cannot be modified by operators at the therapy console.
5. Read back the two modified electrometer gains to verify that the DMC correctly received them. If there is a discrepancy the DMC is considered to be in an erroneous

state and its software interlock is set. A message is displayed and logged, indicating the error and advising the operator to select the field again.

6. Initiate the ionsource servo.

7. Initiate the quadrant servo.

8. Enable outputs from the servos.

9. Load the preset dose and time, dose rate of the day, and maximum and minimum rates. The preset dose and time and also the dose rate of the day are based on values read from the prescription file and the calibration factors file, but may be modified by operators at the therapy console (chapter 8 in [2]). The maximum and minimum dose rate are read from the calibration factors file and cannot be modified by the operators.

10. Read back the preset dose and time to verify that the DMC correctly received them. If there is a discrepancy, handle the error as described above.

Here is an example of the dialog with the DMC:

```
CON SEL ISO
$
INP CVOLT1  699 CVOLT2  712 IONFAC   5000
$
OUT CVOLT1 CVOLT2
0699 0712 #
$
INP XCFACT 30000 YCFACT -30000 XRFACT    100 YRFACT   -100
$
INP LOWFAC     1 HIGHFAC 32000 SERVMIN     10 SERVMAX     50
$
CON SERV OUT ON
$
CON SERV CURR ON
$
CON SERV IONS ON
$
INP SETD 2380 TIME  952 RATES  500 MAXR  550 MINR  450
$
OUT SETD TIME
238.0 09.52 #
$
```

After loading the DMC, the control program starts its software *dosimetry setup timer*. This timer is cancelled when the treatment run is begun by sending the `CON START` command to the DMC. Otherwise the timer expires after 15 minutes; it is not possible to begin a treatment run after the timer expires. If the operator still wishes to begin a treatment run after the 15 minutes have elapsed, it is necessary to select Auto Setup again. Invoking Select Field also clears the timer.

6.4 Port Film

Therapists may take an X-ray port film with the patient and machine in the treatment configuration (section 6.5.6 in [2]). Usually two exposures are made on one film: the treatment field and an open field. Several open field sizes are provided for the latter exposure.

To take a film, the therapist enters the treatment room and uses the local controls on the pedestal to move the X-ray drawer into the X-ray position. If the prescribed field includes a wedge, this also has the effect of selecting no wedge.

On the X-ray console in the control room there are five illuminated pushbuttons for the five open field sizes 10 x 10, 16.5 x 16.5, 20.5 x 20.5, 24.5 x 24.5 and 28.5 x 32.5 (fully open). There is one additional button for the Prescribed field. Normally the pushbuttons are dark. Pressing one of the open field selection buttons causes the LCC to automatically set up that field (the exact field shapes are stored in a file). After the pushbutton is pressed, its lamp blinks while the leaves are in motion. When leaf motion stops, the lamp in the pushbutton stops blinking and remains lit as long as the leaves remain in position. The leaf collimator subsystem is NOT READY when the leaves are set to an open field.

Pressing the Prescribed field button on the X-ray console sets up the prescribed field shape again. This button has exactly the same effect as the AUTO SETUP key for the LCC at the terminal keypad. The lamp in this button blinks while the leaves are in motion and remains lit when the prescribed settings are achieved.

After the X-ray films have been taken, the therapist must use the local controls to restore the X-ray drawer to the safe position, and must replace any wedge that was removed when the X-ray drawer was moved and clear any DMC error caused by the X-ray dose.

6.4.1 PLC

Several PLC signals support taking X-ray port films (Table 6.2).

Signal	PLC	Type
10 x 10 field requested	Therapy	Input (from PLC)
16.5 x 16.5 field requested	Therapy	Input
20.5 x 20.5 field requested	Therapy	Input
24.5 x 24.5 field requested	Therapy	Input
28.5 x 32.5 field requested	Therapy	Input
Prescribed field requested	Therapy	Input
Leaves ready	Therapy	Output (to PLC)

Table 6.2: PLC signals that support taking X-ray port films.

The five (Open) field requested signals and the Prescribed field requested signal are inputs from the PLC to the neutron therapy computer. They correspond to six illuminated buttons at the X-ray controller. If the operator presses one of these buttons, the corresponding signal turns on. Leaves ready is an output from the neutron therapy computer to the PLC. This output is on when the one of the field requested signals is on and the leaf collimator is set up for that field (one of the open fields or the prescribed field). When a field requested signal is on but the Leaves ready signal is off, the request is pending; usually, leaves are in motion in this state.

These additional rules complete the specification of the signals: If the Leaves ready signal does not turn on within 80 seconds after field requested turns on, field requested times out (turns off). If Leaves ready does turn on within 80 seconds, field requested remains on as long as Leaves ready does. When the Leaves ready turns off (for example, because a new field has been selected), then field requested turns off also. Only one field requested signal can be on at one time. When leaves are in motion, a new field cannot be requested: if a field selection button is pressed when another field requested signal is on but the Leaves ready signal is off, that button press is ignored (because it is not possible to communicate with the LCC when it is in motion). Once a setting is achieved, another field can be requested: if a field requested signal and the Leaves ready signal are both on, pressing a different field selection button turns them both off and turns the new field requested signal on.

The lamps are controlled by the PLC internal program, not the neutron therapy control program. Each lamp is dark when its field requested signal is off, blinks when its field requested signal is on but the Leaves ready signal is off, and is on (sustained, not blinking) when its field requested signal is on and the Leaves ready signal is on.

The PLC also provides the appropriate motion enable signals for the LCC (section 6.3.3).

6.4.2 LCC

When a field requested signal turns on, the LCC performs the same actions that it does during the **AUTO SETUP** operation (section 6.3.2). There is only one difference: if one of the five (Open) field requested signals turns on, the program loads the LCC with the corresponding open field leaf settings, not the prescribed field settings. These open field settings are always stored in control program memory; they are read in from a file at startup and when the **LCC Calibration Factors** operation is invoked.

6.4.3 TMC

If the prescribed field contains a wedge, moving the X-ray drawer to the X-ray position has the effect of selecting no wedge. After the filming session, it is necessary to replace the wedge to proceed with the treatment. The therapist can accomplish this by using AUTO SETUP in the usual way.

6.4.4 DMC

When the X-ray exposure for the port film is made, the DMC will detect some dose. This will cause the DMC to issue an unsolicited error message[6] This in turn will cause the DMC software interlock to become set. It is necessary to clear this interlock to proceed with the treatment. The therapist can accomplish this by using SELECT FIELD in the usual way.

6.5 Beam On/Off

The operator starts a treatment run by pressing the START button on the therapy control console. This button is connected to the cyclotron PLC (not the treatment room PLC which is connected to the neutron therapy computer). Usually the treatment run ends when the DMC opens the dosimetry relay in the hard wired safety interlocks system (HSIS), but the operator can also turn off the beam by pressing the BEAM OFF button, which directly opens the HSIS line.

Details of the treatment sequence appear in chapter 6 in [2].

[6] Error 46: Dose is registered even if Faraday cup is closed. ...?

6.5.1 PLC

The PLC continually monitors all of the interlock signals described in chapter 5.

6.5.2 DMC

The control program monitors all the hardware interlocks listed in Table 5.3 and also the software therapy sum interlock. When all of these interlocks *except the dosimetry relays* are clear, the control program sends the `CON START` command to the DMC. Usually this occurs when the therapy room door reaches the closed position after the therapists finish setting up the patient and leave the room. The DMC responds by resetting both dose monitors and closing the dosimetry relay.

When the dosimetry relay closes the entire HSIS is clear. The THERAPY I-LOCK lamp on the console turns off, indicating that the operator may turn on the therapy beam. At this time the Dosimetry/Room Interlock subsystem status "lamp" on the therapy terminal screen turns green, and the subsystem displays show that no interlocks are set. A message appears on the screen: "Push START to Begin Treatment, Use CANCEL RUN to cancel."

When the control program sends `CON START` to the DMC, it also starts the software *dosimetry start timer*. This timer runs for 30 seconds. If the operator presses START before the timer expires, the cyclotron PLC turns on the therapy beam. If the timer expires or the operator presses CANCEL RUN, the control program resets the DMC, and the dosimetry relay in the HSIS opens. If the operator wishes to begin a treatment after that, it is necessary to select Auto Setup again.

The 30-second dosimetry start timer is distinct from the 15-minute dosimetry setup timer discussed above (Section 6.3.4). Sending the `CON START` command cancels the 15-minute setup timer and starts the 30-second start timer.

Several operations (selecting a field, editing preset dose etc.) are disabled when a therapy run is in progress (Section 8.8.2 in [2]). For the purposes of those requirements, a run begins when the control program sends the `CON START` command.

When the control program sends the `CON START` command, it also sends the command to set the DMC rate delay to one cycle. This is the dialog with the DMC:

```
CON START
$
```

```
INP RATEDLY  1
$
```

Then the control program polls the DMC once per second. During each polling cycle it commands the DMC to report the current dose and rate from both Dose Terminators (DT), the elapsed treatment time, the proton current on the target, and the integrated current on the target. The program reads each response, checks that it has the expected syntax and checks that each number is a valid value for its parameter. It also checks that both dose terminators show less than the preset dose, and that the elapsed time counter shows less than the elapsed time.

If any of these checks reveals an error, the control program turns off the beam by setting the DMC software interlock and sends the `CON STOP` command to the DMC.

This example shows several cycles of polling:

```
OUT DOSE1 DOSE2 RATE1 RATE2 ELATIM CURTARG INTTARG
000.0 000.1 003.1 003.1 00.05 03.27 000.1 #
$
OUT DOSE1 DOSE2 RATE1 RATE2 ELATIM CURTARG INTTARG
000.4 000.5 013.5 013.6 00.10 22.36 000.6 #
$
OUT DOSE1 DOSE2 RATE1 RATE2 ELATIM CURTARG INTTARG
006.6 006.7 049.8 049.7 00.24 56.00 007.4 #
$
```

Usually this continues until the DMC detects that the preset dose has been delivered and issues the `END` message. Then the therapy control program continues to poll the DMC to confirm that the dose is no longer increasing. During this interval the dose and time actually delivered remain visible on the dosimetry LED displays on the therapy console, so the therapist has time to note them.

Here is an example:

```
OUT DOSE1 DOSE2 RATE1 RATE2 ELATIM CURTARG INTTARG
233.5 233.3 049.8 049.8 05.17 56.29 261.8 #
$
END   00 ;Dose reached! *
$
```

```
OUT DOSE1 DOSE2 RATE1 RATE2 ELATIM CURTARG INTTARG
238.1 237.8 000.1 000.1 05.29 00.00 266.9 #
$
OUT DOSE1 DOSE2 RATE1 RATE2 ELATIM CURTARG INTTARG
238.1 237.8 000.1 000.0 05.29 00.00 266.9 #
$
...
```

Meanwhile the control program also polls the PLC, which monitors the beam plug sensor signal (provided by the cyclotron PLC). When the sensor indicates the beam plug is closed, the beam is certainly off. At that time the control program sends the `CON TERM` command to cause the DMC to execute its termination self-test.

Here is an example:

```
...
OUT DOSE1 DOSE2 RATE1 RATE2 ELATIM CURTARG INTTARG
238.1 237.8 000.1 000.0 05.29 00.00 266.9 #
$
CON TERM
$
```

When the self-test begins, the delivered dose and time no longer appear on the LED displays; they are replaced by other numbers indicating the self-test in progress (however the delivered dose and time remain on the Dosimetry display on the therapy console terminal screen). First the self-test checks that the second dose monitor channel could have stopped the treatment; this part of the test takes only a few seconds. Then the self-test checks that the backup timer could have stopped the treatment; this part of the test can take several minutes. If a self-test fails, the DMC sends a message; the control program displays and logs this message and sets the DMC software interlock.

The control program does not enforce completion of the DMC termination self-test. While the self-test is still running, the therapist can select a new field; this will reset the DMC and cancel any self-test in progress.

Instead of waiting for the preset dose to be delivered, the operator might pause the treatment by pressing the BEAM OFF button on the console. Or, some interlock other than the DMC might become set. In that case a relay in the HSIS opens, the beam turns off, and FC1 and the beam plug close. The DMC elapsed timer stops and dose stops accumulating but the DMC does not send any message to the control computer (the DMC timer is gated by the timer enable signal from the cyclotron PLC directly to a hardware input on the DMC). The therapy control program continues polling the DMC in this paused state. A message "Treatment interrupted" appears on the screen.

If all interlocks are clear, the operator can resume a paused treatment by pressing the START button on the console once again. The HSIS closes, FC1 opens, the beam turns on, the DMC timer resumes and dose accumulates again. Polling continues. No time limit is enforced for such an interruption; it is assumed that the therapists will keep this time reasonably brief.

The treatment run stops if the DMC detects an error. The DMC might respond to a polling command with an error message, or it might send an unsolicited error message at any time (for example, if the DMC reads an excessive dose difference between the two dose terminator channels). When the DMC issues an error message during a therapy run, the dosimetry relay opens, the beam turns off, FC1 closes, the timer stops and dose stops accumulating. When the control program receives the error message it sets the DMC software interlock and the therapy sum interlock. The control program stops polling and sends the `CON STOP` command to the DMC (which causes the dosimetry relay to open if it is not already open). In this stopped state the therapy console LED displays hold the accumulated dose and time.

After an error, the DMC remains in the stopped state. The operator can only exit from the stopped state by selecting the **Cancel Run** operation at the therapy console terminal (section 8.9.11 in [2]). **Cancel Run** causes the control program to reset the DMC. The operator can also use **Cancel Run** to exit from the paused state. **Cancel Run** is the only way to exit from the paused or stopped states; the control program does not permit the operator to select a new field when a run is in progress[7]. In these states the screen displays the message "Use CANCEL RUN to terminate treatment".

The run is considered to be finished when the DMC responds to `CON TERM` with the completion signal, or when the control program resets the DMC in response to **Cancel Run**.

The control program displays and logs a message each time the beam turns on or off. For this purpose the beam is considered to turn on or off whenever the DMC timer enable signal from the cyclotron PLC turns on or off. When the beam turns off, the message includes the reason why. There are three possibilities: normal termination, DMC detects error (the DMC error message is included in the log message), or other interlock (the log message may provide some information about which interlock).

Whenever one of these log messages is written, a treatment record is written also. The treatment record includes the log message and many other items as well (section 3.9).

[7]Reference [2] does not distinguish the paused state from the stopped state.

Controller	Poll during	Period
PLC	All stages	1 second
TMC	All stages, even while motions is in progress	1 second
LCC	All stages, except while motion is in progress	1 second
DMC	Only during treatment runs	1 second

Table 6.3: Controller polling schedules

6.5.3 TMC and LCC

The TMC and LCC usually do not participate during treatment runs, however both controllers are polled during treatment runs. If polling indicates that actual settings have changed from their preset positions, the therapy sum interlock will be set, the HSIS will open and the beam will turn off, an appropriate message will appear, but no commands are sent to the DMC. The operator may choose to cancel the run.

6.6 Poll

The control program polls the controllers periodically in order to update displays and determine system readiness. The polling schedule for each controller appears in Table 6.3 and is described in the following sections.

6.6.1 PLC

The PLC is polled all the time the control program is running. On each polling cycle, the program reads all the signals that the PLC provides, including beam interlocks and motion enable interlocks. Moreover the control program may command the PLC to change its outputs (in particular the therapy sum output) at each polling cycle. This is in contrast to the other controllers, which are only commanded to change their outputs at particular stages in the treatment sequence.

During each polling cycle, the control program sends these commands to the PLC:

1. **Read input status** to read the status of all the coils listed in Table C.2. It is necessary to issue a separate command for each block of coils that have consecutive addresses.

2. **Force single coil** to change output coils, in particular the therapy sum output. This output is recomputed each polling cycle, in order to respond promptly to interlocks and changes in actual setting values. There is a separate force coil command for each coil.

3. **Read coil status** to confirm that the commands to the output coils have taken effect. There is one command for each output coil. If the response indicates that the commands have not taken effect, the PLC is considered to have failed.

One of the coils in the PLC is a watchdog timer that monitors the neutron therapy computer and its control program. The control program toggles this coil on each polling cycle. If the PLC internal program detects that this coil remains in one state for too long, the therapy computer or its control program are considered to have failed. The PLC opens a relay in the HSIS to ensure the beam stays off and disables all motions controlled by the TMC and LCC.

The PLC latches such failures. The watchdog relay in the HSIS remains open if the watchdog timer resumes toggling. The operator must manually reset the watchdog to clear the interlock.

The watchdog interlock appears on the cyclotron safety status display.

6.6.2 TMC

The TMC is polled all the time the control program is running, except when it is briefly occupied executing other commands. On each polling cycle the program reads the treatment unit motions: table linear motions and the rotations of the gantry, turntable, and collimator, the filter and wedge selections, and the wedge rotation.

On each polling cycle, the TMC is commanded to output all actual setting values[8].

`OUT ALL`	Command: output all
fil col ver lat lon flo top gan wedt wedr xf yf `#`	Response: ack, data
`$`	Response: completed

[8]The nominal field sizes *xf* and *yf* are reported after the `OUT ALL` command but are not used by the control program. The TMC `OUT STATUS` command is not used during polling.

6.6.3 LCC

The LCC is polled all the time the control program is running, except when it is performing the *CONTROL RUN* command (for approximately 25 seconds), and when it is (briefly) performing the commands for the other stages.

On each polling cycle, the LCC is commanded to output all actual leaf positions[9].

```
OUT ACT 00 TO 09
-081.7 -081.9 -081.6 -081.9 -081.4 -081.6 -000.6 -000.3 -000.2 +000.3 #
$
OUT ACT 10 TO 19
-081.8 -081.9 -081.6 -082.0 -081.7 -081.9 +000.0 +000.0 +000.4 -000.4 #
$
OUT ACT 20 TO 29
+081.7 +082.1 +081.5 +082.2 +082.4 +081.6 +000.0 +000.0 +000.0 +000.0 #
$
OUT ACT 30 TO 39
+082.4 +081.8 +081.7 +081.8 +081.4 +081.9 -000.1 +000.0 +000.0 +000.3 #
$
```

6.6.4 DMC

The DMC is polled once a second while a treatment run is in progress. On each polling cycle the program reads accumulated dose and treatment time.

6.7 Calibrate

6.7.1 PLC

No calibration procedure is needed for the PLC.

[9]The LCC `OUT STATUS` command is not used during polling (in fact, it appears not to work).

6.7.2 TMC

The control program need not provide a calibration procedure for the TMC.

6.7.3 LCC

The control program provides a calibration procedure for the LCC.

At the operator's command, the control program sets the leaves to a 20 by 32.5 cm field (by definition all positions are referenced to the isocenter plane). The "north" leaves (which carry the collision microswitches) are then at +10.0 cm, the "south" leaves at −10.0 cm.

The operator manually aligns the leaves. At the operator's command, the control program sends the `CON CALIB MAX` command to the LCC. The LCC reads and stores the readout voltage from the position potentiometer for each leaf.

At the operator's command, the control program sets the "north" leaves (leaves 20 – 39, with the microswitches) about 2 cm from the centerline and the "south" leaves (leaves 0 – 19, with the more accurately defined light field edge) on the centerline. The operator manually aligns the south leaves, then closes the north leaves against them. At the operator's command, the control program sends the `CON CALIB MIN` command to the LCC. The LCC reads and stores the readout voltage from the position potentiometer for each leaf, and computes the new scale factors.

The control program reads the new calibration factors back from the LCC by using `OUT MINPOS`, `OUT MAXPOS`, and `OUT SCAFAC` and saves them in a file on the remote computer.

6.7.4 DMC

The DMC is calibrated by the morning monitor unit measurement and the procedures described in section 8.9.13, pages 213 – 215 in Volume II.

Appendix A

Prescription File Format

A.1 File structure

The prescription file is an ASCII text file. Each line or *record* is identified by a record type code the first two positions. The following record types are defined:

00	Comment lines
11	Patient information record #1
12	Patient information record #2
13	Patient information record #3 (Optional)
21	Prescription record #1
22	Prescription record #2
23	Prescription record #3
24	Prescription record #4 (Optional)

Figure A.1 shows the prescription file structure. For each patient there is a *patient information block* and several *prescription blocks*, one for each field. The patient information block contains 2-3 records. The prescription block contains 3-7 records[1].

[1]In the Scanditronix system, the file must have 1 to 200 patients with 1 to 20 prescription blocks per patient.

```
PATIENT #1

   PATIENT INFORMATION BLOCK
     PATIENT INFORMATION RECORD #1
     PATIENT INFORMATION RECORD #2
     PATIENT INFORMATION RECORD #3

   PRESCRIPTION BLOCK #1
     PRESCRIPTION RECORD #1
     PRESCRIPTION RECORD #2
     PRESCRIPTION RECORD #3
     PRESCRIPTION RECORD #4

   PRESCRIPTION BLOCK #2
        .
        .

   PRESCRIPTION BLOCK #20

 PATIENT #2
    .
    .

PATIENT #200

END-OF-FILE
```

Figure A.1: Prescription file structure

A.2 Record structure

Maximum line length is 80 characters. Text fields are left justified. Unused (trailing) positions are filled with spaces. Numeric fields are right justified; leading zeroes may be suppressed (replaced by spaces). Date fields are text fields with format `dd-mmm-yy`. In the following figures, all text fields are underlined with the equal sign `=` and and all numeric fields are underlined with the hyphen `-`.

A.2.1 Patient identification

Patient record type 1 is patient indentification. Patient number ranges from 1 to 99999.

```
01 04    10                             41              57
!  !     !                              !               !
11 aaaaa bbbbbbbbbbbbbbbbbbbbbbbbbbbbbb ccccccccccccccc dd-ddd-dd
-- ----- ============================== =============== =========
!  !     !                              !               !
!  !     !                              !            Date entered
!  !     !                              Hospital number
!  !     Patient name
!  Patient number
Record ID
```

A.2.2 Total dose

Patient record type 2 is prescription information. The prescribed (total) dose for the patient ranges from 0.1 - 99999.9. The accumulated dose is always 0.0.

```
01 04                             35      43
!  !                              !       !
12 aaaaaaaaaaaaaaaaaaaaaaaaaaaaaa bbbbb.b ccccc.c
-- ==============================  ------- -------
!  !                              !       !
!  !                              !       Accumulated dose
!  !                              Prescribed dose
!  Physician's name
Record ID
```

A.2.3 Comment

Patient record type 3 is a comment.

```
01 04
!  !
13 aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
-- =============================================================
!  !
!  Comment line
Record ID
```

A.2.4 Field identification

Prescription record type 1 is field, room and equipment identification.

```
                                        40  44
01 04 07                             38! 42!
!  !  !                              ! ! ! !
21 aa bbbbbbbbbbbbbbbbbbbbbbbbbbbbbb c d e f
-- -- ============================== = = = =
!  !  !                              ! ! ! !
!  !  !                              ! ! ! PSA indicator
!  !  !                              ! ! External block indicator
!  !  !                              ! Arc therapy indicator
!  !  !                              Treatment room indicator
!  !  Field description
!  Field number
Record ID
```

Field number	1 - 99	
Treatment room indicator	I = Isocentric room	
	F = Fixed beam room	(FIX)
Arc therapy indicator	Y = Arc therapy	(ISO)
	N = No arc therapy	
External block indicator	Y = External block	
	N = Blocks present	
PSA indicator	T = Table	(ISO)
	C = Chair	(FIX)

A.2.5 Field dose

Prescription record type 2 is field dose.

```
                                33
01 04 07 10     17     24     31! 35 38
!  !  !  !      !      !      ! ! !  !
22 aa bb cccc.c dddd.d eeee.e f g hh -iii.i
-- -- -- ------ ------ ------ - - -- ------
!  !  !  !      !      !      ! ! !  !
!  !  !  !      !      !      ! ! !  Collimator rotation
!  !  !  !      !      !      ! ! Collimator ID
!  !  !  !      !      !      ! Wedge rotation
!  !  !  !      !      !      Wedge type
!  !  !  !      !      Daily setting
!  !  !  !      Accumulated dose
!  !  !  Prescribed dose
!  !  Accumulated treatments
!  Prescribed treatments
Record ID
```

The meaning and ranges of the fields are as follows. The accumulated doses are always 0.0 in the prescription file.

Prescribed no. of treatments	1 – 99
Accumulated no. of treatments	0 – 99
Prescribed dose	0.1 – 9999.9 rads
Accumulated dose	0.0 – 9999.9 rads
Daily setting	1 – 999.9 M.U.
Wedge type	0 = No wedge
	1 = 30 degrees wedge
	2 = 45 degrees wedge
	3 = 60 degrees wedge
Wedge rotation	0 = 0 degrees, 1 = 90, 2 = 180, 3 = 270
Collimator number	0 = Variable collimator (ISO)
	> 0 = Fixed collimator
Collimator rotation	76.0 - 284.0 degrees

A.2.6 Treatment motions

Prescription record type 3 is the linear and rotational treatment motions.

```
01 04     11     18     25     32     39     46
!  !      !      !      !      !      !      !
23 -aaa.a -bbb.b cccc.c -ddd.d -eee.e -fff.f -ggg.g
-- ------ ------ ------ ------ ------ ------ ------
!  !      !      !      !      !      !      !
!  !      !      !      !      !      !      Gantry stop angle
!  !      !      !      !      !      Gantry start angle
!  !      !      !      !      PSA, top rotation
!  !      !      !      PSA, floor rotation
!  !      !      PSA, longitudinal position
!  !      PSA, lateral position
!  PSA, vertical position
Record ID
```

The meanings and ranges of the fields are

PSA, vertical position	148.0 - 212.0 cm	(ISO)
	148.0 - 218.0 cm	(FIX)
PSA, lateral position	125.0 - 175.0 cm	
PSA, longitudinal position	0.0 - 99.9 cm	
PSA, floor rotation	0.0 - 176.0 degrees	(ISO)
PSA, top rotation	135.0 - 460.0 degrees	
Gantry start angle	0.0 - 360.0 degrees	(ISO)
Gantry stop angle	0.0 - 360.0 degrees	(ISO)

A.2.7 Leaf positions

Prescription record type 4 is leaf positions. There must always be 4 records if this record type is present, i.e. if collimator ID = 0.

Leaf positions range from −5.0 to +15.0 cm. Sequence numbers are

```
     06
01 04!     12    18    24    30    36    42    48    54    60
!  ! !     !     !     !     !     !     !     !     !     !
24 a -bb.b -cc.c -dd.d -ee.e -ff.f -gg.g -hh.h -ii.i -jj.j -kk.k
-- - ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
!  ! !     !     !     !     !     !     !     !     !     !
!  ! !     !     !     !     !     !     !     !     !  Leaf a+10
!  ! !     !     !     !     !     !     !     !     Leaf a+9
!  ! !     !     !     !     !     !     !     Leaf a+8
!  ! !     !     !     !     !     !     Leaf a+7
!  ! !     !     !     !     !     Leaf a+6
!  ! !     !     !     !     Leaf a+5
!  ! !     !     !     Leaf a+4
!  ! !     !     Leaf a+3
!  ! !     Leaf a+2
!  ! Leaf a+1
!  Sequence number
Record ID

Sequence number
0 = Leaf 00-09
1 = Leaf 10-19
2 = Leaf 20-29
3 = Leaf 30-39
```

A.3 Example

This sample prescription file is based on a real example (the patient names have been changed).

```
11     1 FILM FILE                          53-81-70         3-MAY-85
12 PRETREATMENT                         1.0      0.0
13 FILM FILE
21  1 blank                             I N N T
22  1  0    4.0    0.0    4.0 0 0  0  270.0
23  150.0  150.0   10.0  180.0  180.0  180.0  180.0
24 0  -2.3  -2.3  -1.7  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0
24 1  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0
24 2   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
24 3   3.1   2.6   2.2   0.0   0.0   0.0   0.0   0.0   0.0   0.0
21  2 blank                             I N N T
22  1  0    4.0    0.0    4.0 0 0  0  270.0
23  120.0   50.0   50.0  180.0  180.0    0.0    0.0
24 0  -2.3  -2.3  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0
24 1  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0  -0.0
24 2  -0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
24 3   3.1   2.6   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
11     2 PHANTOM 10x10                      00 00 00         5-FEB-92
12 DR J                                  0.0      0.0
13 FILTER 1 OR 2 TEST
21  1 10X10                             I N N T
22 10  0 1000.0    0.0  100.0 0 1  0  270.0
23  110.8   67.7   10.0  180.0  180.0  270.0  270.0
24 0  -6.2  -6.2  -6.2  -6.2  -6.2   0.0   0.0   0.0   0.0   0.0
24 1  -6.2  -6.2  -6.2  -6.2  -6.2   0.0   0.0   0.0   0.0   0.0
24 2   6.2   6.2   6.2   6.2   6.2   0.0   0.0   0.0   0.0   0.0
24 3   6.2   6.2   6.2   6.2   6.2   0.0   0.0   0.0   0.0   0.0
11  4001 PHANTOM BLOCKED                    02-50-56         9-APR-93
12 RUEDI                                 0.0      0.0
13 PHANTOM
21  1 HALF BEAM BLK                     I N N T
22  6  0  100.0    0.0  100.0 0 1  0  180.0
23  120.0   50.0   50.0  180.0  180.0    0.0    0.0
24 0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
24 1 -10.3 -10.3 -10.3 -10.3 -10.3 -10.3 -10.3   0.0   0.0   0.0
24 2  10.3  10.3  10.3  10.3  10.3  10.3  10.3   0.0   0.0   0.0
```

```
24 3   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
21  2 MIDLINE BLK                   I N N T
22  6  0  516.4    0.0  100.0 0 1  0  180.0
23  120.0   50.0   50.0  180.0  180.0  180.0  180.0
24 0   0.0   0.0 -10.3 -10.3 -10.3 -10.3 -10.3   0.0   0.0   0.0
24 1   0.0   0.0 -10.3 -10.3 -10.3 -10.3 -10.3   0.0   0.0   0.0
24 2   0.0   0.0  10.3  10.3  10.3  10.3  10.3   0.0   0.0   0.0
24 3   0.0   0.0  10.3  10.3  10.3  10.3  10.3   0.0   0.0   0.0
21  3 QUARTER BLOCKED               I N N T
22  5  0  624.0    0.0  100.0 0 1  0  180.0
23  120.0   50.0   50.0  180.0  180.0  180.0  180.0
24 0 -10.3 -10.3 -10.3 -10.3 -10.3 -10.3 -10.3   0.0   0.0   0.0
24 1   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
24 2  10.3  10.3  10.3  10.3  10.3  10.3  10.3   0.0   0.0   0.0
24 3  10.3  10.3  10.3  10.3  10.3  10.3  10.3   0.0   0.0   0.0
21  4 ant scf                       I N N T
22  6  0  469.4    0.0  100.0 0 1  0  270.0
23  120.0   50.0   50.0  180.0  180.0    0.0    0.0
24 0  -0.0  -5.0  -5.0  -5.0  -5.0  -5.0  -5.0   0.0   0.0   0.0
24 1  -0.0  -5.0  -5.0  -5.0  -5.0  -5.0  -5.0   0.0   0.0   0.0
24 2   0.0   5.0   5.0   4.0   4.0   3.0   2.0   0.0   0.0   0.0
24 3   0.0   5.0   5.0   4.0   4.0   3.0   2.0   0.0   0.0   0.0
21  5 L shaped                      I N N T
22  6  0  514.2    0.0  100.0 0 1  0  270.0
23  120.0   50.0   50.0  180.0  180.0  180.0  180.0
24 0  -6.3  -6.3  -6.3  -6.3  -6.3   0.0   0.0   0.0   0.0   0.0
24 1  -0.0  -0.0  -0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

24 2   6.3   6.3   6.3   6.3   6.3   0.0   0.0   0.0   0.0   0.0
24 3   6.3   6.3   6.3   6.3   6.3   0.0   0.0   0.0   0.0   0.0
11   154 Three field sacrum            2-87-79-14       5-Dec-94
12 Gl                             1900.0     0.0
13 3-FLD SACRUM
21  1 POST RED PELVIS               I N N T
22  6  0  330.0    0.0   55.0 0 0  0  270.0
23  120.0   50.0   50.0  180.0  180.0  180.0  180.0
24 0  -3.7  -3.7  -3.7   0.0   0.0   0.0   0.0   0.0   0.0   0.0
24 1  -3.7  -3.5  -3.2  -2.9  -1.3   0.0   0.0   0.0   0.0   0.0
24 2   3.6   3.3   2.8   2.5   2.1   0.0   0.0   0.0   0.0   0.0
24 3   3.6   3.6   3.6   0.0   0.0   0.0   0.0   0.0   0.0   0.0
21  2 RT LAT REDUCED                I N N T
22  6  0  636.0    0.0  106.0 1 2  0  270.0
```

```
23  120.0   50.0   50.0  180.0  180.0  270.0  270.0
24 0  -3.7  -2.9  -2.5   0.0   0.0   0.0   0.0   0.0   0.0   0.0
24 1  -4.3  -4.3  -4.3  -4.3  -3.4   0.0   0.0   0.0   0.0   0.0
24 2   0.9   0.9   0.6   0.3  -0.1   0.0   0.0   0.0   0.0   0.0
24 3   1.6   2.7   2.7   0.0   0.0   0.0   0.0   0.0   0.0   0.0
21  3 LT LAT REDUCED                 I N N T
22  6  0  648.0    0.0  108.0 1 0  0  270.0
23  120.0   50.0   50.0  180.0  180.0   90.0   90.0
24 0  -1.6  -2.7  -2.7   0.0   0.0   0.0   0.0   0.0   0.0   0.0
24 1  -0.9  -0.9  -0.6  -0.3   0.1   0.0   0.0   0.0   0.0   0.0
24 2   4.3   4.3   4.3   4.3   3.4   0.0   0.0   0.0   0.0   0.0
24 3   3.7   2.9   2.5   0.0   0.0   0.0   0.0   0.0   0.0   0.0
11   139 BILAT H&N                      7-75-81-07       7-Dec-94
12 TG                              1300.0     0.0
13 BILAT H&N 8X100=800NcGY
21  1 RT LAT OFF CORD #2             I N N T
22  3  0  174.0    0.0   58.0 0 0  0  270.0
23  120.0   50.0   50.0  180.0  180.0  270.0  270.0
24 0  -2.0  -2.0  -2.0  -1.0   0.0   0.0   0.0   0.0   0.0   0.0
24 1  -2.0  -2.0  -2.4  -2.9  -3.1   0.0   0.0   0.0   0.0   0.0
24 2   4.5   4.5   4.5   4.5   4.5   0.0   0.0   0.0   0.0   0.0
24 3   8.0   8.2   8.2   7.5   0.0   0.0   0.0   0.0   0.0   0.0
21  2 LT LAT OFF CORD #2             I N N T
22  3  0  183.0    0.0   61.0 0 0  0  270.0
23  120.0   50.0   50.0  180.0  180.0   90.0   90.0
24 0  -8.0  -8.2  -8.2  -7.5   0.0   0.0   0.0   0.0   0.0   0.0
24 1  -4.5  -4.5  -4.5  -4.5  -4.5   0.0   0.0   0.0   0.0   0.0
24 2   2.0   2.0   2.4   2.9   3.1   0.0   0.0   0.0   0.0   0.0
24 3   2.0   2.0   2.0   1.0   0.0   0.0   0.0   0.0   0.0   0.0
11   165 RAO/LPO LUNG                   8-87-85-95      12-Dec-94
12 griffin                         1920.0     0.0
13 RAO/LPO LUNG: 19.20nGY / 1.2nGY
21  1 Rao lung                       I N N T
22 16  0 1472.0    0.0   92.0 0 0  0  270.0
23  120.0   50.0   50.0  180.0  180.0  340.0  340.0
24 0  -5.0  -5.0  -4.8  -4.8  -4.8   0.0   0.0   0.0   0.0   0.0
24 1  -5.0  -5.0  -5.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
24 2   3.3   2.7   2.1   0.0   0.0   0.0   0.0   0.0   0.0   0.0
24 3   3.3   2.6   2.0   1.3   0.8   0.0   0.0   0.0   0.0   0.0
21  2 Lpo lung                       I N N T
22 16  0 1408.0    0.0   88.0 0 0  0  270.0
23  120.0   50.0   50.0  180.0  180.0  160.0  160.0
```

```
24 0  -3.6  -2.8  -2.2  -1.4   0.0   0.0   0.0   0.0   0.0   0.0
24 1  -3.6  -2.8  -2.1   0.0   0.0   0.0   0.0   0.0   0.0   0.0
24 2   5.0   5.0   5.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
24 3   5.0   5.0   5.0   5.0   0.0   0.0   0.0   0.0   0.0   0.0
```

Appendix B

Maintaining the prescription file

The prescription file is maintained by software that runs on the remote computer. This software is not part of the therapy control system, but it does affect neutron therapy from the operators' point of view so it is described here.

Therapists add entries to the prescription file by using the department's Prism treatment planning software [5, 6]. Therapists use Prism to select patients and fields from the department's treatment planning archive that they wish to add to the neutron prescription file. Optionallly they may edit field information at this stage, so the settings entered into the prescription file might not be the same as stored in the Prism archive. The Prism software writes the selected patients and fields in the format required for entries in the neutron prescription file and appends the new entries to the prescription file.

In addition to using Prism to (indirectly) maintain the prescription file, therapists can log in on the remote computer and use a text editor to change the prescription file. This is necessary with the present Scanditronix system for two reasons. There is no other way to delete entries from the prescription file. Moreover, the Scanditronix control software requires that fields for the same patient must be contiguous in the prescription file. If new or revised fields are added for a patient already under treatment, it is usually necessary to use the text editor to rearrange entries into contiguous order. This is inconvenient, so therapists usually edit the file to make small changes in the prescription, rather than transfer a new field from Prism.

We intend that when the new therapy control program is in use, it will not be necessary for therapists to edit the prescription file on the computer for any reason. The first hurdle is overcome because the new therapy control software does not require that fields for the same patient be contiguous in the file. To overcome the second hurdle, we will provide a small program that enables therapists to delete a patient and all the patient's fields from the prescription file by making selections from a menu.

Appendix C

Programmable Logic Controller (PLC)

This appendix describes the interface to the PLC, a Modicon 984E [7, 8, 9]. It describes the connections, protocol, and commands.

C.1 Connection and protocol

One of the neutron therapy computer RS232 serial lines is connected to the Modbus port on the Modicon controller. Communication uses these settings:

baud rate 9600
7 bits per character
even parity
one stop bit

The second 984E Modicon controller can be connected to the first through the standard Modicon controller network (Modbus Plus), which makes it addressable (via the *slave address*) by the Therapy Control System computer via the Modbus connection on the first controller.

Communication uses a protocol called *Modbus* in ASCII mode [9]. Modbus also supports a *binary mode* which we do not use.

A device connected to the Modbus port on the 984E Modicon controller is defined by Modicon to be the *master* of the device. The neutron therapy computer is the master device, and the 984E controller is the *slave*. All communication is initiated by the master. The master sends a message to the slave, and the slave should always respond immediately (within about 50 msec) by sending a message back to the master. The slave never sends unsolicited messages to the master.

C.2 Message format

Each message (to the PLC and from the PLC) is delimited as follows: the first character is a colon (:, ASCII 3A hex), the last two characters are a carriage return (ASCII 0D hex) and line feed (ASCII 0A hex) in that order; the intervening characters are collectively referred to as the *command* when sent to the PLC and the *response* when sent by the PLC, and the delimiting characters together with the command are referred to as the *message*. Successive characters in a message cannot be separated in time by more than one second.

Every command string represents a sequence of bytes. Each byte is transmitted as two printing ASCII characters which show the value of the byte in base 16 represented as two hexadecimal digits.

The last byte (the last two characters in the message) is a *Longitudinal Redundancy Check* (LRC). The LRC is the two's complement of the sum (with carries discarded) of the bytes in the command. The LRC is computed by the sending device, and may be confirmed (used as an error check) by the receiving device. If the LRC in the command is not correct, the Modicon will not do anything and will not send a response.

C.3 Message contents

These items appear in messages.

A *slave address* (sa) is the network address of Modicon controller that controls the coils of interest. This address is determined by switch settings in the controller (section C.6). The address for the 984E controller connected to the neutron therapy computer is 01.

A *coil address* (ca) is one less than the last four digits of the coil number that appears in the ladder logic program (network diagram). For example, a valid coil number in the diagram is 00001, and the coil address of this coil in the message is 0000. The coil address in the message is expressed in hexadecimal digits, whereas the coil number on the network diagrams used to define the controller is expressed in decimal digits.

An *input address* (ia) is one less than the last four digits of the input number that appears in the ladder logic program. Again, the input address in the message is specified in hexadecimal digits, whereas the input number on the network diagram is expressed in decimal digits. For example, a valid input number in the network diagram is 10018, the coil address of this coil in the message is 0011 hex ($0018 - 0001 = 0017$, 0017 decimal $=$ 0011 hex).

Here follow the contents of particular commands and responses.

Read Input Status The following command format is used to request input status data from the PLC. It is possible to request the status of any number of consecutive coil addresses in this fixed-length message.

Byte 1	slave address	sa	
Byte 2	function	02	
Byte 3	input address, high	ia	address of first input, high byte
Byte 4	input address, low	ia	address of first input, low byte
Byte 5	number of points, high	nn	
Byte 6	number of points, low	nn	
Byte 7	LRC	lr	

For example, the following string of text is the command text just as it is sent to the PLC: `01020000000AF3`. In this command, $sa = 01$, $function = 02$, $ia = 0000$, $nn = 000A$, and $lr = F3$.

The response from the PLC has this form:

Byte 1	slave address	sa	
Byte 2	function	02	
Byte 3	byte count	bb	number of bytes of coil status bits
Byte 4	input status	ss	status of ia thru $ia + 7$, one bit per coil
⋮	⋮	⋮	⋮
Byte $(bb + 3)$			
Byte $(bb + 4)$	LRC	lr	

The first two bytes (four characters) are the same in the response as in the command. However the length of the response is variable; it depends on the range of addresses specified in the command. The status of each input coil is represented by a single bit, packed eight per byte. The status of the coils with lower addresses appear in the less significant bits, so the least significant bit of byte 4 is the status of the coil at input address ia.

Read Coil Status The following command format is used to request coil status data from the PLC.

Byte 1	slave address	sa	
Byte 2	function	01	
Byte 3	coil address, high	ca	address of first coil, high byte
Byte 4	coil address, low	ca	address of first coil, low byte
Byte 5	number of coils, high	nn	
Byte 6	number of coils, low	nn	
Byte 7	LRC	lr	

The response from the PLC has this form:

Byte 1	slave address	sa	
Byte 2	function	01	
Byte 3	byte count	bb	number of bytes of coil status bits
Byte 4	coil status	ss	status of ca thru $ca + 7$, one bit per coil
$\vdots$	$\vdots$	$\vdots$	$\vdots$
Byte $(bb + 3)$			
Byte $(bb + 4)$	LRC	lr	

Force Single Coil The following command format is used to force a coil's state in the PLC.

Byte 1	slave address	sa	
Byte 2	function	05	
Byte 3	coil address, high	ca	
Byte 4	coil address, low	ca	
Byte 5	Force Data High	dd	FF forces coil high, 00 forces coil low
Byte 6	Force Data Low	00	
Byte 7	LRC	lr	

For example the command `01050024FF00D7` forces coil 00037 high.

In this case the PLC should simply echo the command; the response sent by the PLC is identical to the force coil command.

Byte 1	slave address	sa	
Byte 2	function	05	
Byte 3	coil address, high	ca	
Byte 4	coil address, low	ca	
Byte 5	Force Data High	dd	FF coil forced high, 00 coil forced low
Byte 6	Force Data Low	00	
Byte 7	LRC	lr	

C.4 Interactions with PLC program

There are two programs to consider: in addition to the therapy control program on the neutron therapy computer, there is the ladder logic program on the PLC. Coils that are driven by the therapy control program appear in PLC ladder logic programs, and coils in ladder logic programs are read by the therapy control program. Therefore, both programs must be coordinated; certain rules must be followed to make it possible for the two programs to work together.

First of all, any given coil must only be driven by one program, either the therapy control program or the ladder logic program. It must not be possible for both programs to attempt to force the same coil. However any coil may be read by both programs.

The Modicon controller has a *memory protect* switch. However, the therapy control program can force coils in the controller even when memory protection is turned on. It appears that memory protection only prevents the ladder logic program from being erased or overwritten.

When the PLC is configured, a coil may be *enabled* or *disabled* (pages 4-8, 4-9 in [7]). An enabled coil cannot be forced by the therapy control program; only disabled coils can be forced via Modbus commands.

It is possible to issue a Force Single Coil command for a coil which is also controlled by the ladder logic program. In that case the setting that the coil is forced to remains in effect until the controller's own logic next solves the coil; otherwise the coil remains at the forced setting indefinitely. At network power-up, the coil is set to the value specified in the controller's logic.

We observe these rules: Every coil to be forced by the therapy control program is not connected into the controller logic as an output, is disabled, and is specified in the controller logic as a normally open or normally closed coil depending on the desired state at controller power-up.

C.5 Examples

Here are some examples of dialogs with the PLC, consisting of a series of commands and responses[1]. The complete message strings in both directions are shown verbatim, except the (invisible) carriage return and line feed characters are shown here as `<cr><lf>`.

This dialog demonstrates how to control an output coil. The coil was disabled. The coil address was 0037, which becomes 0024 in the command strings ($0037-1 = 36$, 36 decimal $=$ 24 hex). Correct operation was confirmed by observing the LED driven by the coil.

`:010100240001D9<cr><lf>`	Command: read coil status
`:01010100FD<cr><lf>`	Response: coil is low (last digit in byte 4 is 0)
`:01050024FF00D7<cr><lf>`	Command: force coil high
`:01050024FF00D7<cr><lf>`	Response: confirmed (LED turns on)
`:010100240001D9<cr><lf>`	Command: read coil status
`:01010101FC<cr><lf>`	Response: coil is high (last digit in byte 4 is 1)
`:010500240000D6<cr><lf>`	Command: force coil low
`:010500240000D6<cr><lf>`	Response: confirmed (LED turns off)
`:010100240001D9<cr><lf>`	Command: read coil status
`:01010100FD<cr><lf>`	Response: coil is set low

[1] These are transcripts from sessions where an operator typing at a terminal took the place of the neutron therapy computer; responses from the PLC appeared on the terminal screen.

The following dialog confirms that it is not possible to control an enabled coil (number 0078) from the neutron therapy computer.

`:0101004D0001B0<cr><lf>`	Command: read coil status
`:01010100FD<cr><lf>`	Response: coil is low
`:0105004DFF00AE<cr><lf>`	Command: force coil high
`:0105004DFF00AE<cr><lf>`	Response: confirmed (LED remains off)
`:0101004D0001B0<cr><lf>`	Command: read coil status
`:01010100FD<cr><lf>`	Response: coil is low

C.6 Mapping addresses to physical locations

The coil addresses and input addresses in the command strings are addresses in network diagrams (ladder logic programs). These program addresses are mapped to physical locations (slots in equipment racks) by the Modsoft software that runs on the PC connected to one of the Modicon controller units. The mapping defined by Modsoft is downloaded to the controller's non-volatile RAM.

Modsoft shows input/output numberings and their mapping to installed I/O devices. For example:

Slot	Output (coil)	Unit type	Unit ID
102	00033 - 00048	16-Out TH	B824

Slot	Input	Unit type	Unit ID
201	10001 - 10032	32-In TH	B827

This indicates that coils 00033 through 00048 are assigned to the 16 outputs available at the unit installed in slot 102. The "TH" indicates logical true is high. Also, inputs 10001 through 10032 are assigned to the 32 inputs available at the unit installed in slot 201.

Example Given the third input on the Modicon 32 bit input unit installed in slot number 203, what is its address for a Modbus command?

Check I/O Map for controller logic programmed using Modsoft, for slot 203:

Slot	Input	Unit type	Unit ID
203	10065 - 10096	32-In TH	B827

The third input on the unit in slot 203 has been assigned the input number 10067. To determine the input address, remove the leading digit (always a 1 to indicate input), subtract one, and convert from decimal format to hexadecimal format: 10067 $\rightarrow$ 0067 $\rightarrow$ 0066 decimal $\rightarrow$ 0042 hex.

To address this input in a Modbus command the slave address must also be determined. The slave address is the node address assigned to the controller with which this Modicon input unit is connected. The controller's node address setting is set by a series of six DIP switches on the bottom of the unit; read switches 1 through 6 (where 1 is the least significant bit) and add 1 to the resulting number to get the node address (see [8], p.26). The node address for the most recently installed modicon unit is 01.

Since the command strings refer to the program addresses, it should not be necessary to change those commands (or the software that generates them) when the mapping defined by Modsoft changes. However the slave addresses do occur in the command strings; if the node address switches are changed, commands will no longer work.

C.7 Signals and address assignments

Tables C.1 and C.2 list the signals connected to both Modicons that are used by the therapy control program. The Check-and-Confirm and Enable signals are coils; the rest are inputs[2].

Communications between the neutron therapy computer and the Modicon is more efficient when the inputs are sequentially located (e.g. 10033 through 10064) so that one Request Input Status command can be used to access all the desired input signals[3]

[2]What about a watchdog timer output from the neutron therapy computer to the PLC?

[3]At this writing, addresses have not yet been assigned.

	Signal Name	Node	Address
1	Check and Confirm OK, Line A	(01 or 02)	(coil address)
2	Check and Confirm OK, Line B		
3	LCC Motion Enable		
4	TMC Motion Enable		
	(Floor tracking signals)		(input address)

Table C.1: PLC signals used by therapy control program

	Input Signal Name	Node	Input Address
1	Isocentric Console Enabled	(01 or 02)	
2	Isocentric Console Test Mode Enabled		
3	Isocentric Console Test Mode Selected		
4	Isocentric Console Treat Mode Selected		
5	Fixed Console Enabled		
6	Fixed Console Test Mode Enabled		
7	Fixed Console Test Mode Selected		
8	Fixed Console Treat Mode Selected		
9	Isocentric Room Closed		
10	Isocentric Glass Stop Open		
11	Isocentric Glass Stop Closed		
12	Isocentric Drawer In Safe		
13	Isocentric Drawer In Treat		
14	Isocentric Local Pedestal Off		
15	Isocentric Therapy Console On		
16	Isocentric Collision Detector		
17	Isocentric Patient Movement Detector		
18	Isocentric Target Cooling Flow		
19	Isocentric Target Temperature Sensor		
20	Isocentric Motion Stop OK		
21	Isocentric Drawer In X-Ray		
22	Fixed Room Closed		
23	Fixed Glass Stop Open		
24	Fixed Glass Stop Closed		
25	Fixed Drawer In Safe		
26	Fixed Drawer In Treat		
27	Fixed Local Pedestal Off		
28	Fixed Therapy Console On		
29	Fixed Collision Detector		
30	Fixed Patient Movement Detector		
31	Fixed Target Cooling Flow		
32	Fixed Target Temperature Sensor		
33	Fixed Motion Stop OK		
34	Fixed Drawer In X-Ray		
35	Dosimetry Relay Activated, line A		
36	Dosimetry Relay Activated, line B		
37	Check and Confirm Relay Activated, line A		
38	Check and Confirm Relay Activated, line B		
39	DMC Timer Enabled		

Table C.2: PLC input signals used by therapy control program

Appendix D

Scanditronix controllers

This appendix describes features common to all three Scanditronix controllers: the treatment motion controller (TMC), leaf collimator controller (LCC) and dose monitor controller (DMC). Each treatment room has its own TMC and DMC; only the isocentric room has an LCC. Subsequent chapters describe the details of particular controllers.

More information about the controllers appears in the Scanditronix documents (Part 9 in [10]).

D.1 Connections and protocols

Each Scanditronix controller is connected to one of the therapy computer RS232 serial lines. Communication uses these settings:

baud rate 1200 (except LCC uses 9600)
7 bits per character
even parity
one stop bit

Most communications are initiated by the therapy control computer: it sends a command to a controller, and the controller responds by sending back some messages. First, the controller responds immediately (within a fraction of a second) with an *acknowledgement* message to indicate that it has received the message. Then the controller performs the commanded action. When the controller has completed the action, it sends a *completion* message. In most cases the completion message arrives less than a second after the command is received, but some commands take an appreciable interval to perform; the command to set the collimator leaves takes about 25 seconds to execute. A controller ignores any commands sent while it is executing a command; a controller can only process a command after it has issued a completion message.

Not all communications are initiated by the therapy control computer. A controller can send unsolicited messages to the control computer; the therapy control program must be able to handle this. Each controller sends a message when it is reset at power up or when its hardware reset button is pressed. In addition, the DMC can send unsolicited messages to indicate it has detected various fault conditions.

D.2 Message format

Messages are strings of ASCII characters. In the following descriptions non-printing or invisible characters such as line feed and carriage return are shown as in `<lf><cr>` and all the printing ASCII characters appear in typewriter font (as in `CON RUN`). In some contexts the space character is indicated `<space>` to avoid confusion or ambiguity.

Every command to a controller is terminated by a carriage return *but no line feed.*

Every message from a controller is terminated by a line feed and a carriage return *in that order.*

Controllers respond to every command with the *acknowledgement sequence*, a space character followed by a line feed and carriage return: `<space><lf><cr>`.

Controllers indicate they have finished performing a command by sending the *completion sequence*, a dollar sign (and then the line feed and carriage return): `$<lf><cr>`

When a controller sends data it terminates each string of data values with a pound sign (etc.): `#<lf><cr>`. This is called the *continuation sequence* because it is always followed by another line of message text, with more data or the completion sequence. If there are more than ten data values, the controller sends ten values on one line, then the continuation sequence, and then more data on the next line(s)[1].

[1] The SCX documentation suggests that multiple lines of data are possible. In the present system there is never more than a single line of data because the present PDP11 software never requests more than ten items at a time. The new system could be more efficient (send fewer messages) if it could request more than ten items at a time, but we should run some tests to confirm that this actually works as described.

D.3 Commands

Commands are messages from the therapy control computer to the Scanditronix controllers. There are four kinds of commands: reset, control, input and output. Controllers respond to these, and can also issue error messages.

Most commands consist of a one or two word command name and then some parameters, which are usually setting names and/or numbers. Command names and setting names can be abbreviated (to the fewest uniquely indentifying characters), so these two commands mean the same thing:

```
INPUT SET WEDTYPE  0 WEDROT 0

IN SET WEDT  0 WEDR 0
```

Many commands take variable numbers of parameters, so you can have a few long commands or many short ones. The following two commands together have the same effect as either of the preceding commands.

```
IN SET WEDT  0

IN SET WEDR  0
```

D.3.1 Reset

Reset commands reinitialize the controller. A reset command sets certain of the controller's settings and other internal parameters to default values set in the controller's program in ROM. A reset command may change or cancel setting values that were set by previous input commands.

The reset command is a single ASCII *escape* character (1B hex, also indicated `<esc>`) followed by a carriage return.

The controller responds to the reset command with a text string or *banner* that identifies the controller, then `<lf><cr>`, then the completion sequence (but no acknowledgement sequence). The contents of the banner are different for each controller.

A reset initiated by a command is called a *software reset*. It is also possible to cause a *hardware reset* by turning on the controller power or pushing its reset button. After a hardware reset, a controller prints its banner and then the completion sequence. However a hardware reset does not have exactly the same effect as a software (commanded) reset; some settings assume different values after a hardware reset.

D.3.2 Control

Control commands tell the controller to perform some action. Usually the action depends on the values of settings that have been established by preceding input commands.

Control commands have the form `CON` *action* `<cr>`. The controller responds by sending the acknowlegment sequence and then the completion sequence.

D.3.3 Input

Input commands load the controller with input data that will be used during subsequent control and output commands. Reset commands may have the effect of cancelling preceding input commands, returning internal data to default or undefined values.

Input commands assign values to named settings, using this data item name/value pair syntax: `INP` $name_1$ $value_1$ $name_2$ $value_2$ ...`<cr>`. The controller responds by sending the acknowlegment sequence and then the completion sequence.

Some controllers store two values for each setting name, the input value and the actual (measured) value. In that case the command to load the input values is `INP SET` $name_1$ $value_1$ .... The command `INP ACT` $name_1$ $value_1$ ... is accepted without eliciting an error message, but has no effect.

Input commands work properly if the names and values are separated by a single space or additional spaces. Examples in the vendor's documents [10] usually show the numeric values padded with leading blanks (as if they were right justified) but the leading blanks are not required[2].

[2] The present control programs issue commands with leading blanks before many numeric values, but our experiments show they are not required.

D.3.4 Output

Output commands request the controller to send the values of a sequence of named data items. Usually these are values actually measured by sensors in the controller, so they can differ from the values previously loaded by input commands.

An output command names the data items whose values are requested: `OUT` $name_1$ $name_2$ ...`<cr>`. The controller responds by sending the acknowlegment sequence, and then the data line(s) terminated by the continuation sequence, and finally the completion sequence.

For those controllers that store both input and actual values, the values of both can be output by the commands `OUT INP` $name_1$ ... and `OUT ACT` $name_1$ ... respectively.

Some controllers provide an `OUT ALL` command to output all values.

D.4 Error messages

Error messages can be issued by controllers in response to commands. The DMC can also issue unsolicited error messages when it detects various fault conditions.

The format of an error message is `ERROR` n `;` *message*`<lf><cr>` where n is the error number. When a command evokes an error message, first the controller responds with the acknowledgement sequence, then the error message, and finally the completion sequence.

Every controller responds to command syntax errors, error number 1, For example this is the syntax error message from the TMC[3].

```
ERR1 ; SYNTAX ERROR!<lf><cr>
```

In addition to syntax errors, each controller issues other error messages related to its specific functions. These are listed in subsequent chapters.

[3]The error messages for other controllers differ slightly in appearance (they say `ERROR 1` etc.).

D.5 Other errors

Certain commands have no effect, or have an effect other than suggested by the command text, yet they elicit no error message; instead, the controller responds with the appropriate protocol for a succesful command. Warnings about these commands appear in subsequent chapters.

Appendix E

Treatment motion controller (TMC)

This appendix describes part of the command set for the Scanditronix Treatment Motion Controller (TMC). Additional details appear in Part 9.10 in [10].

E.1 Commands

E.1.1 Reset

The TMC responds to the reset command by printing a banner within approximately 500 msec, then the completion sequence after another 500 msec. The TMC banner is

```
TMC Vers 1.1 841206  . Pha.
```

E.1.2 Input

None of the input commands causes any motion. Use the enable commands to actually command motions.

The TMC responds to input commands with the acknowledge and completion sequences, within approximately 100 msec.

The command to load wedge type is

```
INPUT SET WEDTYP <type><lf><cr>
```

where <type> is 0 for no wedge, 1 for 30 degree wedge, 2 for 45 degree wedge, or 3 for 60 degree wedge. For example:

```
INPUT SET WEDTYP 1<lf><cr>
```

The command to load wedge rotation is

```
INPUT SET WEDROT <type><lf><cr>
```

where <type> is 0 for 0 degrees, 1 for 90 degrees, 2 for 180 degrees, or 3 for 270 degrees. For example

```
INPUT SET WEDROT 3<lf><cr>
```

The command to load the flattening filter selection is

```
INPUT SET FILPOS <type><lf><cr>
```

where <type> is 0 for no filter, 1 for small filter, or 2 for large filter. For example

```
INPUT SET FIL 0<lf><cr>
```

It is also possible to load more than one setting in a single command:

```
INP SET WEDTYP 0 WEDROT 0
```

Input commands are used to load set values. It is also possible to issue input commands on actual values: INPUT ACT FIL ... etc. These commands do not elicit any error message, but subsequent OUT ACT FIL ... commands reveal that they have no effect.

E.1.3 Enabling motions

Use the enable command to actually command motions to occur. This enable command selects (moves to) the flattening filter, wedge type and wedge rotation specified by preceding input commands

```
CON ENA WEDT WEDR FIL<lf><cr>
```

The TMC responds within approximately 100 msec. It does not appear to wait for the physical motion to complete before responding with the completion sequence.

E.1.4 Disabling motions

Send this command to disable motions within the TMC:

```
CON DIS WEDT WEDR FIL<lf><cr>
```

The TMC responds within approximately 100ms.

E.1.5 Output

Motions Send this command to cause the TMC to output measured motion settings.

```
OUTPUT ALL<lf><cr>
```

The TMC responds (with floating point formatted data for angles and integer for types) for the following fields (separated by one space): filter type, collimator position, vertical position, lateral position, longitudinal position, floor position, top position, gantry position, wedge type, wedge rotation, xfield, yfield. and terminated with the data sequence. Angles are in degrees, to a tenth of a degree (e.g. 179.7). All twelve items appear on a single line, terminated with the continuation sequence.

The TMC responds to this command within approximately 100ms.

Status Send this command to cause the TMC to output its current status

```
OUT STA<lf><cr>
```

The TMC responds with two eight bit bytes, encoded as two hexadecimal digits (printable ASCII characters), for example: `4720<lf><cr>`. The bits are defined as shown in Table E.1. The example in Figure E.1 shows how the status bytes are decoded (bit 7 is the most significant bit).

E.2 Unused settings

The control program does not set the TMC `XFIELD` and `YFIELD` settings.

These two settings are intended to represent the maximum open field dimensions in the x and y directions. The control program could calculate these settings from the leaf settings used by the LCC. These settings can appear on the isocentric room wall display, which is driven by the TMC. They do not affect the actual treatment machinery controlled by the TMC.

E.3 Errors

When an error condition is detected the TMC responds with a string of the form

`ERR`*n* `;` *message*`!<lf><cr>`

where n is the numerical error code and *message* is the error message text[1].

E.4 Example

Here is an example dialog with the TMC showing the commands and responses to treat a single field[2]. The first line shows the TMC response to a software reset. Nonprinting characters such as carriage return and line feed are indicated in the usual way, not by `<cr>` etc.

[1] There is no list of errors for the TMC in [10]. Perhaps it only recognizes syntax errors.

[2] This example was recorded from the original Scanditronix control system, not the system described in this document.

```
TMC Vers 1.1 841206  . Pha."
$
CON DIS COL WEDT WEDR VER LAT LON FLO GAN FIL
$
OUT ACT COL WEDT WEDR VER LAT LON FLO GAN FIL TOP
269.8 00 018.0 108.0 044.4 065.1 180.1 3701 2 180.4 #
$
INP SET WEDTYP  0 WEDROT  0
$
INP SET FILPOS  1
$
CON ENA WEDT WEDR FIL
$
INP ACT XFIELD  11.8 YFIELD  14.3
$
CON DIS WEDT
$
```

	Low byte (bit number, meaning)
7	1=arc therapy enabled
	0=arc therapy disabled
6	1=emergency stop
	0=no emergency stop
5	not used
4	not used
3	1=auto enable on (computer controlled motion?)
	0=auto enable off (manual controlled motion?)
2	1=speed > 0
	0=no motion
1	1=console key on
	0=console key off
0	1=collision detected
	0=no collision detected

	High byte (bit number, meaning)
7	not used
6	1=gantry in treatment window
	0=gantry not in treatment window
5	1=FC1 open
	0=FC1 closed
4	not used
3	not used
2	1=internal enable
	0=internal disable
1	1=motion in progress
	0=no motion
0	1=motion complete
	0=motion not complete

Table E.1: TMC status codes

In this example the status bytes string is `4720`

```
   4    7    2    0

0010 0111 0010 0000
 *|   ||| ||   ||||
 Gantry not in treatment window
  *   ||| ||   ||||
  FC1 open
      *|| ||   ||||
      Internal enable
       *| ||   ||||
       Motion in progress
        * ||   ||||
        Motion complete
          *|   ||||
          Arc therapy disabled
           *   ||||
           No emergency stop
               *|||
               Auto enable off
                *||
                No motion
                 *|
                 Console key off
                  *
                  No collision detected
```

Figure E.1: Decoding TMC status bytes

Appendix F

Leaf Collimator Controller (LCC)

This appendix describes the commands and features specific to the Scanditronix Leaf Collimator Controller (LCC) (Part 9.6 in [10]).

None of the commands except `CONTROL RUN` causes any motion. Use the enable commands to actually command motions. The LCC responds to all commands except `CONTROL RUN` within approximately 100 msec. The `CONTROL RUN` command can take up to 25 seconds to complete.

F.1 Commands

F.1.1 Reset

After a reset the LCC prints this banner[1]:

```
SCANDITRONIX LCC VER 2.1#
```

F.1.2 Leaf positions

The command to load leaf positions is

[1] Isn't the LCC banner just a right angle bracket `>` after a hadware reset?

`IN S` n pos_1 pos_2 ... pos_n<lf><cr>

where n is the decimal number of a leaf (in the range 0 – 39), pos_1 is the desired (decimal) leaf position (in the range −160.0 to +160.0 millimeters) of leaf number n, pos_2 for leaf number $n+1$, etc. The sequence maximum number of leaves that can be entered for one command is 10. For example:

```
IN S 10 130.0 130.0 130.0 130.0 130.0 130.0<lf><cr>
```

(are spaces significant?)

The LCC responds with the acknowledge and completion sequences.

Another syntax for loading leaf positions, when they are all the same, is

`IN S` n `TO` m pos <lf><cr>

where $n < m$ and the range and units are as described above. This loads the same data into all leaves in the inclusive range of the two leaf numbers. The LCC responds with the acknowledge and complete sequences.

F.1.3 Leaf motion

Use the Control Run command to actually command leaf motion to occur.

```
CON RUN<lf><cr>
```

The LCC responds with an acknowledge sequence, and when the leaves all reach their commanded positions the LCC sends the complete sequence. The maximum time between the acknowledge and complete sequences is approximately 25 seconds. The LCC does not respond to any commands during this interval.

F.1.4 Calibration factors

Use this command to load the calibration factors into the LCC:

`IN SCA` n $value_1$ $value_2$ $\ldots value_m$<lf><cr>

where n is the decimal number of a leaf (in the range 0 – 39), $value_1$ is the scale factor (decimal) for leaf number n, $value_2$ is for the leaf at $n+1$, etc. Scale factors range from -3600.0 to $+3600.0$ (unitless). Up to 10 scale factors can be input in one command. The LCC responds with the acknowledge and complete sequences. For example

```
IN SCA 12 -3098.9<lf><cr>
```

Loading of the `MAXPOS`, `MINPOS`, and `SCACAL` calibration values differs from the description above by substituting the appropriate keyword for `SCAFAC`.

Send this command to load the tolerance window (the allowable deviation between the prescribed and measured leaf position):

```
IN WIN value<lf><cr>
```

The *value* is small, typically 1.0 (millimeter). The LCC responds with the acknowledge and completion sequences.

F.1.5 Output

Leaf positions Send this command to retrieve the actual leaf positions from the LCC:

```
OUT ACT n TO m<lf><cr>
```

where n and m specify the range of leaf numbers (within 0 – 39). The LCC responds by sending the requested data in the same order it is requested (e.g. first value is for leaf n, the second is for leaf $n+1$, etc.) terminated with the data sequence.

You can request up to 40 output values, but no more than 20 will be returned: the command `OUT ACT 00 TO 39` has the same effect as `OUT ACT 00 TO 19`.

Leaf positions are given in millimeters. For example this command

```
OUT ACT 00 TO 03<lf><cr>
```

invokes an acknowledgement sequence, the following response, and then the completion sequence (acknowledge, data, complete):

```
000.5 033.2 000.0 #<lf><cr>
```

Calibration factors To read the MAXPOS, MINPOS, SCAFAC and SCACAL calibration values, send a command like the preceding, except substitute the appropriate keyword for ACTPOS.

Tolerance window Send this command to retrieve the tolerance window currently loaded into the LCC:

```
OUT WIN<lf><cr>
```

and the LCC responds with the acknowledge sequence, a string consisting of the window value (in millimeters) terminated with the data sequence and the completion sequence.

Status Send this command to cause the LCC to output its current status

```
OUTPUT STATUS<lf><cr>
```

The LCC responds with an eight bit byte, encoded as one hexadecimal digits (printable ASCII character), for example: 41<lf><cr>. The bits are defined as shown in Table F.1. The example in Figure F.1 shows how the status byte is decoded (bit 7 is the most significant bit).

F.1.6 Glass Stop

There are commands to position the glass stop, but they are not used by the therapy control program. The glass stop is positioned by the Programmable Logic Controller, PLC.

F.2 Errors

The LCC may not be able to complete the control run command. If it detects and error, it responds with an error message, rather than the completion sequence. An error message has this form: of the form:

```
ERROR n ; message!<lf><cr>
```

These are the LCC error codes:

n	*Message*	*Description*
2	LOCAL MODE	The field control switch on the therapy room pedestal set to local. Positioning by the LCC is not possible.
3	SETUP INPUT ERROR	Leaves cannot be positioned due to wrong prescribed data. Typically this error message will be generated when the prescribed position data call for two leaves to overlap each other.
4	LEAF NO MOTION ERROR	A leaf has not reached its prescribed position and is not moving. The reason for this error is usually a mechanical malfunction in the collimator.

(Are there other kinds of errors?)

F.3 Example

Here is an example dialog with the LCC, showing the commands and responses needed to treat a single field[2]. The first line shows the LCC response to a software reset. Nonprinting characters such as carriage return and line feed are indicated in the usual way, not by `<cr>` etc.

```
SCANDITRONIX   LCC   VER 2.1#
$
OUT WIN
+000.9 #
$
IN MAX 00   290.2   291.8   294.8   293.8   289.3   285.7   298.2   298.2
$
IN MAX 08   291.8   295.9   299.2   301.5   280.2   285.2   294.5   297.4
$
IN MAX 16   290.0   292.9   284.6   297.1   297.1   290.9   293.9   286.8
$
IN MAX 24   290.7   296.8   297.7   302.4   284.2   286.9   292.9   293.4
$
IN MAX 32   292.2   293.5   296.5   294.1   293.5   292.4   285.0   299.7
$
```

[2]This example was recorded from the original Scanditronix control system, not the system described in this document

```
IN MIN 00    99.7   101.5   107.1   102.2   100.4    94.8   107.1   109.6
$
IN MIN 08   102.1   103.9   109.0   109.4    87.6    95.1   103.0   102.8
$
IN MIN 16    98.3   100.6    92.4   103.9    97.2    96.2    98.4    91.8
$
IN MIN 24    97.6    99.9   102.5   107.7    92.5    93.5    97.2    97.2
$
IN MIN 32    94.9    96.2    99.0    96.9    99.1    96.4    89.7   105.0
$
IN SCA 00 -3113.4 -3109.8 -3062.1 -3133.2 -3084.3 -3120.6 -3124.2 -3078.8
$
IN SCA 08 -3098.9 -3140.3 -3108.0 -3142.1 -3151.0 -3106.2 -3131.4 -3185.9
$
IN SCA 16 -3135.0 -3145.6 -3143.9 -3161.5 -3184.2 -3187.7 -3201.4 -3192.8
$
IN SCA 24 -3159.8 -3225.3 -3196.3 -3187.7 -3135.0 -3165.0 -3204.9 -3213.4
$
IN SCA 32 -3232.0 -3232.0 -3235.4 -3230.3 -3182.5 -3210.0 -3198.0 -3187.7
$
OUT MAXPOS 00 TO 07
+290.2 +291.8 +294.8 +293.8 +289.3 +285.7 +298.2 +298.2 #
$
OUT MAXPOS 08 TO 15
+291.8 +295.9 +299.2 +301.5 +280.2 +285.2 +294.5 +297.4 #
$
OUT MAXPOS 16 TO 23
+290.0 +292.9 +284.6 +297.1 +297.1 +290.9 +293.9 +286.8 #
$
OUT MAXPOS 24 TO 31
+290.7 +296.8 +297.7 +302.4 +284.2 +286.9 +292.9 +293.4 #
$
OUT MAXPOS 25 TO 39
+292.2 +293.5 +296.5 +294.1 +293.5 +292.4 +285.0 +299.7 #
$
OUT MINPOS 00 TO 07
+099.7 +101.5 +107.1 +102.2 +100.4 +094.8 +107.1 +109.6 #
$
OUT MINPOS 08 TO 15
+102.1 +103.9 +109.0 +109.4 +087.6 +095.1 +103.0 +102.8 #
$
OUT MINPOS 16 TO 23
```

```
+098.3 +100.6 +092.4 +103.9 +097.2 +096.2 +098.4 +091.8 #
$
OUT MINPOS 24 TO 31
+097.6 +099.9 +102.5 +107.7 +092.5 +093.5 +097.2 +097.2 #
$
OUT MINPOS 32 TO 39
+094.9 +096.2 +099.0 +096.9 +099.1 +096.4 +089.7 +105.0 #
$
OUT SCAFAC 00 TO 07
-3113.4 -3109.8 -3062.1 -3133.2 -3084.3 -3120.6 -3124.2 -3078.8 #
$
OUT SCAFAC 08 TO 15
-3098.9 -3140.3 -3108.0 -3142.1 -3151.0 -3106.2 -3131.4 -3185.9 #
$
OUT SCAFAC 16 TO 23
-3135.0 -3145.6 -3143.9 -3161.5 -3184.2 -3187.7 -3201.4 -3192.8 #
$
OUT SCAFAC 24 TO 31
-3159.8 -3225.3 -3196.3 -3187.7 -3135.0 -3165.0 -3204.9 -3213.4 #
$
OUT SCAFAC 32 TO 39
-3232.0 -3232.0 -3235.4 -3230.3 -3182.5 -3210.0 -3198.0 -3187.7 #
$
IN WIN 1.0
$
IN S 00  -82.0  -82.0  -82.0  -82.0  -82.0  -82.0    0.0    0.0    0.0    0.0
$
IN S 10  -82.0  -82.0  -82.0  -82.0  -82.0  -82.0    0.0    0.0    0.0    0.0
$
IN S 20   82.0   82.0   82.0   82.0   82.0   82.0    0.0    0.0    0.0    0.0
$
IN S 30   82.0   82.0   82.0   82.0   82.0   82.0    0.0    0.0    0.0    0.0
$
CON RUN
$
OUT WIN
+001.0 #
$
OUT ACT 00 TO 09
-081.7 -081.9 -081.6 -081.9 -081.4 -081.6 -000.6 -000.3 -000.2 +000.3 #
$
OUT ACT 10 TO 19
```

```
-081.8 -081.9 -081.6 -082.0 -081.7 -081.9 +000.0 +000.0 +000.4 -000.4 #
$
OUT ACT 20 TO 29
+081.7 +082.1 +081.5 +082.2 +082.4 +081.6 +000.0 +000.0 +000.0 +000.0 #
$
OUT ACT 30 TO 39
+082.4 +081.8 +081.7 +081.8 +081.4 +081.9 -000.1 +000.0 +000.0 +000.3 #
$
```

	Bit number, meaning
7	1=CONTROL GLASS OUT command received
	0=CONTROL GLASS IN command received
6	not used
5	1=CONTROL GLASS MANUAL mode
	0=CONTROL GLASS AUTO mode
4	not used
3	1=Local field control selected on therapy pedestal
	0=Auto field control selected on therapy pedestal
2	not used
1	1=Error detected after latest CONTROL RUN command
	0=No error detected after latest CONTROL RUN command
0	1=Control run mode terminated
	0=Control run mode active

Table F.1: LCC status codes

In this example the status byte string is `41`

```
  4    1

0100 0001
* |  | ||
Control glass in command received
  *  | ||
  Control glass auto mode
     * ||
     Auto field control selected at therapy pedestal
       *|
       No error detected after latest CONTROL RUN command
        *
        Control run mode terminated
```

Figure F.1: Decoding LCC status byte

Appendix G

Dose Monitor Controller (DMC)

This section describes the commands and features specific to the Scanditronix Dose Monitor Controller (DMC) (Part 9.8 in [10]). More about the DMC appears in [11] and [12][1].

G.1 Overview

The DMC measures the dose emerging from the treatment head and is responsible for shutting off the beam when the prescribed dose has been delivered to the patient. While the beam is on, the DMC performs additional control functions besides those required to shut the beam off when the treatment is complete. Based on the instantaneous dose rate, it generates correction signals that are used to keep the dose rate nearly constant and to steer the beam.

Figure G.1 illustrates the DMC and some other components of the treatment control system. Two *ion chambers* (IC1 and IC2) provide analog inputs to the DMC. The neutron beam emerging from the treatment head passes through both ion chambers and partially ionizes the air within. Each ion chamber is subjected to a DC voltage and the resulting current is proportional to the number of ionized air molecules and thus to the instantaneous radiation dose rate. Each ion chamber is connected to a *dose terminator* (DT1 and DT2) within the DMC. Each dose terminator includes a current-to-frequency converter, a digital counter, a preset dose register, a digital comparator, and an interlock relay. The current-to-frequency converter translates the ion chamber current into a train of digital pulses whose frequency

[1] The Overview, Command Sequencing and Error Handling sections in this appendix are excerpted from [12].

is proportional to dose rate. The pulses are applied to the counter, which constitutes a digital integrator: the value of the count is proportional to the integrated dose delivered since the counter was last reset. The preset dose register holds a value proportional to the prescribed dose. The digital comparator opens the interlock relay when the value in the counter exceeds the value in the preset dose register, indicating that the prescribed dose has been delivered. This is the usual way to turn off the beam at the end of a treatment. The interlock relays in both dose terminators must be closed to enable the beam to be on. There are two independent dose monitoring channels to guard against the possibility that one might fail.

The dose terminators are largely constructed of discrete electronic components, but they are controlled by a microcomputer embedded in the DMC. The microcomputer performs extensive monitoring and self-tests of the DMC analog and digital electronics, resets the counters, loads the preset dose registers, and performs some other functions. Each of these actions occurs at the appropriate time in the treatment sequence, which is ultimately under the control of the therapy operator. The operator's actions are mediated by another computer, called the *Control Computer* in Fig. G.1.

The control computer and the DMC communicate by sending strings of ASCII text back and forth over an RS-232 serial line. For example, before each treatment begins, the control computer sends a command to the DMC to load the preset dose registers with the prescribed dose. The DMC responds to each command by sending an acknowledgement string or an error message. The DMC can also send unsolicited messages to the control computer, for example when a dose terminator opens its interlock relay at the end of a treatment.

There is a third interlock relay in the DMC called the *timer relay*. This relay must also be closed to enable the beam to turn on. A "watchdog timer" circuit ensures that this relay can be closed only when the microcomputer provides repetitive pulses at a high rate under program control. The microcomputer program generates these pulses only during those portions of the treatment sequence when the beam is allowed to be on. To provide an additional safety check in case both dose terminators should fail, there is an elapsed time counter which is implemented by the microcomputer program and an external counter/timer circuit. A preset time register is loaded with the estimated duration of each treatment, calculated by dividing the prescribed dose by the nominal dose rate of the machine. The microcomputer causes the timer interlock relay to open when the value in the elapsed time counter exceeds the value in the preset time register, indicating that the estimated treatment time has passed. This turns of the beam, if it is not already off. A typical treatment lasts about one or two minutes.

Another input to the DMC comes from *Faraday Cup 1* (FC1). The Faraday Cup is a barrier that can be dropped into the beam line to prevent the beam from reaching either treatment room. This information is needed by the DMC because the neutron beam cannot possibly

(Insert Figure 1.1 from Alex Barke thesis)

Figure G.1: Dose Monitor Controller (DMC) and other treatment control components be on in a treatment room when this Faraday Cup is closed. The DMC elapsed time counter only counts up when FC1 is open[2].

The values of the preset time, preset dose, elapsed time, and measured dose (in both channels) held in the DMC registers and counters are continuously shown on dedicated numeric displays on the treatment operator's console.

The three DMC interlock relays control a single relay called the *dosimetry relay* in another treatment subsystem called the *hard-wired safety interlock system*, or HSIS (see Fig. G.1). When any switch in the HSIS is open, the beam is off and cannot be turned on. When all of the switches in the HSIS are closed, an operator may turn on the beam by pressing a button on the console.

The state the dosimetry relay in the HSIS is displayed on the therapy terminal (in the Dose/Intlk display) and also at the cyclotron control console. The position of Faraday Cup 1 is displayed at the cyclotron control console but not the therapy terminal.

G.2 Command sequencing

The eight commands shown in Table G.1 are particularly pertinent to programming the treatment sequence. The table also shows their descriptions, paraphrased from [10].

A reset command can be performed without error anytime; it always opens the dosimetry relay.

The DMC command interpreter enters the software reset state (the state the follows a reset command) after performing the `CON TERM` command, and after many (but not all) errors. In this state, the dosimetry relay is open.

One of the analog control commands, `INP RATES` (to set the nominal dose rate) has to be sent after reset but before `CON START`.

After reset but before `CON START`, `INP SETD` and `INP TIME` may be sent in any order, and may be repeated indefinitely many times. The new values simply overwrite the previous values. Futhermore, after `CON SEL` is sent, then prior to `CON START`, either `INP` command as well as `CON SEL` may be repeatedly sent in any order.

The Scanditronix control software does not use the `CON STOP` and `CON CONTI` commands,

[2] The *DMC timer enabled* input also includes the effect of the beam plug (how?).

(reset)	Reset DMC and initialize some parameters with default values.
`CON SEL`	Perform self-test and initialize console displays. This command must be given prior to every treatment.
`INP TIME`	Load treatment time.
`INP SETD`	Load prescribed dose.
`CON START`	Close interlock relays, making it possible to begin a treatment. This command must be preceded by `INP TIME` and `INP SETD` This command will result in FC1 opening. When FC1 opens, the elapsed timer begins counting.
`CON STOP`	Interrupt a treatment so it can subsequently be continued. The treatment may be continued without the usual start up procedure. Opens an interlock relay, which causes FC1 to close. The elapsed timer stops.
`CON CONTI`	Continue a treatment after STOP. Closes the HSIS, which opens FC1. The elapsed timer continues.
`CON TERM`	Perform self-test at end of treatment. This is different from the self-test performed by SELECT.
`CON TEST`	Enable analog functions to be tested. Tests may be performed without the usual start up procedure. WARNING: This command sets preset dose and time to large values. This command opens FC1.

Table G.1: Some DMC commands

ERROR 01	Command string cannot be interpreted.
ERROR 30	`CON START` attempted before `CON SEL` performed.
ERROR 31	`CON START` attempted before `INP SETD` performed.
ERROR 32	`CON START` attempted before `INP TIME` performed.
ERROR 33	`INP TIME` or `INP SETD` attempted while treatment in progress.

Table G.2: Some DMC errors

even when the operator stops and then resumes a treatment run.

`CON STOP` and `CON CONTI` are usually accepted without invoking an error message. `CON STOP` has no effect unless it is sent after `CON START`. `CON CONTI` does not cause the dosimetry relay to close unless it follows `CON STOP`.

In the reset state, the elapsed timer does not count up even if Faraday Cup 1 is open. After `CON START`, the elapsed timer counts when FC1 is open and stops when FC1 is closed. If FC1 is prevented from closing after `CON STOP` (this does not normally occur), the elapsed timer continues counting. The elapsed time counter is turned off and on by FC1 position, not by `CON STOP` and `CON START`.

After the beam turns off, or after `CON STOP`, `CON TERM` invokes the final self-test, succeeded by the reset condition.

`CON TEST` does not close the dosimetry relay. It appears to be an alternative to a series `INP` commands.

Several comments in [10] paraphrased in Table G.1 suggest that commands to the DMC can cause FC1 to open or close. In fact the DMC does not have any outputs that can control FC1 directly. The comments describe how other other control system components control FC1, to coordinate its activities with the DMC. For example the HSIS and the cyclotron PLC cause FC1 to close whenever the HSIS turns of the beam for any reason.

G.3 Error handling

The five error conditions shown in Table G.2 are particularly pertinent to programming the treatment sequence. The table also shows their descriptions, paraphrased from [10].

A nonsense string always elicits the error message, `Error 01; Syntax error!`. After `CON START` it opens the dosimetry relay and proceeds to the reset condition; otherwise there is no further effect.

In the reset state many commands are not considered erroneous. Therefore, the DMC often issues no error message when an erroneous command is repeated. The first time an erroneous command is presented, the DMC responds with the appropriate error message. However if the erroneous command is repeated, the DMC responds with the usual acknowledgement string, not an error message.

Most commands elicit Error code 33 if they are sent after `CON START`. The text of the error message is `Error 33; command not allowed!` When this message appears, the dosimetry relay opens and the DMC enters its reset condition. After `CON START`, the commands that result in this message are `INP TIME`, `INP SETD`, `CON SEL`, `CON START`, `CON CONTI`, `CON TERM`, and `CON TEST`.

Similarly, after `CON STOP` the commands `INP TIME`, `INP SETD`, `CON SEL`, `CON START`, and `CON TEST` elicit Error 33 and the reset state. And likewise, after a dose terminator or the elapsed timer stops the treatment, but before `CON TERM` is sent, then `INP TIME`, `INP SETD`, `CON SEL`, `CON START`, and `CON TEST` elicit Error 33 and the reset state.

After `CON START`, `CON TERM` elicits Error 33 and the Reset condition. In other conditions, `CON TERM` causes the DMC to enter a "hung" state in which it stops responding to other commands until a reset command is sent.

G.4 Commands

G.4.1 Reset

After a reset the DMC prints this banner.

```
"SCANDITRONIX DMC VER 1.2"
```

G.4.2 Calibration

This is the command to load the calibration voltages into the DMC:

INP CVOLT1 n_1 CVOLT2 n_2 IONFAC m<lf><cr>

where n_1 and n_2 are in the range 0 – 1023 (decimal), and m is in the range 0 – FFFF (hexadecimal).

(Must these be right justified in four spaces? Example looks like it)

For example

```
INP CVOLT1  699 CVOLT2  712 IONFAC    5000<lf><cr>
```

The DMC responds with the acknowledge and completion sequences.

Use this command to load the feedback factors into the DMC:

INP XCFACT n_1 YCFACT n_2 XRFACT n_3 YRFACT n_4<lf><cr>

where n_1 etc. are in the range $-32,767$ to $32,767$. An example is:

```
INP XCFACT  30000 YCFACT -30000 XRFACT    100 YRFACT   -100<lf><cr>
```

(Don't we know the ranges for each cal factor? These also look right justified.)

The DMC responds with the acknowledge and completion sequences.

Use this command to load the servo factors into the DMC:

INP LOWFAC n_1 HIGHFAC n_2 SERVMIN m_1 SERVMAX m_2<lf><cr>

where n_1 and n_2 are in the range 0 – 15000 hundreds of microamps, and m_1 and m_2 are in the range 0 – 15000 hundreds of microamps. For example:

```
INP LOWFAC     1 HIGHFAC 32000 SERVMIN     10 SERVMAX     50<lf><cr>
```

(Again, this looks right justified.)

The DMC responds with the acknowledge and completion sequences.

Use this command to load the number of cycles between rate difference checks into the DMC:

```
INP RATEDLY n<lf><cr>
```

where n is in the range 0 – 99. An example is:

```
INP RATEDLY  1<lf><cr>
```

The DMC responds with the acknowledge and completion sequences.

G.4.3 Dose and time

The command to load the dose, time, and dose rates for a single treatment run is:

```
INP SETD d TIME t RATES r MAXR x MINR m<lf><cr>
```

where d is the dose in the range 0 – 9999 (tenths of Monitor Units), t is treatment time in the range 0 – 9999 (hundredths of minutes), r is doserate in range 0 – 9999 (tenths of MU/minute), x is maximum allowed rate in range 0 – 9999 (tenths of MU/minute), and m is minimum allowed dose rate in range 0 – 9999 (tenths of MU/minute). An example is:

```
INP SETD 2380 TIME  952 RATES  500 MAXR  550 MINR  450<lf><cr>
```

(This looks right justified)

The DMC responds with the acknowledge and completion sequences.

G.4.4 Control

The command to select the therapy room that the beam will go to, and initiate self-tests is

```
CON SEL c"<lf><cr>
```

where c is `ISO` for isocentric or `FIX` for fixed. The DMC responds with the acknowledge and completion sequences.

The command to initiate the ionsource servo is

```
CON SERV OUT ON<lf><cr>
```

The DMC responds with the acknowledge and completion sequences.

The command to initiate the quadrant servo is

```
CON SERV CURR ON<lf><cr>
```

The DMC responds with the acknowledge and completion sequences.

The command to enable outputs from the servos is

```
CON SERV IONS ON<lf><cr>
```

The DMC responds with the acknowledge and completion sequences.

The command to close the dosimetry relay is

```
CON START<lf><cr>
```

Closing the dosimetry relay allows the run to be started, but does not actually run the beam to the target.

The DMC responds with the acknowledge and completion sequences, and when the prescribed dose or time is reached, the DMC will send the dose/time reached sequence.

The DMC can continue to respond to output commands even as it counts up the accumulating dose and time while the beam is running (before the dose/time reached sequence is received).

The command to force a run to stop and close the faraday cup is

```
CON STOP<lf><cr>
```

The DMC responds with the acknowledge and completion sequences.

(We need a bit more detail about what actually happens. See Alex Barke's thesis).

The command to continue a run after it has been stopped by `CON STOP` is

```
CON CONTI<lf><cr>
```

The DMC responds with the acknowledge and completion sequences.

(Again, what actually happens?)

To command to terminate a run and and force preset values to expire is

```
CON TERM<lf><cr>
```

The DMC responds with the acknowledge and completion sequences.

(But what else happens?)

G.4.5 Dose/time reached

When the DMC reaches either the prescribed dose or time limit it sends a text string terminated with the following characters: *<lf><cr>. This will be referred to as the *dose stopped sequence*. For example

```
END 00 ;Dose reached!  *<lf><cr>
```

If the DMC reaches the time limit, an error string (see error 44) is also sent.

G.4.6 Output

The DMC can respond to output requests when the beam is on, while it is counting/ monitoring dose (before it sends the dose/time reached sequence).

Calibration The command to read the calibration voltages is

```
OUT CVOLT1 CVOLT2<lf><cr>
```

The DMC responds with a string of the following form:

n_1 n_2 #<lf><cr>

where n_1 and n_2 are integer decimals number in the range 0 – 1023. An example is:

```
0699 0712 #<lf><cr>
```

Then the DMC also sends the completion sequence.

Prescribed dose, time and dose rate The command to read the dose, time and dose rate settings is

```
OUT SETD TIME RATES MAXR MINR<lf><cr>
```

The DMC responds with a string of the following form

n m r_1 r_2 r_3 `#<lf><cr>`

where n is in the range 0.0 – 999.9 MU, m is in the range 0 – 99.9 minutes, and r_1, r_2 and r_3 are all in the range 0 – 999.9 MU/minute. An example is:

```
238.0 09.52 050.0 055.0 045.0 #<lf><cr>
```

Then the DMC also sends the completion sequence.

Actual dose The command to read the actual dose, dose rates, elapsed treatment time and target currents most recently measured by the DMC is:

```
OUT DOSE1 DOSE2 RATE1 RATE2 ELATIM CURTARG INTTARG<lf><cr>
```

The DMC responds with a string of the following form:

d_1 d_2 r_1 r_2 t i q `#<lf><cr>`

where d_1 and d_2 are in the range 0.0 – 999.9 MU, r_1 and r_2 are in the range 0– 999.9 MU/minute, t is in the range 0 – 99.99 minutes, i is in the range 0-99.99 microamps, and q is in the range 0 – 999.9 microamp-minutes. An example is:

```
057.5 057.5 049.9 49.9 01.27 56.39 065.3 #<lf><cr>
```

Then the DMC sends the completion sequence.

G.5 Error messages

The DMC may send error messages to the Therapy Control System. Most of these errors are in direct response to receipt of a string from the Therapy Control System (such as numbers 01 and 05). The error messages are of the form: ”

`ERROR` *n* `;` *message* `!<lf><cr>`

where *message* is less than 80 characters of description, and *n* is the error number that appears in the first column of Table G.3, a list of DMC errors. We define an error type in an attempt to categorize the faults; they appear in the second column of the table.

	Error type
1	Serial line or communication problem
2	Hardware, electronics, dosimeter problem
3	Error in command sequence
4	Potentially hazardous condition or inconsistency

G.6 Example

Here is an example dialog with the DMC, showing the commands and responses needed to treat a single field[3]. The first line shows the DMC response to a software reset. Nonprinting characters such as carriage return and line feed are indicated in the usual way, not by `<cr>` etc.

```
"SCANDITRONIX DMC VER 1.2"
$
CON SEL ISO
$
INP CVOLT1  699 CVOLT2  712 IONFAC   5000
$
OUT CVOLT1 CVOLT2
0699 0712 #
$
```

[3]This example was recorded from the original Scanditronix control system, not the system described in this document.

```
INP XCFACT 30000 YCFACT -30000 XRFACT    100 YRFACT   -100
$
INP LOWFAC     1 HIGHFAC 32000 SERVMIN     10 SERVMAX     50
$
CON SERV OUT ON
$
CON SERV CURR ON
$
CON SERV IONS ON
$
INP SETD 2380 TIME  952 RATES  500 MAXR  550 MINR  450
$
OUT SETD TIME RATES MAXR MINR
238.0 09.52 050.0 055.0 045.0 #
$
CON START
$
INP RATEDLY  1
$
OUT DOSE1 DOSE2 RATE1 RATE2 ELATIM CURTARG INTTARG
000.0 000.1 003.1 003.1 00.05 03.27 000.1 #
$
OUT DOSE1 DOSE2 RATE1 RATE2 ELATIM CURTARG INTTARG
000.4 000.5 013.5 013.6 00.10 22.36 000.6 #
$
OUT DOSE1 DOSE2 RATE1 RATE2 ELATIM CURTARG INTTARG
006.6 006.7 049.8 049.7 00.24 56.00 007.4 #
$
(continues for some time...then)
OUT DOSE1 DOSE2 RATE1 RATE2 ELATIM CURTARG INTTARG
233.5 233.3 049.8 049.8 05.17 56.29 261.8 #
$
END   00 ;Dose reached! *
$
OUT DOSE1 DOSE2 RATE1 RATE2 ELATIM CURTARG INTTARG
238.1 237.8 000.1 000.1 05.29 00.00 266.9 #
$
OUT DOSE1 DOSE2 RATE1 RATE2 ELATIM CURTARG INTTARG
238.1 237.8 000.1 000.0 05.29 00.00 266.9 #
$
CON TERM
$
```

n	*Type*	*Description*
01	1	DMC has received a string not possible to interpret
05	1	DMC has received a string with wrong baud rate, parity, etc.
08	2	Permit relay on card 8 not energized when it should be.
09	2	Permit relay on card 8 on when not energized.
10	2	Permit relay on card 12 not energized before accumulated dose in DT2 has reached set dose.
11	2	Permit relay on card 12 does not terminate treatment when accumulated dose has reached set dose value.
12	2	Permit relay on card 12 not activated even if all conditions are fulfilled.
14	2	Low voltage test failed on DT1. This test includes a check of the voltages +5, +-15 and +24V feeding DT1.
15	2	The high voltage in DT1 card 1 failed. The high voltage is the polarization voltage for the ionchambers connected to DT1. The high voltage is tested on the return from the ionchambers.
16	2	Overload on any of the dose meter cards 2-5 in DT1.
17	2	High voltage is detected in DT1 even if the high voltage relay is deenergized.
19	2	No accordance between the setdose given to DT2 and the setdose that can be read back from the DT.
20	2	Same as ERROR 10 but valid for card 6 and DT1 instead.
21	2	Same as ERROR 11 but valid for card 6 and DT1 instead.
22	2	Permit relay on card 6 not activated even if all conditions are fulfilled.
24	2	Same as ERROR 14 but valid for DT2 instead.
25	2	Same as ERROR 15 but valid for card 17 and DT2 instead.
26	2	Overaload on any of the dosemeter cards 13-16 in DT2.
27	2	Same as ERROR 17 but valid for DT2 instead.
29	2	Same as ERROR 19 but valid for DT1 instead.
30	3	Selftest of the DMC not performed before a CON START command.
31	3	Setdose not given to the DMC before a CON START command.
32	3	Treatment time not given to the DMC before a CON START command.
33	3	New setdose or time is given to the DMC when a treatment has started.
40	4	Allowed dose difference between DT1 and DT2 is reached.
42	4	The doserate exceeds its upper limit.
43	4	The doserate is below its lower limit.
44	4	Treatment time has not terminated the treatment when time has run out.
45	4	Accumulated dose in DT1 exceeds setdose but DT1 has not terminated the treatment.
46	4	Dose is registrated even if faraday cup is closed.
48	4	Neutron rate has exceeded rate window (as defined by MAXRSET and MINRSET) for longer than MOBTIME (as input to DMC).
49	4	Proton/neutron exchange efficiency (at the target) is notably poor.

Table G.3: DMC error codes

Appendix H

Controlled Parameters

(Insert copy of spreadsheet printout here)

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