Model 9010
Radiation
Monitor
Controller

Manual

Radcal Corporation

Warranty for the Model 9010 Radiation Monitor Controller

Radcal Corporation warrants that, in the event that any defects in material or workmanship should develop within one year of the date of shipment, the company assumes full responsibility for servicing equipment of its manufacture without charge upon return of the equipment to Radcal, with shipping costs prepaid by the customer. Costs to return–ship to customers will be paid by Radcal if the repairs are warranty–applicable.

Radcal shall not be held liable for damages or delays caused by defects beyond making repairs or furnishing replacement parts, nor shall Radcal be liable for any defective material replaced without Radcal's consent during the period of this warranty. Radcal reserves the right to perform warranty services at its own factory.

This warranty specifically excludes batteries.

Non–Warranty Repairs

The calibration of this instrument was correct within specified limits when the instrument left our factory. Radcal cannot be responsible for injury or damage resulting from improper use or calibration errors which develop subsequent to our shipment of the instrument.

If Radcal determines that a fault has been caused by misuse, abnormal operating conditions, or repairs by unauthorized personnel during the warranty period, repairs and shipping costs will be billed at normal rates.

If the equipment is found to be in proper working condition, Radcal will return–ship the equipment at customer expense.

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Contents

Introduction

This manual introduces you to Radcal corporation's Model 9010 Radiation Monitor. It provides you with the necessary information to set up, test, and use the 9010. Appendixes to the manual provide more material about the options that are available with the machine, specifications for its use with various ion chambers and converters, and other useful information. Instructions for setup and use are provided in an easy, step–by–step format, with many illustrations of the various display responses you will get from the 9010.

The 9010 is one of the latest in Radcal's line of radiation measurement instruments. It has a wide dynamic range and it is easy to use. In keeping with Radcal's philosophy, it is compatible with equipment in Radcal's other lines, such as the 20–Series ion chamber/converters and the 10X5–Series ion chambers, as well as the 90–Series, which provides full support for 9010 functions and has an improved dynamic range. This flexibility is a great convenience for Radcal's long–time customers.

A factory–installed option permits the 9010 to process signals from the Radcal kVp instruments to measure and display kV and dose values.

The 9010 provides the capability of data capture and remote control via a serial communications port. An optional Excel spreadsheet add–in uses this serial communications capability to analyze test results and prepare reports.

In the past 20 years, Radcal has become an industry leader in providing radiation monitoring equipment to a wide range of users. Their customers are engaged in such activities as:

- Compliance Monitoring—Used by many federal agencies and virtually every state government, as well as hospitals and equipment manufacturers that must test for compliance.

- Service—Used by most x–ray machine manufacturers and many service organizations that must make x–ray measurements in connection with routine or unscheduled service.

- Quality Assurance—Used by hospitals and other health organizations with quality assurance programs.

Radcal is committed to innovation as well as to continuity. On an on–going basis, we enhance existing products and develop new products to meet the changing market needs. This product development program, and the commitment and philosophy behind it has made Radcal a market leader.

We hope you will be pleased with the 9010's accuracy, flexibility, and ease–of–use.

Radcal Corporation

Description

Radcal's Model 9010 is a radiation-monitoring instrument that can utilize a wide range of Radcal ion chambers. Typical applications include direct beam measurements for diagnostic x-ray, mammography, fluoroscopy, cine and CT, as well as gamma radiation fields.

The control unit displays measurement results and menu selections on a two-line liquid-crystal display. The main user controls are the SELECT dial and the ENTER push-button located on the face of the control unit. Rotating the SELECT dial causes the menu selections to appear. ENTER activates the menu selection and starts the measurement. Menu selections depend on the Sensor and the options installed in the control unit. They include *Dose*, *Dose Rate*, *Auto Dose*, *Max Dose Rate*, *Pulsed/Cine*, and others. A programmable setup mode allows the user to set time and radiation units, temperature and pressure compensation modes, chamber correction factors, and other parameters.

The 9060 converter permits use of Radcal's 10-series interchangeable ion chambers.

With the 90A25 adapter cable, you can use the control unit with any of Radcal's 20x5-series sensor assemblies.

The instrument includes an RS–232 serial port that allows remote control and readout. Optional spreadsheet software (XLPRO) is available to automate many common measurements.

Three 9–volt batteries in the 9010 provide about 40 hours of normal use before replacement. A "Replace Battery" message is displayed when there is about an hour of life left in the batteries.

Options include provision for connecting a Radcal Accu–kV or other kV sensor for x–ray tube voltage measurements (Option C, see Appendix A) and an automatic barometric-pressure compensator (Option P, see

Appendix A). These options, if installed, may add items to the Self-Test, the Function Selection Menu, and the Setup Menu. Option-related selections do not display if the option is not installed.

Specifications

*Note: Many specifications are chamber-dependent. For specifications of
        the control unit with different sensor assemblies, see
                Appendix E.*

Features

Display:	16-character/line, two-line liquid-crystal
Power:	Three 9V, #522 batteries
Detector Bias:	260 Volt Electronic Bias Supply

Measurement Modes

*Note: Measurement functions are selected from the Function Selection
        Menu. The default items on this menu are Dose Rate, Dose, Auto
        Dose, and Power* Off. *To activate other menu items, use the Setup
        Menu item* Function Menu *described on page 47.*

Auto Zero
Provides enhanced low–dose–rate capability using a bias current and
background subtraction.

Note: 20-series sensors do not have Auto Zero *capability*.

Dose Rate
Measures dose rate and displays the result once per second. In the sensor's
lowest decades, the measurement interval is automatically extended to
improve the measurement accuracy, and may be up to 10 seconds long.

Max Dose Rate
Measures dose rate and displays the largest value found. Maximum dose rate determination requires as little as 0.3 seconds.

Dose
Accumulates integrated dose. The display updates once per second. Pressing ENTER halts integration. Pressing ENTER a second time resets the display and restarts integration.

Auto Dose
Starts accumulation of integrated dose when the dose rate exceeds a threshold, and ends accumulation when the rate falls below that threshold for 2 seconds. After the measurement is completed, the instrument automatically rearms and awaits a subsequent exposure. See Appendix E for threshold values for each sensor.

Last Dose
Integrates total dose continuously. After dose accumulation begins, each subsequent press of ENTER freezes the display at the total dose to that instant. Pressing ENTER does not reset the integration.

Pulsed/Cine
Provides readout in units of dose per pulse or dose rate; automatic triggering for repeating measurements; and convenient switching between user–selected pulse rates. The x-ray machine must be operating while the measurement is being taken.

kVp Pulse (Requires Option C and an Accu–kV)
Measures and displays   kVp, duration of the kV waveform, and dose. Uses a *Radcal* Accu–kV and any 9010–compatible sensor. Can replay the kV device voltage waveform for oscilloscope viewing. Can output the digitized voltage waveform for analysis or plotting.

kVp Fluoro
Operates like *kVp Pulse*. Provides continuous measurements of dose rate and kVp. The results are updated every 1 to 3 seconds.

Power Off
Turns the control unit off.

Setup Menu

Provides access to configuration options with which the user can easily program: operating modes, calibration factors, radiation and time units, temperature and pressure compensation, selection of menu items, etc.

The default setup parameters are:

Temperature:	22°C
Pressure:	101.3 kPa; automatic if Opt P installed
Time Units:	Minutes
Radiation Units:	Roentgens
Power Off Delay:	15 minutes
Function Selection Menu Items:	*Dose Rate*
	Dose
	Auto Dose
	Power Off

Performance

Accuracy:	±4% of reading, ±1 digit
Repeatability:	±1% of reading, ±1 digit
Energy Response:	See individual chamber tables, Appendix E.
Resolution:	See individual chamber tables, Appendix E.

Environment

Operating temperature:	5°C to 45°C
Humidity:	less then 80% RH, 20 g/m^3 max
Storage Temperature:	-40°C to +65°C

Getting started

This discussion tells you how to assemble, turn on, and test Radcal's Model 9010 Radiation Monitor. No radiation is needed for this step-by-step tutorial. The test button simulates radiation exposure.

The Model 9010 Radiation Monitor provides many functions that may be new to you. When your instrument left the factory it was set up with only the basic functions—*Dose*, *Dose Rate* and *Auto Dose*—activated. If you have the Option C installed, *kVp Pulse* and *kVp Fluoro* are activated as well. You can customize your instrument's activated functions to fit your needs using the Setup Menu.

For this tutorial you will need the following:

> 1) Radiation Monitor control unit
> 2) 90C5-6 Extension Cable
> 3) The 9060 converter assembly with a 10X5-6 chamber. (Other sensors may be substituted, and the readings will vary accordingly.)

Assembly

The 9010 is shipped with batteries installed. To change batteries, see the instructions on page 51.

Connect the male end of the 90C5-6 cable to the sensor connector on the left side of the control unit; align the dots and push the connectors together. Connect the female end of the 90C5-6 cable to the 9060 sensor in the same manner. Connect the 10X5–6 ion chamber to the 9060 sensor.

Turn-on and setup

With the instrument off and the display blank, press and release ENTER. The control unit will enter the *Power On* mode and perform the following self-test sequence:

> Display test
> PROM Checksum
> Converter test
> Option(s) test
> Temperature test
> Pressure test
> Battery test
> Chamber voltage stabilization

The Chamber Voltage Stabilizing message may be displayed for up to 60 seconds while the bias voltage comes to equilibrium.

As Self-test proceeds, the test is displayed and on OK indicates it was successful. The message displays for a fixed time; press ENTER to end the display and go on to the next step. Speeding up the self-test does not reduce the stabilizing time for the chamber and converter.

If any of the self-test functions fails to complete, a message will appear on the second line of the display and the system will wait for you to press ENTER before resuming the self-test sequence. If a "failed" message appears, we recommend that you do not use the instrument. In the case of chamber bias failure, the system will not proceed.

During the *Power On* mode, the instrument identifies the ion chamber and the converter in the sensor assembly.

The instrument uses a menu system to access each function. Rotating the SELECT dial up or down displays the menu selections. The top of the menu is reached by rotating SELECT up. When the top of the menu is reached, additional rotation of SELECT produces no change. Similarly, when the

bottom of the menu is reached by rotating SELECT down, additional rotation produces no change. The first item on the menu (top of the menu) is "Chamber," and the last item (bottom of the menu) is "Power off."

- Rotate SELECT up until you reach the top of the menu and "Chamber" is displayed in the top line.
- Rotate SELECT down until "Dose Rate" shows in the bottom line of the display:

<div align="center">

6cc Corr 1.00
Dose Rate

</div>

- Press ENTER once. The display will change to:

<div align="center">

Dose Rate
0.0mR/min

</div>

Accessing setup

You can customize many of the features of the instrument. Use the Setup Menu for this purpose. To access the Setup Menu:

- Press and hold the ENTER button while rotating the SELECT dial at least six steps up or down. When you release ENTER, the display will show the top item on the Setup Menu.

<div align="center">

Serial No. xxxx
Version x.xx

</div>

- Rotate SELECT down. The next item should be:

<div align="center">

Temperature nn C
Using Fixed 22 C

</div>

- Rotate SELECT down. The next item should be:

Pressure nnk
Fixed 101.3 kPa

- Rotate SELECT down. The next item should be:

Chamber
90X6 6cc

- When an item appears whose parameters you want to adjust, press ENTER, then use SELECT to set parameter values.

- For this operational test, set values to 22°C fixed, 101.3 kPa, and use a 6cc chamber.

- Continue rotating SELECT and confirm that the time units being used are minutes and the radiation units being used are Roentgens. When you reach the end of the Setup Menu, the display shows:

Press Enter to
Exit Setup

- Press ENTER. The control unit will perform a quick test, displaying the temperature and pressure settings in use, Battery and Chamber OK messages, and the chamber type.

Operational Test

The values displayed in this example are based on a 6cc chamber and standard pressure and temperature settings. Your readings will vary inversely with chamber volume, and directly with the correction factor.

Dose Rate:

- Rotate SELECT, if necessary, until the display shows:

6cc Corr 1.00
Dose Rate

- Press ENTER.

Initially the top line will contain "Dose Rate" and the second line will be blank. An arrow will appear at the left end of the bottom line. After several seconds, the value of 0.0 or 1 mR/Min should appear.

Dose Rate
0.0 mR/min

- Press and hold the TEST button (found on the left side of the instrument). The instrument should display a dose rate between 25 and 125 R/min. Note your reading. We use 50 R/min in the following examples.

- Release the TEST button. The display should return to 1 mR/min or less.

Dose:

- Rotate SELECT until the display shows:

6cc Corr 1.00
Dose Accum/Hold

- Press ENTER to begin accumulating. The display will change to:

Dose Accumulate
0.00mR

- Wait for the arrow to appear in the lower left corner of the display and then press TEST for 30 seconds. Because the display updates about once per second, counting the number of display updates is an easy way to count out 30 seconds. The display will increase at the rate measured

above. After you release TEST, the new reading should be half of the first reading, or 25.00 R in this example.

- Press TEST again for 30 seconds. The display should increase to the value noted, 50.00 R in this example. The arrow should be displayed throughout these measurements.

- Now press ENTER. The display should change to:

Dose Hold
50.00 R

You have stopped accumulating dose; the arrow should disappear. Pressing ENTER while "Hold" is displayed resets the display and restarts *Dose* in Accumulate. Try it:

Dose Accum
0 mR

Auto Dose:

- Rotate SELECT until the display shows:

6cc Corr 1.00
Auto Dose

- Press ENTER:

Auto Dose
Waiting

- Press TEST for 12 seconds. While TEST is pressed, the display will read:

Auto Dose
Accumulating

And then:

Auto Dose
10.000 R

...corresponding to one-fifth minute (12 seconds) at 50R/min.

- Press TEST for six seconds. The "Accumulating" message should appear while TEST is pressed, and then "Auto Dose 5.000R" should be displayed. This reading corresponds to six seconds at 50R/min.

This completes the operational test.

Power Off

- Rotate SELECT toward you until "Power off" shows in the display:

- Press ENTER to turn the instrument off.

This completes the tutorial.

Operation

This section describes the operation of Radcal's Model 9010. It is important to know that the control unit shuts off after a user-set time delay. A timer in the control unit is reset whenever ENTER or SELECT is activated or whenever there is a non-zero reading displayed. If the timer gets to zero, the display is cleared and the power supply shuts off. In practice, this means automatic shutoff is unlikely to occur in any of the dose modes, but will occur if the displayed dose rate is zero or if the control unit is left in a menu selection mode.

The control unit also turns off if the sensor is not connected.

The control unit has two menus: the Function Selection Menu and the Setup Menu. The Function Selection Menu may contain:

Auto Zero
Dose Rate
Max Dose Rate
Dose
Auto Dose
Pulsed/Cine
Last Dose
kVp Pulse (available with Option C)
kVp Fluoro (available with Option C)
Power Off

The control unit saves the last menu selection in which a measurement has been made and will return to that selection, ready for a measurement to start, when you press ENTER following automatic or manual power off.

Assembly

The control unit has two user controls: the SELECT dial and the ENTER button. The sensor connector is on the left side of the control unit along

with the TEST button. Connectors for the analog and serial-communication options are located on that side if these options are installed.

90C5-6 extension cable

The 90C5-6 is a six-meter cable that connects the sensor and control unit. The cable allows the control unit to remain outside the radiation field being measured.

90-series sensor-to-control unit connection

The instrument uses a 16-pin friction fit, push-to-connect/pull-to-release, metal-shell connector to connect the control unit to the sensor. To connect the extension cable to the control unit, align the red dot on the connector of the extension cable with the red dot on the sensor connector of the control unit and push together. Next align the red dot on the other end of the extension cable with the red dot on the connector on the sensor and push together. To disconnect, pull firmly on the connector housing.

Turn On and Stabilization

After attaching a sensor, press ENTER to turn on the instrument. This enters the *Power On* mode, which includes a self-test sequence during which the system micro-controller, the display, the converter, and the bias supply are tested. Any installed options are also tested at this time. The ion chamber and the converter are identified during this mode.

After the instrument is turned on, there is a stabilization interval that may last for several tens of minutes. During this time the ion chamber output fluctuates as the insulators in the chamber reach charge equilibrium while voltage from the electronic bias supply is applied. Similar equilibration occurs in the converter. To ensure accurate low-level measurements, place the instrument in *Dose Rate* mode until the fluctuations are within the range needed for your measurement. All listed specifications will be met

following a stabilization of 10 minutes. If the chamber is touched or handled, an effect similar to that observed following turn-on will occur.

Temperature stabilization is also required. The instrument uses unsealed ion chambers, so the reading from the ion chamber must be corrected for temperature and for atmospheric pressure. It takes about 15 minutes for the ion chamber to come to equilibrium after a temperature change of 10°C. In addition, while the temperature is changing, the zero level of the converter may vary.

Do not attempt Auto Zero during stabilization because the auto zero measurement assumes that whatever background conditions are present will also be present in subsequent readings.

Measurement Functions

The factory default Function Selection menu items are Chamber, Dose Rate, Dose, Auto Dose and Power Off. Rotating SELECT down will display all the menu items until you reach Power Off at the bottom of the menu. Rotating SELECT up scrolls back through the list until you reach Chamber at the top of the list. The Setup Menu allows you to add or delete Function Selection menu items.

The top line of the display shows the chamber volume and a correction factor. The correction factor is applied by the control unit in calculating dose. It includes temperature, pressure and chamber (Kq) factors. The second line of the display shows the function that will be activated when you press ENTER. When the desired function is displayed, press ENTER. The display then changes and describes the selection.

To leave a function and return to the Function Selection menu, rotate SELECT.

Note: *All display illustrations below assume the use of a 10X5-6 ion chamber with a 9060 converter, that units of R and min are selected, and that Auto Zero is set to off.*

Chamber

Chamber displays the chamber volume and the associated chamber correction factor "Kq". ENTER has no effect on these settings, which may be changed from the Setup menu item *Chamber Override.*

Auto Zero

Auto Zero provides increased resolution for low-rate measurements. For most measurements it isn't necessary, however it is useful for low-level measurements such as image intensifier input, x-ray tube head leakage and protection-level measurements. Activate *Auto Zero* only after adequate stabilization has occurred following turn-on. If the **Auto Zero** function is not available, go to **Setup** mode, select Function Menu, and increase the setting by one, to the next odd value.

• Rotate SELECT to the *Auto Zero* mode. The display will initially look like this:

**Auto Zero on
running..**

or

**Auto Zero off
running..**

After a few seconds the display will change to:

**Auto Zero on
0.0mR/min**

or

Auto Zero off
0mR/min

If the display reads "Auto Zero on", evaluate the displayed dose rate in *Auto Zero* on mode to see if it appears correct and stable. If it is acceptable, use SELECT to leave *Auto Zero* active.

If the display reads "Auto Zero off," press ENTER to start the auto zero setting sequence. Be careful not to disturb the instrument during the sequence.

First, the instrument tests to assure that the background and leakage currents are within the range of the Auto Zero functions. These are shown by the following displays:

    First:

A/Z Set
High

    Next:

A/Z Set
Low

If the test was successful, the display will show eight readings: 128, 64, 32, 16, 8, 4, 2, 1, as the bias current is set to approximately 30 fA.

A/Z Set
nnn

The total input current, consisting of the bias and any leakage currents and radiation background, is then measured repeatedly and the results of the measurement and the resulting dose rate are displayed.

A/Z Measure
0.3 mR/min

followed by:

A/Z Measure
nnn

The result of the above determinations is displayed as if the controller were operating in *Dose Rate* mode. Allow at least three cycles for best results.

- When these readings appear correct, press ENTER to return to the *Auto Zero* On mode and continue to observe the displayed dose rate.

Auto Zero On
0.0mR/min

- If it appears reasonable, proceed to make a measurement by using SELECT to exit the *Auto Zero* mode with *Auto Zero* On. Otherwise, press ENTER to go to *Auto Zero* Off and make measurements in that mode, or press ENTER and retry the setting process.

Dose Rate

Dose Rate mode is used for measurements such as dose rate in Fluoro procedures and in checking shielding integrity.

- Rotate SELECT to the *Dose Rate* mode.

6cc Corr 1.00
Dose Rate

- Press ENTER to begin rate measurements. The display will initially change to:

Dose Rate

Within a few seconds the display will change to:

Dose Rate
0mR/min

An arrow in the lower left corner of the display indicates that radiation is being measured. The arrow blinks when the display is updated with a new measurement.

Maximum Dose Rate

Maximum Dose Rate mode is used to see the peak dose rate attained during an exposure, such as in fluoroscopy. The maximum rate will be displayed and held until you clear it.

- Rotate SELECT to the *Maximum Dose Rate* mode.

6cc Corr 1.00
Max Dose Rate

- Press ENTER to begin sampling for maximum dose rate measurement. The display will initially change to:

Max Dose Rate

Within a second or so, an arrow will appear in the lower left corner of the display. The arrow indicates that a measurement is being made; when the

arrow blinks, the maximum dose rate value is updated. For low dose rates, this updating takes several seconds, while at higher rates, the updating occurs in a few tenths of a second.

<div align="center">

Max Dose Rate
0mR/min

</div>

As the radiation level increases, the display will update.

- **Press ENTER again to reset the Max Dose Rate display.**

Dose

Dose mode is used for measurements of total dose such as during a diagnostic, fluoro, or CT x-ray procedure. It is also used in determining low-level environmental exposures when using a large-volume ion chamber such as the 90X6-180 or the 90X6-1800.

- Rotate SELECT to the *Dose* mode.

<div align="center">

6cc Corr 1.00
Dose Accum/Hold

</div>

- Press ENTER to begin dose measurement. The display will change to:

<div align="center">

Dose Accumulate
0.0mR

</div>

An arrow in the lower left corner of the display indicates that radiation is being measured. The dose readout is updated periodically during accumulation. To stop accumulation, press ENTER. The display will change to:

<div align="center">

Dose Hold
123.4mR

</div>

- Press ENTER again to reset and begin a new measurement.

Auto Dose

Auto Dose is used for repeated "hands-off," total-dose measurements such as repeatability, mA linearity, and timer linearity procedures on an x-ray machine where the instrument setup doesn't change after each dose.

• Rotate SELECT to the *Auto Dose* mode.

6cc Corr 1.00
Auto Dose

• Press ENTER to begin an auto dose measurement. The display will change to:

Auto Dose
Waiting

• Begin the exposure. The display will change to:

Auto Dose
Accumulating

At the end of the exposure, the "Accumulating" message will be replaced by the measured dose.

Auto Dose
123.4mR

The control unit is now waiting for another dose. During this waiting period the display will continue to show the previous dose. When another exposure begins the display will change to:

Auto Dose
Accumulating

At the end of the exposure, the "Accumulating" message will be replaced by the new dose.

Auto Dose
430.2mR

This process may be repeated until the required number of dose readings are obtained. Subsequent dose readings are measured and displayed automatically; you don't need to press ENTER.

Pulsed/Cine

Pulsed/Cine mode is used with x–ray machines that produce periodic x–ray pulses, such as Cine and pulsed fluoroscopic machines. You must set the pulse rate.

> *Note:* *The 9010 measures dose. It computes the dose per pulse. Obtaining a correct reading requires that the x–ray machine operate at the expected rate for the duration of the measurement.*

• Rotate SELECT to the *Pulsed/Cine* mode.

60cc   Corr 1.00
Pulsed/Cine

This is the entry to *Pulsed/Cine* Mode.

• Press ENTER to select one of 6 (0 ... 5) preset pulse rates:

Select Preset
Nr 2 7.5 Pls/s

This allows you to select from one of 6 preset values. Defaults are 1, 2, 4, 7.5, 15, 30 and 90 pulses/s for presets 0 through 5, respectively. The rate assigned to each preset may be programmed in **Setup** mode. This example

shows that preset 2 is set to 7.5 pulses per second. Rotate SELECT to display the other presets.

- Press ENTER to start the measurement using the displayed pulse rate.

6.25 Pulses/s

Within a second or so the second line of the display changes to:

6.25 Pulses/s
Wait for Signal

The 9010 is waiting for the *Pulsed/Cine* dose rate threshold (default is 34.5 mR/s for a 6cc chamber) to be reached. When the threshold is reached (or you press ENTER), the display changes:

6.25 Pulses/s
Delay

This remains for the SETUP–selected delay interval (default is 6 pulses). When the delay is over, the display changes:

6.25 Pulses/s
Acquire

while dose is accumulated for the SETUP–selected Acquire interval (default is 5 pulses). The dose per pulse is computed by dividing the accumulated dose by the number of pulses and the result appears on the second line.

6.25 Pulses/s
34.5 mR/pls

After making this initial measurement, the 9010 automatically repeats the threshold, delay and acquire phases. The previously–measured result remains on display until replaced by a new measurement, so **Waiting for Signal, Delay** and **Acquire** aren't displayed; the lower left corner of the

display shows **?**, <blank> and **?** during these operations respectively. The display is updated at the time the arrow disappears after each Acquire interval. If the signal is already above the threshold when the **?** is present, **Delay** is skipped and **?** starts immediately.

Setup mode allows each of the 6 presets to be assigned a pulse rate, selection of the exposure rate threshold and the number of pulses in Delay and in Acquire. See the setup mode discussion for a listing of the available values for these programmable parameters. Because the 9010 does not respond to individual pulses, Delay and Acquire are converted to time intervals based on the selected pulse rate.

Press ENTER to return to the threshold phase during the measurement. Rotate SELECT to go to another mode.

To select a different preset pulse rate, rotate SELECT one click to leave Pulsed Radiation mode, then rotate SELECT the other direction so Pulsed Radiation reappears, press ENTER and then use SELECT as above to select one of the preset rates. This will cause Delay and Acquire to be recalculated based on the newly–selected pulse rate.

Last Dose

This mode is useful for determining the total accumulated dose at any time during a continuous exposure.

Last Dose is similar to the "split" function on a stop watch. The first time you press ENTER, the *Last Dose* mode starts. Each time you subsequently press ENTER, the display shows the total dose to that instant.

• Rotate SELECT to the *Last Dose* mode.

<div align="center">

6cc Corr 1.000
Last Dose

</div>

- Press ENTER to begin dose measurement. The display will change to:

Last Dose
0.0mR

For this example, assume that an exposure is started at 300 mR/min. As the exposure begins, the display will update showing the dose as it is received. Pressing ENTER one minute after beginning the exposure produces the following display:

Last Dose
300.0mR

The display is now frozen at the dose value that was reached at the instant ENTER was pushed.

- Wait another 30 seconds, then press ENTER again.

Last Dose
450.0mR

Power Off

Power Off turns off the instrument. Because this removes the bias voltage from the ion chamber, even a brief interval of power off will require that the instrument restabilize.

- Rotate SELECT to Power Off.

Power Off

- Press ENTER to turn the control unit off.

RS-232 interface

The RS-232 interface allows the 9010 to communicate with an external computer. Radcal's Microsoft Excel spreadsheet add-in—XLPRO—uses this option to analyze the results of a series of measurements.

The electrical interface connects to an IBM 9-pin RS-232 interface with a pin-to-pin cable.

The format is: no parity, 8 bits, 2 transmitted stop bits, one stop bit for receive. Parity and data format are fixed. Baud rate is selected by the user.

Normally the serial data consists of the information that appears on one line of the display with no leading spaces and with multiple spaces converted to single spaces, followed by a carriage return and a line feed. RTS (RS-232, Pin 7) must be positive (>4V) at the time data is to be sent or the sending process will not start and the message is lost. RTS is not checked during a message.

In the kVp modes, additional data may be transmitted. See the kVp write-up in the Analog Signal Capture section of Appendix A for details.

Remote Computer Operation

External control of the 9010 via the serial port can be implemented with an ASCII terminal program running on a PC. For example, the Hyperlink program included with Windows may be used. In Hyperlink, set the communications to parameters to 19200–8–N–1 and select the serial port to which the 9010 will be connected. Use Setup in the 9010 to set the baud rate to 19200, and exit Setup. When you press Enter in *Dose Rate* mode you should see the words "Dose Rate" on the computer screen. See Appendix D for more details about serial–port operation.

Setup

The Setup Menu provides access to user-selectable operating parameters. To reach the Setup Menu, press ENTER and hold it in the depressed position while rotating SELECT six or more steps. When you release ENTER, the display will show:

Serial No. nnnn
Version n.nn

The serial number should match the label on the control unit. The Version is the software version number. This manual describes operation of version 3.27 or greater.

Rotating SELECT will display the items available in the Setup Menu. The last item in the menu is:

Press Enter to
Exit Setup

Temperature

Selection of the temperature used to correct the ion chamber readings may be automatic or manual. This setup function allows using measured or a fixed temperature value. You may select a fixed temperature value from 0°C to 50°C, in 1°C increments.

• Rotate SELECT to the *Temperature* mode.

Temperature nn C
Using Measured

or:

Temperature nn C
Using Fixed nn C

• Press ENTER to switch to the Set Temperature display:

Set Temperature
Use Actual nn C

or:

Set Temperature
Use Fixed nn C

Rotating SELECT toggles between "Use Actual ..." and "Use
Fixed ...". Each time the "Use Fixed nn C" appears, the "nn" will be shifted
$1°C$ up or down depending on the direction that you rotate SELECT. This
allows you to set the temperature that will be used for dose calculations.
The first time you switch from measured to fixed temperature, the fixed
value is the measured temperature.

- Press ENTER to return to the Setup Menu. The temperature and mode
  you selected will be used for dose calculation.

Pressure

You may select the pressure used to correct the ion chamber readings using
this Setup function. You can set the pressure to values between 40.5 kPa
and 120.5 kPa with 0.1 kPa resolution. Option P provides automatic
pressure compensation. See Appendix A for further information.

- Rotate SELECT to the *Pressure* mode.

Pressure 101.3 kPa
Using Fixed

- Press ENTER to produce the display below.

Set Pressure to
101.3 kPa

- Rotate SELECT to change the pressure setting.

- Press ENTER to return to the Setup Menu with the displayed pressure in
  effect. The pressure you selected will be used for dose calculation.

Chamber Override

This menu item allows you to override the automatic chamber identification performed during Power On. It allows you to select any ion chamber that is supported by the converter type (see Appendix E). It can be used to correct the misidentification of a 90X6-6M chamber as a 90X6-6, for example.

- Rotate SELECT to the *Chamber Override* mode.

Chamber
90X6 6cc

- Press ENTER to produce the display below:

Chamber Override
90X6 6cc

- Rotate SELECT to scroll through the list of chambers for the converter.

- Press ENTER to select a new chamber and return to the Setup Menu. The control unit will use the newly selected chamber rather than the type determined during Power On.

This override function has two side effects:

1) When the chamber being used does not match the automatic selection, the instrument pauses at the Chamber display at the top of the Function Selection menu for confirmation; and
2) The control unit saves the override chamber when power is shut off. It will assume that same type of chamber is still being used next time the power is turned on.

Chamber Kq

The chamber correction factor, Kq, permits the user to compensate for known variations in detector response. Kq is a multiplication factor applied to all chamber readings. The factory default is 1.000 for all sensors.

There are separate correction factors stored in the control unit for each chamber, The factor you change corresponds to the chamber displayed in the Chamber item in the Function Selection Menu. You can set Kq to a value between 0.800 and 1.200, with .005 resolution.

- Rotate SELECT to the *Chamber Kq* mode.

Chamber Kq
6cc Kq 1.000

- Press ENTER to change Kq for this chamber. The display will change to:

Set Chamber Kq
6cc Kq 1.000

- Rotate SELECT to change Kq.

- Press ENTER to save Kq and return to the Setup Menu. The factor will be used for all dose and dose rate measurements.

Pulsed Preset

This allows you to set each of the 6 preset rates to any of the allowed values. The values range from 0.25 to 90 pulses per second. The choices are displayed as SELECT is rotated.

- Rotate SELECT to the *Pulsed Preset* mode.

Pulsed Preset
Nr 5 90Pls/s

This display indicates that preset 5, set to 90 pulses/sec, is active.

- Press ENTER. The display will change to:

Select Preset Nr

Nr   5 90Pls/s

- Rotate SELECT to view the rate assigned to each of the other presets.

- Press ENTER when the preset you want to change is displayed.

Select Rate
Nr 1 0.25 Pls/s

- Rotate SELECT to choose a pulse rate for preset 1.

- Press ENTER to assign that rate to preset 1.

- Press ENTER to return to the Setup Menu.

The new rate for the selected preset will be available in the *Pulsed/Cine* mode.

Repeat the process for any other presets you wish to change.

Pulsed Start at

This is the dose rate that allows a Pulsed Radiation measurement to begin. The rates that may be used depend upon the sensor connected to the 9010 control unit. The examples below are based on the use of a 9060 converter and a 10X5–60 ion chamber. The rates available for this sensor are 0.02, 0.03, 0.06, 0.10, 0.19, 0.34, 0.60, 1.08, 1.93, and 3.45 mR/s. Rates for other chambers are inversely proportional to the chamber volume (the maximum threshold for a 90x6–6 is 34.5 mR/s) If the threshold is 0 the Acquire phase starts immediately.

- Rotate SELECT to the *Pulsed Start at* mode.

Pulsed Start at
0.02 mR/s

- Press ENTER to enter this mode. The display will change to:

Set Start Rate
0.02 mR/s

- Rotate SELECT until the desired start rate appears.

- Press ENTER return to the Setup Menu. The selected dose rate will be used to start Pulsed Radiation mode.

Pulsed Radiation Units

This selects the dose units displayed in the *Pulsed/Cine* mode. The dose is measured during the acquire interval, and then computed in terms of dose per pulse, sec, minute or hour as selected here. This selection is independent of the *Time Units* selection

- Rotate SELECT to the *Plsd Rad Units* mode.

Plsd Rad Units
Seconds

- Press ENTER to enter this mode. The display will change to:

Set Rad Units
Seconds

- Rotate SELECT until the desired units appear.

- Press ENTER return to the Setup Menu. The selected units will be displayed in start Pulsed Radiation mode.

Pulsed Delay

This is the delay following the threshold phase in *Pulsed/Cine* mode. The user sets it to a number of pulses between 1 and 255; it is converted to a time interval based on the selected pulse rate.

- Rotate SELECT to *Pulsed Delay* mode.

<div align="center">

Pulsed Delay
10 Pulses

</div>

- Press ENTER. The display will change to:

<div align="center">

Select Delay
10 Pulses

</div>

- Rotate SELECT to set the delay interval.

- Press ENTER to return to the Setup Menu. The selected delay will be used in *Pulsed Radiation* mode.

Pulsed Acquire

This is the interval used for integrating the dose for computing the dose per pulse in *Pulsed Radiation* mode. The user sets it to a number of pulses; it is converted to a time interval based on the selected pulse rate.

- Rotate SELECT to the *Pulsed Acquire* mode

<div align="center">

Pulsed Acquire
12 Pulses

</div>

- Press ENTER. The display changes to:

<div align="center">

Select Acquire
12 Pulses

</div>

- Rotate SELECT to change the Acquire value.
- Press ENTER to return to the Setup Menu. The selected number of pulses will be used for the Acquire phase of the *Pulsed Radiation* mode.

Time Units

The time unit used to calculate dose rate in Dose Rate, Auto Zero, kVp Fluoro, and Max Dose Rate is set here. Units available are seconds, minutes, and hours.

- Rotate SELECT to the *Time Units* mode.

<div align="center">

Time Units
Minutes

</div>

The second line of the display shows the time unit currently in use.

- To change the time unit press ENTER. The display will change to:

<div align="center">

Set Time Units
Minutes

</div>

- Rotate SELECT to display your choices.

- Press ENTER to return to the Setup Menu. The selected time unit will be used for dose rate calculations.

Radiation Units

The radiation unit used for dose calculations is selected here. The conversion factors employed by the instrument are:

$$1\ R \quad = 0.008764\ Gy$$
$$= 0.000258\ C/Kg$$
$$= 0.010\ Sv.$$

- Rotate SELECT to the *Radiation Units* mode.

<div align="center">

Radiation Units
Roentgens

</div>

The second line of the display shows the radiation unit currently in use.

- Press ENTER to change the unit. The display will change to:

<div align="center">

Set Rad Units
Roentgens

</div>

- Rotate SELECT to change to Roentgens, Coulombs/kg, Sieverts, or Grays.

- Press ENTER to return to the Setup Menu. The selected radiation unit will be used for dose and dose rate calculations.

Baud Rate

Select the Rs232 baud rate. Available baud rates are Off, 300, 1200, 2400, 9600 and 19,200. Use 19200 baud for best remote data collection performance.
Off removes power from the serial interface for improved battery lifetime.

- Rotate SELECT to the *Baud Rate* mode.

<div align="center">

Baud Rate
Off

</div>

The second line of the display shows the baud rate currently in use. To change the rate press ENTER. The display will change to:

<div align="center">

Set Baud Rate
Off

</div>

Rotate SELECT to display the available baud rates. When the desired baud rate is displayed, press ENTER to enable the serial port at that baud rate and return to the Setup Menu.

Serial Test

This provides a convenient way to verify RS-232 serial communications.

- Rotate SELECT to the *Serial Test* mode.

Serial Test
Serial Test Off

- Press ENTER. The display will change to:

Serial Test Off

- Rotate SELECT. If the serial port is properly connected the display will change to:

RADCAL 9000 TEST
0123456789abcdef

While in this mode, the displayed message is repeatedly broadcast through the RS-232 serial port. If the RTS line isn't connected or if it is negative, "RTS not positive" will be displayed on the bottom line, but the message is sent anyway.

- Press ENTER to halt the test and return to the Setup Menu.

Power Off Delay

This controls the automatic power-off time delay. The delay may be disabled or set to a value from 1 to 99 minutes.

- Rotate SELECT to the *Power Off Delay* mode.

Power off delay
15 min

- Press ENTER to enter this mode. Now the display will change to:

Set pwr off time
15 min

- Rotate SELECT to set the delay time. A delay of zero disables the function.

- Press ENTER to return to the Setup Menu. The selected power off time is now in effect.

Function Menu

Function Menu allows you to select the items available from the Function Selection Menu. Each measurement function is assigned a base value (a power of 2); these values are shown in the table below. Set the Function Menu number to the sum of the values for the menu items you wish to have available in the Function Selection Menu. For example, the factory default value of 26 is equal to the sum of the values for Dose (8), Dose Rate (2), and Auto Dose (16). Adding Auto Zero (1) to the Function Selection Menu would make the value 27. The base values are:

Measurement Function	Base Value
Auto Zero	1
Dose Rate	2
Maximum Rate	4
Dose	8
Auto Dose	16
Pulsed/Cine	32
Last Dose	64

- Rotate SELECT to the Function Menu function.

Function Menu
26

- Press ENTER to change the number.

Set Func Menu
26

- Rotate SELECT to set the value.

- Press ENTER when the value corresponds to the combination of Measurement Functions you want. In this example, Dose, Dose Rate and Auto Dose would be the only three menu items available on the Function Selection Menu. 127 selects all available functions and is a good setting for most users. Any odd value enables **Auto Zero**; any even value disables **Auto Zero**.

Confirm

This allows you to change the confirm setting used in display of operating parameters during Power On. If *Confirm* is set, then you must press ENTER to acknowledge the pressure, temperature, and chamber settings before you reach the Function Selection Menu. If it is clear, the pressure, temperature and chamber settings are displayed, but pressing ENTER is not required.

- Rotate SELECT to the *Confirm* mode.

<div align="center">

Confirm Bit
clear

</div>

- Press ENTER to obtain the Set Confirm Bit display:

d

<div align="center">

Set Confirm Bit
set

</div>

- Rotate SELECT to toggle the setting between set and clear.

- Press ENTER to return to the Setup Menu. Your selection is now active.

Exit Setup

- Rotate SELECT until you reach the last item in the Setup Menu. The display will show:

<div align="center">

Press Enter to
Exit Setup

</div>

- Press the ENTER key to leave setup.

Upon leaving setup, the control unit displays temperature and pressure and checks the battery and chamber voltage before going to the Function Selection Menu.

Checks, Errors and Corrections

Circuit Check

The TEST button, located at the left of the control panel, may be used to check (NOT CALIBRATE) the operation of the control unit and its attached sensor. It permits you to test most dose and dose rate functions without applying radiation.

• Connect a sensor to the control unit.

• Press ENTER to turn on the instrument.

• Use the Function Selection Menu to select Dose Rate, and press ENTER to begin measuring Dose Rate.

In this example, we assume that you are using a 6cc chamber and units of Roentgens and minutes. If your setup varies, you can use the Setup Menu to conform to these settings, or scale the readings appropriately.

With no radiation present and the TEST button unpressed, the display should read less than about 1 mR/min. This test checks leakage and noise performance.

• Press the TEST button. The dose rate should read between 25 R/min and 125 R/min.

• Release the TEST button. The dose rate should drop to less than 1mR/min within 30 seconds.

Other operating modes may be tested with the TEST button. The radiation it simulates may be calculated from the dose rate determined above and the time the TEST button is depressed.

Batteries

The 9010 obtains its operating power from 9V batteries. During Self-Test, if the battery voltage is less than 5.25V, the message "Replace Batteries" is displayed in place of "OK." A 9010 Radiation Monitor will operate for about an hour after this message first appears. If the battery voltage reaches the point where accuracy is affected, the message "Battery Failed" appears for about 20 seconds, and the instrument shuts off.

To install batteries, first select Power Off from the Function Selection Menu. Turn the 9010 over and remove the battery access cover by pressing on the center of the ribbed edge of the battery cover. Lift out and disconnect the batteries and install the replacements. The connectors plug into the batteries only one way.

Auto Zero

Auto Zero cannot function if there is too much background or leakage current. If you encounter problems, measure the dose rate in the configuration you intend to use. For auto zero to work, the background rate must be less than 10 times the minimum dose rate given in Appendix E for the sensor you are using.

A*uto Zero* will be unreliable if the system hasn't stabilized before auto zero is determined. Observe the *Auto Zero* On rate before using this mode.

Offset and leakage currents change with time and temperature. You should recheck the *Auto Zero* setting occasionally while making measurements. We recommend making a *Dose* measurement (with Auto Zero on) for a known interval and comparing that auto-zero-corrected reading with your measurement needs.

Errors

If the instrument encounters a problem, it displays an error message. In many cases, the display instructs you to press ENTER to resume. In others,

the instrument can recover from the error without intervention. For example, a momentary overload in *Dose Rate* measurement produces a single bad reading, while an overload invalidates a *Dose* Accumulation.

If the battery voltage is insufficient for accurate operation, the display shows "Battery Failed" and the instrument will turn off after 20 seconds.

If the sensor is disconnected from the control unit, the display shows "No converter" and the instrument will turn off after 20 seconds.

A list of error messages and their meanings is in Appendix F.

Reinitializing the system

If the instrument enters a state in which it will not respond to the ENTER or SELECT controls, it can be reset if you disconnect the batteries for 30 seconds, reinsert them again, and then perform a parameter reset.

Parameter reset

User-set parameters such as chamber correction factors and operating modes—essentially all the items chosen in the Setup Menu—are stored in an Electrically Alterable Read Only Memory (EAROM). These parameters can be reset to factory default values using the following procedure.

- If the display is not blank, turn the power off using the Function Selection Menu *Power Off* command.

- With power off, press and hold the TEST button. Turn on the instrument using the ENTER button. The control unit will perform a self-test. Part way through, it will display the message "Hold Test to Reset Parameters." Press and hold TEST to do so.

- After five seconds, the display will change to "Release Test to Reset Parameters." Do so. The display should then read "Parameters Set to Defaults." The control unit will then proceed to complete the self-test.

Parameters will be reset to the following values:

Temperature	Fixed 22°C
Pressure	101.3 kPa (Measured if Option P installed)
Chamber	as measured
Chamber Kq	1.000 for all chamber/converter types
kVp modes	(See Appendix A)
Pulsed/Cine Units	/pls
Pulse rate presets	1/4/7.5/15/30/90 pulses per second
Pulsed/Cine Threshold	34.5 mR/s for a 6cc chamber.
Delay	6 pulses
Acquire	5 pulses
Time Units	Minutes
Radiation Units	Roentgens
Baud Rate	9600
Power Off Delay	15 min.
Dose Function Menu	26 (*Dose Rate, Auto Dose, Dose*)
kVp Menu	3 (both)
Confirm	Clear

System Reset
If the instrument will not respond to the ENTER or SELECT controls, reset it by disconnecting the batteries for 30 seconds, reinsert them again, and then perform a parameter reset.

Pressure, Temperature Correction

The 9000 Series instruments are calibrated at 22°C and 101.3 kPa. Because the chambers are unsealed, operation at other pressures and temperatures requires correction of the reading. The response of an ion chamber is proportional to the amount of gas in the chamber. The ion chamber output increases with increasing pressure and decreases with increasing temperature.

Internal Correction

The instrument measures the temperature of the control unit and, if Option P is included, the atmospheric pressure as well. These measured values can be used to correct the reading of the instrument. Alternatively, you may enter fixed values for the pressure and temperature. In either case, the necessary calculations are performed before dose and dose rate readings are displayed. The amount of this correction is displayed in the correction factor displayed during operation of the Function Select Menu.

Be sure that the temperature of the ion chamber and the control unit have stabilized before making a measurement. A temperature difference of 1°C corresponds to a correction of 0.3%. It typically takes 15 minutes for the instrument to come to equilibrium after a 10°C temperature change. Pressure response time is less than 1 second.

Manual Correction

The following procedure may be used to correct for local temperature and pressure:

$$CorrectionFactor = \frac{273 + T}{273 + 22} \; X \; \frac{101.3}{P}$$

Where: T is the local temperature in °C,
          P is the local pressure in kPa,
          and the control unit is set to fixed 22°C and fixed 101.3 kPa.

Multiply all readings obtained by the calculated factor to obtain the correct result.

If pressure is obtained in units other than kPa, use the appropriate conversion factor from the following:

- for converting millibars to kPa, multiply by 0.1;
- for converting in Hg to kPa, multiply by 3.39;
- for converting mm Hg to kPa, multiply by 0.133;
- for converting inches H_2O to kPa, multiply by 0.249.

Note: *Some medical facilities are equipped with positive-pressure air-filtration systems, with over-pressures usually expressed in inches of water. Also, atmospheric pressure changes with altitude at the rate of approximately 5 kPa per thousand feet near sea level.*

Glossary

9010
A complete instrument capable of measuring radiation. A 9010 control unit and a sensor.

Accu–kV
A Radcal 4000–Series kV sensor consisting of a control unit and a kV sensor. Option C is required to use this with the 9010.

Control unit
Includes controls, display, processor and power supply for the instrument.

Converter
Circuit that converts the ion-chamber current into digital pulses for processing in the control unit.

ENTER
Refers to the ENTER push-button. ENTER activates the selected menu item.

Function Selection Menu
Displays measurement functions that can be activated using ENTER when SELECT is rotated.

Ion Chamber
Responds to ionizing radiation by producing a (small) current, $3.09 * 10^{-10}$ C/R per cm^3 volume at 22 C and 101.3 kPa. . Radcal ion chambers are not sealed, so pressure and temperature compensation are necessary.

Item
A measurement function available in the Function Selection Menu or a parameter displayed in the Setup Menu.

Measurement function
A function such as *Dose Rate*, *Dose*, *Auto Zero*, etc.

SELECT
Refers to the SELECT dial. Rotating SELECT causes different menu selections to appear on the control unit's display.

Self-Test
Operations that occur following power-on that test the instrument. Progress is displayed as they occur.

Sensor
Converts ionizing radiation to digital signals for the control unit to process and display. Converter and ion chamber.

Setup
Operating mode allowing access to operating parameters.

Setup Menu
Setup mode. Displays setup parameter values and allows user to change values.

Appendix A: Options

This appendix describes the options available for the control unit:

- an analog signal capture option (Option C);
- a barometric pressure transducer option (Option P).

Analog Signal Capture (Option C)

The analog signal capture option provides a means for analyzing a kV waveform in conjunction with an ion-chamber-based measurement of dose or dose rate. *kVp Fluoro* mode used with fluoroscopic x-ray machines provides dose rate and kVp measurements approximately once per second. *kVp Pulse* mode used with pulsed machines provides measurements of dose, kVp and pulse duration following a pulsed exposure. Automatic scaling to kV units is provided when used with the *Radcal* Accu–kV Non–invasive kV Meter or with the Keithley 35080–series dividers. The option records up to 2 seconds of 0-5V data with a resolution of 0.1 ms and 1.25 mV.

Operating the kVp functions

These instructions describe operation of the Option C in conjunction with a Radcal Accu–kV instrument. They describe operation with the 4083; other versions are similar.

- Turn on the 9010 control unit. During *Power On* the display should show:

<div align="center">

Analog Capture
OK

</div>

If this message doesn't appear, the kVp modes will not be available.

- Rotate SELECT to see if the kVp measurement functions are enabled. If they do not appear, use the Setup function *kVp Menu* to set the menu code to 1, 2 or 3 to enable *kVp Pulse*, *kVp Fluoro* or both respectively.

- Connect the BNC on the 4083 control unit to the dual banana jacks labeled "input" on the control unit. The red jack is signal (0 to +5V) and the black jack is return. Do not connect to the jacks labeled *Output*; they are for connecting an oscilloscope to view the stored waveform.

kVp Filter selection

You may use the Setup function *kV Filter* to select a particular kV sensor for your use. This is convenient if you are using only a single kV sensor; otherwise we suggest *Auto*.

kVp Filter – Auto

The Auto type uses the output voltage in Accu–kV's Test or the 35080A's CAL mode to identify the sensor. To use *Auto*, select *kVp Pulse* or *kVp Fluoro* using the Function Select Menu. If *the Auto* selection is in effect, the display will show something like:

6cc Corr 1.00
kVp Pulse ??

If ?? does not appear, and the incorrect sensor is displayed, use the Setup Menu *kVp Filter* function to select the *Auto* type.

- With ?? displayed in *kVp Pulse* or *kVp Fluoro,* apply the calibration voltage by pressing and holding the TEST or FLUORO control on the Accu–kV or switching the 35080A to CAL.

- Press ENTER. The ?? should change to the correct type.

- Press ENTER again to lock in this setting. This setting will now be used until the instrument is turned off or you go back to Setup, *kVp Filter*, and select Auto.

- Release the Accu–kV control, or switch the 35080A to RUN.

If the Test voltage is outside the specified range, the ?? will not change. Pressing ENTER with ?? showing will make measurements in Volts mode. However, Volts is not locked in, so you can try again.

kVp Pulse

- Rotate SELECT to the *kVp Pulse* function.

6cc Corr 1.00
kVp Pulse ??

- Press ENTER to display

kVp Pulse
0.002 V volts

This displays the kV Sensor voltage. This voltage must be less than the *kV Trig* setting. If the abbreviation correctly identifies the sensor, you may skip the step below:

- Press and hold Test on the 4081, Fluoro on the 4082 or 4083 or select CAL on the 35080A so the kV sensor makes the calibration voltage. If the calibration voltage corresponds to one of the pre–programmed sensors, "volts" will change to identify the sensor, Radcal 40X5–MO Mammographic sensor in this example:

kVp Pulse
0.916 V RMamm

- Press ENTER if the identification is correct. The display will change to:

kVp Pulse RMamm

This is the measurement mode. As kVp Pulse starts, the radiation sensor enters Dose Accumulate mode. An arrow appears in the lower left corner of the display while the dose is accumulating. The analog capture board records data for 100 ms after starting the measurement, and then looks for a trigger. The trigger occurs when the detected voltage exceeds the kVp Trigger voltage. The following 400 ms of signal is saved along with 100 ms of signal preceding the time at which the trigger was exceeded. The end of the pulse is identified as the time the signal from the kV sensor remains below the trigger for 20 ms. Approximately two seconds after the end is located, the mode switches to Dose Hold and the pulse width is determined. Because dose is accumulated for the entire interval between starting the measurement and two seconds after the end of the pulse, the displayed dose may exceed that produced during the kV pulse interval.

The peak value of the input waveform is determined as the pulse is being digitized. The pulse width is measured at 75% of the maximum kVp (including the offset if there is one) or the trigger voltage, whichever is larger. For Radcal sensors, the offset is zero and the timing threshold is 75% of the signal level unless the trigger threshold is set to a value above 500 mV (75% of 22kV, the minimum signal from the 40x5 Mo sensor).

For Keithley sensors, the timing threshold is more complex. For example, if the kVp is 80 and the Wide Range sensor is being used with nominal gain and offset numbers, the maximum voltage would be 400 mV. Seventy-five percent of the maximum kVp is 60 kVp. This corresponds to a voltage of 200 mV, (60 kV - 40 kV) x 10mV/kV. If the voltage threshold had been set to 50 mV, then the reported width would be based on 200 mV. If the peak were 55 kV, just within the range of the WR sensor, then the peak of the voltage waveform would be 150 mV, and 75% of the kVp would be at 12.5 mV. Because this is less than the 50 mV voltage threshold, 50 mV would be used for determining the pulse width.

The 100-ms interval preceding the trigger is included in the pulse width calculation, so if the kV threshold is reached during this interval, the pulse width can include all or part of the 100 ms.

Although the pulse memory is limited to 2000 ms, pulses up to 6.5 s can be analyzed. After 6.5s, the measurement aborts, displaying "????" for width and "----" for kVp.

With a kV sensor connected to the Analog In and the sensor's ion chamber in the x-ray beam, the control unit will indicate kVp and pulse width on the top line, and total dose on the bottom line of the display:

104.6 kVp 68.7ms
15.13 mR

After the pulse is analyzed and the results displayed, the control unit rearms with Dose mode active and the trigger enabled and awaiting subsequent pulses.

kVp Fluoro

•   Rotate SELECT to the *kVp Fluoro* function.

6cc Corr 1.00
kVp Fluoro ??

•   Press ENTER to display

kVp Fluoro
0.002 V volts

This displays the kV Sensor voltage. If the abbreviation correctly identifies the sensor, you may skip the step below:

- Press Test on the Accu–kV, Fluoro on the 4082 or select CAL on the 35080A so the kV sensor makes the calibration voltage. If the calibration voltage corresponds to one of the pre–programmed sensors, the display will become:

kVp Fluoro
0.916 V RDiag

- Press ENTER if the identification is correct. The display will briefly change to:

kVp Fluoro RDiag
─────

and then (assuming there are no x–rays being generated):

───── Vp
─────

This is the *kVp Fluoro* measurement mode. With a kV sensor connected to Analog In and the ion chamber in the x-ray beam, the top line of the display shows kVp and the bottom line shows dose rate. The five dashes on the first line indicate the kVp is below the kV sensor calibration range the five dashes in the second line indicate the dose rate is below the threshold for this radiation sensor.

The dose rate is measured as with Auto Zero disabled, subject to a minimum rate of 120 mR/min (90X6-6 Sensor). The measurement is repeated about once per second. kVp is determined at the end of each rate measurement. The display will show kVp on the upper line and dose rate in the second line.

The arrow in the lower left corner of the display is on while rate is being measured:

104.6 kVp
70.98 R/min

kV Setup Parameters

The default values for the kVp Trig, kV Gain and kV Offset parameters are usually correct, however these instructions describe how to adjust them if necessary. To access setup mode, press and hold ENTER and rotate SELECT 6 or more steps in either direction.

kV Trig

This parameter controls the voltage at which the capture card starts accumulating waveform data. If it is too small, the card will start sampling before the exposure begins an will probably miss the real signal. To adjust this value:

- Measure the no–signal output from the sensor using a meter or the 9010.

- In Setup, select *kV Trig*. The display will show:

<div align="center">

kVp Trigger
0.125 Volts

</div>

and then:
<div align="center">

Set Trig Voltage
0.125 Volts

</div>

- Set the *kV Trig* voltage to a value that is larger than the no–signal voltage.

Allowable values range from 0.025 volts to 4.5 volts in increments ranging from 0.005 volts to 0.5 volts. For the Radcal Accu–kV sensors, we recommend a setting of 0.300.

kV Gain

This setting should normally be left at the default value. See the supported kV sensors list on page 70 for defaults.

- In Setup, select *kV Sensor* and press ENTER.

- Rotate SELECT until the kV sensor you want to adjust is displayed.
- Press ENTER to choose that sensor's settings.

- select *kV Gain.*

<div align="center">

kV Gain
32.8 kV/V

</div>

- Press ENTER and use SELECT to adjust the gain for the selected sensor.

<div align="center">

Set Gain Factor
32.8 kV/V

</div>

kV Offset

This setting should normally be left at the default value. See the supported kV sensor list on page 70 for defaults.

- In Setup, select *kV Sensor* and press ENTER.

- Rotate SELECT until the kV sensor you want to adjust is displayed.

- Press ENTER to choose that sensor's settings.

- select *kV Offset.*

<div align="center">

KV Offset
0.0 kV

</div>

- Press ENTER and use SELECT to adjust the offset for the selected sensor.

<div align="center">

Set kV Offset
0.0 kV

</div>

After making these adjustments, the correct parameters, including those adjustments you have entered, will be used in calculating kVp. You will need to reset Sensor to Auto after making these adjustments. The kV Gain and kV Offset parameters are stored separately for each sensor type. To see the values, and to adjust them if required, a specific Sensor Type must be selected. If Sensor Type is *Auto*, these setup selections will not appear.

kVp calculation

kVp is calculated from the recorded kV sensor output. A 50 ms interval is examined to determine the kVp. Ten samples are averaged to obtain a 1 ms "boxcar" average. 500 of these averages are computed, starting each 0.1 ms over the span. The interval starts 10% of the x–Ray exposure interval after the exposure begins. After the exposure ends (signal below threshold for 20 ms) and the exposure duration is known, the interval is selected and the computation performed. If the duration is less than 50 ms the end of the interval is made to coincide with the pulse end. If the 50 ms interval would extend past the stored values, the last 50 ms stored is used.

kV–mode Dose

When measuring dose in conjunction with *kVp Pulse* mode, the sensors are operated with *Auto Zero* off. Dose is measured with the resolution shown below for the sensors typically used for these procedures. The value for other sensors is inversely proportional to the chamber volume. See Appendix E.

Ion Chamber	Dose Resolution
6cc, 6M	1 µR .01 µGy
60cc	1 µR 1 nGy
180cc	0.01 µR 0.1 nGy

kV–mode Dose Rate

In *kVp Fluoro* mode, dose rate is measured only if it exceeds the dose–rate threshold value shown below. The maximum resolution for these sensors is also given. The value for other sensors is inversely proportional to the chamber volume. See Appendix E.

Ion Chamber	Threshold	Resolution
6cc, 6M	120 mR/min	0.1 mR/min
	18 μGy/s	0.01 μGy/s
60cc	1.2 mR/min	0.01 mR/min
	1.8 μGy/s	0.001 μGy/s
180cc	4.0 mR/min	0.001 mR/min
	600 nGy/s	0.1 nGy/s

kV–mode errors

Three messages are used to notify the user that an attempted measurement wasn't successful.

- "———" is displayed when a time or a measured voltage is below the useful range of the instrument. Applied to time, "———" appears when the pulse width is less than 5 ms. Applied to kVp, it appears when the kV is below the specified range of the selected sensor.

- "+++++ " appears when the pulse width was over 6.5 S, and when the kV is above the specified range of the selected sensor.

- "?????" appears when a measurement value is uncertain. For example a time display of "-----" will be accompanied by a kVp "?????" because the pulse is too short to accurately measure.

kV–mode Playback

The recorded waveform may be played back for detailed analysis in analog or digital form. Setup Menu items allow selection of playback type and selection of full or partial playback of the recorded data.

The Setup Menu item *kV Readout* lets you select the playback mode. Digital readout uses the RS-232 interface. Dig ascii outputs each sample in the selected readout range, in millivolts. Dig Comp is a binary output format. Contact Radcal for details and a sample program to read Dig Comp data. The display says "Sending Data" in the second line while output is occurring. Pressing ENTER or moving SELECT ends the readout.

Analog readout replays the waveform in real time, ~100 μs per sample, with a full-scale sync pulse at the start of the playback. The voltage is the inverse of the input. Use the invert control present on most oscilloscopes to restore the sense of the input. The display says "Playback" in the second line while the analog readout is happening. The analog readout repeats until you press ENTER to go back to measuring kVp, or rotate SELECT to leave this mode.

kV–mode Readout Mode

Allows you to configure the output data format of the control unit.

kV Readout Mode
Ana off Dig off

Available selections are: Ana Off Dig Off; Ana On Dig Off; Ana Off Dig Comp, Ana On Dig Comp, An Off Dig ascii, Ana On Dig ascii.

kV–mode Playback Time

Allows you to choose full or partial playback of the recorded data.

kV Playback Time
500 ms

Allowed values are 10 ms to 500 ms.

kV–mode Out Delay

Allows you to select the starting point of the playback, referred to the trigger point on the kVp waveform for kV Pulse, and to 500 ms before the end of the measurement in kVp Fluoro.

kV Out Delay
-100 ms

Allowed values are - 100 ms to 500 ms.

Supported kV Sensors

Pre-programmed values for Radcal Accu–kV and some Keithley 350080 kV sensors are listed below. The *Auto* selection accessible through the Setup Menu function *kV Sensor* will select the correct sensor based upon the distinct test voltage generated by each of the sensors listed, or you may select a particular sensor.

Radcal Accu–kV with 40X5–W sensor

Abbreviation:	RDiag
Full name:	Radcal Diag
Range:	40 to 160 kV
Sensitivity	30.52 mV/kV (32.8 kV/V)
Zero offset	0
Calibration Voltage:	3.052 V (100 kV)

Radcal Accu–kV with 40X5–Mo sensor

Abbreviation: RMamm
Full name: Radcal Mammo
Range: 22 to 40 kV
Sensitivity   30.52 mV/kV (32.8 kV/V)
Zero offset   0
Calibration Voltage: 0.916 V (30 kV)

Keithley 35080A with 37617C Wide Range filter pack

Abbreviation: WR
Full Name: Wide Range
Range: 50 to 150 kV
Sensitivity: 10 mV/kV (100 kV/V)
Zero   40 kV
Calibration voltage   400 mV (80 kV)

Keithley 35080A with 33551C CT filter pack

Abbreviation: CT
Full Name: CT
Range: 70 to 140 kV
Sensitivity: 10 mV/kV (100 kV/V)
Zero   60 kV
Calibration voltage   644 mV (124.4 kV)

Keithley 35080A with 37946C Mobile filter pack

Abbreviation: MOBL
Full Name: Mobile
Range: 50 to 135 kV
Sensitivity: 10 mV/kV (100 kV/V)
Zero   40 kV
Calibration voltage   600 mV (100 kV)

Keithley 35080A with 37355C Cadmium K-edge Mammo filter pack

Abbreviation: K mm
Full Name: K edge Mammo
Range: 27.5 to 29.5 kV
Sensitivity: 100 mV/kV (10 kV/V)

Zero   27.0 kV
Calibration voltage   750 mV

Keithley 35080A with 37351C Linear Mammo filter pack

Abbreviation: L mm
Full Name: Linear Mammo
Range: 22.0 to 40.0 kV
Sensitivity: 10 mV/kV (100 kV/V)
Zero: 0
Calibration voltage: 200 mV (20.0 kV)

Defaults for the Analog option

The setup parameters have the following default values from the factory and the unit returns to them whenever the Parameter Reset function is performed:

    kVp Trigger: 60 mV
    kVp Filter: Auto
    kV Gain: Nominal (see supported kV sensor list)
    kV Offset: Nominal (see supported kV sensor list)
    kV Readout mode: Ana Off Dig Off
    kV Playback Time: 500 ms
    kV Out Delay: -100 ms
    kV Menu: 3 (both enabled)

Option C Specifications

Voltage
    Operating: +.001 to +4.99V
    Withstand: +30V to -30V without damage
    Impedance: 1 Megohm ±1%
    Filter: 40 µs, single-pole
    Accuracy: ±(0.003V +0.4% of value)

Time
    Resolution: 100 µs
    Accuracy: 0.05% of value
    Range: 5 ms to 6.5s

Output
    Range: 0 to -5V
    Accuracy: ±(.020V + 1% of value)
    Load: >10K
    Withstand: Short to ground

Barometric pressure transducer (Option P)

The barometric pressure transducer option measures atmospheric pressure to compensate chamber readings for changes in barometric pressure. When used in combination with automatic temperature compensation, the reading is automatically adjusted for pressure and temperature changes between 60.0 and 105.0 kPa and 0° and 50°C. The accuracy of the correction is 2.5%. If the correction factor due to temperature and pressure were 10% (Corr=1.10), then the automatic correction would be between 1.098 and 1.102.

The pressure transducer alters the self-test, the Power-On display, and the Setup Menu to display information on pressure. The Setup Menu allows selection of either user-set or measured pressure compensation.

During self-test, the display shows "Pressure Sensor" on the top line. The results of the test are shown on the second line. "OK" means that the circuit works correctly and that the measured pressure was within the range specified for correct operation. A display of "Failed" means that the circuit did not pass test. Displays of "++++" or "__" indicate that the circuit appears to be working but the pressure reading is outside the 60-to-105-kPa range. The system will not use measured pressure if the self-test fails or if the measured value is out of range.

If measured pressure is in use, the "fail" message will not clear until you press ENTER. If fixed pressure is in effect, the "fail" message will be displayed for about one second and then disappear. This self-clearing also occurs with out-of-range indications.

During Power On, the control unit displays the selected mode and value for the pressure transducer. There are three possibilities:

If the option is not installed, the display is:

Pressure
Set to 101.3kPa

If the option is installed and fixed pressure is in use, the display is:

Pressure 100.0k
Fixed 101.3k

If the option is installed and measured pressure is in use, the display is:

Pressure
100.0k

If measured pressure is in use, pressure is measured at the start of a measurement but not during the measurement itself. The pressure is measured at the control unit.

Pressure

Activate the Setup Menu and select Pressure mode. This allows the selection of a fixed pressure for compensation or for use of measured pressure. If the option is not installed or has failed self-test, the display shows:

Pressure
Set to 101.3kPa

- Press ENTER to get the no-option pressure-setting display.

Set Pressure to
Fixed 100.0k

- Rotate SELECT to change the fixed pressure by 0.1 kPa per step. You may select a pressure between 40.5 and 120.5 kPa.

- Press ENTER to exit the setup mode with the displayed pressure in effect.

If the pressure option is installed and measured pressure is in use, the display shows:

Pressure
100.0kPa

If the pressure option is installed and fixed pressure is in use, the display shows:

Pressure 100.0k
Fixed 101.3kPa

- Press ENTER to select fixed or measured pressure.

Set Pressure to
Fixed 100.0k

- Rotate SELECT to alternate between the fixed-pressure setting display and

Set Pressure to
Measured 100.0kPa

The initial value for fixed equals the measured pressure, so you start from ambient pressure rather than from any previously set value.

If the measured pressure is outside the calibrated range of the transducer, 60 to 105 kPa, the measured display will show "++++" or "----," and user-set values will be used for pressure compensation.

Appendix B: 20–series sensors

With the 90A25 Adapter Cable, you can use your 20–series sensors with the 9010 control unit. The 90A25's plastic connector plugs into the 20x5 sensor; the metal connector attaches to the 9010 control unit. Either the 90C5–6 extension cable or the 20C5 extension cable is used to connect the control unit and the sensor.

Performance of the sensor is essentially the same as with the 2025 control unit. See the specifications in Appendix E for details. Features of the 9010 that won't work properly with the older converters will not appear on the menu and cannot be entered with the serial port commands. These include are *Auto Zero, Auto Dose*, and *Cine*.

The rate–too–high error message produced by the 90–series converters when the radiation level is too large for accurate measurement is not available for the 20–series converters except for the 20X5–3.

Sensor selection

The 20–series chambers are coded only as 3cc or 180cc volume. Instead of the multiplication factor tables found on the other chambers, use the *Chamber Override* item in the Setup Menu to set the chamber volume.

Suppose you are using a 60cc chamber. The 9010 will identify it as a 3cc because that is the way it is coded. Select 60cc using *Chamber Override*, then make some measurements and shut off the 9010. If the control unit identifies a 3cc chamber code when *Power On* mode occurs when you next turn on the 9010, it assumes the chamber is still 60cc. You can proceed with measurements. If, however, you connect a 180cc chamber, the instrument recognizes that as a different sensor and will use the 180cc sensor parameters. Note that in identifying the 180, it has forgotten about the 3cc–to–60cc switch, so that if you connect the 60 after the 180, the instrument will have reverted to recognizing a 3cc volume for that chamber.

20x5 chambers that are calibrated in Grays (there will be a label indicating this on the sensor housing) must have their chamber correction factor set to 1.145.

Appendix C: Calibration

Calibration of the 9000 series of radiation monitors involves several steps:

• Check the reference voltage.

• Check the current–to–frequency converter and adjust if necessary.

• Check the temperature measurement circuit and calibrate if necessary.

• Check and calibrate the pressure measurement circuit if it is installed.

• Check the calibration of the Analog Signal Capture board if it is installed.

• Calibrate the ion chamber in an x–ray beam.

To perform these calibrations, you will need the following equipment and conditions:

1) A voltmeter accurate to 1 mV at 5V. Input resistance> 10 Megohms;
2) A voltage source settable and stable to 0.5 mV at 1.000V. This is used with the charge source and the Analog Signal Capture board;
3) A calibrated charge source. See figure. The 330kΩ/1uF filter is required to limit the peak input applied to the current–to–frequency converter. Capacitor C2 is connected to reduce errors due to input–circuit voltage offsets. The charge is nominally 1 nC per volt.
4) Pressure and temperature calibration can be changed in the field only if the serial port is installed.
5) A 9600–baud serial terminal to connect to the 9010 serial port.
6) Temperature environment stable to 0.5°C/hour.

7) Means of varying the pressure applied to the pressure transducer and means for measuring the applied pressure with an accuracy of 0.1 kPa. A pressure of 60 to 70 kPa and 95 to 105 kPa is required.

8) Radiation calibration equipment. See Appendix E for details of beam codes for the various ion chambers.
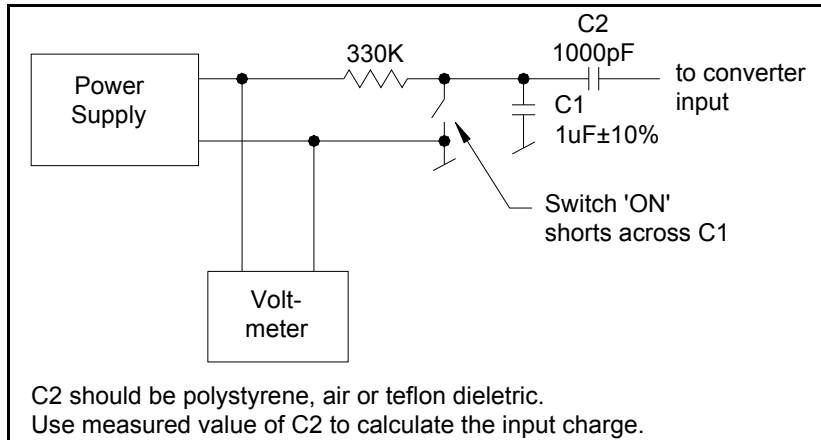
Setup

Note: *This instrument contains static–sensitive components. Perform all adjustments in a static–controlled environment.*

• Disconnect the batteries. Remove the four screws holding the base to the cover (they also affix the rubber feet). The circuit board immediately below the one holding the display is the processor board.

• A set of terminals that accept standard 0.1–inch jumper blocks is located at the accessible end of the board. Install a jumper in the location marked JP2. Installing JP2 puts the instrument in a *Test* mode in which pressure, temperature, and R–48 corrections are set to 101.3 kPa, 22°C, and 1.00, respectively.

Current–to–frequency converter calibration

• Remove the cover from the sensor. Unscrew and disconnect the gold–plated coaxial connector that carries the signal from the ion chamber into the shielded input section of the converter.

• Connect the sensor to the control unit and turn on power. Measure the voltage on J1 pin 12. It should be between 4.995 and 5.005 V. If it is out of tolerance repair is necessary..

• Connect the charge source (see figure) in place of the ion chamber.

• Set the input voltage to the source to produce 1000 pC (1.000V if capacitor C2 is 1000 pF).

- Put the switch in the *On* position. Place the 9010 in *Dose Accumulate*. When the arrow appears, observe the results for at least three readings to be sure there is no leakage current. Then, turn the switch off. The reading should increase to 539.9 ± 0.5 mR within five seconds and should remain unchanged thereafter. If necessary, adjust the trimmer capacitor, C4, to obtain the correct reading.

C2 should be polystyrene, air or teflon dieletric.
Use measured value of C2 to calculate the input charge.

Temperature calibration

To re–calibrate the temperature measurement, you will need to connect the serial terminal, install the WR jumper on the processor board, and enter a new calibration factor.

- Place the 9010 in a known temperature for at least half an hour. Observe the temperature in the Setup Menu, *Temperature* mode. Because JP2 is installed , the temperature displays with $0.1\,°C$ resolution. The temperature should be within $0.5\,°C$ of the standard.

- Connect the serial terminal.

- Be sure JP2 is the only jumper installed.

- Type 0000SETTC<cr>.

- Note the response on the terminal. This is the original calibration factor.

- Type 0000RADCT<cr>.

- Note the response. This is NCal.

- Compute NO = NCal −354. Convert the result to a two–character hexadecimal value, NHex.

- TCal is the measured temperature.

- Compute TO = 20* (TCal − 16). Convert the result to a two–character hexadecimal value, THex.

- Install the WR jumper on the processor board near where JP2 is installed.

- Type NHexSETTC<cr>. The response to this should be the decimal equivalent of the 4–character code, NHex, Thex.

Pressure calibration

To re–calibrate the pressure measurement, you will need to connect the serial terminal, install the WR jumper on the processor board, and enter a new calibration factor.

- Connect the pressure source to the pressure transducer located on the processor board opposite JP2. Access the Setup Menu and select *Pressure.* Apply pressures near 60 kPa and near 100 kPa. The measured readings should be within 0.5% of the correct ones.

- Connect the serial terminal.

- Be sure JP2 is the only jumper installed.

- Type 0000SETPC<cr>.

- Note the response on the terminal. This is the original calibration.

- Adjust the pressure to a value near 100 kPa. This is the Pa.

- Type 0000RADCP<cr>. This is Na.

- Adjust the pressure to a value near 60 kPa. This is Pb.

- Type 000RADCP. This is Nb.

- Compute DelC $= 1024 * \left[\left(\dfrac{Pa - Pb}{Na - Nb} \right) - 1.3 \right]$

- Convert the rounded result to a two–character hexadecimal value, CHex.

- Compute DelD $= 127 + 2 * \left(\dfrac{NaPb - NbPa}{Na - Nb} \right)$

- Convert the rounded result to a two–character hexadecimal value.

- Install the WR jumper on the processor near where JP2 is installed.

- Type CHexDHexSETPC<cr>. The response should be the decimal equivalent of the 4–character hex code, CHex, DHex.

- Remove the WR jumper.

Option C

Use the Setup Menu to access the *kVp Filter* and select *Volt.* Return to the Function Selection Menu and select *kVp Fluoro* mode. Input a known DC

voltage between 0 VDC and 5 VDC to the Analog In banana jacks. Verify that the displayed voltage matches the input voltage from the DC source.

Radiation calibration

Each sensor assembly is calibrated at five energy points in initial production to verify its energy response curve. The correction factor of the sensor assembly is then adjusted to 1.00 ± 0.01 at a particular energy point de–pending on the intended use of the ion chamber. Since the energy response of the ion chamber is fixed by the materials used in the original construction, a calibration check of the sensor assembly only needs to verify the gain settings of the converter, unless the ion chamber has been damaged or repaired. For this purpose, a single energy point measurement at the energy used for the final adjustment of a particular ion chamber is sufficient to verify the proper calibration of a sensor assembly.

The energy points that Radcal uses for final adjustment of its various ion chambers are listed in Appendix E.

After the 9060 converter has been adjusted as described above, the correction factor for the 10X5–series ion chamber is made using the potentiometer that is in the stem of each ion chamber.

A verification measurement of the correction factor should be made with a final radiation exposure.

Appendix D: RS–232 remote commands

Command processing

Serial commands received by the control unit are stored in a 16–character circular buffer until a carriage return, Hex character 0D, symbolized <cr>, is received. Upon receipt for a <cr>, the received string is examined starting with the last character received. When the received character string matches one of the commands listed below, the corresponding action is performed. If the received string differs from the table, the string is echoed to the serial port with a "?" appended and the control unit restarts. An otherwise valid command that can't be executed because the hardware isn't available—for example, issuing KVPLS with no Option C installed—will produce a reset and "KVPLS?" on the terminal screen.

It can take up to 100 ms for the control unit to respond after receiving a <cr> (one second in *Cine* mode). Wait at least this long after <cr> before sending additional commands.

Control commands

The control commands mimic the functions of the SELECT and ENTER controls.

Command	Control	Notes
<cr>	ENTER	Characters entered after <cr> may be ignored.
+, <cr>	Rotate SELECT up	
–, <cr>	Rotate SELECT down	

Function Selection Menu commands

These commands provide access to the Function Selection Menu items. The commands place the control unit in the state that would have been reached by rotating SELECT. Send the ENTER code to start a measurement.

Function Selection

Command	Menu Item	Notes
AERO	Auto Zero	See Auto Zero mode description.
EXERT	Dose Rate	ENTER starts measurement.
MAXRT	Max Dose Rate	ENTER starts or restarts measurements.
EXPSR	Dose Accum/Hold	ENTER switches between Accum and Hold.
AXPSR	Auto Dose	ENTER arms the automatic mode.
LXPSR	Last Dose	ENTER to start; then ENTER to freeze display.
CNSPR	Cine	See Cine mode description.
KVPLS	kVp Pulse	Only available if Option C is installed.
KVFLR	kVp Fluoro	Only available if Option C is installed.
PWOFF	Power Off	ENTER shuts power off.
HELP	None	List of valid commands.

Test mode commands

These commands select modes used for testing. They work like Function Selection Menu commands, usually requiring an ENTER to be actuated.

Command	Function	Notes
CDRAT	CD Rate	Measures converter output frequency.
CNVID	Ch Conv ID	Measures and displays converter type, chamber volume, and chamber cal factor.
EARMG	EAROM status	Displays EAROM cycle count.
RADCT	Temperature adc	Temperature transducer readout in adc units.
RADCP	Pressure adc	Pressure transducer readout in adc units.
TSTON	Test mode on	Simulates JP2 installed.
TSTOF	Test mode off	Simulates JP2 removed.

Calibration commands

These commands are used for calibration. They are useful to check the calibration values stored in the instrument.

Note: Remove all jumpers before sending these commands.

Command	Function	Notes
SETSN	Read serial number	Read numeric part of serial number.
SETTP	Read serial prefix	Read serial number control unit prefix.
SETOP	Read options	Read installed option codes.
SETPC	Read pressure cal	Read pressure transducer calibration value.
SETTC	Read temperature cal	Read transducer calibration value.

Spreadsheet commands

These commands are used by the 9000–series spreadsheet add–on programs. Contact Radcal for details.

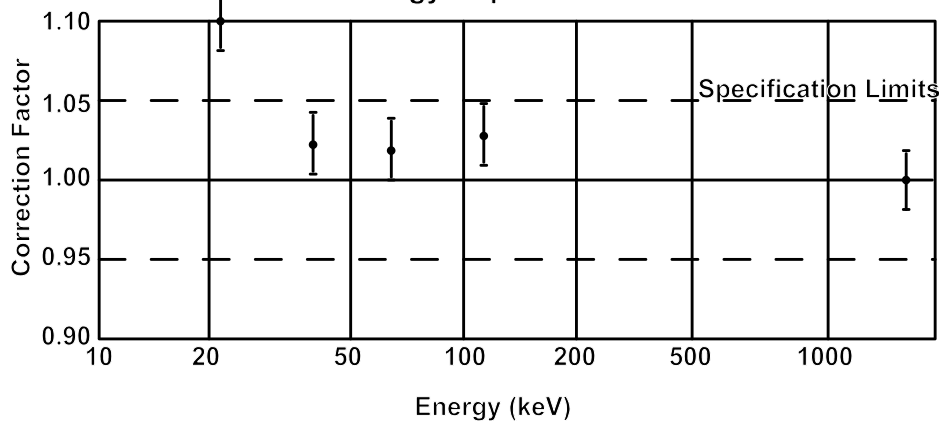|	
RESET	Sets the instrument to a special state for spreadsheet control.
nSETKV	Sets the kVp filter type.

Appendix E: Sensor Specifications

Specification tables, chamber energy dependence graphs, and chamber schematics begin on the next page. Specifications apply to the listed sensor connected to a 9000–series control unit.

0.18cc Ion Chamber

	9060/10X5–0.18	20X6–0.18, 20X5–0.18
Mode		
– Dose Rate	0.1 R/hr to 650 kR/h (1 mGy/h to 5.7kGy/h)	1 R/hr to 600 kR/h (0.01 Gy/h to 5.3 kGy/h)
– Dose	0.01 mR to 2.3 MR (0.1 µGy to 20 kGy)	0.6 mR to 2 MR (5 µGy to 17 kGy)
– Maximum Dose Rate	Same as Dose Rate	Same as Dose Rate
– Auto Dose	20 R/min Threshold	N/A
– Last Dose	Same as Dose	Same as Dose
– Cine Mode	1 µR/f (0.01 µGy/f)	N/A

Accuracy

– Resolution	0.1 R/h (1 mGy/h) and 0.5% or 0.01 mR (0.1 µGy)	1 R/h (0.01 Gy/h) and 0.5% or 0.6 mR (5 µGy)
– Energy Dependence	±5%, 45 keV to 1.33 MeV	
– Rate Dependence	±2%, 10 R/h (100 mGy/h) to 650 kR/h (5.7 kGy/h) average	
– Calibration Accuracy	±4% after temperature and pressure corrections, using ^{60}Co	

Miscellaneous Specifications

– Chamber	Fully–guarded; C552 air–equivalent walls and electrode; polyacetal exterior cap; 0.18 cm^3 active volume; unsealed	
– Cable	3 meter low–noise triax	
– Weight	0.45 kg (conv), 0.1kg (chbr)	0.30 kg

-0.18 Ion Chamber
Energy Dependence

Correction Factor vs Energy (keV)

Specification Limits

Center of
Sensitive
Volume

9

14Ø

3Ø

12Ø

19

45
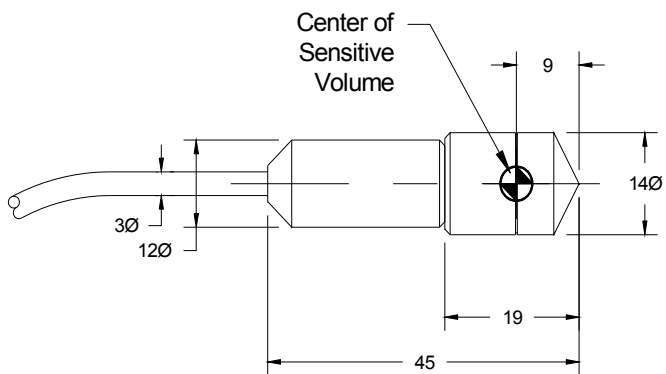
Dimensions in millimeters

0.6cc Ion Chamber

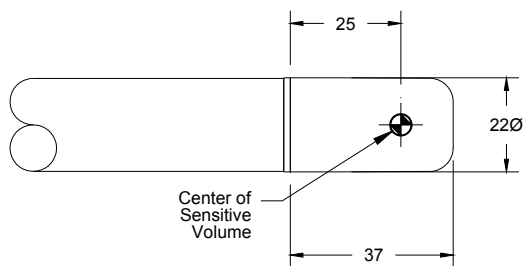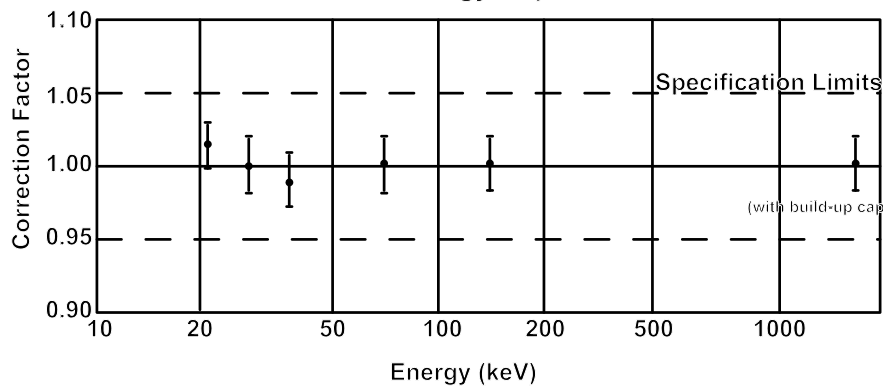|	9060/10X5–0.6	20X6–0.6, 20X5–0.6
Mode		
– Dose Rate	1 mR/min to 8 kR/min (1µGy/min to 74 Gy/min)	0.01 R/min to 10 kR/min (0.1 mGy/min to 100 kGy/min)
– Dose	0.01 mR to 700 kR (0.1 µGy to 6 kGy)	0.3 mR to 1.15 MR (3 µGy to 10 kGy)
– Maximum Dose Rate	Same as Dose Rate	Same as Dose Rate
– Auto Dose	6 R/min Threshold	N/A
– Last Dose	Same as Dose	Same as Dose
– Cine Mode	1 µR/f (0.01 µGy/f)	N/A
Accuracy		
– Resolution	1 mR/min (1 µGy/min) and 0.5% or 0.01 mR (0.1 µGy)	0.01 R/min (0.1 mGy/min) and 0.5% or 0.3 mR (3 µGy)
– Energy Dependence	±5%, 40 keV to 1.33 MeV (with build–up cap)	
– Rate Dependence	±2%, 0.6 R/min (6 mGy/min) to 6 kR/min (60 kGy/min) average	
– Calibration Accuracy	±4% after temperature and pressure corrections, using ^{60}Co	
Miscellaneous Specifications		
– Chamber	Fully–guarded; C552 air–equivalent walls and electrode; polyacetal exterior cap; 0.6 cm^3 active volume; unsealed	
– Cable	10–meter, low–noise triax	
– Weight	0.45 kg (conv), 0.28 kg (chbr)	0.48 kg

-0.6 Ion Chamber
Energy Dependence

Specification Limits

(with build-up cap)

Correction Factor vs. Energy (keV)

Center of
Sensitive
Volume

12

3Ø

12Ø

9Ø

21

54

2 MeV
Build-up
Cap

15Ø

16

38
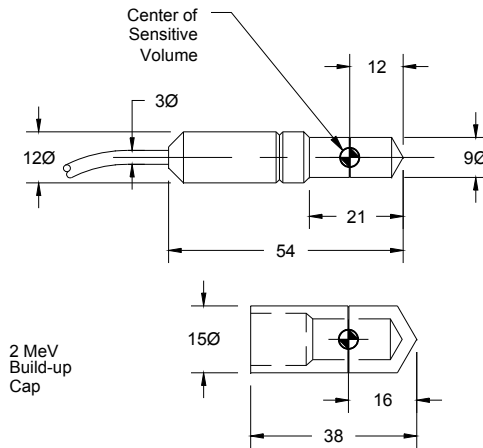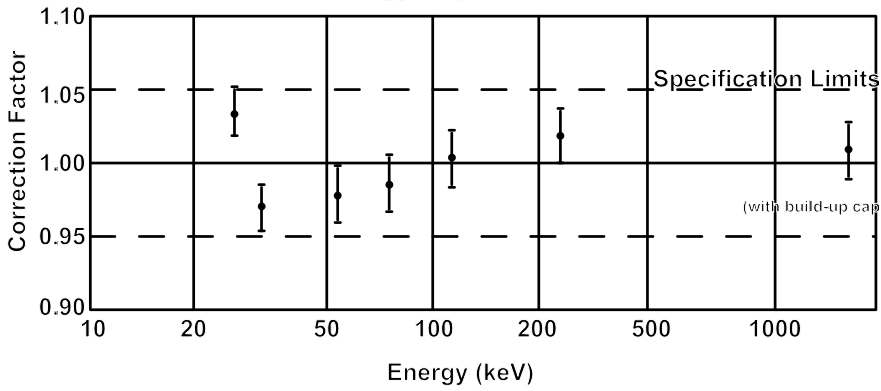
Dimensions in millimeters

3cc Ion Chamber

	20X5–3
Mode	1 mR/min to 1000 R/min (0.01 mGy/min to 9 Gy/min)
– DoseRate	0.03 mRto 115 kR (0.3 µGy to 1kGy)
– Dose	Same as Dose Rate
– Maximum Dose Rate	N/A
– Auto Dose	Same as Dose
– Last Dose	N/A
– Cine Mode	N/A

Measurement Accuracy

– Resolution	1 mR/min (0.01 mGy/min) and 0.5% or 0.03 mR (0.3 µGy)
– Energy Dependence	±5%, 20 keV to 1.33 MeV (with build–up cap)
– Rate Dependence	±5%, .02 R/min (0.2 mGy/min) to 1000 R/min average and up to 500 R/s (5 Gy/s) for 10 ms pulses
– Calibration Accuracy	±4% after temperature and pressure corrections at 150 kVp and 10.2 mm AL HVL

Miscellaneous Specifications

|	
– Chamber	Fully guarded; polycarbonate walls and electrode; conductive graphite interior coating; $3cm^3$ active volume; unsealed
– Weight	0.30 kg

20X5-3

Ion Chamber Energy Dependence

Specification Limits

(with build-up cap)

25

22Ø

Center of
Sensitive
Volume

37

Dimensions in millimeters

3CT Ion Chamber

	9060/10X5–3CT	20X5–3CT
Mode		
– Dose ate	0.1 mR/min to 1.7 kR/min (1 µGy/min to 15 Gy/min)	1 mR/min to 1000 R/min (0.01 mGy/min to 9 Gy/min)
– Dose	1 µR to 140 kR (0.01 µGy to 1.2 kGy)	0.03 mR to 115 kR (0.3 µGy to 1 kGy)
– Maximum Dose Rate	Same as Dose Rate	Same as Dose Rate
– Auto Dose	1200 mR/min threshold	N/A
– Last Dose	Same as Dose	Same as Dose
– Cine Mode	0.1 µR/f (1 nGy/f)	N/A

Accuracy		
– Resolution	0.1 mR/min (1 µGy/min) and 0.5% or 1 µR (0.01 µGy)	1 mR/min (0.01 mGy/min) and 0.5% or 0.03 mR (0.3 µGy)
– Energy Dependence	±5%, 3mm Al to 20mm Al HVL	
– Rate Dependence	±2%, 2 mR/s (0.2 µGy/s) to 40 R/s (300 mGy/s) average	
– Calibration Accuracy	±4% after temperature and pressure corrections, using moderately filtered x–rays at 150 kVp and 10.2mm Al HVL	

Miscellaneous Specifications

– Partial volume and uniformity of response	$\pm$ 5% to within 0.25 cm of chamber ends for constant volume slice	
– Chamber	Fully guarded; 9.1mm dia.; active length 10cm; polyacetal exterior cap; C552 air–equivalent walls and electrode; $3cm^3$ active volume; unsealed	
– Cable	2–meter, low–noise triax	
– Weight	0.45kg (conv), 0.11kg (chbr)	0.30kg

3CT Ion Chamber

Chamber Energy Dependence

HVL (mmAl)
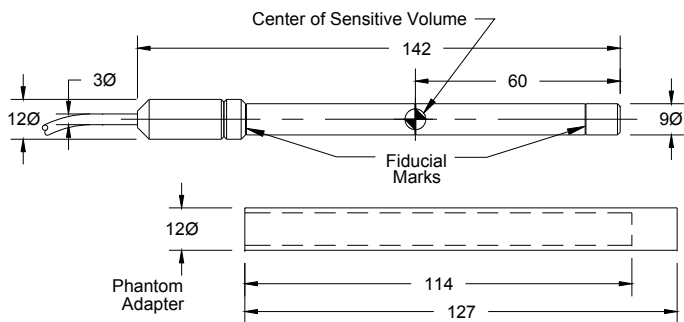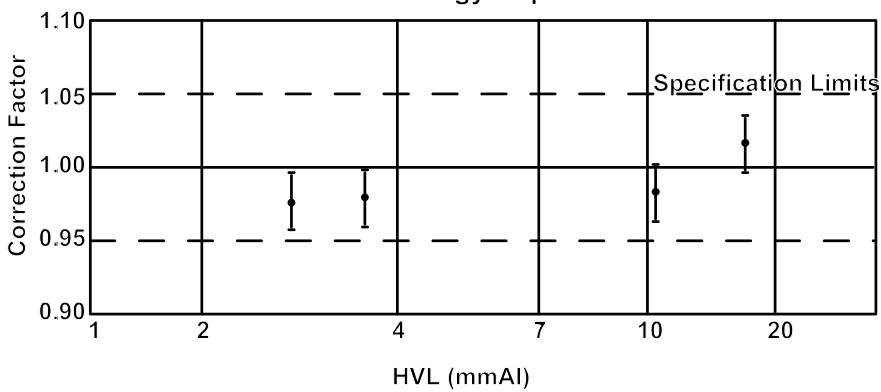
Dimensions in millimeters

6cc Ion Chamber

	9060/10X5–6	20X5–6
Mode		
– DoseRate	0.1 mR/min to 840 R/min (0.1 µGy/min to 7.4 Gy/min)	N/A
– Dose	1 µR to 70 kR (0.01 µGy to 600 Gy)	N/A
– Maximum Dose Rate	Same as Dose Rate	Same as Dose Rate
– Auto Dose	600 mR/min threshold	N/A
– Last Dose	Same as Dose	Same as Dose
– Cine Mode	0.1 µR/f (1 nGy/f)	N/A
Accuracy		
– Resolution	0.1 mR/min (0.1 µGy/ min) and 0.5% or 1 µR (0.01 µGy)	N/A
– Energy Dependence	±5%, 30 keV to 1.33 MeV (with build–up cap)	
– Rate Dependence	±5%, 0.4 mR/s to 80 R/s average and up to 500 R/s for 50 µS pulses	
– Calibration Accuracy	±4% after temperature and pressure correction at 60 kVp and 2.8mm Al HVL	
Miscellaneous Specifications		
– Chamber	Polycarbonate walls and electrode; unsealed;$6cm^3$ active volume	
– Cable	3 meter low–noise triax	
– Weight	0.45kg (conv), 0.05kg (chbr)	N/A

-6 Ion Chamber
Energy Dependence

Correction Factor vs. Energy (keV). Specification Limits at 1.05 and 0.95. (w/build-up cap)

Center of Sensitive Volume

25

25Ø

38
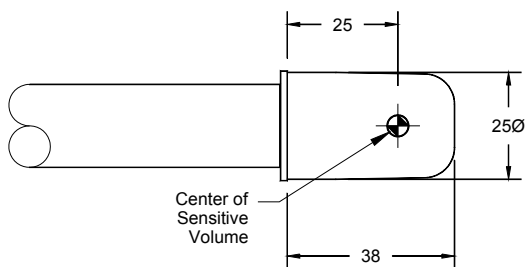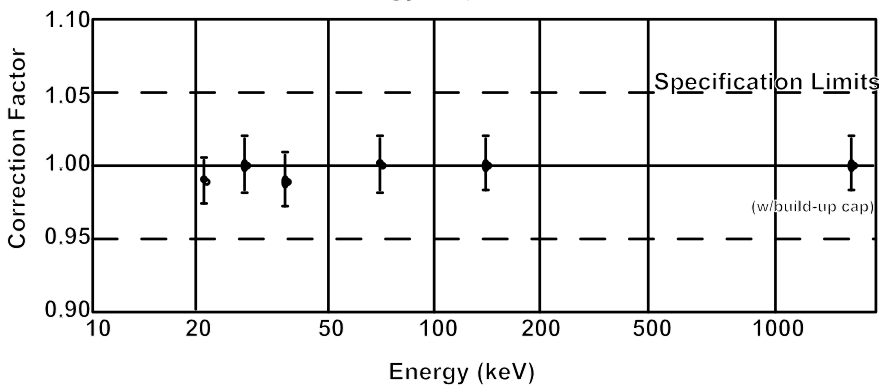
Dimensions in millimeters

6M Ion Chamber

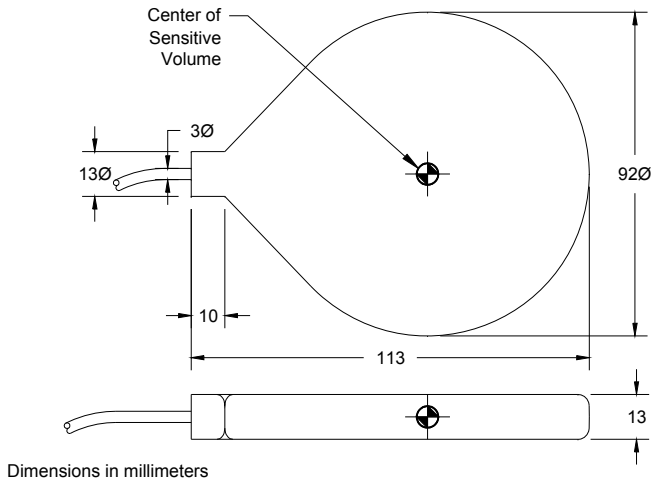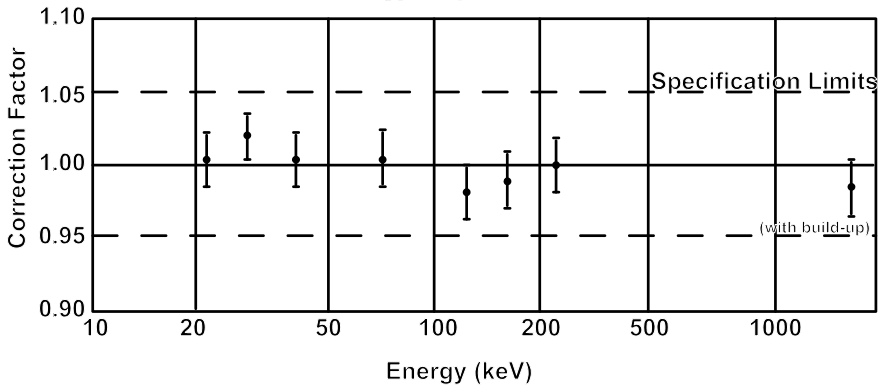|	9060/10X5–6M	20X5–6M
Mode		
– Dose Rate	0.1 mR/min to 840 R/min (0.1 µGy/min to 7.4 Gy/min)	1 mR/min to 1000 R/min (0.01 mGy/min to 9 Gy/min)
– Dose	1 µR to 70 kR (0.01 µGy to 600 Gy)	.03 mR to 115 kR (0.3 µGy to 1 kGy)
– Maximum Dose Rate	Same as Dose Rate	Same as Dose Rate
– Auto Dose	600 mR/min threshold	N/A
– Last Dose	Same as Dose	Same as Dose
– Cine Mode	0.1 µR/f (1 nGy/f)	N/A
Accuracy		
– Resolution	0.1 mR/min (0.1 µGy/min) and 0.5% or 1 m R (0.01 µGy)	1 mR/min (0.01mGy/min) and 0.5% or 0.03 mR (0.3 µGy)
– Energy Dependence	±5%, 10 keV to 40 keV	
– Rate Dependence	±5%, 0.02 R/min (0.2 mGy/min) To 600 R/min (6 Gy/min) average	
– Calibration Accuracy	±4% after temperature and pressure corrections with lightly filtered x–rays at 20 kVp and 0.26mm Al HVL	
Miscellaneous Specifications		
– Chamber	Fully guarded;0.7 mg/cm^2 metallized polyester window; polyacetal exterio; 6cm^3 active volume; unsealed	
– Weight	0.45kg (conv), 0.08kg (chbr)	0.32kg

-6M Ion Chamber
Energy Dependence

Correction Factor vs HVL(mmAl)

Specification Limits

Center of
Sensitive
Volume

44Ø

Volume
Centerline

9

26
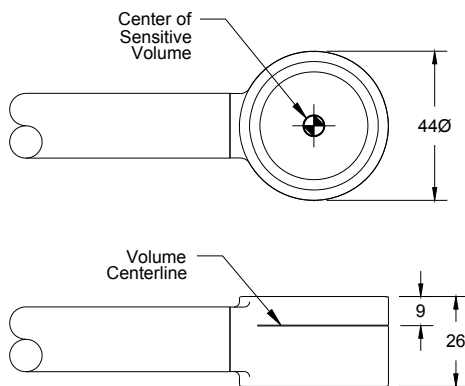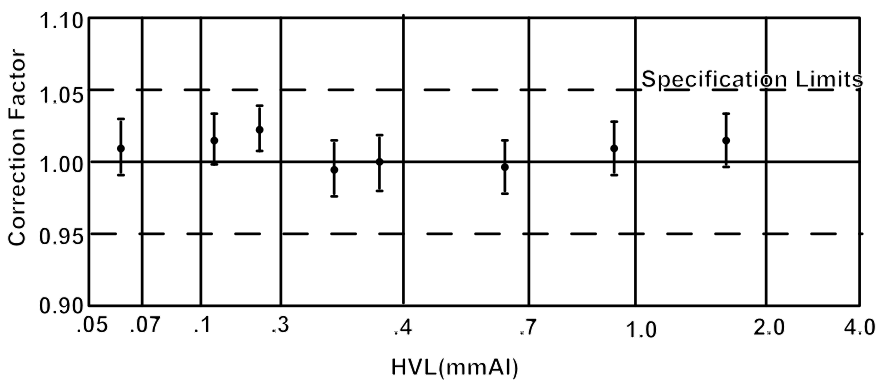
Dimensions in millimeters

60cc Ion Chamber

	9060/10X5–60	20X5 – 60
Mode		
– Dose Rate	0.01 mR/min to 80 R/min (0.01 µGy/min to 730 mGy/min)	0.1 mR/min to 70 R/min (1 µGy/min to 600 mGy/min)
– Dose	0.1 µR to 7 kR (1 nGy to 60 Gy)	3 µR to 11.5 kR (0.03 µGy to 100 Gy)
– Maximum Dose Rate	Same as Dose Rate	Same as Dose Rate
– Auto Dose	60 mR/min threshold	N/A
– Last Dose	Same as Dose	Same as Dose
– Cine Mode	0.01 µR/f (0.1 nGy/f)	N/A

Accuracy		
– Resolution	0.01 mR/min (0.01 µGy/min) and 0.5% or 0.1 mR (1 nGy/f)	0.1 mR/min (1 µGy/min) and 0.5% or 3 µR (0.03 uGy)
– Energy Dependence	±5%, 20 keV to 1.33 MeV (with build–up material)	
– Rate Dependence	±5%, 0.002 R/min (0.02 mGy/min) to 200 R/min (1.8 Gy/min) average	
– Calibration Accuracy	±4% after temperature and pressure corrections at 150 kVp and 10.2 mm Al HVL	

Miscellaneous Specifications

– Chamber	Fully–guarded; polycarbonate walls; conductive graphite exterior coating; 60 cm^3 active volume; .030" wall; unsealed	
– Cable	3 meter, low–noise triax	
– Weight	0.45 kg (conv), 0.13 kg (chbr)	0.32 kg

-60 Ion Chamber
Energy Dependence

Dimensions in millimeters

180cc Ion Chamber

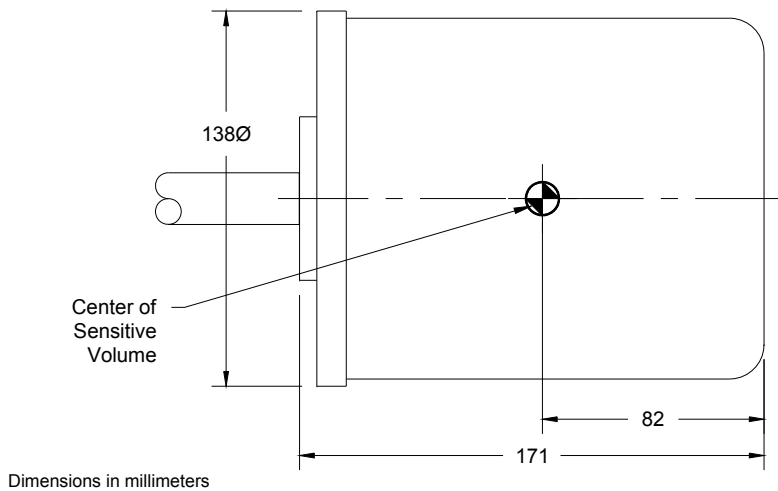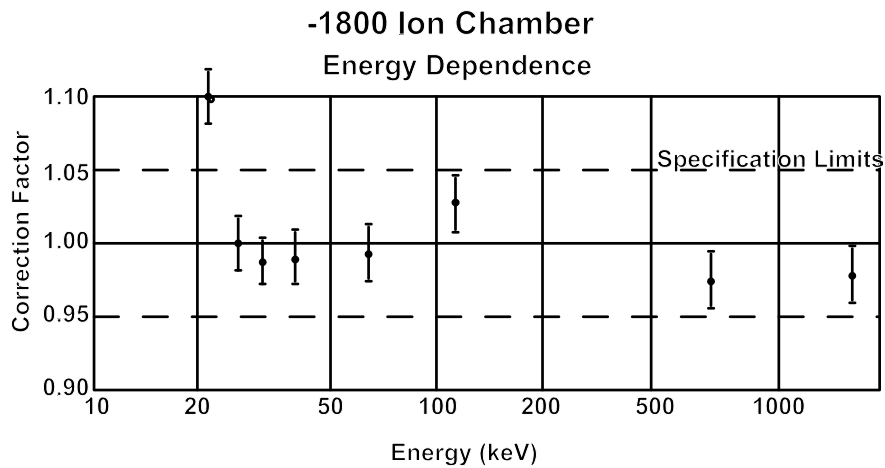|	9060/10X5–180	20X5
Mode		
– Dose Rate	0.1 mR/h to 1.7 kR/h (1 µGy/h to 15 Gy/y)	1 mR/h to 1000 R/h (0.01 mGy/h to 10 Gy/h)
– Dose	0.01 µR to 2.3 kR (0.1 nGy to 20 Gy)	0.6 µR to 2 kR (5 nGy to 17 Gy)
– Maximum Dose Rate	Same as Dose Rate	Same as Dose Rate
– Auto Dose	20 R/min threshold	N/A
– Last Dose	Same as Dose	Same as Dose
– Cine Mode	1 nR/f (0.01 nGy/f)	N/A
Accuracy		
– Resolution	0.1 R/h (1 µGy/h) and 0.5% or 0.01 m R (0.1 nGy)	1 mR/h (0.01 mGy/h) and 0.5% or 0.6 µR (5 nGy)
– Energy Dependence	±5%, 30 keV to 1.33 MeV (with build–up material)	
– Rate Dependence	±5%, 0.02 R/h (0.2 mGy/h) to 2000 R/h (20 Gy/h) average	
– Calibration Accuracy	±4% after temperature and pressure corrections at 150 kVp and 10.2 mm AI HVL	
Miscellaneous Specifications		
– Chamber	Fully–guarded; polycarbonate walls and electrode; conductive graphite exterior coating; 100 cm^2 ; 180^3 active volume; unsealed	
– Weight	0.45 kg (conv), 0.1 kg (chbr)	0.35 kg

-180 Ion Chamber
Energy Dependence
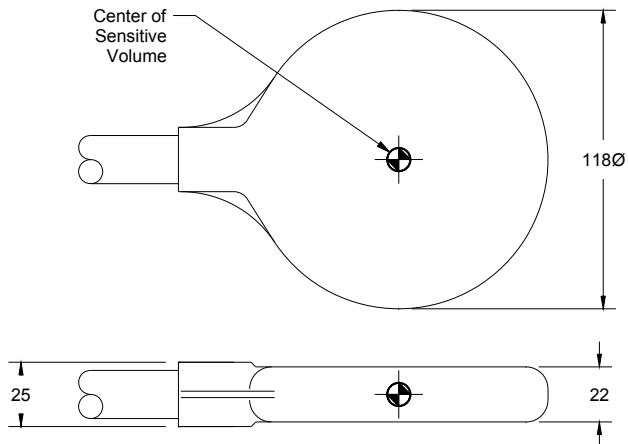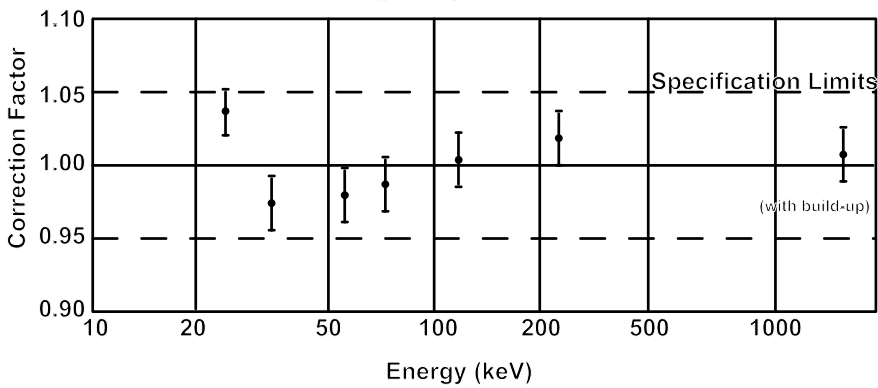
Dimensions in millimeters

1800cc Ion Chamber

	9060/10X5–1800	20X5–1800
Mode		
– Dose Rate	0.01 MR/h to 65 R/h (0.1 µGy/h to 575 mGy/h)	0.1 mR/h to 65 R/h (1 µGy/h to 575 mGy/h)
– Dose	1 nR to 230 R (0.01 nGy to 2 Gy)	0.06 µR to 200 R (0.5 nGy to 1.7 Gy)
– Maximum Dose Rate	Same as Dose Rate	Same as Dose Rate
– Auto Dose	2 mR/min threshold	N/A
– Last Dose	Same as Dose	Same as Dose
– Cine Mode	0.1 nR/f (1 pGy/f)	N/A

Accuracy		
– Resolution	0.01 mR/h (0.1 µGy/h) and 0.5% or 1 nR (0.01 nGy)	0.1 mR/h (1 µGy/h) and 0.5% or 0.06 µR (0.5 nGy)
– Energy Dependence	±5%, 33 keV to 1.33 MeV	
– Rate Dependence	+0, –5%, 0.1 mR/h (0.01 µGy/h) to 20 R/h (200 mGy/h) and –10% to 65 R/h (650 mGy/h) average	
– Calibration Accuracy	±4% after temperature and pressure corrections, using moderately filtered x–rays at 150 kVp and 10.2 mm Al HVL	

Miscellaneous Specifications		
– Chamber	Fully–guarded; polycarbonate walls and electrode; conductive graphite exterior coating; 1800 cm^3 active volume; unsealed	
– Weight	0.45 kg (conv), 0.54 kg (chbr)	0.88 kg

-1800 Ion Chamber
Energy Dependence

Chart: Correction Factor vs Energy (keV) with Specification Limits marked at 0.95 and 1.05.

138Ø

Center of
Sensitive
Volume

82

171

Dimensions in millimeters

Appendix F: Error Messages

When the 9010 Controller displays an error message, "Press Enter to Resume" appears on the top line of the display, with a specific error described on the second line. Once you press ENTER, you will return to the measurement that was being made when the error occurred.

"Temperature Err"
The temperature measurement failed. Retry or use Fixed Temperature.

"Pressure Error"
The pressure measurement failed. Retry or use Fixed Pressure.

"Rate too high"
The dose rate exceeds the chamber or converter limits. Move the chamber away from the source or use a smaller chamber.

"Rate too low"
The dose rate was below the value that Auto Zero can tolerate. Rerun *Auto Zero*. If *Auto Zero* is not active, the converter failed to respond to a test signal.

"Converter Error"
the converter has failed in *Auto Zero.*

"Leakage too high"
The background signal is too high for *Auto Zero* to accept.

"Count overflow"
The total dose accumulated is too large. The 9010 is designed to operate for at least 80 minutes at maximum exposure rate before this occurs.

"Chamber bias low"
The chamber bias voltage didn't come into tolerance. The supply may be overloaded by a faulty chamber.

"Unstable zero"
The converter did not respond to a low–level input. The chamber may have been moved, electrical noise may have coupled in through the chamber, or the system may not have stabilized. Retry the measurement.

"Conv Reset Error"
The converter failed during self-test. Press and hold the Test button and try again.

"LED on Fail"
The converter failed to respond to a large signal during self-test. Press and hold the Test button and try again.

"LED lo Fail"
The converter failed to respond to a small signal during self-test. Press and hold the Test button and try again.

"Unstable zero"
The converter failed to respond to a small signal during self-test. This condition can occur following a dose measurement; it usually clears by itself. If not, press and hold the Test button and try again.

"Conv input minus"
The converter did not respond as to a large signal during reset. If it persists, press and hold the Test button and try again.

Other errors not on this list generally mean that the Controller has mal–functioned. Please make a note of the circumstances that result in the error, record the exact contents of the display, and contact Radcal.

Appendix G: Using XLPRO

XLPRO is a microsoft Excel addin that allows using the computational and display capabilities of Excel to record, analyze and display 9010 measurement results on a PC. It uses the RS-232 serial port to control and read out the 9010. See the XLPRO documentation for details.. These notes apply to version 3.15 or higher of the spreadsheet add–on.

- Set the 9010 baud rate to 19,200.
- Connect the serial cable between the computer and the 9010.
- Start XLPRO and attempt to make a measurement, Dose Rate for example. If a 'Com Port unavailable' message appears when you attempt to make a measurement, it is likely that the incorrect com port is selected.
- Enter the XLPRO settings area (CTRL+Shift+S) and set the COM port to 'Search' (COM0).
- When a measurement command is executed and the COM port is set to 'Search' XLPRO will scan the computer serial ports starting with Com 1 until it finds one that responds correctly to the command "RESET". It takes about ½ second per port to perform this check, so it may take an appreciable time if the designation for the serial port is 10 or 20, as is common with USB-adapter ports.
- Once the com port is identified it is written into the settings area.
- XLPRO issues a "RESET" command to place the 9010 in a known operating state. This sets the dose calculations to use 22C and 101.3kPa and disables Setup mode. It reads the temperature (and pressure if available) and can use these values to correct readings. Because the display is using fixed temperature and pressure, the display value on the 9010 and the corrected value in XLPRO may not agree.
- After using XLPRO, you may need to cycle power on the 9010 to return to normal manual operation.

Declaration of Conformity
According to ISO/IEC Guide 22 and EN 45014

The Radcal Corporation declares, under our sole responsibility, that the **model 9010** X-Ray system conforms to the following product specifications.

EMC: CISPR 11, EN 55011, Class A
  EN61000–4–2, EN50082–2, 6 kVCD, 8 kV AD
  EN61000–4–4, EN50082–2, 1 kV
  ENV50140/ENV50204, EN50082–1, 3 V/m
  EN61000–4–8, EN50082–2, 30 A/m

QA Manager
Date: 2 November 1999

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