Initial Operator Training for the RS-2000 X-Ray Irradiator

This training module is intended to provide initial radiation safety training for individuals who wish to use the Rad Source RS-2000 X-Ray irradiator at the University of Nebraska Medical Center (UNMC). There are two RS-2000 irradiators on campus, one in the Animal Facility of DRC II and the other in DRC II 5015. While both irradiators are identical, the primary use of the Animal Facility irradiator is to irradiate small animals (and will be referred to as the "Animal Irradiator") while the unit in 5015 is intended for cell culture irradiation and will be referred to as the "Cell Irradiator".

The following topics will be discussed in this training;

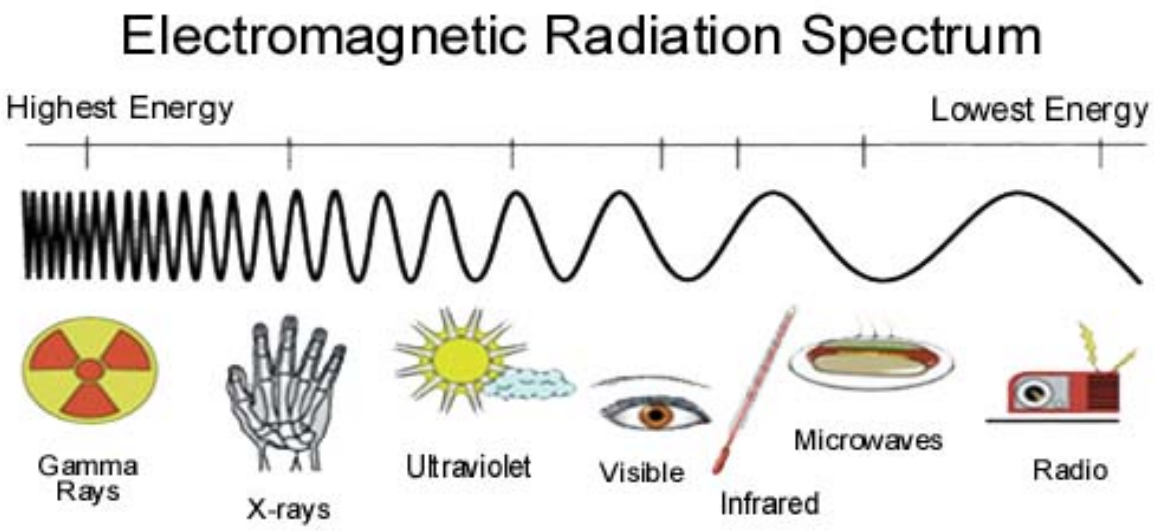
- What are Ionizing Radiation and X-rays?
- How are X-rays produced?
- Radiation Dose
- Health Effects & Regulatory Dose Limit
- General Hazards Associated with the X-Ray Irradiator
- Safety Instructions Regarding the RS-2000 Irradiator
- Operating Instructions for the RS-2000 Irradiator

More complete and detailed information regarding the RS-2000 can be found in the RS-2000 Owner's Manual (one manual in each of the irradiator rooms) or by going to the Rad Source website (www.radsource.com).

In addition, this training material, the Dose Chart for each irradiator scheduling use of either irradiator, and other pertinent information is available on the Biological Irradiator Core website at www.bic.unmc.edu.

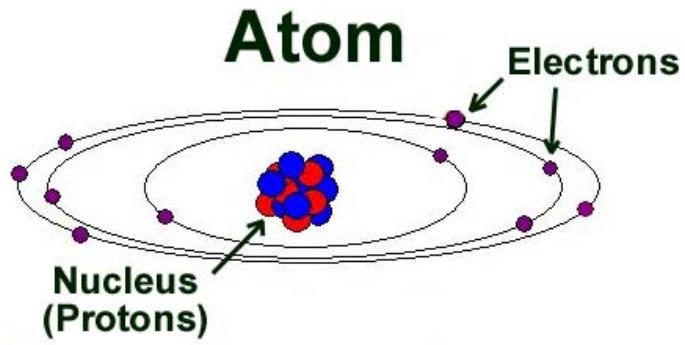
What are X-rays & Ionizing Radiation?

Everyone knows that x-rays are a type of radiation, but what exactly is radiation? Radiation is simply energy in motion. As you look at the figure below, there are many types of radiation that you are already familiar with:

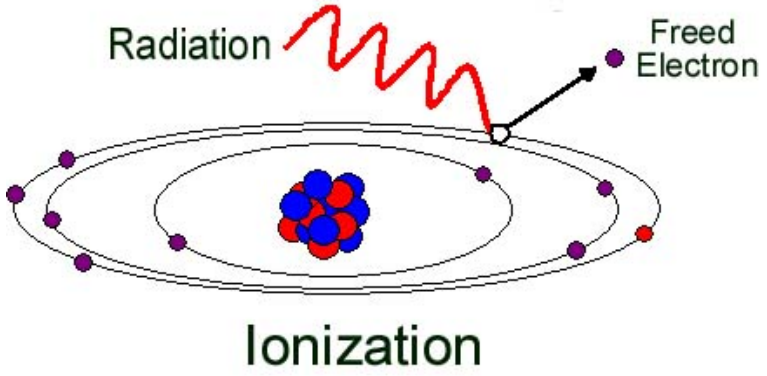


While all these types of radiation have many traits in common (e.g., all travel at the speed of light) only x-rays and gamma rays have enough energy to cause **ionization** when they interact with the body. So our next question is "What is ionization and why is it a concern?"

All matter is made up of atoms. Atoms contain a small central nucleus containing protons, which have electrically positive charges. Orbiting the nucleus are electrons which are small particles with electrically negative charges. In a neutral atom the number of positive (+) and negative (-) charges are equal (see the figure below).

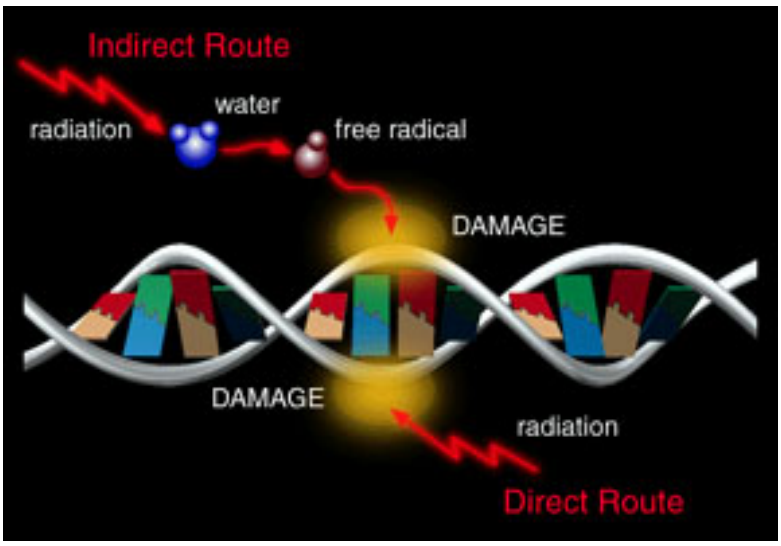


When an x-ray or gamma ray is traveling through the human body, it will sometimes interact with an orbital electron of an atom. During the interaction the radiation can impart enough energy to the electron to "free" it from the atom. The atom now has one less electron, which results in the atom having more positive than negative charges. An atom that does not have the same number of positive & negative charges is called an **ion**. The process of ionization is illustrated below;



Ionization

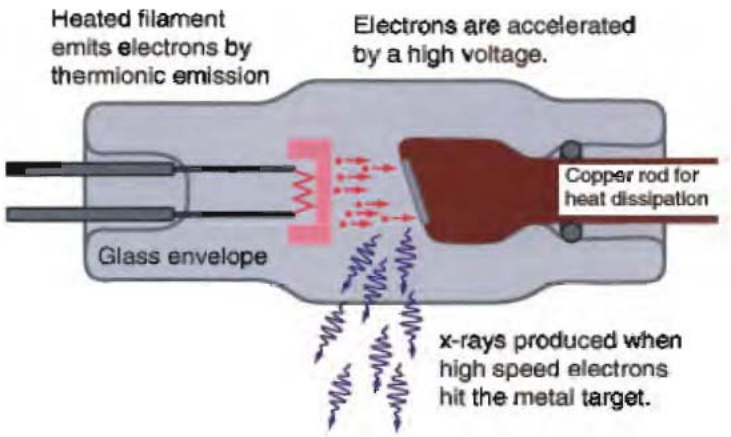
This "freed" electron can potentially cause damage to living cells or DNA. The damage can be repaired from small amounts of radiation, however if enough radiation is imparted, biological damage can occur. The biological damage can include the death of the cell, mutation of the DNA, or preventing the cell from reproducing.



How are X-rays Produced?

Most irradiators traditionally use a radioactive substance which continuously gives off gamma radiation. The RS-2000 uses an x-ray tube to produce x-rays as its ionizing radiation source. It should be noted that the only thing that differs between an x-ray and gamma ray is where they were originated (x-rays are produced outside the nucleus, gamma rays originate inside the nucleus), otherwise you can't tell the difference between either.

Like the x-ray machine used to take x-rays on patients, the RS-2000 irradiator uses an x-ray tube to generate x-rays (see picture below). Basically, what happens is that a metal filament is heated up to a very high temperature allowing electrons from the metal to essentially "boil" off. Electrons, the small negatively charged particles orbiting the nucleus, are then accelerated across the glass tube to a positively charged anode. While the majority of the electrons collide with the metal anode and generate heat, some of the electrons lose their energy in the form of x-rays.



An important distinction that should be made between traditional irradiators that use a radioactive source and the RS-2000 unit which uses an x-ray tube is that no radiation is produced in the x-ray tube when the power is off (while the radioactive source continuously gives off radiation).

Radiation Dose

When x-rays interact with the specimen being irradiated, the radiation interacts with orbital electrons of the atoms and radiation (energy) is deposited. The amount of radiation deposited is called the **radiation dose** (or simply "**dose**") and is measured in either **rad** or **Gray (Gy)**. A Gray is 100 times greater than a rad. For the specimens being irradiated in the RS-2000 the dose typically ranges from a few Gray to tens of Gray.

The rate at which the radiation is delivered is the **dose rate** and is in either in units of **rad/hr** or **Gray/hr** (**Gy/hr**). A Gray/hr is 100 times greater than a rad/hr. In the RS-2000 the dose rate used is highly dependent upon how close the specimen is to the x-ray tube, but will vary from around 1.2 to almost 9 Gy/minute.

The next question you might ask is "How much radiation will I receive from handling irradiated specimens and from using this irradiator?". As for handling irradiated specimens, they do **NOT** become radioactive after an irradiation and you will not receive any radiation from handling irradiated these specimens.

As for using (or being near) the irradiator, the unit is heavily shielded and minimal radiation is given off outside the unit. In addition, an interlock system will shut off the x-ray tube if the door to the RS-2000 is opened. Therefore, you should expect virtually NO radiation exposure from using the RS-2000 and therefore, individuals using the unit are NOT required to wear radiation badges to monitor exposure (**NOTE: If the interlock system is somehow defeated or if the shielding is removed, individuals could receive DANGEROUS radiation doses**).

Radiation Dose ("Dose") measured in rad or Gray (Gy)

100 rad = 1 Gy

Dose Rate measured in rad/hr or Gy/hr

100 rad/hr = 1 Gy/hr

Irradiated specimens do NOT give off radiation

Radiation levels outside the RS-2000 are minimal

Warnings, Precautions Using the RS-2000

Radiation Exposure

As previously discussed, radiation exposure should be minimal unless the unit itself is compromised. Examples of unsafe conditions which could result in potentially dangerous radiation levels include;

- Door interlock to the RS-2000 does not work
- Shielding has been damaged
- Evidence of machine tampering

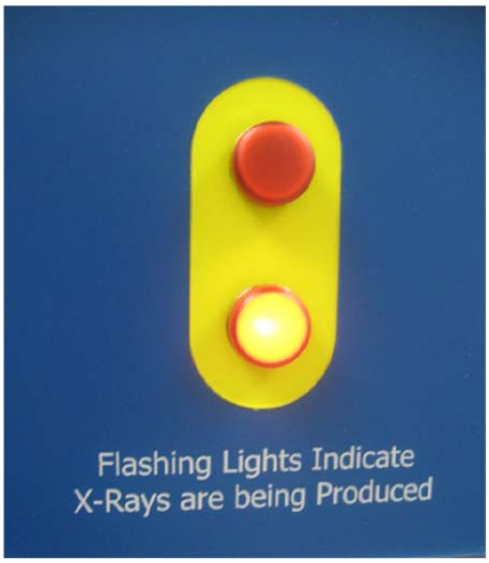
IF UNSAFE CONDTIONS ARISE WITH THE RS-2000:

1. **Stop Work!**
2. **Turn power off**
3. **Notify Radiation Safety IMMEDIATELY (ext. 9-6356)**

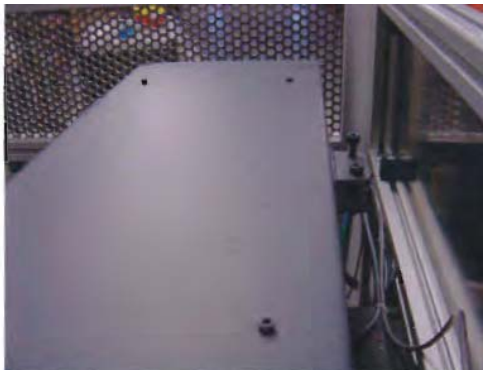
Other Precautions

- Another serious hazard from an x-ray device is electrical shock. The x-ray generator is a highly regulated DC power supply that applies a voltage of 160 kilovolts.
- No unauthorized personnel may defeat or override any safety features on the x-ray generator, collimator, or shielding, without permission of the manufacturer (Rad Source). The RS-2000 is to be serviced by trained personnel only.
- Please keep unit dry. When cleaning do not allow cleaners or water to drip into panels or chamber. Use only a damp cloth with mild soaps for cleaning.
- Do not use the top of the unit as a storage area. Do not place any heavy items or items containing liquids or materials that may harm the unit if they leaked or spilled on top or inside.
- **The x-ray tube can be damaged if power is shut off immediately following an irradiation. After the irradiation is completed, wait 5 minutes before turning the unit off.**

Integrated Safety Features



Flashing X-ray Indication Lights, show when X-rays are being produced



Shielded and Interlocked X-Ray Tube Chamber, to prevent X-ray production if panel should be opened

Door Handle Double Safety Interlocked to prevent X-ray production while door is unlatched

How to Use the RS-2000

In this section the basic operation of the RS-2000 will be discussed. The procedure for basic operation is posted on the unit and is also provided at the end of this section.

WARNING

Any use of the RS-2000 not for its intended use may result in an unsafe condition. Do NOT insert any flammable or potentially explosive materials into the unit, or apply toxic or corrosive chemicals.

If you have any questions about its use, please refer to the Operating Manual (located in irradiator room) or contact Rad Source Technologies.

Getting Started/Prerequisites

1. To use the RS-2000 an individual complete initial training which consists of completing this training module and perform a hands-on irradiation with Radiation Safety (contact Radiation Safety at ext. 9-6356 to set up a time).

2. Irradiations using RS-2000 must be reserved and are scheduled using the Research Support System (RSS);

   RSS→Core Facilities → Instrument Schedules→ Biological Irradiator Core

   Note 1: You can schedule use on the biological irradiator core (BIC) website at www.bic.unmc.edu which provides a link to the RSS.

   Note 2: For the Animal Irradiator reservations are for 1 hour sessions.

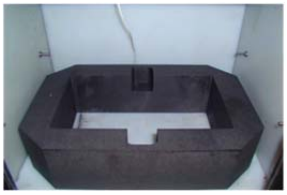
3. Cell Irradiator BSC Use: If you need to use the biosafety cabinet or CO_2 incubators in this room you need to fill out the request form and submit to the facility supervisor (Dr. Mayumi Naramura). Please note that users must provide their own consumables (cultureware, culture medium, etc.) and dispose of them appropriately. Any items left in the room without authorization may be removed at the discretion of the facility supervisor.

4. Animal Irradiator Use:
   Note: Irradiator use must be approved on your IACUC protocol.
   a. Must wear PPE (gloves and lab coat).
   b. Must NEVER leave animals unattended in this room.
   c. Animal cages must be opened within the Biosafety Cabinet (BSC).
      i. Transfer animals into a sterilized Allentown Cage without bedding, food, or water.
      ii. A maximum of five (5) mice per cage is recommended for accurate results.
      iii. Transfer animals back to their home cages immediately after irradiation treatment.
      iv. Target irradiation shields are stored in a sterile cage within the biosafety cabinet. In an effort to prevent potential contamination of your animals, please dip the shield in Clidox before and after use. When you are finished, please spray the shield with 70% ETOH and leave it in the biosafety cabinet to dry.
      v. Prepare and anesthetize the animal inside the biosafety cabinet, position the animal and shield inside the Allentown cage. Place the cage at the appropriate level inside the irradiator. Do not place mice directly onto the stage in the irradiator.


Target Radiation Shields

Performing an Irradiation

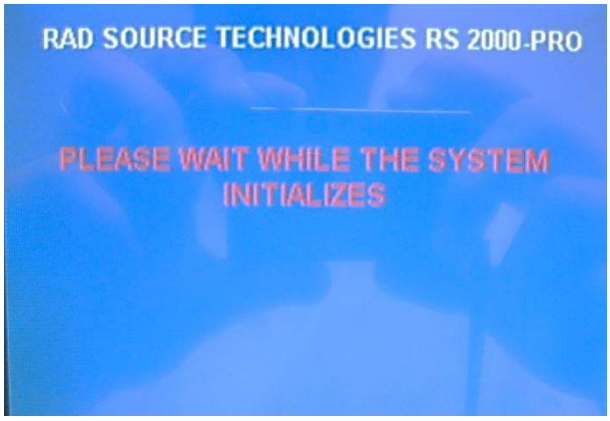
1. When you open up the chamber door there should be a **RAD+** reflector block (see picture) which is used to produce a more uniform dose distribution within the block. Do NOT remove this block unless cleaning is required.


RAD+ Reflector

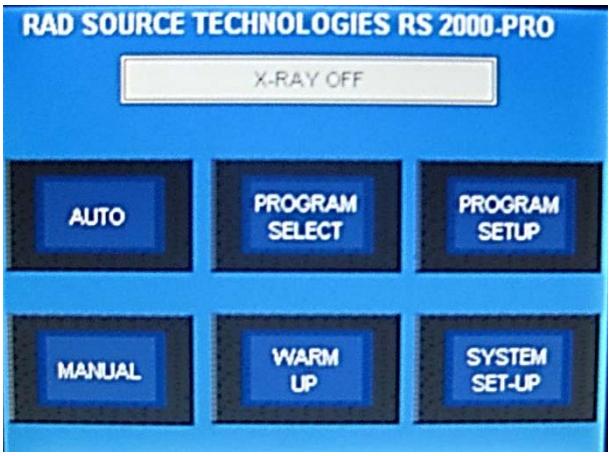
2. To prepare for operation, close the front door and turn the handle clockwise until fully engaged (unit will not operate if not properly closed).

3. Use the key to turn the power on/off switch to on (the key to power on the unit should already be in the unit and should remain inserted).

The Operator Touch Panel Control Screen will illuminate, control power is applied to the high voltage power supply and the following screen should be displayed:



After approximately 30 seconds, the system is initialized and the main menu, shown below, is displayed (Note: if at any time after the system is initialized a fault is detected the ALARM SCREEN will be displayed).



Main Menu

The main menu enables the operator to access all the features of the RS-2000. The white rectangular system status box is used to display the machine status. Possible machine statuses include:

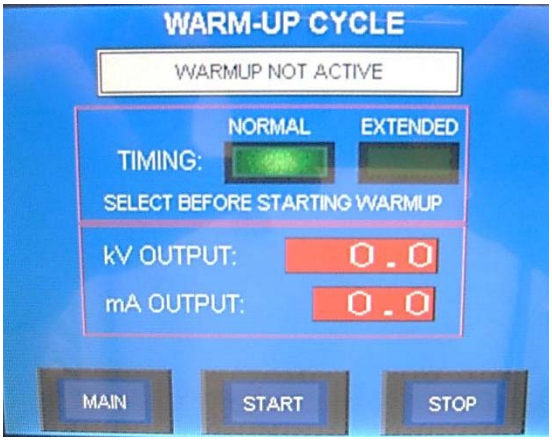
- WARMUP REQUIRED
- WARMUP IN PROGRESS
- X-RAY ON
- X-RAY OFF

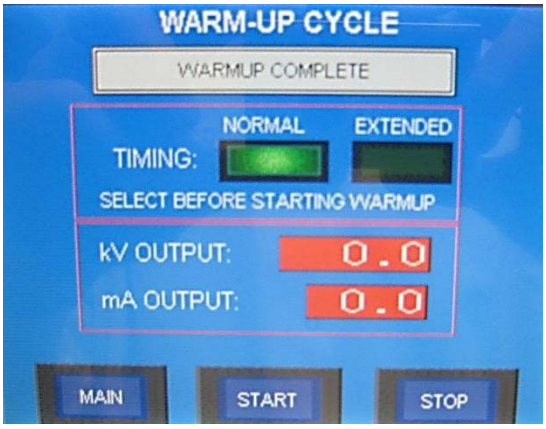
The WARMUP cycle will be discussed in the next section.

Warm-Up Cycle

When you first power on the unit, the x-ray tube may or may not need to be properly warmed up (a warm-up is required every 40 hours). If the x-ray tube needs to be warmed up the system status box will say **WARMUP REQUIRED**. **It is important to perform the warmup message appears.** If the tube doesn't need to be warmed up, the status box will say X-RAY OFF. To initiate a warm-up;

1. Press Warm Up on the main menu
2. The WARM-UP CYCLE menu will appear (see figure at the right).
3. There are two pre-programmed warm-up cycles labeled NORMAL and EXTENDED. Unless you know that the unit hasn't been used for a couple of months, select NORMAL
4. Press START (at the bottom of the screen).
5. The message in the system status box will indicate WARMUP IN PROGRESS. The flashing indicator lights on the unit will flash on and off indicating that x-rays are being produced.
6. After the warmup is completed (the NORMAL warm-up cycle takes approximately 10 minutes), that system status block will indicate **WARMUP COMPLETE**. Press MAIN to take you back to the main menu. You are now ready to perform an irradiation which is discussed in the next section.





Determining Irradiation Time

Levels inside the Chamber

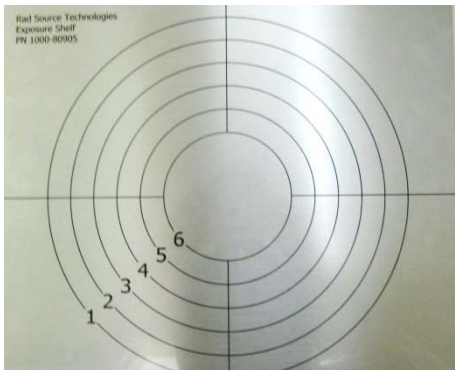
Before performing an irradiation, you obviously need to first determine how long to irradiate, which corresponds to what level inside the irradiator chamber you will be placing the specimens. So what do we mean by levels?

If you open the door and look inside the irradiation chamber of the RS-2000 you will see various levels indicated along each side. Although you can't see it, because the **RAD+** reflector is covering it, the bottom level is labeled "1". The levels increase in number as you go up higher in the chamber (although not labeled, the level above 5 is level 6).

Because the x-ray tube is located above the chamber in the RS-2000, the higher numbered levels correspond to higher dose rates (& shorter irradiation times).

Animals:
Small animals must be placed in a filtered cage filtered cage and are typically irradiated on Level 1 (i.e., within the black **RAD+** reflective chamber on the floor of the chamber).

Non-Animals (e.g., cells, well plates, flasks):
These specimens are typically irradiated on Levels 3, 4, 5, or 6 using the Aluminum Specimen Shelf ("shelf plate").



Aluminum Specimen Shelf

A couple of points regarding using levels and the shelf-plate:

- To ensure relative dose uniformity; if you are using the shelf plate, the specimen(s) should fit within the circular area of the level you are irradiating at (85% dose uniformity within the circle). For the animal cage inside the **RAD+** reflector block, the uniformity is 95%.
- The radiation dose rate is highly dependent upon the distance from the radiation source (x-ray tube). Therefore, for certain specimens (e.g., test tube) you may achieve more uniform irradiation by laying it horizontal.

- Although Level 6 provides the highest dose rate, caution should be used at this level since it is close to the x-ray tube and the dose rate can vary if the specimen is not small.

The dose rates and corresponding irradiation times are given on a “Dose Chart” which is posted on the side of each irradiator. An example is shown below:

RAD SOURCE RS 2000 X-RAY IRRADIATOR DOSE CHART

UNMC Animal Facility (SN 3196) Machine Settings: 160 KV 25mA 0.3 mm Cu

LEVEL 1
Dose Rate: 1.2 Gy/min (Inside the RAD+)

rad	Gray	Min	Sec
200	2.0	1	40
250	2.5	2	5
300	3.0	2	30
350	3.5	2	55
400	4.0	3	20
450	4.5	3	45
500	5.0	4	10
550	5.5	4	35
600	6.0	5	0
650	6.5	5	25
700	7.0	5	50
750	7.5	6	15
800	8.0	6	40
850	8.5	7	5
900	9.0	7	30
950	9.5	7	55
1000	10.0	8	20
1050	10.5	8	45
1100	11.0	9	10
1150	11.5	9	35
1200	12.0	10	0
1250	12.5	10	25
1300	13.0	10	50
1350	13.5	11	15
1400	14.0	11	40
1450	14.5	12	5
1500	15.0	12	30

LEVEL 3
Dose Rate: 2.0 Gy/min

rad	Gray	Min	Sec
200	2.0	1	0
250	2.5	1	15
300	3.0	1	30
350	3.5	1	45
400	4.0	2	0
450	4.5	2	15
500	5.0	2	30
550	5.5	2	45
600	6.0	3	0
650	6.5	3	15
700	7.0	3	30
750	7.5	3	45
800	8.0	4	0
850	8.5	4	15
900	9.0	4	30
950	9.5	4	45
1000	10.0	5	0
1500	15.0	7	30
2000	20.0	10	0
2500	25.0	12	30
3000	30.0	15	0
3500	35.0	17	30
4000	40.0	20	0
4500	45.0	22	30
5000	50.0	25	0
5500	55.0	27	30
6000	60.0	30	0
6500	65.0	32	30
7000	70.0	35	0
7500	75.0	37	30
8000	80.0	40	0
8500	85.0	42	30
9000	90.0	45	0
9500	95.0	47	30
10000	100.0	50	0

LEVEL 4
Dose Rate: 2.9 Gy/min

rad	Gray	Min	Sec
200	2.0	0	41
250	2.5	0	52
300	3.0	1	2
350	3.5	1	12
400	4.0	1	23
450	4.5	1	33
500	5.0	1	43
550	5.5	1	54
600	6.0	2	4
650	6.5	2	14
700	7.0	2	25
750	7.5	2	35
800	8.0	2	46
850	8.5	2	56
900	9.0	3	6
950	9.5	3	17
1000	10.0	3	27

LEVEL 5
Dose Rate: 4.5 Gy/min

rad	Gray	Min	Sec
2000	20.0	4	27
2500	25.0	5	33
3000	30.0	6	40
3500	35.0	7	47
4000	40.0	8	53
4500	45.0	10	0
5000	50.0	11	7
5500	55.0	12	13
6000	60.0	13	20
6500	65.0	14	27
7000	70.0	15	33
7500	75.0	16	40
8000	80.0	17	47
8500	85.0	18	53
9000	90.0	20	0
9500	95.0	21	7
10000	100.0	22	13

LEVEL 6
Dose Rate: 8.5 Gy/min
NOTE: ESTIMATED DOSE RATE

rad	Gray	Min	Sec
2000	20.0	2	21
2500	25.0	2	56
3000	30.0	3	32
3500	35.0	4	7
4000	40.0	4	42
4500	45.0	5	18
5000	50.0	5	53
5500	55.0	6	28
6000	60.0	7	4
6500	65.0	7	39
7000	70.0	8	14
7500	75.0	8	49
8000	80.0	9	25
8500	85.0	10	0
9000	90.0	10	35
9500	95.0	11	11
10000	100.0	11	46

For Doses NOT Listed in the Above Tables

Divide the desired dose (Gy) by Dose Rate for the Level being used to get the minutes of irradiation needed.

Convert irradiation time into minutes and seconds

EXAMPLE:
Your target dose is 45 Gy using Level 3

Dose rate for Level 3 = 2 Gy/min

Irradiation time = 45 Gy ÷ 2 Gy/min = 22.5 minutes

Convert to minutes & seconds format (multiply the decimal remainder by 60 to get seconds) - for this example 0.5 minutes = 0.5 X 60 = 30 sec

Irradiation Time (min sec) = 22 minutes 30 seconds

In most cases, the Dose Chart will provide the irradiation time needed. However, if a dose is not provided you can use the dose rate to calculate the irradiation time, as shown in the example below:

Example: Calculating Irradiation Time If Dose is NOT listed on Dose Chart

Suppose you wish to give a specimen a dose of 3.7 Gy on Level 3. Looking at the Dose Chart, the dose rate at Level 3 is 2.0 Gy/minute. Dividing dose by the dose rate (3.7 ÷ 2) gives a total irradiation time of 1.85 minutes.

Because the RS-2000 requires minutes, seconds input, the 0.85 must be converted to seconds by multiplying by 60 which converts to 51 seconds.

Therefore, 3.7 Gy on Level 3 corresponds to an irradiation time of 1 minute 51 sec

Once you have determined the irradiation time you are ready to enter in the time and perform the irradiation as follows:

1. Place the specimen in the chamber. For small animals, place the HEPA filtered cage within the **RAD+** block. For non-animal specimens, place the shelf plate at the level desired and place the specimen on the plate.

Animal cage placed in RAD+

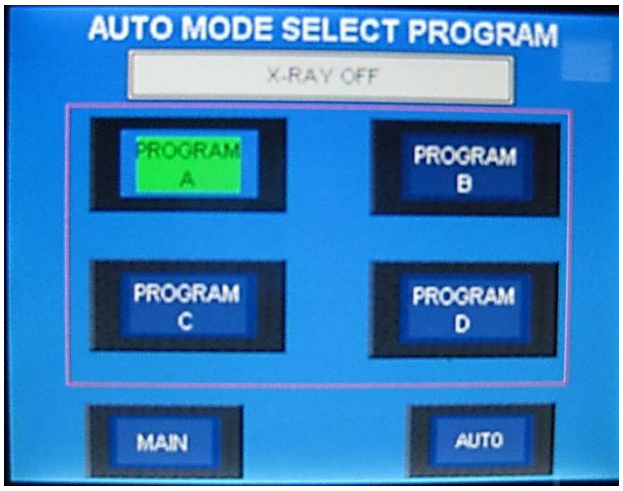
2. On the Main Menu you will select PROGRAM SETUP if you have not already programmed an irradiation time in for one programs (A, B, C, or D). If you have already programmed in an irradiation time go to Step 3.

   After selecting PROGRAM SETUP, the following screen (AUTO PROGRAM SETUP) will appear (Programs C and D can be seen by pressing NEXT);

Keypad; ESC = Escape
ENT = Enter

   For the Program you wish to program an irradiation time for, press MIN or SEC and a keypad will appear on the display which allows entry of the irradiation time. Once the time has been entered, press MAIN to return to the main menu.

3. On the Main Menu, choose PROGRAM SELECT and the following window will appear:



4. Select the program (A, B, C, or D) you wish to run and then press AUTO.

5. Press START and the irradiation will begin (flashing lights on the front of the irradiator will flash on and off indicating that x-rays are being produced).

6. After the irradiation is completed, open chamber and remove specimen.

IMPORTANT NOTE: After the last irradiation has been completed, wait 5 minutes before turning the key to the OFF position. This is an extremely important step to ensure that the tube cools down properly (the tube costs $25,000 to replace).

7. Complete the User's Log (located in the room) to document your irradiator usage.
8. Post Procedure Cleaning: After you have completed using irradiator, perform the following;
    a. Irradiator: Spray a paper towel with Clidox solution and wipe the inside of the irradiator chamber including the shelf plate (if used). Repeat with 70% ETOH.
    b. Biosafety Cabinet: If the BSC is used spray and wipe down all surfaces inside the BSC. Repeat with 70% ETOH.
    c. Please dispose of all debris and waste in the waste basket provided.

d. Allentown Caging must be left on a cage return cart by the exit. Comparative Medicine will wash, sterilize and return cages to the irradiator room for the next user.

e. For the Animal Irradiator, Comparative Medicine will provide routine room sanitation. Additional room cleaning may result in additional charges.

As indicated earlier, the procedure for basic operation of the RS-2000 is posted on the door of each of the irradiators.

Irradiator Use Charge will be billed at the end of each month.

Faults & Possible Causes

If during normal operation of the machine a fault condition is detected an ALARM SCREEN will be displayed. Please contact Radiation Safety immediately if a fault or alarm is indicated. Table 3 in the operating manual lists possible faults and the corrective actions for the RS-2000.

Other Pertinent Information

On the Rad Source website (www.radsource.com) information pertaining to the RS-2000 irradiator can be found. The website also provides contact information should you wish to contact a technical representative directly.

This concludes the Initial Operator Training for the RS-2000 X-Ray Irradiator. After successful completion of the test, contact Radiation Safety to set up a practical training session operating the unit.