Creative Electron, Inc.

Technology | Performance | Value

TruView

User's Manual

TruView User's Manual

Version 7

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Welcome to TruView!

T ruView is a compact x-ray inspection system equipped with high resolution imaging, large board capacity, and a user friendly design for hardware inspection applications (as seen in Figure 1). The state of the art software, originally designed for the Department of Homeland Security, sets TruView apart from the competition. TruView's unique three-monitor system allows for rapid analysis and simultaneous viewing of both x-ray and live feeds. Ideal for counterfeit component detection, TruView® can easily identify shorts or bridges, find open or missing registration, catch contaminants and recognize tampering attempts. Either bench-top or cart mounted, the transportable design allows mobile X-ray capability wherever necessary. TruView's powerful image processing and database software enables expedient and real-time determination of potential problems with the device being inspected.

Figure 1 – Photograph of the TruView Inspection System

TruView is a self-contained and complete x-ray inspection system that includes hardware and software. The TruView software comes pre-installed in the PC that is shipped with the equipment. This software runs on a Windows operational system. The system has a standard Windows installation, so it can easily be integrated into the user's network. Current antivirus software should be kept in the PC at all times. It is also important to keep up with regular Microsoft updates.

Installation Guide

Unpacking TruView

TruView is shipped in a custom 4'x4'x4' wooden crate. First remove the front wall of the crate to access TruView. The front wall is screwed to the crate for easy removal. The crate should not be tipped over. Please follow the instructions on the box to assure the correct storage of the unit. We recommend keeping the crate and shipping materials for future transportation of the equipment.

The following items are shipped with TruView:

1. 1x Cabinet with x-ray source and camera

2. 1x PC with preinstalled TruView software

3. 1x Shelf Assembly with Keyboard/Mouse Combo

4. 3x 19" LCD monitors

5. 1x User's manual

6. 1x TruView Cart (optional)

7. 1x R2R/Conveyor System (optional)

Assembling Monitors on Stands

The three 19" LCD monitors are shipped in the same crate with the TruView device. To attach the monitors onto the vertical stands on the back of TruView please insert the screws on the positions shown by the arrows in Figure 2.
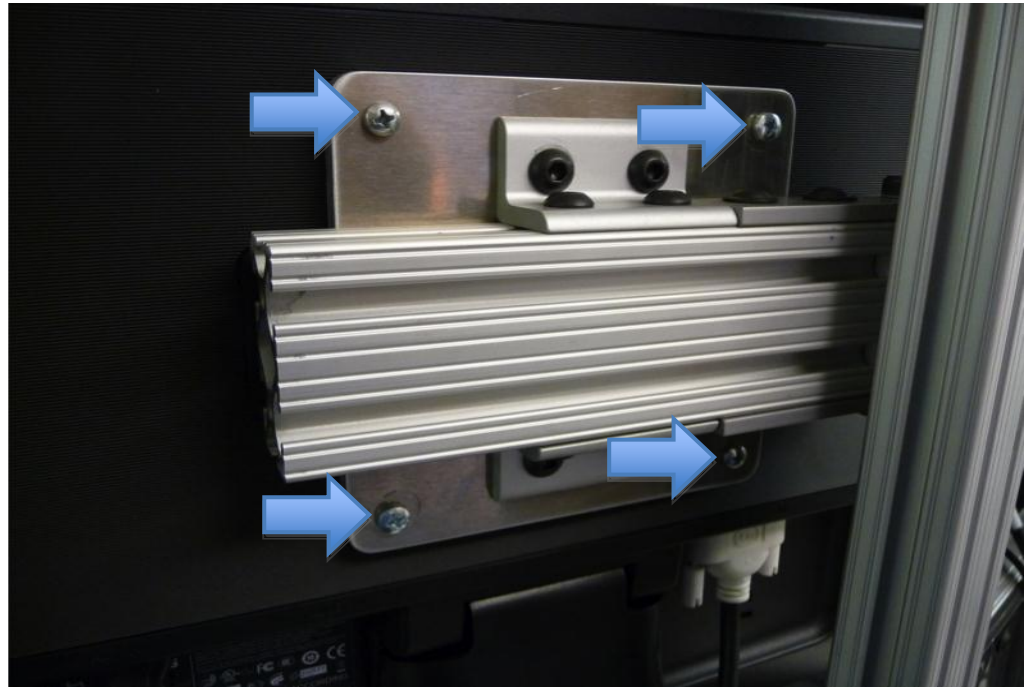
Figure 2 – Assembly of 19" LCD monitors onto vertical stands

Connecting Power and Data Cables

The connection of the monitor cables is shown in Figure 3. Please follow the numbering code from the PC and Figure 3 to assure that the monitors are connected in the correct sequence.
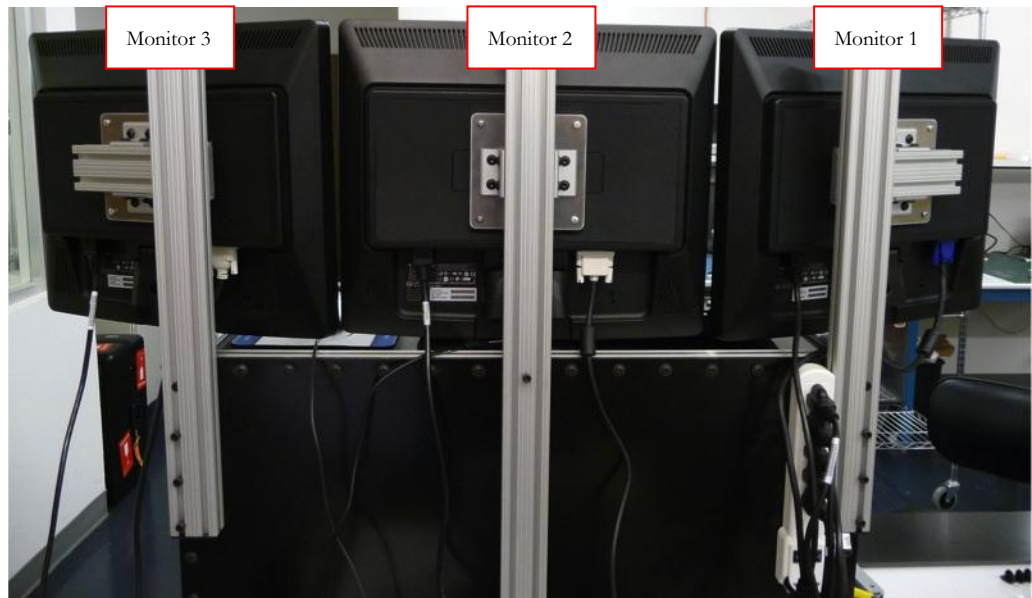
Figure 3 – Photograph of the back of TruView. Note power and data monitor cables

The TruView System has a single power cord which can to be plugged into a standard wall outlet.

Once all data and power cables are connected correctly, it is almost time to turn TruView on! In the next chapter we will review some of TruView's safety features. Please read this chapter before proceeding with the operation of TruView.

Chapter

3

Safety Features

> **Warning!**
>
> Please contact Creative Electron immediately if you notice any damage or malfunction from any of the safety features, including gaskets, interlocks, glass, door hinges, and switches. Failure to do so might result in voiding the warranty of the equipment.

Front Door Interlock

The front door is very convenient to load large trays of components and other parts. This door gives the user direct access to the x-ray source. To minimize unnecessary exposure to radiation, the front door has an interlock that shuts off the x-ray source once the door is opened. Please make sure the door is properly closed before starting the x-ray source by pushing the "ON" button in the software interface. If the door is not closed properly, the x-ray source will not turn on.
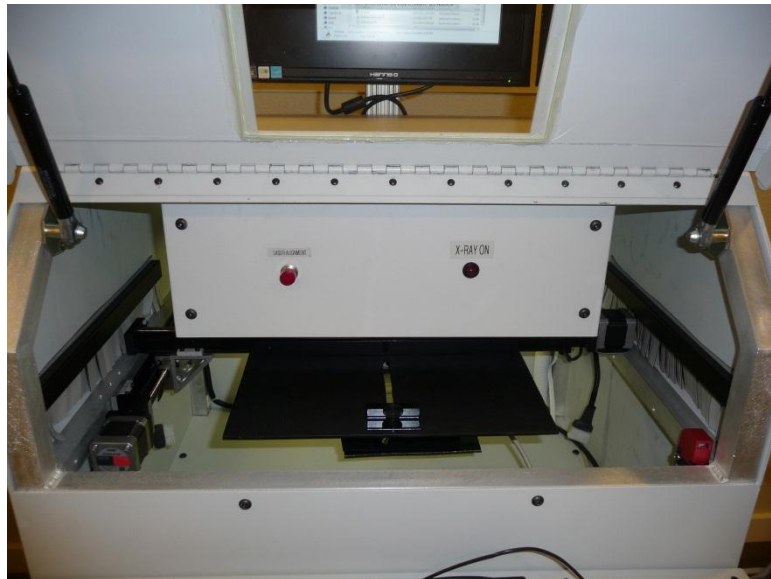
Figure 4 – TruView Door Interlock Location

X-Ray Enable Key

The TruView comes equipped with a unique set of keys. This key is necessary to start the x-ray source. Please contact Creative Electron immediately if your key was lost/misplaced.
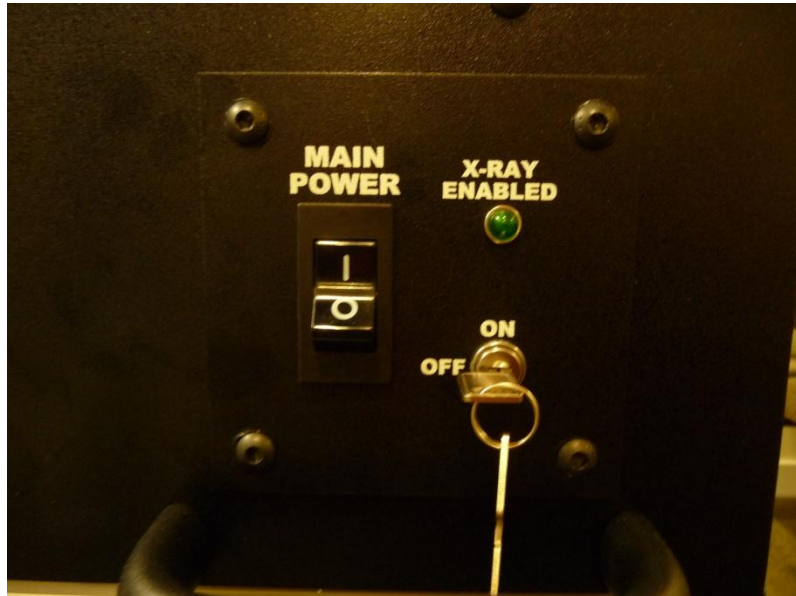
Figure 5 – TruView X-Ray Enable Keyswitch

Emergency Stop Button

The TruView is equipped with a quickly accessible emergency stop button located on the Keyboard Shelf. This large red button is located directly in front of the operator an intended to be used in the case of an unexpected event that would require the immediate shutdown of X-ray generation.

Figure 6 – TruView Emergency Stop Button Location

Front Lead Glass Window

The transparent window in the front panel is made of a special composite of glass and lead. This special window is paramount to keep the x-ray exposure of the user to a minimum. Please inform Creative Electron immediately if this window was in any way compromised. Furthermore, stop operating the equipment until a Creative Electron certified technician inspects it and deems it proper to use.

X-Ray On Indicator Light

The system is equipped with and "X-ray ON". This red indicator light is visible through the front window of the TruView System and when the front access door is open. When X-rays are being generated, this light is illuminated to alert the operator that X-ray generation is occurring. Also, this light is a visual indication that X-rays are not being generated and the system is safe for the operator to access items located inside the machine.

Figure 7 – TruView X-Ray On Indicator

Chapter

4

Operating Instructions

Loading Parts in TruView

TruView's wide working area allows users to load large trays of components or other parts from two different openings:

Front Door

The front door provides easy access to the machine, as seen in the image below. Large or small parts can be conveniently loaded into TruView. Please note that the front door is connected to an interlock. Thus each time the door is opened the x-ray source is turned off. To restart the x-ray source, close the front door and press the "Activate X-Ray" button.
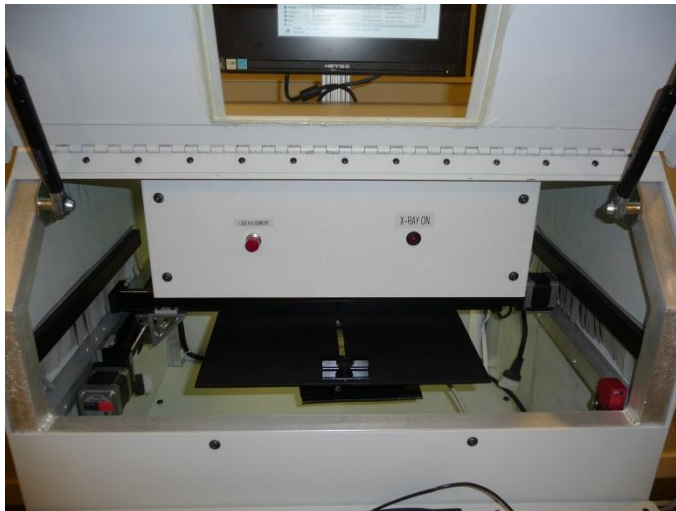
Figure 8 – TruView Front Door Access

Side Openings

TruView has a total of two side openings. These slots have an extra layer of lead shielding, thus allowing the user to insert parts in continuous fashion via the Reel to Reel.

Figure 9 – View of the Side opening that allows Tape passage onto the pick-up reel.

TruView Controls

The hardware controls for the x-ray camera and source are located in the TruView software and are controlled through normal computer user interfacing.

Zoom In/Out

Zoom In/Out Control is the toggle switch located on the right side of the Keyboard Shelf. The Zoom In and Out control is very useful to optimize the field of view with the size of the device under test. Contrary to the zooming capabilities that TruView has in the software, this zoom is analog. Therefore, the resolution of the image is not changed when zooming into a specific area of the field of view. This feature offers magnifications ranging from 4x to 18x.

Figure 10 – TruView Analog Zoom Location

Main Power ON/OFF Switch

The Main Power Switch is located on the left side of the unit. This is the main power switch for the unit and controls power to the entire system.

X-Ray Enable Keyswitch

The X-ray Enable Keyswitch is located on the left side of the unit. This is the main switch that works in conjunction with all interlock devices. When the Keyswitch is turned to the "ON" position, and all interlocks are engaged, the "X-RAY ENABLED" Light on the side panel will illuminate. This indicates that X-Ray generation can be activated via the software controls.
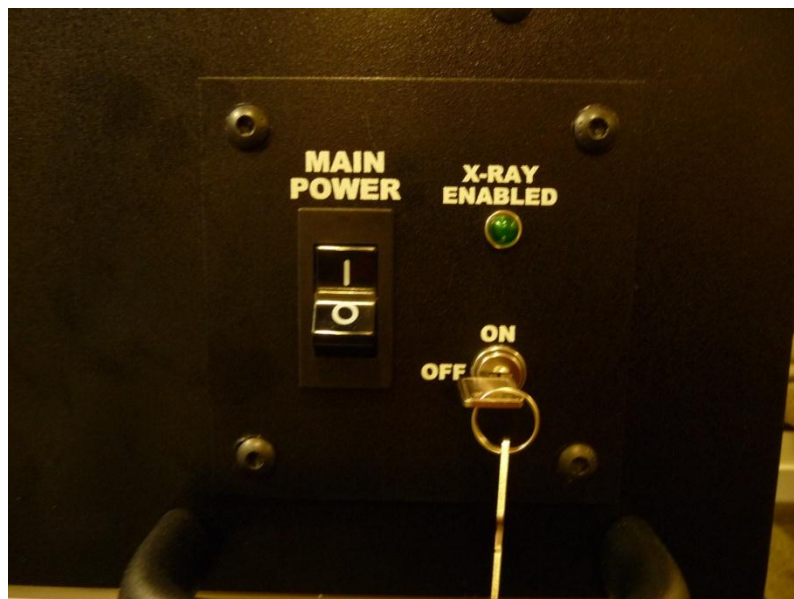
Figure 11 – TruView Main Power/X-Ray Enable Pane

Chapter

5

TruView Software

To open the TruView software, double click on the icon on the desktop called "TruView Inspection". This action opens the TruView software. Once it opens, the program spans the three monitors and both the cameras should be running. Monitor 1 contains the Live Video feed and the corresponding image controls, Monitor 2 contains the TruView Control Panels, and Monitor 3 contains the X-Ray feed and the corresponding image controls. To begin building a library and/or viewing parts, the user must open a TruView Library file.

> **Warning!**
>
> The software in your TruView has been locked to the specific computer shipped with the system. It will only work on this computer. Therefore, it will not work if installed in other computers. Please contact Creative Electron if you experience any problems with TruView's computer to arrange an immediate replacement.

Controlling the X-Ray Source

Activate X-ray Pushbutton

The "Activate" x-ray pushbutton is the last step in turning on the x-ray source. The x-ray source will be active only after the front door is properly closed, all interlocks are engaged, the Keyswitch is in the "ON" position and the X-Ray enabled light is illuminated GREEN.

Timer

TruView comes equipped with a timer which shuts off the x-ray source after a certain amount of time has expired. The default amount of time allotted is 5 minutes and can be changed by 15 second intervals. When the timer hits zero seconds, the x-ray source will automatically turn off. To turn it back on, press the Activate X-Ray Source button.

Voltage and Current

For the TruView models that have a variable x-ray source there are two virtual dials located in the software that allow the user to change the amount of radiation that is produced by the source.

The major components of an X-ray generator are the tube, the high voltage generator, the control console, and the cooling system. X-rays are generated by directing a stream of high-speed electrons at a target material such as tungsten, which has a high atomic number. When the electrons are slowed or stopped by the interaction with the atomic particles of the target, X-radiation is produced.

The X-ray tube is one of the main components of an X-ray generator. The tube cathode (filament) is heated with a low-voltage current of a few amps. The filament heats up and the electrons in the wire become loosely held. A large electrical potential is created between the cathode and the anode by the high-voltage generator.

Electrons that break free of the cathode are strongly attracted to the anode target. The stream of electrons between the cathode and the anode is the tube current. The tube current is measured in milliamps and is controlled by regulating the low-voltage, heating current applied to the cathode. The higher the temperature of the filament, the larger the number of electrons that will leave the cathode and travel to the anode. The milliamp or current setting on the control console regulates the filament temperature, which relates to the intensity of the X-ray output.

Important!

The high-voltage between the cathode and the anode affects the speed at which the electrons travel and strike the anode. The higher the kilovoltage, the more speed and, therefore, energy the electrons have when they strike the anode. Electrons striking with more energy results in X-rays with more penetrating power. The high-voltage potential is measured in kilovolts, and this is controlled with the voltage or kilovoltage control on the control console. An increase in the kilovoltage will also result in an increase in the intensity of the radiation.

Errors

Occasionally, the X-Ray Power Control Panel will indicate that an error has occurred via a RED or YELLOW light. If the interlock is open, a YELLOW light will appear next to the interlock
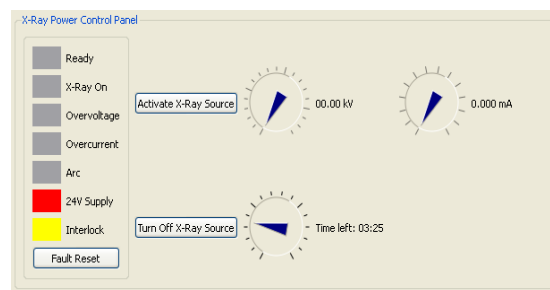
label and the source will shut off as shown to the right. To use the x-ray source again, simply make sure that the front door is closed and the interlock light is GRAY. If the power source is turned OFF, a RED light will appear next to the 24V power supply label. To change the light back to GRAY, make sure that the power supply is in the ON position. All other errors can be fixed by clicking the "Fault Reset" button. When the GREEN ready light turns on, the x-ray source can be activated again.

Cool Down (if available)

If a TruView Reel to Reel system (R2R) was purchased, then there will be a cool down timer that comes with the software. Since the software is designed to be automated, a user does not need to be present while it is running. In turn, the x-ray source and camera must automatically power down to ensure the longevity of both the x-ray source and camera. Therefore, every fifteen minutes, the software will halt and cut the power to the source. The cool down period is five minutes long and the software will reactivate the power and continue inspecting reeled parts once the cool down timer reaches zero.

TruView Calibration Tool

TruView comes with a standalone tool that allows the user to calibrate the x-ray images via software. TruView requires both offset and gain images in order to run properly. The calibration images provided with the software are specific to a new x-ray camera. New calibration images will need to be generated as time goes on and the environment changes. In order to obtain new calibration images, simply double click the TruView Calibration Tool on the Desktop.

Offset Correction

Offset correction is an image processing step that corrects for small variations in the dark image from the x-ray camera. Without light or x-rays, the only signal coming from the camera is an offset voltage and dark current. Although small, both of these can vary on a pixel-by-pixel level. The offset correction algorithm requires an offset image (typically an averaged dark image) to subtract from subsequent frames. To obtain an offset correction image, make sure that the x-ray source is off and that the live feed is black. Once this is completed, simply press the **Acquire Offset Image** button and wait for the dialog to show that the task is finished.

Gain Correction

Gain correction is a crucial processing step that corrects the image for variations in the intensity of the x-ray beam and for gain variations within the x-ray camera. The gain correction algorithm normalizes each acquired image based on a stored flat-field exposure (the gain image), by dividing each pixel value by its corresponding gain image value and then multiplying by the mean value of the gain image. Small local variations in image contrast often become visible only after

the raw image has been processed with the gain correction algorithm. To obtain a gain correction image, turn on the x-ray camera and adjust the x-ray controls to the desired settings. The recommended settings for the gain image are 50 kV and 0.25 mA. Once this is completed, simply press the **Acquire Gain Image** button and wait for the dialog to show that the task is finished.

Pixel Correction

Over time, pixels on the x-ray camera may appear to be dead. This can happen if the x-ray source has been on for excessive amounts of time. All TruView software tools have a timer that automatically turns off the x-ray source to help prolong the life of the x-ray camera. However, if dead pixels are causing significant performance issues, please contact Creative Electron to obtain a new pixel correction file.

Aligning a Component

The TruView System comes with a laser pointer to use as a guide in visually aligning your parts on the stage. Press the red button as seen in Figure 13 to activate the laser. After part is aligned, the laser should be turned off by again pressing the red button. This will help to prolong the life of the laser, and also maintain a clear live image of the part.

Figure 12: Alignment using the Laser Pointer

Opening a Part from the Library

Creative Electron provides the user with a sample library located on the Windows Desktop. In order to open a library, click the **Load Library** button on Monitor 2. A dialog will prompt the user to search for the location of a TruView Library file (.tvl) as shown in Figure 13. Once the desired library has been found, the parts contained in the library file will be loaded into the dropdown menu highlighted in Figure 14. In

order to load a specific part, the user will select it from the dropdown menu and click the **Load Images** button. The two images will be displayed as shown in Figure 15.
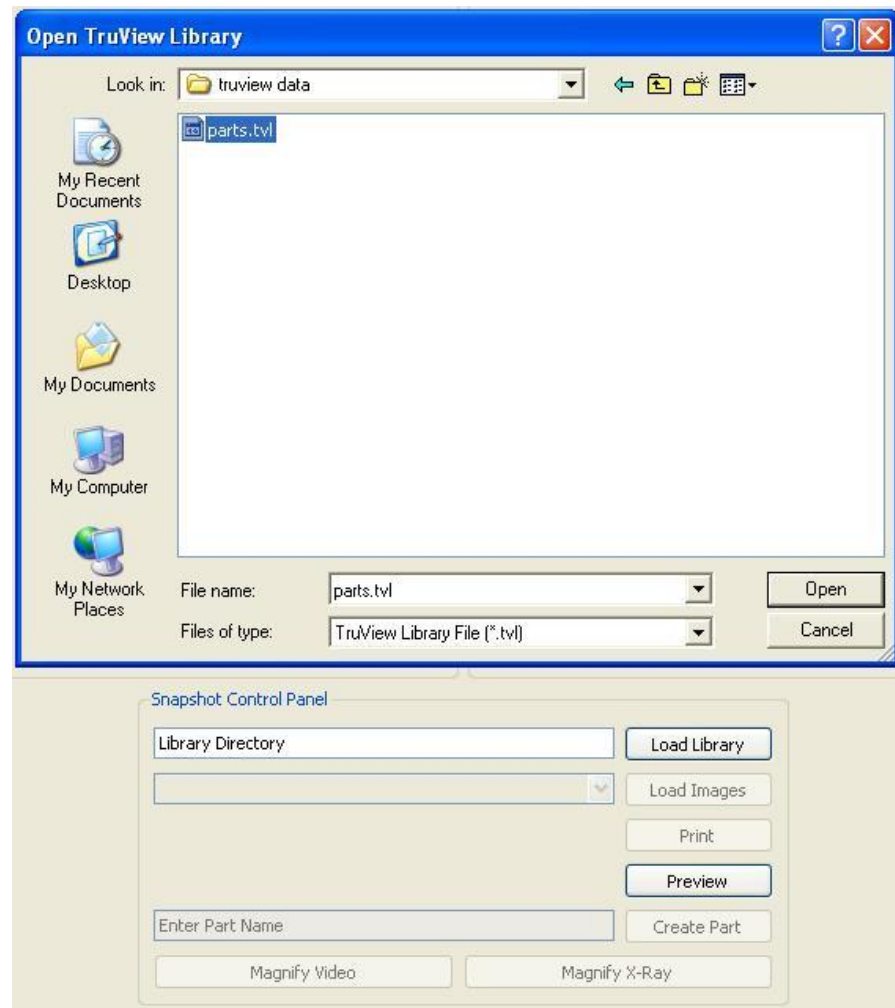
Figure 13 – Software dialog that asks user to locate the library of parts (libraryname.tvl)
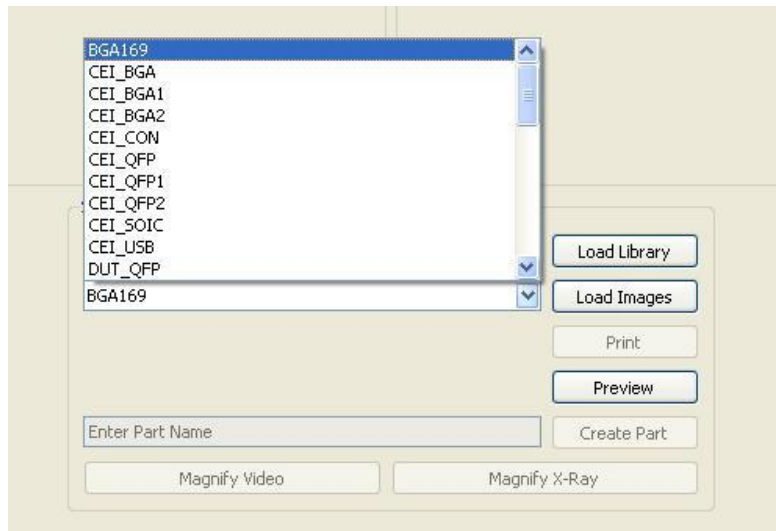
Figure 14 – Selection of TruView images from library

Figure 15 – TruView images from library displayed on center monitor (Monitor 2)

Create New Part in the Library

TruView allows the user to append new parts to existing libraries. In order to create a new library part, a library must be selected. The user must strike the **Preview** button before creating a new part. The **Preview** button simply takes a snapshot of both the X-Ray and Live video feeds. It is recommended that the Freeze Frame option is used on the X-Ray feed so that the part on the live video feed can be readjusted. For further

information on the Freeze Frame option, see the Freezing X-Ray Image section below. Once the desired screenshots have been taken, the user must enter a part name in the field shown in Figure 16. Once the part has been properly named, the user will strike the **Create Part** button. A message will be displayed above the text field indicating that a part has been created and where the corresponding images have been stored as shown in Figure 17. TruView also allows parts to be overwritten if the user would like to take a better snapshot of the part. It should be noted that the images will be stored in the same directory as the current TruView library. Both the library and the images should not be tampered with outside of the TruView software. Tampering with the images or the library may cause the software to work incorrectly.
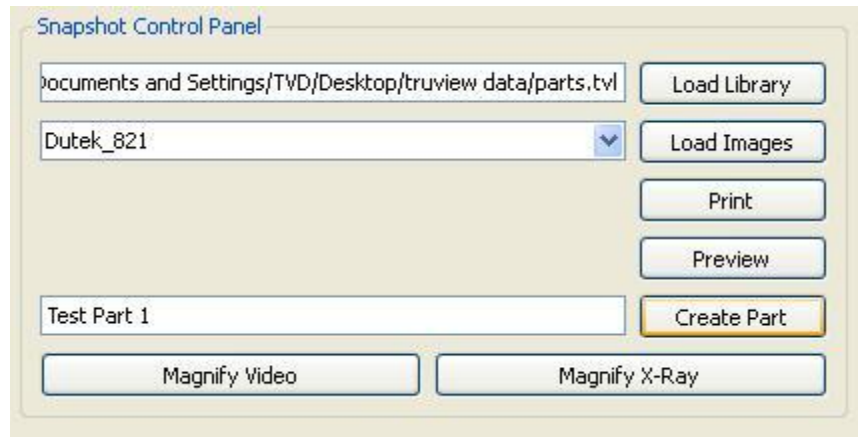
Figure 16 – User input to create new part into library
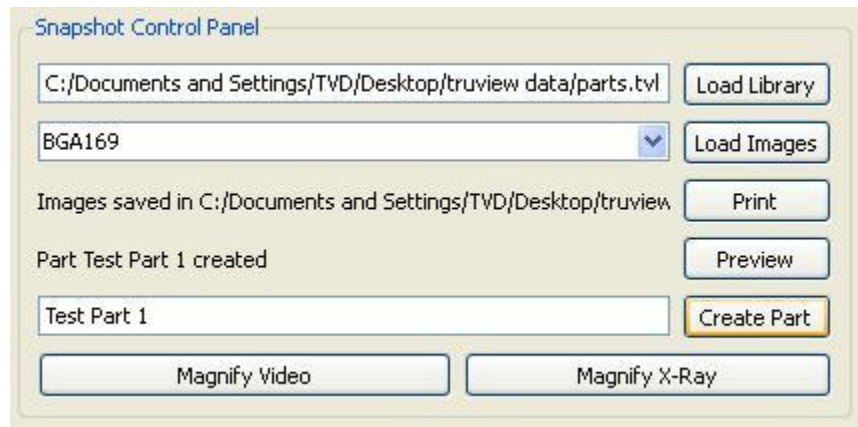
Figure 17 – Message confirming that TruView images were successfully added into library

Creating a New TruView Library

Open an instance of Microsoft Notepad. Click the File menu and 'Save As.' Change the 'Save as type' selection to 'All Files' and enter the name of the library. Be sure to append .tvl to the library name or else it won't be an authentic TruView library file. An example of the Save As window can be seen in Figure 18.
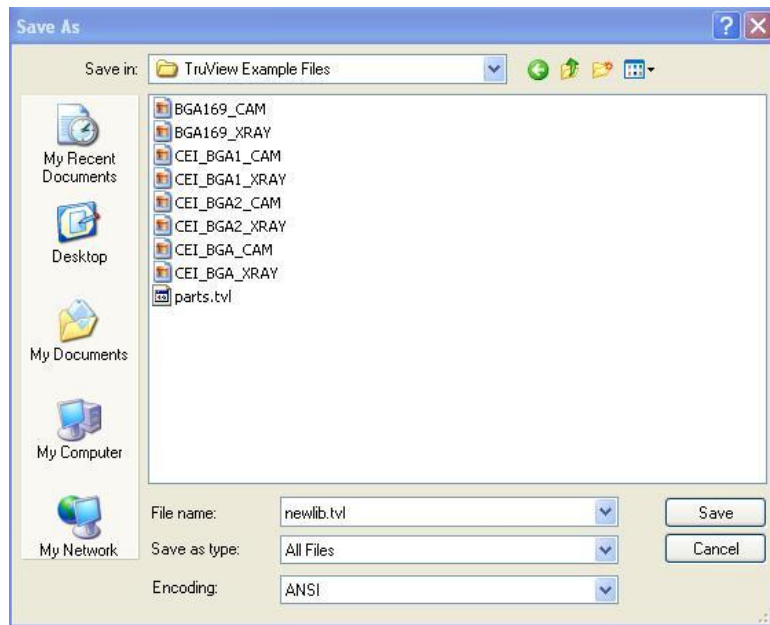
Figure 18 - Creating a new TruView Library

Image Magnification

TruView allows the user to magnify the images in order to easily compare the video feed to the loaded part. This is a crucial feature because it will help the user determine if the suspect component is broken or counterfeit. In order to magnify the image, the user must strike the appropriate button as shown in Figure 19(either **Magnify Video** or **Magnify X-Ray**) and the image will be magnified. To go back to the original screen, the user must press the **Zoom Out** button as shown in **Error! Reference source not found.Error! Reference source not found.**.
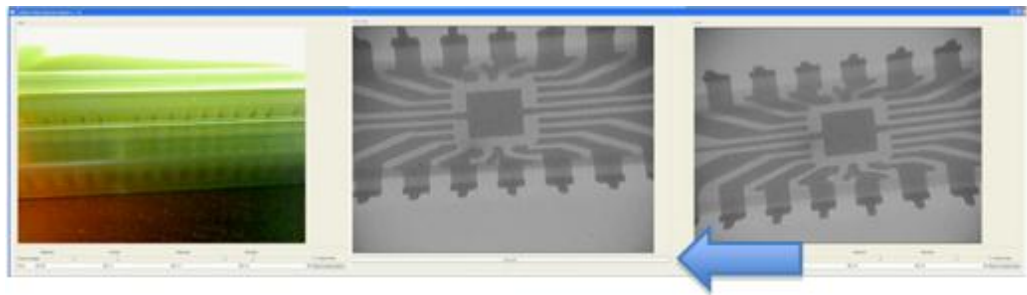
Figure 19 –TruView software expanded in three monitors

Image Controls (If available)

Both the TruView video feeds can adjust the following image properties: Brightness, Contrast, Sharpness, and Saturation. Given that different parts will be inspected with TruView, it is important to be able to adjust certain image properties so that a clear picture can be seen at all times. In order to adjust a particular property, the user can adjust the corresponding slider bar, use the corresponding up and down arrows for fine tuning, or enter an integer between 0 and 100 in the corresponding text box. To restore the settings to the recommended values, the user can strike the **Reset Default Values** button. A diagram of the Image Control Panel can be seen in Figure 20 - Image Control Panel. For the x-ray camera, the black and white thresholds can be adjusted which effectively changes the brightness and contrast of the x-ray image.
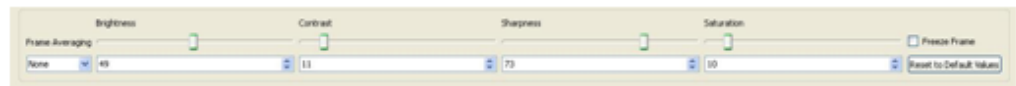
Figure 20 - Image Control Panel

Image Freeze

Given the position of the cameras in the TruView machine, it is difficult to center a part for both the Video and X-Ray feeds. Therefore, a **Freeze Image** check box has been implemented so that the user can center the part on one feed and then center the part on the other feed after freezing the other. The X-Ray feed is commonly frozen once it has been centered so that the user can pose the part for the Video feed correctly. In addition, the **Freeze Image** option is useful when parts are being continuously fed into the TruView system.

Drawing and Measurement Tools

Image Overlay and Transparency

Once an image has been loaded from a library, TruView allows the user to overlay the x-ray image from the preview window onto the live x-ray feed. To overlay an image onto the x-ray feed, simply toggle the **Image Overlay** checkbox to the checked position. This feature can be useful because it allows the user to clearly see differences between the exemplar part found in the library and the part shown on the x-ray feed. Should the library image not line up with parts displayed by the x-ray feed, the user can click the **Move Transparency** button and manually drag the image. In addition, the user can adjust the transparency of the overlay image by sliding the transparency bar.

Pseudo Coloring

TruView has a pseudo coloring option that allows the user to provide false coloring to the x-ray feed. Because the x-ray feed is grayscale, it can be difficult to see wire bonds

or other small features. Pseudo coloring allows users to see small features easier because the human eye can easily distinguish differences in color. An example of the false coloring feature can be seen in Figure X.

Crosshair

TruView allows the user to display a dashed red crosshair on both the video and the x-ray feeds. To turn the crosshair on, simply press the **Display Crosshair** checkbox. This feature allows the user to center a part correctly.

Grid

In addition to the crosshair, TruView allows the user to display a 4x4 grid on the video and x-ray feeds. To turn the grid on, simply press the **Display Grid** checkbox.

Auto-Gamma (if available)

This option will automatically calibrate the camera so that the optimal image will be on the screen.

Exposure Time (if available)

Some TruView models allow the exposure time of the x-ray camera to be set. Longer exposure times allow for cleaner, sharper images but significantly slow down the frame rate. The allowed exposure time is between 370 and 5000 milliseconds. To set the exposure time, enter the desired time and click the **Set Exposure Time** button.

Drawing and Labeling

When the x-ray feed has been frozen by toggling the **Freeze Image** checkbox, the drawing and measurement tools become activated. The drawing tools, shown in Figure 22, allow the user to draw various shapes onto the frozen image. Such features include squares, ovals, lines, arrows, text boxes, and a free hand tool. To use any of

Figure 21 - Drawing Tools

these tools, press the corresponding button and begin drawing. The text box is more involved and requires an additional step. Once the text box has been placed, simply double click the text field and type the desired text.
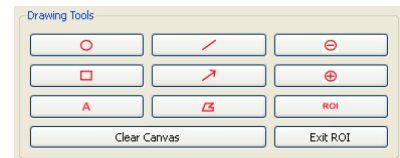
Measurement Tool

The measurement, shown in **Error! Reference ource not found.**, tool allows the user to measure certain features of a part such as dye length, pitch, or BGA ball diameter. Proper use of the measurement tool is a two step process. The calibration step involves selecting the **Calibration** option and entering a length (in

Figure 22 - Calibration and Measurement Tools

mil or mm). Once a length is entered, the user will draw a line that corresponds to a known length. For example, if the known pitch between BGA balls is 2 mm, the user

would enter 2.00 mm with the **Calibration** option selected. Then, the user will click the ruler icon and draw a line between two adjacent BGA balls on the frozen x-ray image. The measurement step involves selecting the **Measurement** option and pressing the ruler button. The user will then be able to measure distances on the x-ray feed. It should be noted that the calibration step must precede the measurement step in all cases.

Digital Zoom

In addition to analog zoom attached to the TruView casing, TruView has a digital zoom feature. The digital zoom can be accessed by two methods. The first method involves clicking the **+** button found on the **Drawing Tools**. Each click magnifies the image by 2x and the maximum magnification is 8x. To zoom out, the user must click the **-** button. The second way to zoom in uses the **ROI** button. The ROI feature allows the user to draw a rectangle on the x-ray feed and the system will zoom in on that box area. To remove the ROI effect, simply press the **Exit ROI** button.

Printing a Part

Occasionally, the user will want to have hard copies of the images displayed on the center screen. The TruView software comes with a **Print** button that will open a print dialog where the user can select a printer to print the images to. The printer dialog that TruView software opens is the standard Windows dialog. Therefore, the user can print to both local and network printers.

BGA Inspector

In order to start the BGA Inspector software, the user opens "BGAInspector.exe" then uses the "Load BGA Image" button to load an image. Once the image is loaded, the image color scheme can be modified using the Image Coloring Features and BGA Inspection tools can be started by clicking "Start BGA Inspector."
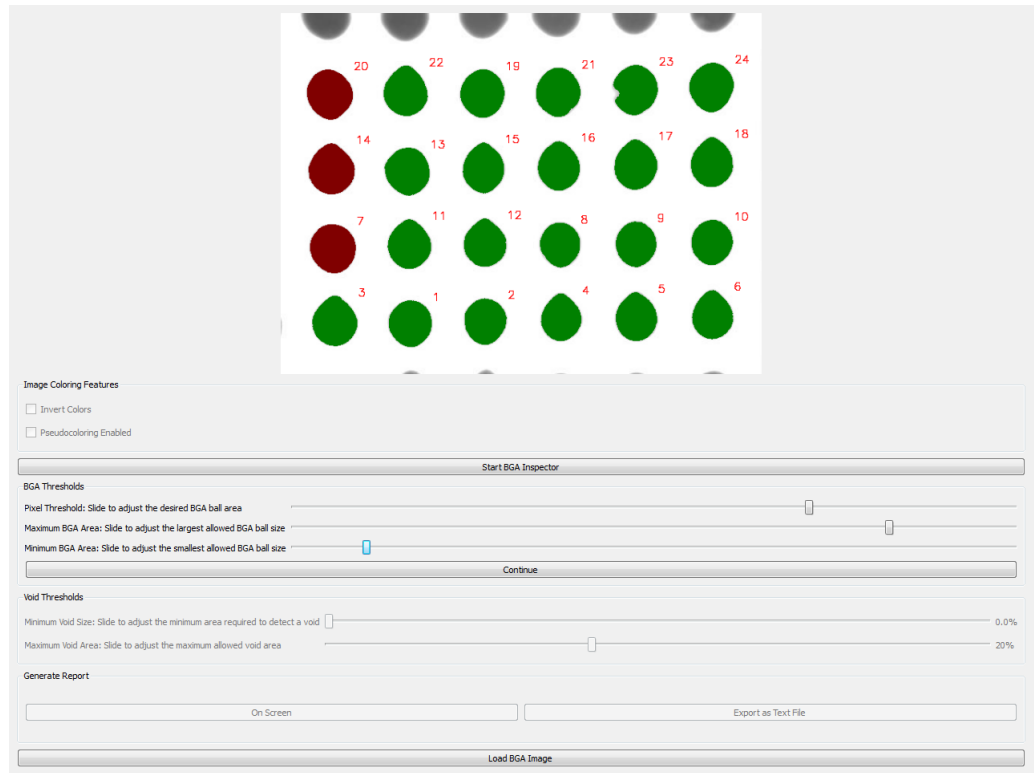
Figure 23 - BGA Thresholding Interface

Once the BGA Inspector starts, the Pixel Threshold slider should be set to the value that best matches the outlines of the BGA balls. The Maximum and Minimum BGA Area sliders should then be set to represent the tolerances acceptable to the user. Pressing "Continue" will then enable the Void Thresholding Interface.
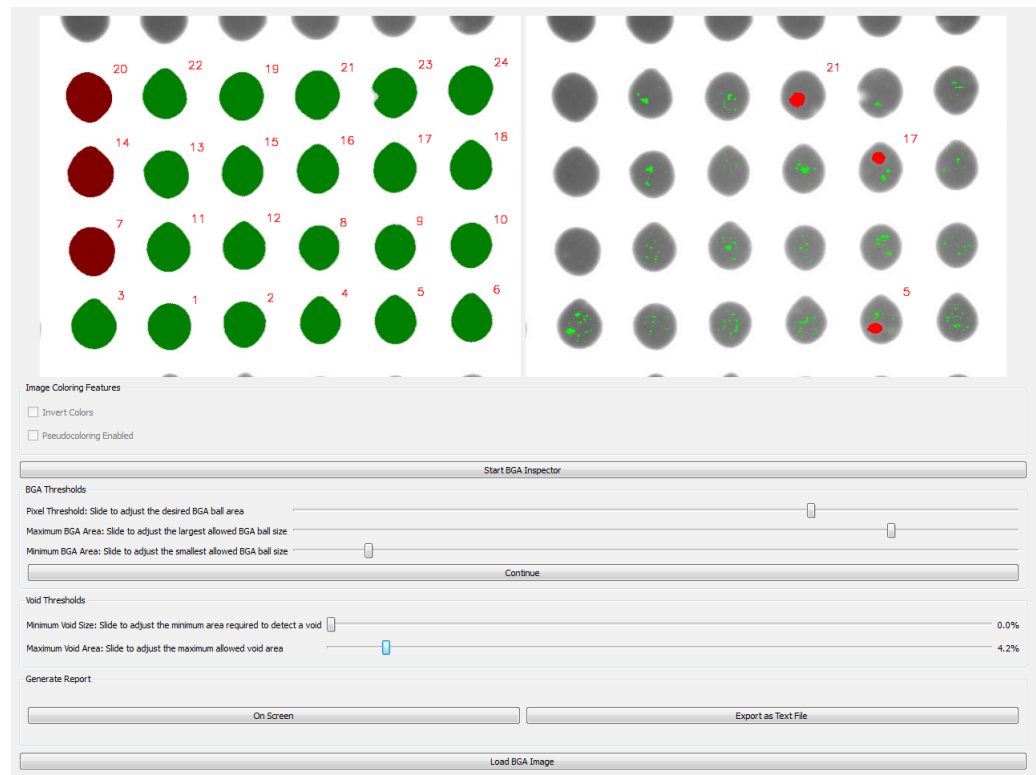
Figure 24 - Void Thresholding Interface

The Minimum Void Size slider should be set to the value that best represents the voids in the BGA balls. Then the user sets the Maximum Void Area slider to the acceptable tolerances.

After all the thresholds are satisfactorily set, the user can either generate a report on screen or export it as a text file by pressing the appropriate button. The on-screen report can be seen in Figure 25 - BGA Inspector Report.

BGA Solder Balls

BGA Voids

ID	Area Pass/Fail	Area	Average Diameter	Eccentricity	Associated Ball	Percentage of Ball
B1	Pass	2658.0	59.5	1.0	None	100%
B2	Pass	2548.0	59.0	1.0	None	100%
B3	Pass	2869.5	63.5	1.0	None	100%
B4	Pass	2417.0	58.5	1.0	None	100%
B5	Pass	2586.0	60.0	1.0	None	100%
B6	Pass	2532.5	60.5	1.0	None	100%
B7	Fail	2984.5	63.0	1.0	None	100%
B8	Pass	2342.5	56.5	1.0	None	100%
B9	Pass	2414.5	57.5	1.0	None	100%
B10	Pass	2455.0	57.5	1.0	None	100%
B11	Pass	2736.5	62.0	1.0	None	100%
B12	Pass	2604.0	60.0	1.0	None	100%
B13	Pass	2800.0	62.0	1.0	None	100%
B14	Fail	3000.5	65.0	1.0	None	100%
B15	Pass	2644.5	61.5	1.0	None	100%
B16	Pass	2653.5	61.0	1.0	None	100%
B17	Pass	2766.0	62.0	1.0	None	100%
B18	Pass	2689.0	61.0	1.0	None	100%
B19	Pass	2808.5	61.5	1.0	None	100%
B20	Fail	2991.0	64.0	1.0	None	100%
B21	Pass	2836.5	62.0	1.0	None	100%
B22	Pass	2824.0	63.0	1.0	None	100%
B23	Pass	2869.0	63.5	1.0	None	100%
B24	Pass	2840.0	62.5	1.0	None	100%
V1	Fail	192.5	18.0	1.0	B5	7.443%
V2	Fail	197.0	17.0	1.0	B17	7.122%
V3	Fail	278.0	21.0	1.0	B21	9.8%

Figure 25 - BGA Inspector Report

TruView Reel to Reel Acquisition

If purchased, TruView comes with an attachable reel to reel (R2R) system. This revolutionary system allows a user to quickly inspect thousands of parts within an hour. The R2R system also comes with software that can automatically inspect parts without an individual present. To open this software, simply double click on the TruView R2R icon on your desktop.

Overview

The R2R software is divided into six sections, shown in Figure 26 - R2R Software.
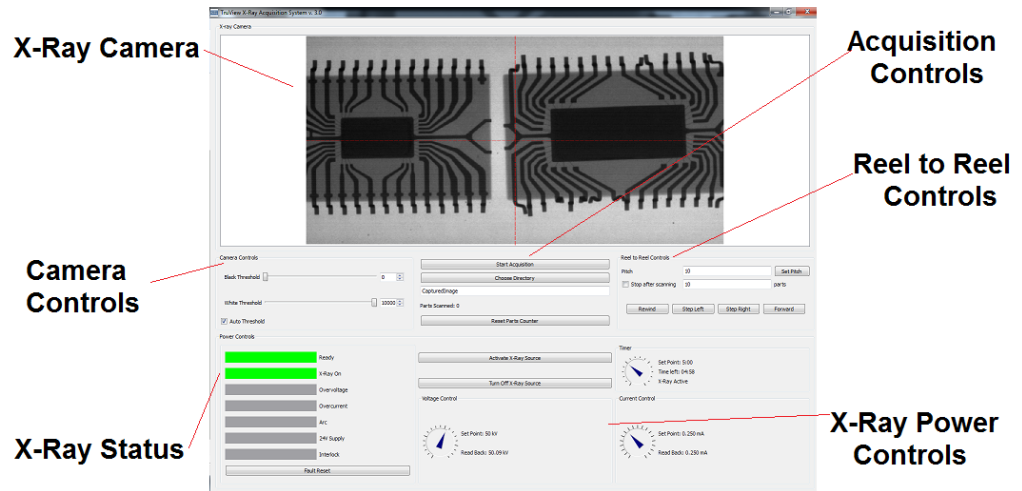
Figure 26 - R2R Software

The **X-Ray Camera** displays a live stream of the parts that are being acquired. Brightness and contrast settings for the camera are controlled in the **Camera Controls** section. The **X-Ray Status** section shows the status of the x-ray source and the **X-Ray Power** Controls allow the user to change the voltage and current for the source. The Acquisition Controls allow the user to reset the parts counter, start and stop acquisition, and name images. Lastly, the **Reel to Reel Controls** allow the user browse through and manipulate the reel.

Loading a Reel

Before images are acquired, the reels must be properly attached. Place the reel on the left spindle. Manually slide the tape through the x-ray machine and attach the tape to the reel on the right post. There must be enough slack for the tape to go through the parts counter. Finally, adjust the parts counter so that the tape can move freely between reels but won't move in the adjacent direction. Adjust the both spacer shafts down to spread the blades of the carriers apart. This provides needed tension to the carrier, as well as aiding in the transition of tape from one reel to the other.

Setting the Pitch

The part pitch is equivalent to the number of holes per part. This number tends to be between 0.5 and 4. Once the pitch has been determined, enter the number and click **Set Pitch**. It should be noted that this number must be an integer or 0.5 (two parts per hole).

Aligning the Parts for Acquisition

Once the leader portion of the tape has been attached to the receiving reel, the tape must be fed until the amount of white space to the right of the first part is less than the

width of the part itself. To feed the tape, activate the X-Ray source and press the **Feed** button and wait until some parts can be seen on the X-Ray Camera. Press **Stop** and then use the **Step Left** and **Step Right** buttons to fine tune the position of the parts shown in Figure X. The stepping buttons will move the tape by one hole in the desired direction. Lastly, the tape must be aligned in the vertical direction and this can be done by adjusting the optic sensor shown in Figure 28.

Figure 27: Shows the optic sensor location.

Creating a Part Name and Directory

Most of the time, the user will want label the part that they are acquiring (i.e. SamsungMemory) and place the images in a special folder on their computer. To change the name of a part, simply edit the **Part Name** field. To change the save location for the images, click the **Choose Directory** button to browse the computer and select a directory. The default part name is "CapturedImage" and the default location for the images is "/TruView R2R/Captured Images".

Acquiring the Images

Once the above steps have been completed, press the **Start Acquisition** button and the software will automatically acquire the images. The software will stop acquisition and turn off the x-ray once there are no more parts being displayed. If you would like stop scanning after a certain number of parts, put an integer number in the proper field and check the **Stop After Scanning** checkbox as shown in Figure X. Once all parts have been acquired, the process can be repeated after pressing the **Reset Parts Counter** button.

Object Functionality

Below is a summary of every button, slider, checkbox, and dial that is present in the R2R software.

<u>Camera Controls:</u>

- **Black Threshold Slider and Spinbox**: The black threshold is the necessary value for a pixel to be completely black. Pixel values below this threshold will be black and values above the threshold will be interpolated between the black and white thresholds.

- **White Threshold Slider and Spinbox**: The white threshold is the necessary value for a pixel to be completely white. Pixel values above this threshold will be white and values below the threshold will be interpolated between the black and white thresholds.

- **Auto Threshold Checkbox**: If this box is checked, the black and white thresholds are calculated automatically. The white threshold is set to the maximum pixel value and the black threshold is set to the minimum pixel value.

Reel to Reel Controls

- **Set Pitch Button and Text Field**: When pressed, this sets the pitch of the part based on the value in the corresponding text field. The pitch is equivalent to the number holes per part and this value must be an integer or 0.5.

- **Stop After Scanning Checkbox and Text Field**: When checked the software will run until X number of parts have been scanned, where X is equal to the value in the corresponding text field. The value must be a positive integer.

- **Rewind Button**: When pressed, the tape will rewind back to the starter reel. To stop rewinding the tape, simply press the button again.

- **Step Left Button**: When pressed, the tape moves to the left by one hole.

- **Step Right Button**: When pressed, the tape moves to the right by one hole.

- **Forward Button**: When pressed, the tape will move forward to the receiving reel. To stop feeding the tape, simply press the button again.

Acquisition Controls

- **Start Acquisition Button**: When pressed, the software will automatically acquire images and move the tape appropriately. To stop automatic acquisition, press the button again.

- **Choose Directory Button**: When pressed, a window will pop up prompting the user to select a directory to save acquired images.

- **Part Name Text Field**: This text field contains the name of the part. The default part name is "CapturedImage." All images are in the following format: PartName_PartNumber_XRAY.tif

- **Reset Parts Counter Button**: When pressed, this button will reset the number of parts scanned.

TruView XY Table Acquisition

If purchased, TruView comes with an XY table that allows for quick and easy inspection of both trays and tubes. The XY manipulation system also comes with software that can automatically inspect parts without an individual present. To open this software, double click on the TruView XY-Inspection icon on your desktop.

Overview
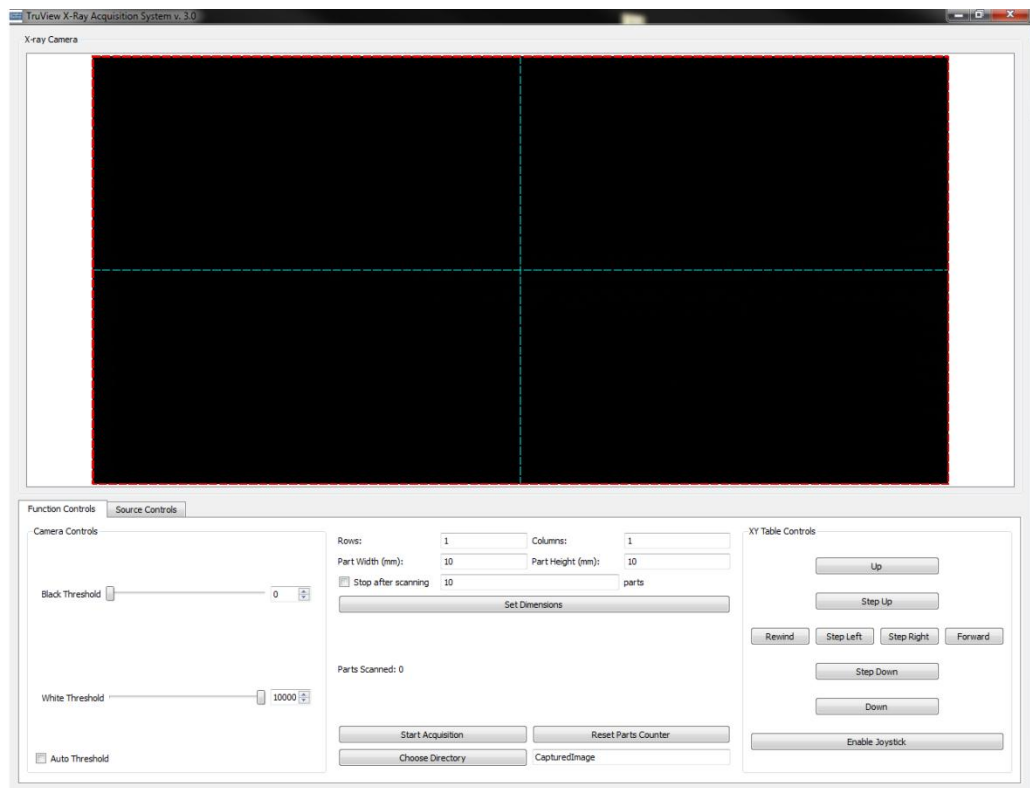
Figure 28 - TruView XY Inspection Software

The XY-Inspection software is divided into six sections shown in Figure 29. The **X-Ray Camera** displays a live stream of the parts that are being acquired. The **Source Controls** tab contains the X-Ray Status and X-Ray Power Controls. The **X-Ray Status** section shows the status of the x-ray source and the **X-Ray Power Controls** allow the user to change the voltage and current for the source. The **Function Controls** tab contains the controls for camera brightness, table manipulation, and

image acquisition. Brightness and contrast settings for the camera are controlled in the **Camera Controls** section. The Acquisition Controls allow the user to reset the parts counter, start and stop acquisition, and name images. Lastly, the **XY Table Controls** allow the user browse to manipulate the position of the tube or tray.

Loading a Tube

Before images can be acquired, the tube must be properly attached to the platform as shown in Figure 30. It must be placed against the back support of the stage, and clamped down using the attached thumbscrew. For automatic acquisition, the table should be manipulated so that left part of the tube is in the field of view.

Figure 29: Loading of Tray for XY Inspection

Loading a Tray

Before images can be acquired, the tray must be properly attached to the platform as shown in Figure 30. It must be placed against the back support of the stage, and clamped down using the attached thumbscrew. For automatic acquisition, the table should be manipulated so that upper-left corner of the tray is in the field of view.

Setting the Part Dimensions

Before the automatic acquisition tool can be used, the dimensions must be set by using the widget shown in Figure 31. For trays, simply enter in the number of rows and columns for the tray.

Figure 30 - Part Dimensions Widget

For tubes, the number of rows should be set to 1 and the number of columns should be equal to the number of parts inside of the tube. The width and height of each part are measured in millimeters (rounded to the nearest millimeter). Once the dimensions

have been determined, enter the dimensions and click **Set Dimensions**. It should be noted that all numbers must be integers.

Aligning the Parts for Acquisition

Once the dimensions have been entered, the tray or tube must be properly aligned before the automatic acquisition can proceed. To move the XY-Table, simply use the **Up**, **Down**, **Rewind**, and **Forward** buttons in Figure 32. For fine tuning, click the **Step Up**, **Step Down**, **Step Left**, and **Step Right** buttons. Alternatively, the joystick may be used to manipulate the XY-Table. To enable the joystick, press the **Enable Joystick** button. As stated previously, the upper left corner of a tray must be in the field of view in order for the automatic acquisition to work properly. For tubes, the left end of the tube must be in the field

Figure 31 - XY-Table Controls

of view. The turquoise cross represents the center of the field of view so the center of the part should match the intersection.

Creating a Part Name and Directory

Most of the time, the user will want label the part that they are acquiring (i.e. SamsungMemory) and place the images in a special folder on their computer. To change the name of a part, simply edit the **Part Name** field. To change the save location for the images, click the **Choose Directory** button to browse the computer and select a directory. The default part name is "CapturedImage" and the default location for the images is "/TruView R2R/Captured Images".

Selecting the Image Boundary

This optional step allows you to precisely select the region that you want to acquire. The advantage of this step is that no other components will be in the image and the images will be smaller in size. To select the image boundary, click on the upper left corner of the desired boundary and drag the dashed red box to the lower right corner of the boundary. The default image boundary is simply the entire field of view.

Acquiring the Images

Once the above steps have been completed, press the **Start Acquisition** button and the software will automatically acquire the images. The software will stop acquisition and turn off the x-ray once there are no more parts being displayed. If you would like stop scanning after a certain number of parts, put an integer number in the proper field and check the **Stop After Scanning** checkbox. Once all parts have been acquired, the

process can be repeated after pressing the **Reset Parts Counter** button. It should be noted that tray parts are acquired in a snaking motion. The first row is acquired by moving the tray to the left while the following row acquires images by moving the tray to the right. This process repeats itself until all parts have been acquired.

Chapter

6

Troubleshooting

Video and/or X-ray Camera does not work

The first step is to make sure that both the USB camera connections are secure to the back of the PC. If secure, press the **Reset Default Settings** button on the TruView control panel to ensure that the camera settings are correct. Lastly, restart the computer and start TruView again. Should the problem persist, please contact CEI so that our engineers can diagnose the problem.

One of the library images (X-Ray or Video Camera) does not show in center monitor

If one or more of the library images do not show in the center monitor, go to the directory where the library file is located. Make sure that two images exist for the selected part. The live image should have a _CAM appended to the part name and the x-ray image should have a _XRAY suffix. If they do not, it is recommended that the images be recreated in the TruView software with the **Create Part** option.

Noise in the image

If there is significant noise in either the Live Video feed or the x-ray feed, use the Frame Averaging feature to mitigate the noise. Using 16 frames for frame averaging should remove virtually all the noise in the system. Another technique to reduce noise in the system is to manually turn down the energy of the x-rays. The drawback to this technique is that the x-ray feed will be fainter.

Images and feeds are swapped

If the x-ray feed appears on the left side monitor and the Live Video feed appears on the right monitor, TruView should be closed immediately. To solve this problem, unplug the USB connection labeled "X-Ray" and restart the computer. Once Windows has loaded, plug the connection back into the computer. If the problem persists, please contact CEI so that our engineers can solve the problem.

Other Issues

If there are any issues that are not covered in Chapter 6 of this manual, please contact CEI for immediate technical support.

Chapter

7

Radiation Safety
Reference Manual

This Training and Reference Manual (TRM) presents the information necessary for users of radioactive materials and radiation producing machines to properly establish, understand, and follow the policies and procedures related to users of x-ray inspection systems. Some of the topics covered by the Radiation Safety Manual (RSM) include:

- The nature of radiation and its interaction with matter

- Definitions of units and terms used to describe radiation and radioactive material

- Methods of calculating and measuring radiation levels for a variety of sources

- The biological effects of ionizing radiation

- Safety precautions for the use of radiation producing machines.

Radiation Fundamentals

For the purposes of this manual, we can use a simplistic model of an atom. The atom can be thought of as a system containing a positively charged nucleus and negatively charged electrons that are in orbit around the nucleus.

The nucleus is the central core of the atom and is composed of two types of particles, protons that are positively charged and neutrons that have a neutral charge. Each of these particles has a mass of approximately one atomic mass unit (amu). (1 amu $\approx$ 1.66 x 10^{-24}g).

 Electrons surround the nucleus in orbitals of various energies. (In simple terms, the farther an electron is from the nucleus, the less energy is required to free it from the atom.) Electrons are very light compared to protons and neutrons. Each electron has a mass of approximately 5.5 x 10^{-4}amu.

A *nuclide* is an atom described by its *atomic number (Z)* and its *mass number (A)*. The Z number is equal to the charge (number of protons) in the nucleus, which is a characteristic of the element. The A number is equal to the total number of protons and neutrons in the nucleus. Nuclides with the same number of protons but with different numbers of neutrons are called *isotopes*. For example, deuterium ($^2_1$H) and tritium ($^3_1$H) are isotopes of hydrogen with mass numbers two and three, respectively. There are on the order of 200 stable nuclides and over 1100 unstable (radioactive) nuclides. Radioactive nuclides can generally be described as those which have an excess or deficiency of neutrons in the nucleus.

Radioactive Decay

Radioactive nuclides (also called *radionuclides*) can regain stability by nuclear transformation (*radioactive decay*) emitting radiation in the process. The radiation emitted can be particulate or electromagnetic or both. The various types of radiation and examples of decay are shown below.

ALPHA (α)

Alpha particles have a mass and charge equal to those of helium nuclei (2 protons + 2 neutrons). Alpha particles are emitted from the nucleus during the decay of some very heavy nuclides (Z > 83).

$$226_{88}Ra \rightarrow 222_{86}Rn + {}^4_2\alpha$$

BETA (β-, β+)
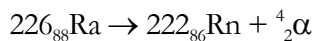
Beta particles are emitted from the nucleus and have a mass equal to that of electrons. Betas can have either a negative charge or a positive charge. Negatively charged betas are equivalent to electrons and are emitted during the decay of neutron rich nuclides.

$$14_6C \rightarrow 14_7N + 0_{-1}\beta + \nu$$
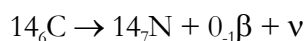
Positively charged betas (positrons) are emitted during the decay of proton rich nuclides.

$$22_{11}Na \rightarrow 22_{10}Ne + 0_1\beta + \gamma$$
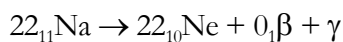
GAMMA (γ)

Gammas (also called gamma rays) are electromagnetic radiation (photons). Gammas are emitted during energy level transitions in the nucleus. They may also be emitted during other modes of decay.

$$99m_{43}Tc \rightarrow 99_{43}Tc + \gamma$$
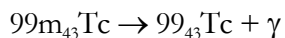
ELECTRON CAPTURE

In certain neutron deficient nuclides, the nucleus will capture an orbital electron resulting in conversion of a proton into a neutron. This type of decay also involves gamma emission as well as x-ray emission as other electrons fall into the orbital vacated by the captured electrons.

$$125_{53}I + 0_{-1}e \rightarrow 125_{52}Te + \gamma$$
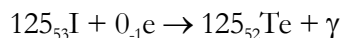
FISSION

Fission is the splitting of an atomic nucleus into two smaller nuclei and usually two or three neutrons. This process also releases a large amount of energy in the form of gammas and kinetic energy of the fission fragments and neutrons.

$$235_{92}U + 1_{0}n \rightarrow 93_{37}Rb + 141_{55}Cs + 2(1_{0}n) + \gamma$$
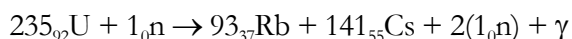
NEUTRONS

For a few radionuclides, a neutron can be emitted during the decay process.

$$17_{7}N \rightarrow 17_{8}O* + 0_{-1}\beta \quad (*\text{excited state})$$

$$17_{8}O* \rightarrow 16_{8}O + 1_{0}n$$
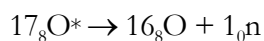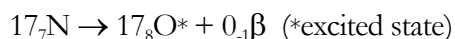
X-RAYS

X-rays are photons emitted during energy level transitions of orbital electrons.

Bremsstrahlung x-rays (braking radiation) are emitted as energetic electrons (betas) are decelerated when passing close to a nucleus. Bremsstrahlung must be considered when using large activities of high-energy beta emitters such as P-32 and S-90.

Characteristics of Radioactive Decay

In addition to the type of radiation emitted, the decay of a radionuclide can be described by the following characteristics.

HALF-LIFE

The half-life of a radionuclide is the time required for one half of a collection of atoms of that nuclide to decay. Decay is a random process that follows an exponential curve. The number of radioactive nuclei remaining after time (t) is given by:

$$N_{t} = N_{0}e^{-(0.693t/T)}$$

where N_0= original number of atoms

N_t = number remaining at time t

t = decay time

T = half-life

ENERGY

The basic unit used to describe the energy of a radiated particle or photon is the electron volt (eV). An electron volt is equal to the amount of energy gained by an electron passing through a potential difference of one volt. The energy of the radiation emitted is a characteristic of the radionuclide. For example, the energy of the alpha emitted by Cm-238 will always be 6.52 MeV, and the gamma emitted by Ba-135m will always be 268 keV. Many radionuclides have more than one decay route. That is, there may be different possible energies that the radiation may have, but they are discreet possibilities. However, when a beta particle is emitted, the energy is divided between the beta and a neutrino. (A neutrino is a particle with no charge and infinitesimally small mass.) Consequently, a beta particle may be emitted with an energy varying in a continuous spectrum from zero to a maximum energy (Emax) that is characteristic of the radionuclide. The average energy is generally around forty percent of the maximum.
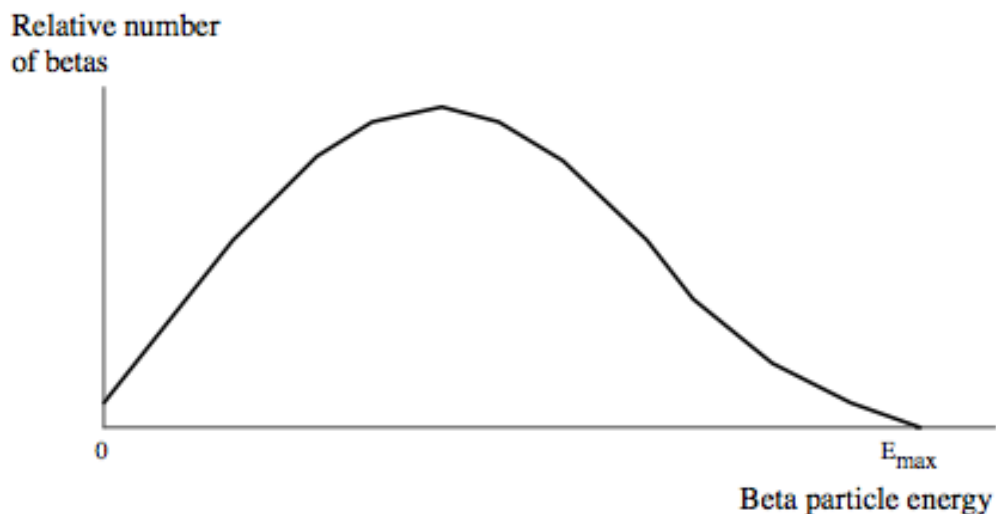
Figure 32 – Typical Beta Spectrum

Interaction of Radiation with Matter

The transfer of energy from the emitted particle or photon to an absorbing medium has several mechanisms. These mechanisms result in ionization and excitation of atoms or molecules in the absorber. The transferred energy is eventually dissipated as heat.

Ionization is the removal of an orbital electron from an atom or molecule, creating a positively charged ion. In order to cause ionization, the radiation must transfer enough energy to the electron to overcome the binding force on the electron. The ejection of an electron from a molecule can cause dissociation of the molecule.

Excitation is the addition of energy to an orbital electron, thereby transferring the atom or molecule from the ground state to an excited state.

ALPHA PARTICLES

Interactions between the electric field of an alpha and orbital electrons in the absorber cause ionization and excitation events. Because of their double charge and low velocity (due to their large mass), alpha particles lose their energy over a relatively short range. One alpha will cause tens of thousands of ionizations per centimeter in air. The range in air of the most energetic alpha particles commonly encountered is about 10 centimeters (4 inches). In denser materials, the range is much less. Alpha particles are easily stopped by a sheet of paper or the protective (dead) layers of skin.

BETA PARTICLES

Normally, a beta particle loses its energy in a large number of ionization and excitation events. Due to the smaller mass, higher velocity and single charge of the beta particle, the range of a beta is considerably greater than that of an alpha of comparable energy. The maximum ranges of beta particles in various absorbing media are shown in Figure 3.1. Since its mass is equal to that of an electron, a large deflection can occur with each interaction, resulting in many path changes in an absorbing medium.

If a beta particle passes close to a nucleus, it decreases in velocity due to interaction with the positive charge of the nucleus, emitting x-rays (bremsstrahlung). The energy of the bremsstrahlung x-rays has a continuous spectrum up to a maximum equal to the maximum kinetic energy of the betas. The production of bremsstrahlung increases with the atomic number of the absorber and the energy of the beta. Therefore, low Z materials are used as beta shields.

A positron will lose its kinetic energy through ionizations and excitations in a similar fashion to a negative beta particle. However, the positron will then combine with an electron. The two particles are annihilated, producing two 511 keV photons called annihilation radiation.

PHOTONS

Gammas and x-rays differ only in their origin. Both are electromagnetic radiations, and differ only from radio waves and visible light in having much shorter wavelengths. They have zero rest mass and travel with the speed of light. They are basically distortions in the electromagnetic field of space, and interact electrically with atoms even though they have no net electrical charge. While alphas and betas have a finite maximum range and can therefore be completely stopped with a sufficient thickness of absorber, photons interact in a probabilistic manner. This means that an individual photon has no definite maximum range. However, the total fraction of photons

passing through an absorber decreases exponentially with the thickness of the absorber. There are three mechanisms by which gammas and x-rays lose energy.

The *photoelectric effect* is one in which the photon imparts all its energy to an orbital electron. The photon simply vanishes, and the absorbing atom becomes ionized as an electron (photoelectron) is ejected. This effect has the highest probability with low energy photons (< 50 keV) and high Z absorbers.

Compton scattering provides a means for partial absorption of photon energy by interaction with a "free" (loosely bound) electron. The electron is ejected, and the photon continues on to lose more energy in other interactions. In this mechanism of interaction, the photons in a beam are scattered, so that radiation may appear around corners and in front of shields. 1

Pair production occurs only when the photon energy exceeds 1.02 MeV. In pair production the photon simply disappears in the electric field of a nucleus, and in its place two electrons, a negatron and a positron, are produced from the energy of the photon. The positron will eventually encounter a free electron in the absorbing medium. The two particles annihilate each other and their mass is converted into energy. Two photons are produced each of 0.511 MeV. The ultimate fate of these two photons is energy loss by Compton scattering or the photoelectric effect.

SECONDARY IONIZATIONS

The electrons from ionizations and pair production will themselves go on to cause more ionization and excitation events in the same way as described for betas.
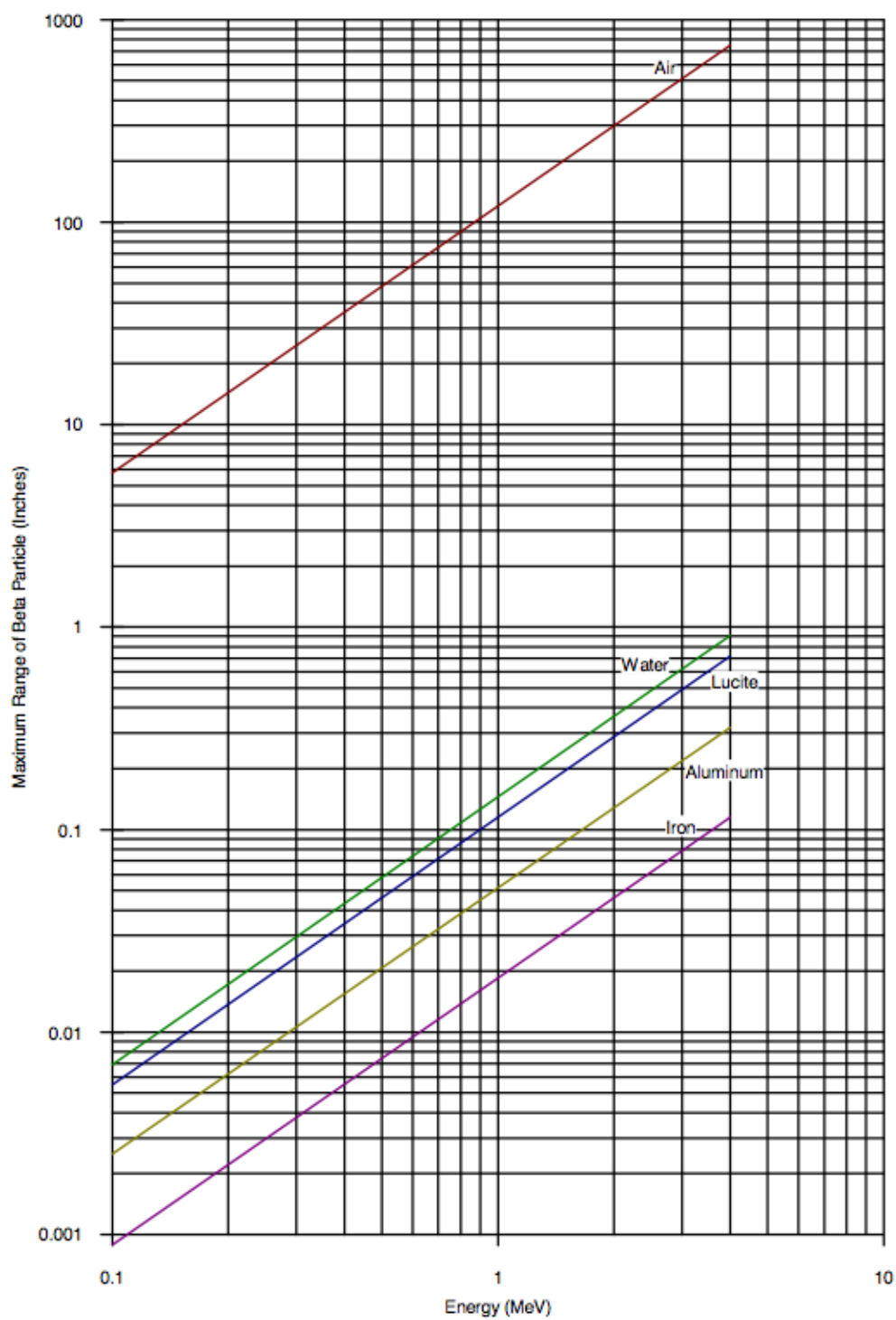
Figure 33 – Penetration Ability of Beta Radiation

Activity, Exposure, and Dose

Activity is the rate of decay (disintegrations/time) of a given amount of radioactive material. *Dose* is a measure of energy deposited by radiation in a material, or of the relative biological damage produced by that amount of energy given the nature of the radiation. *Exposure* is a measure of the ionizations produced in air by x-ray or gamma radiation. The term exposure (with its "normal" definition) is sometimes used to mean dose. (e.g. "He received a radiation exposure to his hand.")

ACTIVITY

Curie (Ci) = 3.7 x 1010 disintegrations per sec (dps). The *Becquerel (Bq)* is also coming into use as the *International System of Units (SI)* measure of disintegration rate. 1 Bq = 1 dps, 3.7 x 10^{10}Bq = 1 Ci, and 1 mCi = 37 MBq.

EXPOSURE

The unit of radiation exposure in air is the *roentgen (R)*. It is defined as that quantity of gamma or x-radiation causing ionization in air equal to 2.58 x 10^{-4}coulombs per kilogram. Exposure applies only to absorption of gammas and x-rays in air.

DOSE

The *rad* is a unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram. (1 erg = 6.24 x 10^{11}eV) The SI unit of absorbed dose is the *Gray (Gy)*. 1 Gy = 1 joule/kilogram = 100 rad. An exposure of 1 R results in an absorbed dose of 0.87 rad.

A *quality factor (Q)* is used to compare the biological damage producing potential of various types of radiation, given equal absorbed doses. The effectiveness of radiation in producing damage is related to the energy loss of the radiation per unit path length. The term used to express this is *linear energy transfer (LET)*. Generally, the greater the LET in tissue, the more effective the radiation is in producing damage. The quality factors for radiations frequently encountered are:

Radiation	Q
Gammas and x-rays	1
Beta particles & electrons	1
Alpha particles & fission fragments	20
Neutrons	10

The *rem* is a unit of dose equivalent. The dose equivalent in rem is equal to the absorbed dose in rad multiplied by the quality factor. Dose equivalent determinations for internally deposited radioactive materials also take into account other factors such as the non-uniform distribution of some radionuclides (e.g. I-125 in the thyroid). The SI unit for dose equivalent is the Sievert (Sv). 1 Sv = 100 rem.

INVERSE SQUARE LAW

Exposure rate varies inversely with the square of the distance from a point source of radiation. This is often referred to as the inverse square law (or $1/r^2$ rule).

$$ER_2 = ER_1 \times (d_1/d_2)^2$$

where ER_2 = exposure rate at distance 2

ER_1 = exposure rate at distance 1

d_1 = distance 1

d_2 = distance 2

BETA DOSE RATES

For a beta emitter point source, the dose rate can be calculated using the empirical equation

$300 \times Ci$ = rad/hr @ 1 foot,

where Ci = source strength in curies.

This calculation neglects any shielding provided by the air, which can be significant. For example, the maximum range in air for a beta from S-35 is less than one foot, so the dose rate at one foot is zero for any size S-35 source.

SKIN DOSE

For energies above 0.6 MeV, the dose rate to the skin from a uniform deposition of 1 $\mu Ci/cm^2$ of a beta emitter on the skin is about 9 rem/hr.

Nuclide	Γ	Nuclide	Γ	Nuclide	Γ
Actinium-227	2.2	Gold-198	2.3	Potassium-43	5.6
Antimony-122	2.4	Gold-199	0.9	Radium-226	8.25
Antimony-124	9.8	Hafnium-175	2.1	Radium-228	5.1
Antimony-125	2.7	Hafnium-181	3.1	Rhenium-186	0.2
Arsenic-72	10.1	Indium-114m	0.2	Rubidium-86	0.5
Arsenic-74	4.4	Iodine-124	7.2	Ruthenium-106	1.7
Arsenic-76	2.4	Iodine-125	1.5	Scandium-46	10.9
Barium-131	3.0	Iodine-126	2.5	Scandium-47	0.56
Barium-133	2.4	Iodine-130	12.2	Selenium-75	2.0
Barium-140	12.4	Iodine-131	2.2	Silver-110m	14.3
Beryllium-7	0.3	Iodine-132	11.8	Silver-111	0.2
Bromine-82	14.6	Iridium-192	4.8	Sodium-22	12.0
Cadmium-115m	0.2	Iridium-194	1.5	Sodium-24	18.4
Calcium-47	5.7	Iron-59	6.4	Strontium-85	3.0
Carbon-11	5.9	Krypton-85	0.04	Tantalum-182	6.8
Cerium-141	0.35	Lanthanum-140	11.3	Tellurium-121	3.3
Cerium-144	0.4	Lutecium-177	0.09	Tellurium-132	2.2
Cesium-134	8.7	Magnesium-28	15.7	Thulium-170	0.025
Cesium-137	3.3	Manganese-52	18.6	Tin-113	1.7
Chlorine-38	8.8	Manganese-54	4.7	Tungsten-185	0.5
Chromium-51	0.16	Manganese-56	8.3	Tungsten-187	3.0
Colbalt-56	17.6	Mercury-197	0.4	Uranium-234	0.1
Colbalt-57	0.9	Mercury-203	1.3	Vanadium-48	15.6
Colbalt-58	5.5	Molybdenum-99	1.8	Xenon-133	0.1
Colbalt-60	13.2	Neodymium-147	0.8	Ytterbium-88	0.4
Colbalt-64	1.2	Nickel-65	3.1	Yttrium-88	14.1
Europium-152	5.8	Niobium-95	4.2	Yttrium-91	0.01
Europium-154	6.2	Osmium-191	0.6	Zinc-65	2.7
Europium-155	0.3	Palladium-109	0.03	Zirconium-95	4.1
Gallium-67	1.1	Platinum-197	0.5		
Gallium-72	11.6	Potassium-42	1.4		

Γ = exposure rate in R/hr at 1 cm from a 1 mCi point source

Γ/10 = exposure rate in mR/hr at 1 meter from a 1 mCi point source

Figure 31 – Gamma exposure constants (Γ)

Biological Effects of Ionizing Radiation

The hazards associated with the absorption of radiation in mammalian systems and tissues are related to both the type of radiation and the nature of the absorbing tissue or organ system.

ALPHA

Alpha particles will be stopped by the dead layers of skin, so they are not an external hazard. However, many alpha emitters or their daughters also emit gammas which are penetrating and therefore may present an external hazard. Internally, alphas can be very damaging due to their high linear energy transfer (LET). That is, they deposit all of their energy in a very small area. Based on their chemical properties, alpha emitters can be concentrated in specific tissues or organs.

BETA

Externally, beta particles can deliver a dose to the skin or the tissues of the eye. Many beta emitters also emit gammas. A large activity of a high energy beta emitter can create a significant exposure from bremsstrahlung x-rays produced in shielding material. Internally, betas can be more damaging, especially when concentrated in specific tissues or organs.

PHOTONS

Externally, the hazard from low energy (< 30 keV) gammas and x-rays is primarily to the skin or the tissues of the eye. Higher energies are more penetrating and therefore a whole body hazard. Internally, gamma emitters can affect not only the tissues or organs in which they are deposited, but also surrounding tissues.

MECHANISMS OF DAMAGE

As discussed earlier, radiation causes atoms and molecules to become ionized or excited. These ionizations and excitations can result in:

- Production of free radicals

- Breakage of chemical bonds

- Production of new chemical bonds and cross-linkage between macromolecules

- Damage to molecules which regulate vital cell processes (e.g. DNA, RNA, proteins).

TISSUE SENSITIVITY

In general, the radiation sensitivity of a tissue varies directly with the rate of proliferation of its cells and inversely with the degree of differentiation.

EFFECTS OF ACUTE HIGH RADIATION DOSES

A whole body radiation dose of greater than 25 to 50 rem received in a short time results in the clinical "acute radiation syndrome." This syndrome, which is dose related, can result in disruption of the functions of the bone marrow system (>25 rem), the

gastro-intestinal system (>500 rem), and the central nervous system (>2000 rem). An acute dose over 300 rem can be lethal.

EFFECTS OF LOW RADIATION DOSES

There is no disease uniquely associated with low radiation doses. Immediate effects are not seen below doses of 25 rem. Latent effects may appear years after a dose is received. The effect of greatest concern is the development of some form of cancer. The National Academy of Sciences Committee on Biological Effects of Ionizing Radiation (BEIR) issued a report in 1990 entitled "Health Effects of Exposure to Low Levels of Ionizing Radiation," also known as BEIR V. The following is an excerpt from the Executive Summary of the report:

On the basis of the available evidence, the population-weighted average lifetime risk of death from cancer following an acute dose equivalent to all body organs of 0.1 Sv (0.1 Gy of low-LET radiation) is estimated to be 0.8%, although the lifetime risk varies considerably with age at the time of exposure. For low LET radiation, accumulation of the same dose over weeks or months, however, is expected to reduce the lifetime risk appreciably, possibly by a factor of 2 or more. The Committee's estimated risks for males and females are similar. The risk from exposure during childhood is estimated to be about twice as large as the risk for adults, but such estimates of lifetime risk are still highly uncertain due to the limited follow-up of this age group.

. . . . .

The Committee examined in some detail the sources of uncertainty in its risk estimates and concluded that uncertainties due to chance sampling variation in the available epidemiological data are large and more important than potential biases such as those due to differences between various exposed ethnic groups. Due to sampling variation alone, the 90% confidence limits for the Committee's preferred risk models, of increased cancer mortality due to an acute whole body dose of 0.1 Sv to 100,000 males of all ages range from about 500 to 1200 (mean 760); for 100,000 females of all ages, from about 600 to 1200 (mean 810). This increase in lifetime risk is about 4% of the current baseline risk of death due to cancer in the United States. The Committee also estimated lifetime risks with a number of other plausible linear models which were consistent with the mortality data. The estimated lifetime risks projected by these models were within the range of uncertainty given above. The committee recognizes that its risk estimates become more uncertain when applied to very low doses. Departures from a linear model at low doses, however, could either increase or decrease the risk per unit dose.

Radiation Dosimetry Program

FILM BADGE

The film badge is used to measure whole body dose and shallow dose. It consists of a film packet and a holder. The film is similar to ordinary photographic film but will be exposed by radiation. (It will also be exposed by light, so if the packet is opened or damaged, the reading will be invalid.) The holder has several filters that help in determining the type and energy of radiation. The badge will detect gamma and x-rays, high-energy beta particles, and in certain special cases, neutrons. It does not register radiation from low energy beta emitters such as ^{3}H, ^{14}C, and ^{35}S, since their betas will not penetrate the paper covering on the film packet. The badge is usually worn at the collar or chest level to measure the radiation dose received by the trunk of the body. When not in use, the badge should be left in a safe place on campus away from any

radiation sources. (Use the film badge rack if one is provided.) Be sure the badge is available for the film packet exchange which is done monthly.

TLD RING

The TLD ring is used to measure dose to the hand. They are issued to individuals who may use millicurie amounts of a gamma or high-energy beta emitter. The TLD is a small crystal that absorbs the energy from radiation. When heated, it releases the stored energy in the form of visible light. The crystal is mounted in a ring that should be worn on the hand which is expected to receive the larger dose. Wear the ring inside your glove with the label facing towards your palm.

PRECAUTIONS

The radiation doses recorded by your dosimeters become part of your occupational radiation dose record. Make sure that this record is valid and accurate by observing the following precautions:

- Always wear your badge when using radioactive materials or radiation producing machines. Wear your ring when using gamma or high-energy beta emitters.

- Keep your dosimeters away from radiation sources when not in use.

- Do not deliberately expose a dosimeter to radiation or wear your badge when receiving medical or dental x-rays. Do not tamper with the film packet or remove it from the holder.

- Never wear someone else's dosimeter or let someone else wear yours.

- Avoid subjecting the badge to high temperatures or getting it wet.

Notify the Safety Office if your badge or ring has been damaged or lost, or if you have reason to believe that you or your dosimeter has received an accidental high dose.

Radiation Safety for X-ray Units

Analytical x-ray machines produce intense beams of ionizing radiation that are used for diffraction and fluorescence studies. The most intense part of a beam is that corresponding to the K emission of the target material and is called characteristic radiation. In addition to the characteristic radiation, a continuous radiation spectrum of low intensity is produced ranging from a very low energy to the maximum kV-peak setting. This is referred to as "bremsstrahlung" or white radiation. Undesirable wavelengths may be filtered out using a monochromator.

X-ray diffraction wavelengths (λ) are selected so as to roughly correspond to the inter-atomic distances within the sample, and to minimize fluorescence. Wavelengths commonly used are 1.54 Å (Cu targets), 0.71 Å (Mo targets), 0.56 Å (Ag targets), and 2.3 Å (Cr targets). The relationship between wavelength and x-ray photon energy is determined by the equation

$$E = hc/\lambda$$

where   E = energy in ergs (1 eV = 1.6 x 10^{-12}erg)

h = Planck's constant = 6.614 x 10^{-27}erg-sec

c = velocity of light = 3 x 10^{10}cm/sec

λ = wavelength in cm (1 Å = 1 x 10^{-8}cm)

X-rays emitted from an open, uncollimated port form a cone of about 30°. The x-ray flux can produce a radiation field at one meter on the order of 10,000 R/hr. A collimator reduces the beam size to about 1 millimeter diameter.

X-RAY HAZARDS AND BIOLOGICAL EFFECTS

X-rays produced by diffraction machines are readily absorbed in the first few millimeters of tissue, and therefore do not contribute any dose to the internal organs of the body. However, the lens of the eye can receive a dose from x-rays of this energy. Overexposure of lens tissue can lead to the development of lens opacities and cataracts.

Absorbed doses of a few hundred rad may produce a reddening of the skin (erythema) that is transitory in nature. Higher doses -- 10,000 rad and greater -- may produce significant cellular damage resulting in pigment changes and chronic radiation dermatitis. Exposure to erythema doses may not result in immediate skin reddening. The latent period may be from several hours to several days.

(Note: X-rays used for medical diagnosis are about one order of magnitude shorter in wavelength. Diagnostic rays are designed for tissue penetration and are carefully filtered to avoid x-ray damage to the skin caused by the longer, more readily absorbed wavelengths).

SOURCES OF IONIZING RADIATION

The primary beam is not the only source of ionizing radiation. Any high voltage discharge is a potential source of x-rays. Faulty high-voltage vacuum-tube rectifiers may emit x-rays of twice the voltage applied to the x-ray tube. Other sources of ionizing radiation are:

- Secondary emissions and scattering from the sample, shielding material, and fluorescent screens

- Leakage of primary or scattered x-rays through gaps and cracks in shielding

- Penetration of the primary beam through or scattering from faulty shutters, beam traps, or collimator couplings

Dose Concepts

This discussion is provided as an additional source of information to those users who desire a more in-depth understanding of radiation dose concepts. Changes to the federal radiation protection regulations took effect in January, 1994. These changes were based on reports and recommendations by the International Commission on Radiological Protection (ICRP), the National Council on Radiation Protection and Measurements (NCRP), and other organizations involved with radiation protection.

TOTAL DOSE CONCEPT

Previously, the radiation doses received from external radiation sources and internally deposited radioactive materials were treated separately. Limits on internal uptake of radioactive materials were based on the dose to a "critical organ" and could not be compared to the "whole body" dose received from an external source.

The external dose number was and still is related to the risk of stochastic effects (primarily cancer). For a stochastic effect, the higher the dose received, the greater the chance of developing the effect. The new regulations have a mechanism for determining the increased risk of stochastic effects from an intake of radioactive material. The dose calculated is based on a variety of factors such as the biological half-life of the material, the distribution of the material in the body, and the type and energy of the radiation. The result is that both the external dose and the internal dose are related to the risk of stochastic effects and thus can be added to obtain a total dose.

ORGAN DOSE

For a few radionuclides, the limits on intake are based on nonstochastic effects rather than stochastic effects. For a nonstochastic effect, the higher the dose received, the more severe the effect. However, unlike stochastic effects, there is a threshold dose, i.e. a certain dose, below which the effect will not occur. Limits on the internal intake of radioactive materials are set to keep organ doses well below the thresholds. Even in these cases, however, the additional risk of stochastic effects must also be determined.

The dose limit for external exposure of the lens of the eye is also based on prevention of a nonstochastic effect (lens opacities).

DEFINITIONS

Absorbed Dose means the energy imparted by ionizing radiation per unit mass of irradiated material.

Dose Equivalent means the product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest.

Deep-dose Equivalent (DDE), which applies to external whole-body exposure, is the dose equivalent at a tissue depth of 1 cm.

Shallow-dose Equivalent, which applies to external exposure of the skin or an extremity, is the dose equivalent at a tissue depth of 0.007 cm.

Eye Dose Equivalent, which applies to the external exposure of the lens of the eye, is the dose equivalent at a tissue depth of 0.3 cm.

Committed Dose Equivalent (CDE) means the dose equivalent to organs or tissues of reference that will be received from an intake of radioactive material by an individual during the fifty-year period following the intake.

Weighting Factor for an organ or tissue is the proportion of the risk of stochastic effects when the whole body is irradiated uniformly.

Committed Effective Dose Equivalent (CEDE) is the sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the CDE to these organs or tissues.

Total Effective Dose Equivalent (TEDE) means the sum of the deep-dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures). TEDE = DDE + CEDE

Total Organ Dose Equivalent (TODE) is the sum of the DDE and the CDE to an organ or tissue.

Annual Limit on Intake (ALI) means the derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man that would result in a CEDE of 5 rem or a CDE of 50 rem to any individual organ or tissue.

Radiation Rules of Thumb

ALPHA PARTICLES

An alpha energy of at least 7.5 MeV is required to penetrate the protective layer of the skin (0.07mm).

BETA PARTICLES

A beta energy of at least 70 keV is required to penetrate the protective layer of the skin (0.07mm). The average energy of a beta-spectrum is approximately one-third the maximum energy. The range of beta particles in air is about 12 ft per MeV. (e.g. The maximum range of P-32 betas is 1.71 MeV x 12 ft/MeV ≈ 20 ft). The skin dose rate

from a uniform thin deposition of 1 μCi/cm2 is about 9 rem/hr for energies above 0.6 MeV. For a beta emitter point source, the dose rate in rem/hr at one foot is approximately 300 x Ci where Ci is the source strength in curies. This calculation neglects any shielding provided by the air, which can be significant. For example, the maximum range in air for a beta from S-35 is less than one foot, so the dose rate at one foot is zero for any size S-35 source.

GAMMAS AND X-RAYS

For a point source gamma emitter with energies between 0.07 and 2 MeV, the exposure rate in R/hr at 1 foot is approximately 6CEn, where C is the activity in curies; E is the energy in MeV; and n is the number of gammas per disintegration. Gammas and x-rays up to 2 MeV will be attenuated by at least a factor of 10 by 2 inches of lead.

Excerpt from US NRC Regulation on Exposure

GUIDE 8.29 — INSTRUCTION CONCERNING RISKSFROM OCCUPATIONAL RADIATION EXPOSURE

This instructional material is intended to provide the user with the best available information about the health risks from occupational exposure to ionizing radiation. Ionizing radiation consists of energy or small particles, such as gamma rays and beta or alpha particles, emitted from radioactive materials, which can cause chemical or physical damage when absorbed by living tissue. A question and answer format is used. Many of the questions or subjects initially were developed by the NRC staff in consultation with workers, union representatives, and licensee representatives experienced in radiation protection training.

This Revision 1 to Regulatory Guide 8.29 updates earlier material on biological effects and risks and on typical occupational exposure. Additionally, it conforms to the revised 10 CFR Part 20, "Standards for Protection Against Radiation," which was required to be implemented by licensees no later than January 1, 1994. The information in this appendix is intended to help develop an attitude of healthy respect for risks associated with radiation, with neither unnecessary fear nor lack of concern. Additional guidance concerning other topics in radiation protection training is provided in other NRC regulatory guides.

1. What is meant by health risk?

A health risk is generally thought of as something that may endanger health. Scientists consider health risk to be the statistical probability or mathematical chance that personal injury, illness, or death may result from some action. Most people do not think about health risks in terms of mathematics. Instead, most of us consider the health risk of a particular action on the basis of whether we believe that particular action will, or will not, cause us some harm. The intent of this appendix is to provide estimates of, and explain the bases for, the possible risk of injury, illness, or death from occupational radiation exposure.

When x-rays, gamma rays, and ionizing particles interact with living materials such as our bodies, they might deposit energy sufficient to cause several different types of damage, such as very small physical displacement of molecules or a change of an atom to a different element, or ionization, which cause electrons to be removed from atoms and molecules. When the energy of these radiations is high enough, biological damage can occur: chemical bonds can be broken and cells can be damaged or killed.

The basic unit for measuring absorbed radiation is the rad (radiation absorbed dose). One rad (0.01 gray in the International System of units) equals the absorption of 100 ergs (a small but measurable amount of energy) in a gram of tissue exposed to radiation. To reflect biological risk, rads must be converted to rems. This conversion accounts for the differences in the effectiveness of different types of radiation to cause damage. The rem is used to estimate biological risk.

2. What are the possible health effects of exposure to radiation?

Potential health effects from exposure to radiation include cancer such as leukemia and bone, breast, and lung cancer. Very high, acute levels of radiation exposure have been known to cause prompt (or early)effects, such as vomiting and diarrhea, skin burns, cataracts, and even death. Radiation exposure has also been linked with the potential for genetic effects in future children of exposed parents. Children who were exposed to elevated levels of radiation prior to birth have shown an increased probability of mental retardation. These effects (with the exception of genetic effects) have been observed in studies of medical radiologists, uranium miners, radium workers, radiotherapy patients, and people exposed to radiation from atomic bombs dropped on Japan. In addition, the radiation effects studies with laboratory animals have provided extensive data on radiation-induced health effects, including genetic effects.

The observations and studies mentioned above involve levels of radiation exposure or exposure rates that are generally higher than those received occupationally today. Although studies have not shown a clear cause-and-effect relationship between current levels of occupational exposure and biological effects, it is prudent to assume that some effects do occur.

3. What is meant by early and continuing effects, delayed effects, and genetic effects?

EARLY AND CONTINUING EFFECTS

Early effects, which are also called immediate or prompt effects, are those that occur shortly after an exposure, within hours to a few days. They are observable after receiving a very large dose in a short period of time -- for example, 300 rems (3 Sv) received within a few minutes to a few days. Early effects are not caused at the levels of radiation exposure allowed under the NRC's occupational limits.

Early effects occur when the radiation dose is large enough to cause extensive biological damage to cells; a large number of cells within a specific organ or the whole body will have been killed. For prompt effects to occur, this radiation dose must be

received within a short time period. This type of dose is called an acute dose or acute exposure. The same dose received over a long time period would not necessarily cause the same effect. Our body's natural biological process is constantly repairing damaged cells and replacing dead cells; if the cell damage is not severe; our body is capable of repairing and replacing the damaged cells without any observable adverse conditions.

For example, a whole body dose of about 300 rems (3 Sv), 60 times the annual occupational dose limit, if received within a short time period (e.g., a few hours) will cause vomiting and diarrhea within a few hours; loss of hair, fever, and weight loss within a few weeks; and about a 50 percent chance of death without medical treatment. These effects would not occur if the dose 300 rems (3 Sv) were accumulated gradually over many years.

It is important to distinguish between whole body and partial body exposure. A localized dose to a small area of the body would not produce the same effect as a whole body dose of the same magnitude. For example, f only the hand were exposed, the effect would mainly be limited to a portion of the skin and underlying tissue of the hand. An acute dose of 600 rem (6 Sv) to the hand would cause skin reddening; recovery would occur over the following months and no long-term damage would be expected. An acute dose of this magnitude to the whole body could cause death within a short time without medical treatment. Medical treatment would lessen the magnitude of the effects and the chance of death; however, it would not totally eliminate the effects or chance of death.

Cataracts are also considered early and continuing effects. A certain level of dose to the lens of the eye is required before any observable visual impairment is observed and the impairment remains after the exposure is stopped. The threshold for cataract development is an acute dose on the order of 100 rem (1 Sv). Further, a cumulative dose of 800 rems (8 Sv) from protracted exposures over many years to the lens of the eye has also been linked to some level of visual impairment. This dose exceeds the amount that can be accumulated by the lens for normal occupational exposure.

DELAYED EFFECTS

Delayed effects may occur years after exposure. These effects are not the immediate, direct result of biological damage to the cells of the body but are caused indirectly when the radiation causes the cells in the body to change, thereby causing the normal function of the cell to change -- for example, turning normal healthy cells into cancer cells. The potential for these delayed health effects is one of the main concerns addressed when setting limits for occupational doses.

GENETIC EFFECTS

Genetic effects can occur when there is radiation damage to the genetic material. These effects may show up as birth defects or other conditions in the future children of the exposed individual and succeeding generations. However, excess genetic effects clearly caused by radiation have not been observed in human populations exposed to

radiation. Continuing evaluations of the atomic bomb survivors (Hiroshima and Nagasaki) have not shown any significant radiation-related increases in genetic defects. Effects have been observed in animal studies conducted at very high levels of exposure and it is known that radiation can cause changes in the genes in cells of the human body. Therefore, it is prudent to assume that radiation exposures, even at the levels allowed under NRC's limits, do pose some risk of genetic effects. Teratogenic effects, or effects that are observable in children who were exposed during fetal and embryonic stages of development, are discussed in Question 5.

4. What is the difference between the effects of acute and chronic radiation exposure?

Acute radiation doses usually refer to a large dose of radiation received in a short period of time. Chronic exposure refers to small doses received repeatedly over long time periods, for example, 20 to 100 mrem (or millirem, which is one-thousandth of a rem) (0.2 to 1 mSv) per week every week for several years. It is assumed that any radiation exposure, either acute or chronic, has a potential for causing delayed effects. However, only acute doses cause early effects; chronic doses do not cause early effects. Since the NRC limits are set to prevent all early effects, concern with occupational radiation risk is primarily focused on chronic exposure to low levels of radiation over long time periods for which the delayed effects such as cancer are of concern. The difference between acute and chronic radiation exposure can also be shown by a comparison with exposure to the sun's rays. An intense exposure to the sun can result in painful burning, peeling, and growing of new skin. However, repeated short exposures provide time for the skin to repair between exposures. Whether exposure to the sun's rays is long term or spread over short periods, some of the injury may not be repaired and may eventually result in skin cancer.

5. What are the health risks from radiation exposure to the embryo/fetus?

During certain stages of development, the embryo/fetus is much more sensitive to radiation than adults are. Studies of atomic bomb survivors exposed to high radiation doses during pregnancy show that children born after these exposures have a higher risk of mental retardation or lower IQ scores. Other studies suggest that an association exists between exposure to diagnostic x-rays before birth and carcinogenic effects in adult life; the magnitude of the risk, however, is uncertain. In recognition of this increased radiation sensitivity, a more restrictive dose limit has been established for the embryo/fetus of a declared pregnant radiation worker. Guidance in conformance with the revised 10 CFR Part 20 is being developed as a proposed Revision 3 to Regulatory Guide 8.13; it has been published as Draft Regulatory Guide DG-8014, "Instruction Concerning Prenatal Radiation Exposure."

If an occupationally exposed woman declares her pregnancy to the licensee, she is subject to the more restrictive dose limits for the embryo/fetus during the remainder of the pregnancy. The dose limit of 500 mrem (5 mSv) for the total gestation period applies to the embryo/fetus and is controlled by restricting the exposure to the declared pregnant woman. Restricting the woman's occupational exposure, if she declares her pregnancy, raises questions about individual privacy rights, equal

employment opportunities, and possible loss of income. Because of these concerns, the declaration of pregnancy by a woman radiation worker is voluntary. Also, the declaration of pregnancy can be withdrawn, for example, if the woman reconsiders and feels that her benefits from receiving the occupational exposure would outweigh the increased risk to her embryo/fetus from the radiation exposure.

6. Can a worker become sterile or impotent from normal occupational radiation exposure?

No. Temporary or permanent sterility can be caused by radiation but not at the levels allowed under NRC's occupational limits. Sterility is an early radiation effect. There is a threshold below which these effects would not occur. Doses on the order of 10 rem (0.1 Sv) to the testes can result in a measurable but temporary reduction in sperm count. Temporary sterility (suppression of ovulation) has been observed in women who have received acute doses of 150 rem (1.5 Sv). The estimated threshold (acute) radiation dose for induction of permanent sterility is about 200 rem (2 Sv) for men and about 350 rem (3.5 Sv) for women.

Although high, acute doses can affect fertility, they have no direct effect on the ability to function sexually. No evidence exists that exposures within NRC's occupational limits have any direct effect on the ability to function sexually.

7. What is meant by external and internal exposure?

A worker's occupational dose may be caused by exposure to radiation that originates outside the body, called "external exposure," or by exposure to radiation from radioactive material that has been taken into the body, called "internal exposure." It is the current scientific consensus that a rem of radiation dose has the same biological risk regardless of whether it is from an external or an internal source. The NRC requires that dose for external exposure and dose for internal exposure be added together to determine compliance with the occupational limits. The sum of external and internal dose is called the Total Effective Dose Equivalent (TEDE).

Radioactive materials may enter the body through breathing, eating, or drinking, or they may be absorbed through the skin, particularly if the skin is broken. The intake of radioactive materials by workers is generally due to breathing contaminated air. Radioactive materials may be present as fine dust or gases in the workplace atmosphere. The surfaces of equipment and workbenches may be contaminated and these materials can be re-suspended in air during work activities.

After entering the body, the radioactive material goes to particular organs, depending on the biochemistry of the material. For example, certain chemical forms of uranium tend to deposit in the bones, where they remain for a long time. These forms of uranium are slowly eliminated from the body, mostly by way of the kidneys. Radioactive iodine is preferentially deposited in the thyroid gland, which is located in the neck.

To limit risk to specific organs and the total body, standards have been established for the annual limit of intake (ALI) for each radionuclide. When more than one radionuclide is involved, the intake amounts of each are reduced proportionally. NRC regulations specify the concentrations of radioactive material in the air to which a worker can be continuously exposed for the entire 2,000 working hours in a year. These concentrations are termed the derived air concentrations (DACs).These limits are the total amounts allowed if no external radiation is received. The resulting dose from the internal radiation sources is the maximum allowed to the organ or to the worker's whole body.

8. How does radiation cause cancer?

When radiation interacts with the cells of our bodies, a number of events can occur. The damaged cells can repair themselves; no resulting damage is caused. The cells can die, much like the millions of cells that die every day in our bodies, and may be replaced through the normal biological process. Or a change can occur in the cell's reproductive structure -- the cells can mutate and subsequently be repaired with no effect, or they can form precancerous cell, which may become cancerous.

Radiobiologists have studied the relationship between radiation and cancer. These studies indicate that radiation damage to chromosomes in the cell nucleus is the main cause of cancer. Chromosome damage may occur directly through the interaction of the ionizing radiation in the cell or indirectly through reactions of chemical products produced by radiation interactions. Cells are able to repair most damage within hours; however, mis-repair may occur. Such misreported damage is thought to be the origin of cancer, but mis-repair does not always cause cancer. Benign changes in the cell can occur or the cell can die; these changes do not lead to cancer.

Many factors can affect susceptibility to the cancer-causing effects of radiation, such as general health, inherited traits, sex, as well as exposure to other cancer-causing agents such as cigarette smoke. However, most diseases are caused by the interaction of several factors. Other detrimental conditions such as smoking appear to increase the susceptibility.

9. If I receive a radiation dose, will it cause me to get cancer?

Probably not. Radiation is like most substances that cause cancer in that the effects can be seen clearly only at high doses. Assessment of the cancer risks that may be associated with low doses of radiation are projected from data available at doses larger than 10 rad (0.1 gray). Generally, for radiation protection purposes, these estimates are made using the straight line portion of the linear quadratic model. We have data on cancer probabilities for high doses. Only in the studies of radiation above occupational limits are there dependable measurements of risk of cancer, primarily because below the limits the effect is small compared to differences in the normal cancer incidence from year to year and place to place. Most scientists believe that there is some risk no matter how small the dose. Some scientists believe that the risk drops off to zero at some low dose, the threshold effect. A few believe that risk levels off so that even very

small doses imply a significant risk. The majority of scientists today endorse the linear quadratic model.

For regulatory purposes, the NRC uses the straight line portion of the linear quadratic model, which shows the number of effects decreasing as the dose decreases. It is prudent to assume that even small doses have some chance of causing cancer. This is as true for natural carcinogens such as sunlight and natural radiation as it is for those that are man-made such as cigarette smoke, smog, and man-made radiation. Thus, a principle of radiation protection is to do more than merely meet the allowed regulatory limits; doses should be kept as low as is reasonably achievable (ALARA). The ALARA concept is discussed in Question 13.

10. What are the estimates of the risk of cancer from radiation exposure?

We don't know exactly what the chances are of getting cancer from a low-level radiation dose, but we can make estimates based on extensive scientific research knowledge. We do know that the estimates of radiation effects are better known and are more certain than are those of most hazardous chemicals (Ref. 5). Being exposed to typical occupational radiation doses is taking a chance, but that chance is reasonably well understood. From currently available data, the NRC has adopted the risk value for an occupational dose of 1 rem (0.01 Sv) as representing a risk of 4 in 10,000 of developing a fatal cancer.

Not all workers incur the same level of risk. The radiation risk incurred by a worker depends on the amount of dose received. Under the linear model explained above, a worker who receives 5 rems (0.05 Sv) in a year incurs 10 times as much risk as another worker who receives only 0.5 rem (0.005 Sv). Only a very few workers receive doses near 5 rems (0.05 Sv) per year.

According to the BEIR V report, approximately one in five adults normally will die from cancer from all possible causes such as smoking, food, alcohol, drugs, air pollutants, natural background radiation, and inherited traits. Thus, in any group of 10,000 workers, we can estimate that about 2,000 will die from cancer in the absence of any occupational radiation exposure. As stated earlier, there is a risk of 4 in 10,000 of a l-rem (0.0l-Sv) dose causing a fatal cancer. Another way of stating this risk of a fatal cancer is 1 in 2,500 per rem (0.01 Sv) received, or 0.0004 per rem (0.01 Sv).

To explain the significance of these estimates, we will use a group of 10,000 people, each exposed to 1 rem (0.01 Sv) of ionizing radiation. In this group of 10,000 workers, we could estimate that 4 would die from cancer because of that dose in addition to the 2,000 normal incidents, although the actual number could be more or less than 4. These deaths would be in addition to the natural death rate for cancer, which is 1 in 5 people. This means that a l-rem (0.01 Sv) dose to each of 10,000 workers might increase each individual worker's chances of dying from cancer from 20 percent to 20.04 percent. If one's lifetime occupational dose is 10 rems, we could raise the estimate to 20.4 percent. A lifetime dose of 100 rems may have increased your chances of dying from cancer from 20 to 24 percent. The average measurable dose for radiation

workers reported to the NRC was 0.3 rem (0.003 Sv) for 1992 (Ref. 6). Today, very few workers ever accumulate 100 rems (1 Sv) and the average career dose of workers at NRC-licensed facilities is 1.5 rem (0.015 Sv), which represents an increased risk of dying from cancer from 20 to about 20.06 percent. It is important to understand the probability factors here. A similar question would be, "If you select one card from a full deck, will you get the ace of spades?" This question cannot be answered with a simple yes or no. The best answer is that your chance is 1 in 52. However, if 1000 people each select one card from full decks; we can predict that about 20 of them will get an ace of spades. Each person will have 1 chance in 52 of drawing the ace of spades, but there is no way we can predict which persons will get the right card. The issue is further complicated by the fact that in a drawing by 1000 people, we might get only 15 successes, and in another, perhaps 25 correct cards in 1000 draws. We can say that if you receive a radiation dose, you will have increased your chances of eventually developing cancer. It is assumed that the more radiation exposure you get, the more you increase your chances of cancer.

The normal chance of dying from cancer is about one in five for persons who receive no occupational radiation dose. The additional chance of developing fatal cancer from an occupational exposure of 1 rem (0.01 Sv) is about the same as the chances of drawing an ace from a full deck of cards three times in a row. The additional chance of dying from cancer from an occupational exposure of 10 rem (0.1 Sv) is about equal to your chance of drawing two aces successively on the first two draws from a full deck of cards.

It is important to realize that these risk numbers are only estimates. Many difficulties are involved in designing research studies that can accurately measure the projected small increases in cancer cases that might be caused by low exposures to radiation as compared to the normal rate of cancer. There is still uncertainty with regard to estimates of radiation risk from low levels of exposure. The numbers used here result from studies involving high doses and high dose rates.

These estimates are considered by the NRC staff to be the best available for the worker to use to make an informed decision concerning acceptance of the risks associated with exposure to radiation. A worker who decides to accept this risk should try to keep exposure to radiation as low as is reasonably achievable (ALARA) to avoid unnecessary risk.

11. How can we compare radiation risk to other kinds of health risks?

Perhaps the most useful way to make these comparisons is to compare the average number of days of life expectancy lost per unit of exposure to each particular health risk. Estimates are calculated by looking at a large number of persons, recording the age when death occurs from apparent causes, and estimating the average number of days of life lost as a result of these early deaths. The total number of days of life lost is then averaged over the total group observed.

Several studies have compared the projected average loss of life expectancy resulting from exposure to radiation with other health risks. The word average is important because an individual who gets cancer loses about 15 years of life expectancy, while his or her coworkers suffer no loss. Some representative numbers are presented in Table 1. For the NRC-regulated industries, the average measurable occupational dose in 1992 was 0.3 rem (0.003 Sv). A simple calculation based on the article by Cohen and Lee shows that 0.3 rem (0.003 Sv) per year from age 18 to 65 results in a projected estimate of life expectancy loss of 15 days. These estimates indicate that the health risks from occupational radiation exposure are smaller than the risks associated with many other events or activities we encounter and accept in normal day-to-day activities. Another useful comparison is to look at estimates of the average number of days of life expectancy lost from occupational exposure to radiation and to compare this number with days lost for several types of industries. Table 2 shows average days of life expectancy lost as a result of fatal work-related accidents. Table 2 does not include non-accidental types of occupational risks such as occupational disease and stress.

12. What are the NRC occupational dose limits?

For adults, an annual limit that does not exceed:

- 5 rems (0.05 Sv) for the Total Effective Dose Equivalent (TEDE), which is the sum of doses from external exposure to the whole body and from the equivalent internal doses from intakes of radioactive material. Doses to an organ or tissue must be multiplied by risk-weighting factors to compare the dose to a whole body exposure before they are added to the external dose.

- 50 rems (0.5 Sv) for the Total Organ Dose Equivalent (TODE), which is the sum of doses from external exposure to the whole body and the dose from intakes of radioactive material to any individual organ or tissue, other than the lens of the eye.

- 15 rems (0.15 Sv) for the Lens Dose Equivalent (LDE), which is the external dose to the lens of the eye.

- 50 rems (0.5 Sv) for the Shallow Dose Equivalent (SDE), which is the external dose to the sensitive portion of the skin or to any extremity.

For minors, the annual occupational dose limits are 10 percent of the dose limits for adult workers.

For the embryo/fetus of a declared pregnant woman, the dose limit is 0.5 rem (5 mSv) during the entire pregnancy.

The occupational dose limit for adult workers of 5 rem (0.05 Sv) TEDE is based on consideration of potential delayed biological effects. The 5-rem (0.05 Sv) limit, together with application of the concept of keeping occupational doses ALARA, provides a level of risk of delayed effects considered acceptable by the NRC. The limits for

individual organs are below the levels of observed early biological effects in the respective organs.

The dose limit for the embryo/fetus of a declared pregnant woman is based on consideration of the special sensitivity to radiation of the embryo/fetus. This limit is in effect only when a woman declares her pregnancy in writing to the licensee.

TABLE 1
Estimated Loss of Life Expectancy from Health Risks[a]

Health Risk	Estimate of Life Expectancy Lost
Smoking 20 cigarettes a day	6 years
Overweight (by 15%)	2 years
Alcohol consumption (U.S. average)	1 year
All accidents combined	1 year
Motor vehicle accidents	207 days
Home accidents	74 days
Drowning	24 days
All natural hazards (earthquake, lightning, flood, etc.)	7 days
Medical radiation	6 days
Occupational Exposure	
0.3 rem/y[b] from age 18 to 65	15 days
1 rem/y from age 18 to 65	51 days

[a] Adapted from Reference 7.
[b] From NUREG-0713, Reference 6.

TABLE 2
Estimated Loss of Life Expectancy from Industrial Accidents[a]

Industry Type	Estimates of Days of Life Expectancy Lost, Average
All industries	60
Agriculture	320
Construction	227
Mining and Quarrying	167
Transportation and Public Utilities	160
Government	60
Manufacturing	40
Trade	27
Services	27

[a] Adapted from Ref. 7.

13. What is meant by ALARA?

ALARA means "as low as is reasonably achievable." In addition to providing an upper limit on an individual's permissible radiation exposure, the NRC requires that its licensees establish radiation protection programs for maintaining occupational exposures, and exposures to the public, as far below the limit as is reasonably achievable. Reasonably achievable also means practical. What is practical depends on the purpose of the job, the state of technology, the costs for reducing the exposures, and the benefits. Although ALARA is a required integral part of each licensee's radiation protection program, it does not establish an occupational dose limit.

In practice, ALARA includes planning tasks involving radiation exposure so as to reduce exposure to individual workers, the work group, and those who, although not part of the work group, may be exposed as a result of the work group's actions. Work practices should be reviewed with the objective of preventing unnecessary exposures.

There are several ways to control radiation doses, e.g., limiting the time in radiation areas, maintaining distance from sources of radiation, and providing shielding of radiation sources to reduce dose rates. The use of engineered controls is also a requirement of the ALARA concept -- from the design of facilities and equipment to the actual set-up and conduct of work activities.

The ALARA concept should also be used in determining the appropriate use of respiratory protection. To the extent practical, engineering controls such as containments and ventilation systems should be used to reduce workplace airborne radioactive materials. In evaluating whether or not to use respirators, the ALARA goal is to achieve the lowest sum of external and internal doses. For example, the use of respirators can lead to increased work time within radiation areas, which increases external dose. The advantage of using respirators to reduce internal exposure must be evaluated against the increased external exposure caused by longer working times. The goal is to maintain total exposure ALARA.

14. How much radiation does the average person who does not work in the nuclear industry receive?

The average person is constantly exposed to ionizing radiation from several sources. Our environment and even the human body contain naturally occurring radioactive materials (e.g., potassium-40 and thorium) that contribute to the radiation we receive. The largest source of human radiation exposure is terrestrial radon, a colorless, odorless, chemically inert gas, which causes about 55 percent of our average, non-occupational exposure. Cosmic radiation originating in space and in the sun contributes additional exposure. The use of x-rays and radioactive materials in medicine and dentistry adds to our population exposure. As shown below in Table 3, the average person receives an annual radiation dose of about 0.36 rem (3.6 mSv). By age 20, the average person will accumulate over 7 rems (70 mSv) of dose. By age 50, the total dose is up to 18 rems (180 mSv). After 70 years of exposure this dose is up to 25 rems (250 mSv).

15. What are the typical radiation doses received by workers?

For 1992, the NRC received reports on about a quarter of a million people who were monitored for occupational exposure to radiation. Almost half of those monitored had no measurable doses. The other half had an average dose of about 300 mrem (3 mSv) for the year. Of the total group of about a quarter of a million people, 97 percent received an annual dose of less than 1 rem (10 mSv); 99.7 percent received less than 2 rems (20 mSv); and the highest reported dose was for an individual who received between 5 and 6 rems (50 and 60 mSv).

Table 4 lists average occupational doses for workers (persons who had measurable doses) in various occupations based on 1992 data.

TABLE 3
AVERAGE ANNUAL EFFECTIVE DOSE EQUIVALENT TO INDIVIDUALS IN THE U.S.[a]

Source	Dose Equivalent (mrems)	
Natural		
Radon	200	
Other than Radon	100	
Total		300
Nuclear Fuel Cycle		0.05
Consumer Products[b]		9
Medical		
Diagnostic X-rays	39	
Nuclear Medicine	14	
Total		53
Total		~360 mrem/year

[a] Adapted from Table 8.1, NCRP 93 (Ref. 8).
[b] Includes tobacco, building material, television receivers, luminous watches, smoke detectors, etc. (from Table 5.1, NCRP 93, Ref. 8).

TABLE 4
Reported Occupational Doses for 1992[a]

Occupational Subgroup	Average Measurable Dose per Worker (millirems)
Industrial Radiography	490
Manufacturing and Distribution	260
Low-Level Waste Disposal	450
Independent Spent Fuel Storage	130
Fuel Fabrication	110
Commercial Power Reactors	310

[a] From Table 3.1 in NUREG-0713 (Ref. 6).

16. How do I know how much my dose (exposure) is?

The NRC requires your employer, the NRC licensee, to determine your exposure, to maintain records of your exposure, and, at least on an annual basis, to inform you of your exposure.

External exposures are monitored by using individual monitoring devices. These devices are required to be used if it appears likely that your external exposure will exceed 10 percent of your allowed annual dose. The most commonly used monitoring devices are film badges, thermoluminescent dosimeters (TLDs), electronic dosimeters, and direct reading pocket dosimeters.

With respect to internal exposure, your employer is required to monitor your occupational intake of radioactive material and assess the dose if it appears likely that you will receive greater than 10 percent of the annual limit on intake (ALI) if you are an adult, or a dose in excess of 0.05 rem (0.5 mSv) from intakes in one year if you are a minor or a declared pregnant worker. Internal exposure can be estimated by measuring the radiation emitted from the body (for example, with a "whole body counter") or by measuring the radioactive materials contained in biological samples such as urine or feces. Dose estimates can also be made if one knows how much radioactive material is in the air and the length of time during which the air was breathed.

17. What happens if a worker exceeds the annual dose limit?

The regulations do not permit any additional occupational exposure to a person who is exposed in excess of the limit during the remainder of the year in which the limit is exceeded. The licensee is also required to file an overexposure report with the NRC and provide a copy to the individual. The licensee will be subject to NRC enforcement action (possibly a fine), just as you are subject to a traffic fine for exceeding the speed limit. The fines and, in some serious or repetitive cases, suspension of license are intended to encourage efforts to operate within the limits.

Radiation protection limits such as 5 rems (0.05 Sv) a year are not absolute limits that determine safe or unsafe levels of radiation exposures. Exceeding this limit does not mean that you will necessarily be harmed. It is assumed that risks are related to the size of the radiation dose. Therefore, when your dose is higher your risk is also higher. These limits are similar to highway speed limits. If you drive at 70 mph, your risk is higher than at the 55 mph limit, even though you may not actually have an accident. Those who set speed limits have determined that the risks of driving in excess of the speed limit are not acceptable. In the same way, the revised 10 CFR Part 20 establishes a limit for normal occupational exposures of 5 rems (0.05 Sv) a year. Although you will not necessarily get cancer or some other radiation effect at doses above the limit, it does mean that the licensee's safety program has failed in some way. Investigation is warranted to determine the cause and correct the conditions leading to the exposure in excess of the limit.

Risks from higher doses that might be incurred in exceptional situations or emergencies are explained in Questions 19 and 22.

18. Is the use of extra workers a good way to reduce dose?

There is a "yes" answer to this question and a "no" answer. For a given job involving exposure to radiation, the more people who share the work, the lower the average dose to individuals. The less the dose, the less the risk. So, for you as an individual, the answer is "yes."

But how about the risk to the entire group of workers? Under assumptions used by the NRC for purposes of protection, the risk of cancer depends on the total amount of radiation energy absorbed by human tissue, not on the number of people to whom this tissue belongs. Therefore, if 30 workers are used to do a job instead of 10, and if both groups get the same collective dose (person-rems), the total cancer risk is the same, and nothing was gained for the group by using 30 workers. From this viewpoint the answer is "no." The risk was not reduced but simply spread around among a larger number of persons.

Unfortunately, spreading the risk around often results in a larger collective dose for the job. Workers are exposed as they approach a job, while they are getting oriented to do the job, and as they withdraw from the job. The dose received during these actions is called nonproductive. If several crew changes are required, the nonproductive dose can become very large. The use of extra workers may actually increase the total occupational dose and the resulting collective risks. The use of extra workers may not be the way to reduce the risk of radiation-induced cancer for the worker population. At best, the total risk remains the same, and it may even be increased. The best way to reduce the risk is to reduce the collective dose; that can be done only by reducing the radiation levels, the working times, or both.

19. What is meant by a planned special exposure?

A "planned special exposure" means an infrequent exposure to radiation, separate from, and in addition to, the doses received under the annual limits. The licensee can authorize additional dose that is equal to the annual occupational dose limits as long as the individual's total dose does not exceed five times the annual dose limits during the individual's lifetime. For example, licensees may authorize "planned special exposures" for an adult radiation worker to receive doses up to an additional 5 rems (0.05 Sv) in a year above the 5-rem (0.05 Sv) annual TEDE occupational dose limit. Each worker is limited to no more than 25 rems (0.25 Sv) from planned special exposures in his or her lifetime. Such exposures are only allowed in exceptional situations when alternatives for avoiding the additional exposure are not available or are impractical. Before the licensee grants approval, the licensee must ensure that the worker is informed of the purpose and circumstances for the planned operation, the estimated doses expected, and the procedures to keep the doses ALARA while considering other risks that may be present. (See Regulatory Guide 8.35, "Planned Special Exposures," for further information.)

20. Why do some facilities establish administrative limits that are below the NRC limits?

There are two reasons. First, the NRC regulations state that licensees should keep exposures to radiation ALARA. By requiring specific approval for worker doses in excess of set levels, more careful risk-benefit analyses can be made as each additional increment of dose is approved for a worker. Secondly, an administrative limit that is set lower than the NRC limit provides a safety margin designed to help the licensee avoid exposures in excess of the limit.

21. Why aren't medical exposures considered as part of a worker's allowed dose?

NRC rules exempt medical exposure, but equal doses of medical and occupational radiation have equal risks. Medical exposure to radiation is justified for reasons that are quite different, however, from those applicable to occupational exposure. A physician prescribing an x-ray should be convinced that the benefit to the patient from the resulting medical information justifies the risk associated with the radiation. Each worker must decide, however, on the benefits and acceptability of occupational radiation risk, just as each worker must decide on the acceptability of any other occupational hazard.

For another point of view, consider a worker who receives a dose of 2 rems (0.02 Sv) from a series of x-rays or a radioactive medicine in connection with an injury or illness. This dose and the implied risk should be justified on medical grounds. If the worker had also received 4 rems (0.04 Sv) on the job, the combined dose of 6 rems (0.06 Sv) would not incapacitate the worker. A dose of 6 rems (0.06 Sv) is not especially dangerous and is not large compared to the allowed cumulative occupational dose. Restricting the worker from additional job exposure during the remainder of the year would have no effect one way or the other on the risk from the 2 rems (0.02 Sv) already received from medical exposure. If the individual worker accepts the risks associated with the x-rays on the basis of the medical benefits and accepts the risks associated with job-related exposure on the basis of employment benefits, it would be unfair to restrict the worker from employment in radiation areas for the remainder of the year.

22. How should radiation risks be considered in an emergency?

Although the use of planned special exposures allows an additional 5 rems (0.05 Sv) a year for special occasions, that allowance does not apply to emergencies. Emergencies are "unplanned" events in which actions to save lives or property may warrant additional doses for which no particular limit applies. Even though the revised 10 CFR Part 20 does not set any dose limits for lifesaving activities, workers should remember that radiation risks increase with increasing dose and that the ALARA principle applies for emergencies as well as routine activities. In addition, any doses received during emergencies have to be reported to the NRC and included on the worker's lifetime dose record. The NRC has not sanctioned any "forgivable" emergency dose that would not be counted in an individual worker's lifetime dose.

The Environmental Protection Agency (EPA) has published emergency dose guidelines (Ref. 2). These guidelines state that doses to all workers during emergencies

should, to the extent practicable, be limited to 5 rems (0.05 Sv). There are some emergency situations, however, for which higher emergency limits may be justified. Justification of any such exposure must include the presence of conditions that prevent the rotation of workers or other commonly used dose reduction methods. Except as noted below, the dose resulting from such emergency exposures should be limited to 10 rems (0.1 Sv) for protecting valuable property, and to 25 rems (0.25 Sv) for lifesaving activities and the protection of large populations. In the context of this guidance, exposure of workers that is incurred for the protection of large populations may be considered justified for situations in which the collective dose avoided by the emergency operation is significantly larger than that incurred by the workers involved.

Situations may rarely occur in which a dose in excess of 25 rems (0.25 Sv) for emergency exposure would be unavoidable in order to carry out a lifesaving operation or to avoid extensive exposure of large populations. However, persons undertaking any emergency operation in which the dose will exceed 25 rems (0.25 Sv) to the whole body should do so only on a voluntary basis and with full awareness of the risks involved, including the numerical levels of dose at which prompt effects of radiation will be incurred and numerical estimates of the risks of delayed effects.

Table 5 presents the approximate risk of premature death for a group of 1,000 workers of various ages who have all received an acute dose of 25 rems (0.25 Sv). If needed, the referenced EPA source document should be used for training regarding risks of high doses.

Even under emergency conditions, licensees and radiation workers should make every effort to evaluate the potential exposures before authorizing additional necessary doses. To the extent possible in an emergency, workers should be informed of the situation and procedures to follow to keep exposures ALARA.

TABLE 5
Risk of Premature Death from Exposure to 25-Rem (0.25-Sv) Dose

Age at Exposure (years)	Estimated Risk of Premature Death (Deaths per 1,000 Persons exposed)
20-30	9.1
30-40	7.2
40-50	5.3
50-60	3.5

Source: EPA-400-R-92-001 (Ref. 2)

23. Who developed the radiation risk estimates used in this guide?

Radiation risk estimates were developed by several national and international scientific organizations over the last 40 years. These organizations include the National Academy of Sciences (which has issued five reports from the Committee on the Biological

Effects of Ionizing Radiations, BEIR), the National Council on Radiation Protection and Measurements (NCRP), the International Commission on Radiological Protection (ICRP), and the United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR). Each of these organizations continues to review new research findings on radiation health risks.

Several recent reports from these organizations present new findings on radiation risks based upon revised estimates of radiation dose to survivors of the atomic bombs at Hiroshima and Nagasaki. For example, UNSCEAR published revised risk estimates in 1988. The NCRP also published a report in 1988, "New Dosimetry at Hiroshima and Nagasaki and Its Implications for Risk Estimates" (Ref. 10). In January 1990, the National Academy of Sciences released the fifth report of the BEIR Committee, "Health Effects of Exposure to Low Levels of Ionizing Radiation". Each of these publications also provides extensive bibliographies on other published studies concerning radiation health effects for those who may wish to read further on this subject.

24. How were radiation dose limits established?

The NRC radiation dose limits in 10 CFR Part 20 were established by the rulemaking procedures required for Federal agencies. Under the rulemaking procedures, the NRC staff developed a proposed rule that was then reviewed and approved by the 5-member Commission that directs the NRC. Following the Commission's approval, the proposed rule was published in the *Federal Register* public comment. The *Federal Register* may be considered to be the government's newspaper. Publication in the *Federal Register* provided legal notice to all persons that the NRC was considering setting new radiation dose limits.

In developing the proposed dose limits, the staff considered the 1987 Presidential Guidance on occupational exposure. That guidance was developed under the lead of the EPA. The guidance was signed by the President and was intended for use by all Federal agencies. The staff also considered the recommendations of the International Commission of Radiological Protection (ICRP) and its U.S. counterpart, the National Council on Radiation Protection and Measurements (NCRP).

In addition to publication of the proposed Part 20 in the *Federal Register* in January 1986, the NRC sent copies to all NRC licensees and to many other interested parties. More than 800 sets of comments were received and considered by the staff in developing the final rule.

Note that the proposed rule presented a tentative NRC position on radiation dose limits. The final rule was developed only after consideration of comments from licensees, labor unions, public interest groups, other Federal agencies, scientific organizations, and other interested parties.

25. Several scientific reports have recommended that the NRC should use lower limits Does the NRC plan to reduce the regulatory limits?

Since publication of the proposed rule in 1986, the ICRP in 1990 revised its recommendations for radiation protection based on newer studies of radiation risks (Ref. 11), and the NCRP followed with a revision to its recommendations in 1993. The ICRP recommended a limit of 10 rems (0.1 Sv) effective dose equivalent (from internal and external sources), over a 5-year period with no more than 5 rems (0.05 Sv) in 1 year. The NCRP recommended a cumulative limit, not to exceed 1 rem (0.01 Sv), times the individual's age with no more than 5 rems (0.05 Sv) in any year.

The NRC does not believe that additional reductions in the dose limits are urgently required. Because of the practice of maintaining radiation exposures ALARA ("as low as is reasonably achievable"), the average radiation dose to occupationally exposed persons is well below the limits in the current Part 20 that became mandatory January 1, 1994, and the average risks to radiation workers are below those limits recommended by the ICRP and the NCRP.

For example, in 1992, only a few workers (0.3 percent) in nuclear facilities reporting to the NRC received annual doses that exceeded 2 rems (0.02 Sv) (Ref. 6), and few are likely to exceed the 5-year limit recommended by the ICRP. The facilities included here were from six of the reporting industries that have the highest potential for occupational radiation exposures: nuclear power plants, industrial radiography, reactor fuel fabrication, low-level waste disposal, spent fuel storage, and radioisotope manufacturing. For another example, in 1992 about 97 percent of the same workers received annual doses of less than 1 rem (0.01 Sv), which provides reasonable assurance that cumulative dose limits based on age as proposed by the NCRP are being met.

The current dose limits contained in 10 CFR Part 20 are also consistent with the Federal guidance on occupational radiation exposure (described in Question 24), and any changes would be the subject of a future rulemaking.

26. What are my options if I decide the risks associated with my occupational radiation exposure are too high?

If the risks from exposure to radiation during your work are unacceptable to you, you could request a transfer to a job that does not involve exposure to radiation. However, the risks associated with the exposure to radiation that workers, on the average, actually receive are considered acceptable when compared to other occupational risks by virtually all the scientific groups that have studied them. From an NRC regulatory basis, your employer is not obligated to guarantee you a transfer if you decide not to accept an assignment that requires exposure to radiation.

You also have the option of seeking other employment in a non-radiation occupation. However, the studies that have compared occupational risks in the nuclear industry to those in other job areas indicate that nuclear work is relatively safe. Thus, you may find different kinds of risk but you will not necessarily find significantly lower risks in another job.

You and your employer should practice the most effective work procedures so as to keep your exposure ALARA. Be aware that reducing time of exposure, maintaining distance from radiation sources, and using shielding can all lower your exposure. Plan radiation jobs carefully to increase efficiency while in the radiation area. Learn the most effective methods of using protective clothing to avoid contamination. Discuss your job with the radiation protection personnel who can suggest additional ways to reduce your exposure.

27. Where can I get additional information on radiation risk?

The following list suggests sources of useful information on radiation risk:

- Your employer - the radiation protection of health physics office where you are employed.

- Nuclear Regulatory Commission Regional Offices:

    King of Prussia, Pennsylvania (215) 337-5000

    Atlanta, Georgia (404) 331-4503

    Lisle, Illinois (708) 829-9500

    Arlington, Texas (817) 860-8100

- U.S. Nuclear Regulatory Commission Headquarters

    Radiation Protection & Health Effects Branch

    Office of Nuclear Regulatory Research

    Washington, DC 20555

    Telephone: (301) 415-6187

- Department of Health and Human Services

    Center for Devices and Radiological Health

    1390 Piccard Drive, MS HFZ-1

    Rockville MD 20850

    Telephone: (301) 443-4690

- U.S. Environmental Protection Agency

    Office of Radiation and Indoor Air

    Criteria and Standards Division

    401 M Street NW.

    Washington, DC 20460

    Telephone: (202) 233-9290

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SI Units and Conversion Factors

SI Units for Radioactive Materials

Prepared by

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202/293-0770

SI (Systeme International) units are now being used in many countries as the primary measurement system, including measurement of radioactivity, and the system is coming into use in the United States. Many journals (including those published by the American Medical Association) now require the use of SI units, and U.S. regulatory agencies are beginning to use SI units as well as conventional units in regulations. It is the policy of the United States Government that regulations should not impede the transition to SI units. The U.S. Trade Act of 1988 includes a provision establishing federal policy to designate the metric system as the preferred measurement system for U.S. trade and commerce. It also requires all federal agencies to adopt the metric system for business-related activities by 1992, except where it proves impractical. USCEA's Committee on Radionuclides and Radiopharmaceuticals is seeking to familiarize users of radioactive materials with SI units and to facilitate their use in the United States. The SI unit for radioactivity is the Becquerel (Bq), and is defined as one nuclear transformation per second. It is a small unit when compared to the curie (Ci), and it is convenient to use multiples of the unit (see listing later in this brochure). It does have the convenience however of relating directly to count rate once corrections have been made for counting efficiency. Most suppliers of radioactive materials including the National Institute of Standards Technology (NIST-formerly NBS) have

been using dual units (curies and Becquerels) in catalogs, product literature and labeling for some time and plan to do so for the foreseeable future. The European Economic Community (EEC) has stated that it will accept only SI units for radioactivity after 1999, and it is anticipated that all suppliers of radioactive products will be using only SI units at that time. In Canada, Atomic Energy Control Board documents produced since 1985 have been in SI units only, and conversion of regulations is in progress. Other SI radiation measurement units are as follows:

Exposure and Exposure Rate

The roentgen (R) is the traditional unit of measurement for exposure, the charge produced in air by γ or x-rays. The SI unit of exposure is coulombs per kilogram (C/kg) of air.

1 C/kg = 3876 R

1 R = 2.58 x 10-4 C/kg

No special name has been given to this SI unit (C/kg) and since there is no convenient conversion to other SI units, it is seldom used. Instead, the observed dose rate in air, that is the air kerma rate, is typically being used as the SI measurement to replace exposure rate. An example of the use of air kerma rate is to define the radiation output from a sealed radioactive source in SI units. The SI units usually used to express air kerma rate are grays/second. In traditional units, exposure rate from a sealed source has typically been expressed in roentgens/hour at a distance of 1 meter from the source. Charge as defined in exposure (charge produced in air by γ and X-radiation) does not include ionization produced by bremsstrahlung arising from absorption of electrons (β-particles). Apart from this difference, which is significant only with high energy β-particles, exposure is the ionization equivalent of air kerma. For a further discussion of air kerma see ICRU (International Commission on Radiation Units and Measurements) Report 33, 1980.

Absorbed Dose

This is the amount of energy imparted to matter, and the rad has been the unit of measurement. The SI unit for absorbed dose is the gray (Gy).

1 Gray (Gy) = 100 rad

1 rad = 0.01 Gy

One roentgen of X-radiation in the energy range of 0.1-3 MeV produces 0.96 rad in tissue.

Dose Equivalent

The dose equivalent is the absorbed dose multiplied by modifying factors such as a quality factor (accounts for the biological effect of different types of radiation) and the

dose distribution factor. The rem is the unit of measurement that has been used, and the SI unit is the sievert (Sv).

1 Sv = 100 rem

1 rem = 0.01 Sv

We are giving advance notice of the change to SI Units to allow users time to become familiar with the new units. Do not hesitate to contact your supplier of radioactive materials or USCEA should you have any questions concerning SI units or the implementation of the change.

CONVERSION TABLE FOR RADIOACTIVITY

Curie Units	Becquerel Units
µCi	kBq
mCi	MBq
Ci	GBq
0.1	3.7
0.25	9.25
0.5	18.5
0.75	27.75
1	37
2	74
3	111
5	185
7	259
10	370
20	740
25	925

Curie Units	Becquerel Units
µCi	MBq
mCi	GBq
Ci	TBq
50	1.85
60	2.22
100	3.7
200	7.4
250	9.25
500	18.5
800	29.6
1000	37

To convert from one unit to another, read across from one column to the other ensuring the units are in the same line of the column headings. For example:

1 Becquerel (Bq) = 1 disintegration/second

1 Becquerel = 2.7027 x 10-11 curie or ≈ 27 picocuries (pCi)

To convert Becquerels to curies, divide the Becquerel figure by 37 x 109 (alternatively multiply the Becquerel figure by 2.7027 x 10-11)

1 curie (Ci) = 3.7 x 1010 disintegrations/second or 37 gigabecquerels (GBq)

To convert curies to Becquerels, multiply the curie figure by 37 x 109

Curie units that are frequently used:

1 Curie (Ci) = 1000 mCi

1 millicurie (mCi) = 1000 µCi

1 microcurie (µCi) = 1000 nCi

1 nanocurie (nCi) = 1000 pCi (picocuries)

Becquerel units that are frequently used:

1 kiloBecquerel (kBq) = 1000 Becquerels (Bq)

1 terabecquerel (MBq) = 1000 kBq

1 gigabecquerel (GBq) = 1000 MBq

1 terabecquerel (TBq) = 1000 GBq

1 Ci = 37 GBq

1 mCi = 37 MBq

1 µCi = 37 kBq

1 nCi = 37 Bq

Glossary of Terms

ABSORBED DOSE: The energy imparted by ionizing radiation per unit mass of irradiated material.

ABSORPTION: The process by which radiation imparts some or all of its energy to any material through which it passes.

ACTIVITY: The rate of decay (disintegrations/time) of a given amount of radioactive material.

ALARA: An acronym for *As Low As* Reasonably *A*chievable. The principal that radiation doses should be kept as low as reasonably achievable taking into account economic and social factors.

ALPHA PARTICLE (α): A strongly ionizing particle emitted from the nucleus during radioactive decay which is equivalent to a helium nucleus (2 protons and 2 neutrons).

ANNIHILATION RADIATION: The two 511 keV photons produced when a positron combines with an electron resulting in the annihilation of the two particles.

ANNUAL LIMIT ON INTAKE (ALI): The derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man that would result in a CEDE of 5 rem or a CDE of 50 rem to any individual organ or tissue.

ATOMIC MASS UNIT (amu): One-twelfth the mass of a neutral atom of C-12. (1 amu $\approx$ 1.66 x 10^{-24} g)

ATOMIC NUMBER (Z): The number of protons in the nucleus of an atom.

ATTENUATION: Process by which a beam of radiation is reduced in intensity when passing through material --- a combination of absorption and scattering processes.

AUTORADIOGRAPH: Record of radiation from radioactive material in an object, made by placing the object in close proximity to a photographic emulsion.

BACKGROUND RADIATION: Ionizing radiation arising from sources other than the one directly under consideration. Background radiation due to cosmic rays and the natural radioactivity of materials in the earth and building materials is always present.

BECQUEREL (Bq): The SI unit of activity equal to one disintegration per second. (1 Bq = 2.7 x 10^{-11} Ci).

BETA PARTICLE (β): A charged particle emitted from the nucleus of an atom, having a mass equal to that of the electron, and a single positive or negative charge.

BIOLOGICAL HALF-LIFE: The time required for the body to eliminate by biological processes one-half of the amount of a substance which has entered it.

BREMSSTRAHLUNG: X-rays produced by the deceleration of charged particles passing through matter.

CARRIER FREE: An adjective applied to one or more radionuclides of an element in minute quantity, essentially undiluted with stable isotope carrier.

COMMITTED DOSE EQUIVALENT (CDE): The dose equivalent to organs or tissues of reference that will be received from an intake of radioactive material by an individual during the fifty-year period following the intake.

COMMITTED EFFECTIVE DOSE EQUIVALENT (CEDE): The sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the CDE to these organs or tissues.

COMPTON SCATTERING: The elastic scattering of a photon by an essentially free electron.

CONTAMINATION: The deposition of radioactive material in any place where it is not desired, particularly in any place where its presence may be harmful.

COUNT: The external indication of a device designed to enumerate ionizing events.

CURIE (Ci): The unit of activity equal to 3.7×10^{10} disintegrations per second.

DEEP-DOSE EQUIVALENT (DDE): The dose equivalent at a tissue depth of 1 cm from external radiation.

DOSE: A general term denoting the quantity of radiation or energy absorbed in a specified mass.

DOSE EQUIVALENT: The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest.

EFFECTIVE HALF-LIFE: Time required for a radioactive nuclide in the body to be diminished fifty percent as a result of the combined action of radioactive decay and biological elimination.

EFFICIENCY: The ratio of the count rate given by a radiation detection instrument and the actual disintegration rate of the material being counted.

ELECTRON CAPTURE: A mode of radioactive decay involving the capture of an orbital electron by its nucleus resulting in conversion of a proton to a neutron.

ELECTRON VOLT (eV): A unit of energy equal to the amount of energy gained by an electron passing through a potential difference of 1 volt.

ERG: A unit of energy. 1 erg = 6.24×10^{11} eV.

ERYTHEMA: An abnormal reddening of the skin due to distention of the capillaries with blood.

EXPOSURE: A measure of the ionizations produced in air by x-ray or gamma radiation. Sometimes used to mean dose.

EYE DOSE EQUIVALENT: The dose equivalent at a tissue depth of 0.3 cm from external radiation at the eye.

FILM BADGE: A packet of photographic film in a holder used for the approximate measurement of radiation dose.

GAMMA: Electromagnetic radiation (photon) of nuclear origin.

GEIGER-MUELLER (G-M) COUNTER: A radiation detection and measurement instrument.

GRAY (Gy): The SI unit of absorbed dose equal to 1 Joule/kilogram.

HALF VALUE LAYER: The thickness of any specified material necessary to reduce the intensity of an x-ray or gamma ray beam to one-half its original value.

HEALTH PHYSICS: The science concerned with the recognition, evaluation, and control of health hazards from ionizing radiation.

ION: Atomic particle, atom, or chemical radical bearing an electrical charge, either negative or positive.

IONIZATION: The process by which a neutral atom or molecule acquires either a positive or a negative charge.

IONIZATION CHAMBER: A radiation detection and measurement instrument.

IONIZING RADIATION: Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, by interaction with matter.

ISOTOPES: Nuclides having the same number of protons in the nuclei, and hence having the same atomic number, but differing in the number of neutrons, and therefore in mass number. Almost identical chemical properties exist among isotopes of a particular element.

LABELLED COMPOUND: A compound consisting, in part, of radioactive nuclides for the purpose of following the compound or its fragments through physical, chemical, or biological processes.

LINEAR ENERGY TRANSFER (LET): Average amount of energy lost per unit track length by the individual particles or photons in radiation passing through an absorbing medium.

MASS NUMBER (A): The number of protons and neutrons in the nucleus of an atom.

NUCLIDE: An atom characterized by its mass number, atomic number, and energy state of its nucleus.

POSITRON: A particle having a mass equal to that of an electron and a charge equal to that of an electron, but positive.

QUALITY FACTOR (Q): The LET-dependant modifying factor that is used to derive dose equivalent from absorbed dose.

RAD: The unit of absorbed dose equal to 100 erg/gram (or 0.01 Joule/kilogram).

RADIATION: Energy propagated through space or a material medium.

RADIOACTIVE DECAY: Disintegration of the nucleus of an unstable nuclide by the spontaneous emission of charged particles, neutrons, and/or photons.

RADIOACTIVE HALF-LIFE: The time required for a radioactive substance to lose fifty percent of its activity by decay.

RADIOACTIVITY: The property of certain nuclides of spontaneously disintegrating and emitting radiation.

RADIONUCLIDE: An unstable (radioactive) nuclide.

RADIOTOXICITY: The potential of a radioactive material to cause damage to living tissue by radiation after introduction into the body.

REM: The unit of dose equivalent equal to the absorbed dose in rad multiplied by any necessary modifying factors.

ROENTGEN (R): The unit of radiation exposure in air equal to 2.58×10^{-4} coulombs/kilogram.

SCINTILLATION COUNTER: A radiation detection and measurement instrument in which light flashes produced in a scintillator by ionizing radiation are converted into electrical pulses by a photomultiplier tube.

SHALLOW-DOSE EQUIVALENT: The dose equivalent at a tissue depth of 0.007 cm from external exposure of the skin or an extremity.

SIEVERT (Sv): The SI unit of dose equivalent equal to 1 Joule/kilogram.

SPECIFIC ACTIVITY: Total activity of a given radionuclide per unit mass or volume.

SYSTEME INTERNATIONAL (SI): A system of units adopted by the 11ᵗʰGeneral Conference on Weights and Measurements in 1960 and used in most countries of the world.

THERMOLUMINESCENT DOSIMETER (TLD): A dosimeter made of a crystalline material which is capable of both storing energy from absorption of ionizing radiation and releasing this energy in the form of visible light when heated. The amount of light released can be used as a measure of absorbed dose.

TOTAL EFFECTIVE DOSE EQUIVALENT (TEDE): The sum of the deep-dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures). TEDE = DDE + CEDE

TOTAL ORGAN DOSE EQUIVALENT (TODE): The sum of the DDE and the CDE to an organ or tissue.

WEIGHTING FACTOR: The proportion of the risk of stochastic effects for an organ or tissue when the whole body is irradiated uniformly.

X-RAY: Electromagnetic radiation (photon) of non-nuclear origin having a wavelength shorter than that of visible light.

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Chapter

8

System Specifications

Dimensions	44" (L) x 39" (W) x 42" (H)
	R2R option expands to 72" (W) and 47" (H)
Weight (with all options included)	~ 450 lbs.
Power Requirements	115V/15A or 230V/10A
X-ray Tube Voltage variable	35 - 80kV mini-focus
	Other x-ray tubes available in special orders
X-ray Tube Current	0 to 1000µA
X-ray Camera	Auto Focus, high resolution
Video Camera	1080i HD pixel sensor
Contrast Resolution	22.5µm to 98µm
Counterfeit Software	Easy comparison of real time image with database image to check for suspect parts
Maximum Sample Size	10" x 30"
Field of View	25mm x 50 mm
Contrast Control	Auto and manual
X-ray Activation	Software Controlled, Interlock Interruptible

Chapter

9

Warranties

We at Creative Electron are committed to your 100% satisfaction. Please contact us with any problems or comments about our products. TruView is covered by our standard warranty policy. All warranties start from the date the equipment is delivered to the customer's location. These warranties are valid for manufacturing defects only. Thus, warranties exclude consequential damage or damage resulting from normal use, accidents, mishandling, or modification. If your equipment needs to be repaired, please contact Creative Electron for a diagnosis and estimate. Repairs performed by personnel not certified by Creative Electron will void the equipment's warranty.

Creative Electron's liability is limited to the repair or replacement of any parts that prove to be defective due to manufacturing. Within the warranty period such parts will be replaced free of charge, FOB San Marcos, CA, USA. If parts need to be replaced for systems in the field, the defective equipment must first be returned to Creative Electron for inspection and determination of the coverage. The client must prepay freight charges for such returned parts.

Warranties are for parts only. Parts will be repaired or replaced at the discretion of Creative Electron, provided that the system is returned to Creative Electron by prepaid transportation, or if the system is serviced by a vendor at a location designated by Creative Electron, and that inspection indicates the problem to be due to a defective part. Shipments from Creative Electron will be on "freight collect" basis. Our standard labor charges for on-site work will include travel, expenses, and our standard hourly rate. These prices will be quoted individually, as they are subject to change. This warranty applies only if the equipment has been operated in accordance with this User's Manual. The warranty does not apply to defects resulting from accidents, alterations, abuse, or misuse.

The equipment you purchased comes with the following warranties:

Hardware: Doors, hinges, and interlocks	12 months
Computer system[*]: CPU, video camera, and monitors	12 months
X-Ray camera	12 months
X-Ray source	12 months

* This warranty does not cover keyboards, mice, and other accessories

Please do not return your equipment to Creative Electron without obtaining a Return Authorization number. Always refer to the system's serial number, which is located on the back of the system.

Chapter

10

Maintenance

TruView was designed for ease of use and maintenance. It is recommended to keep the machine visibly clean. Do not clean the interior of the machine. Any mild surface cleaner may be used to clean the exterior part of the system

It is also important to calibrate and inspect the system on a regular basis. Creative Electron recommends a yearly calibration and preventative maintenance service. If you find that your system is coming close to its calibration and service date, please contact Creative Electron to schedule service. Please contact Creative Electron as early as possible so that a service can be scheduled at a convenient time for you.